Exploring a Methodological Approach to Assessing the Potential Impact of the Implementation of Circular Economy Strategies on Regional Economies Through Environmentally Extended Input–Output Tables

Jabier Retegi[1][ORCID 0000-0001-5953-0274], *Dorleta Ibarra*[1][ORCID 0000-0001-7819-4093], *Juan Ignacio Igartua*[1][ORCID 0000-0002-7039-4629]

[1] *Mechanical and Industrial Production Dept., Mondragon University, Mondragon, Spain*

Abstract: *This article is part of a research stream that aims to evaluate the impact of circular economy policies on greenhouse gas (GHG) emission reduction and the industrial structure of specific regions. Building upon previous research that generates a linear representation of GHG emissions along industrial value chains using environmentally extended input–output tables and employment data pertaining to the region's industrial structure, the study analyses GHG emissions and employment in a three-dimensional space defined by the following axes: 1) productive sectors as homogeneous blocks of the market and technologies/products, 2) value chains as a set of interrelated and dependent activities involved in circular economy implementation and 3) the position of emissions in the value chain. The employed methodology aims to provide a framework to characterise both productive sectors and value chains, offering valuable insights into emission and employment dynamics. This approach facilitates a comprehensive understanding of the potential implications of circular economy initiatives on the overall structure of regional economies.*

Keywords: *circular economy, input–output, greenhouse gases, employment*

1. INTRODUCTION

According to a study conducted by the Instituto Nacional de Estadística (INE, 2020), the manufacturing industry accounted for a substantial portion (25.8%) of the total greenhouse gas (GHG) emissions in Spain in 2020. This empirical evidence underscores the significant environmental impact of the manufacturing sector in terms of carbon emissions. To devise effective GHG reduction programmes, it is imperative to classify emissions into distinct tiers, namely tier 1, tier 2, and tier 3 emissions, as proposed by Ranganathan (2001).

To evaluate the environmental consequences of economic activities, environmentally extended input–output tables (EEIOTs) have emerged as a frequently employed methodology like in Park et al. (2022). Although input–output analysis is considered to possess a degree of imprecision compared to process analysis, it offers a comprehensive lens by integrating detailed major production data (Peters et al., 2010).

To achieve a climate-neutral and circular economy, it is necessary to transform industrial sectors and all value chains, and this will take a generation. Together with industrial strategies, a new circular economy action plan will help modernise the EU's economy and lead to benefits from the opportunities provided by a circular economy both domestically and globally (European Commission, 2019).

The 9R framework, as proposed by Kirchherr et al. (2017) and derived from Potting et al. (2017), is an instrumental tool for circular economy assessment. This framework delineates the transition from recovery loops to refusal loops, with the extent of circularity contingent on the goals ambition pursued. The transformation of society to a circular economy will certainly depend on assessing environmental, economic and industrial factors while, in addition, addressing factors such as labour practices, human rights and community well-being, which have been peripherally and sporadically integrated into the circular economy concept (Mies and Gold, 2021). To achieve a truly sustainable alternative to the current economic system, a more balanced integration of the social sustainability dimension is essential. Public institutions must take into consideration the social aspects of the circular economy, including employment, to ensure the well-being of citizens. At different levels of governance, it is necessary to be able to assess the impact that circular economy projects have on the economies of each region or geographical environment.

Given the difficulties in analysing the interconnections between economic sectors, the goal of this research is to introduce a methodological approach aimed at addressing two fundamental inquiries. First, it seeks to learn how the employment effects of circular economy initiatives on regional economies can be effectively evaluated. Second, it aims to provide insights into how to prioritise projects that optimise the reduction of GHG emissions while concurrently minimising the potential impact on employment. By addressing these critical areas, this research aims to offer valuable guidance in circular economy implementation, ensuring that both environmental sustainability and socioeconomic factors are taken into account.

The impact that emission reduction measures will have on a given territory depends on the distribution of emissions across value chains and on the overall industrial fabric of the region. This study examines the distribution of GHG emissions within the industrial sector in Spain and offers information to qualify the sectors and value chains. To do this, GHG emissions are analysed along a triple axis: 1) the axis of the productive sectors as homogeneous blocks of the market and technologies/products, 2) the axis of the value chains as a set of interrelated and dependent activities in the implementation of the circular economy and 3) the axis of the position of the emissions in the value chain that will condition the relevance of the different loops of the circular economy. In this three-dimensional space, different variables, such as GHG emissions and employment, are analysed using the results of a previous study (Retegi et al., 2023) that configures a linear model of intersectoral relations that covers 94.5% of industrial emissions. By employing this methodological framework, the research endeavours to provide valuable insights by simultaneously considering both levels of emissions and employment dynamics, facilitating a comprehensive understanding of the potential implications of circular economy initiatives on the productive fabric.

2. METHODOLOGY

This study uses secondary data from the latest available version of the input–output economic tables for Spain obtained from the Organisation for Economic Co-operation and Development (OECD, 2021), as well as data on greenhouse gas emissions (INE, 2020) and Spanish firms and employment (INE, 2023). The methodology developed in this research is based on a previous article by the authors (Retegi et al., 2023) in which, based on environmentally extended input–output tables, they studied GHG emissions (CO2-eq) along industrial value chains and represented their dependency links linearly as the first step in assessing the GHG-reducing potential of the circular economy. The result of this previous research was a set of intersector relations (links) arranged based on their belonging to various value chains and their position within these value chains. Each link is assigned a quantity of GHG emissions obtained by the average values of each sector. The sectors included in this research correspond to the statistical classification of economic activities (NACE) codes 10–43 at a 2-digit level of detail, with some groupings of NACE branches of activities due to the availability of data on GHG emissions.

Based on the outcomes of the research conducted in Retegi et al. (2023), a series of E_{ijk} data is available, consisting of the emissions of the activities of sector i in value chain j and in position k, constituting a three-dimensional space configuration. The index k represents a backwards classification of the position of the link within the value chain (link x), from the final demand to basic suppliers. Based on the available data, the new variable J_{ijk} is defined, which represents the employment corresponding to the economic activity of sector i in value chain j and in position k.

The allocation of employment associated with each link is proportionally determined, considering the amount of economic exchange that this link represents in relation to the totality of the exchanges of each sector. In this context, we define a value chain as the necessary economic activities and prior relationships between different sectors required for a sector to provide its products or services to meet the final demand.

3. RESULTS AND DISCUSSION

This section presents the key results obtained by this research. Table 1 presents the emissions associated with the productive sectors, each sector's percentage of the total emissions, their corresponding employment contribution, emissions per job, and the number of value chains in which they are incorporated.

As can be seen in Table 1 above, the NACE 35, NACE 23 and NACE 19 sectors account for 65% (39%, 16% and 10%, respectively) of the total emissions captured within the model. These three sectors exhibit significant participation in a large number of value chains (19, 16 and 10, respectively). Furthermore, these three sectors are characterised by a large amount of emissions generated per job (1,487, 216.7 and 1,574, respectively).

Table 1: Sectors and their corresponding emissions (E_i and J_i)

NACE Code	Emissions (TCO2-eq)	% of Total	Employment	Emissions/Job	Number of VC
NACE 10–12	6,310,613	4%	478,096	13.2	1
NACE 13–15	438,035	0%	119,473	3.7	1
NACE 16	137,539	0%	52,292	2.6	1
NACE 17-18	3,949,863	3%	109,154	36.2	3
NACE 19	14,827,271	10%	9,416	1,574.7	10
NACE 20	13,858,895	9%	97,594	142.0	15
NACE 21	838,595	1%	54,911	15.3	1
NACE 22	200,112	0%	95,453	2.1	1
NACE 23	23,602,326	16%	108,929	216.7	16
NACE 24	10,386,656	7%	60,842	170.7	7
NACE 25	166,167	0%	241,227	0.7	1
NACE 26	27,494	0%	25,476	1.1	1
NACE 27	159,221	0%	67,416	2.4	1
NACE 28	758,468	1%	104,932	7.2	1
NACE 29	509,285	0%	123,217	4.1	1
NACE 30	149,440	0%	43,034	3.5	1
NACE 31–33	173,795	0%	200,743	0,9	1
NACE 35	59,135,046	39%	39,762	1,487.2	19
NACE 36–39	12,758,870	8%	145,719	87.6	12
NACE 41–43	3,140,910	2%	1,049,335	3.0	1

Within the analysed model, only 13 of the 20 sectors were found to be present in a value chain. This indicates that these sectors are vulnerable to implementation decisions based on circular economy strategies focused on specific value chains aimed at the elimination of GHG. For instance, the NACE 10–12 sector will be influenced by decisions or trends within the food value chain but will be unaffected by decisions made in other sectors.

Table 2 presents the GHG emissions associated with specific value chain activities, the percentage of total emissions, the associated employment and the number of emissions per job. The value chain of electricity, gas and steam and the value chain of coke and refined petroleum products have a high level of emissions per job. The electricity, gas and steam value chain in response to final demand accounts for 23% of all emissions and has an emissions rate per job of 1,487 TCO2-eq/job. Moreover, the value chain associated with oil refining emits 12% of the total emissions, which represents 1,337 TCO2-eq/job.

Table 2: Value chains and their corresponding emissions (E_j and J_j)

Value Chains	Emiss. (TCO2-eq)	%Total Emissions	Employment	Emissions/Job
Basic metals	8,250,795	5%	43,800	188
Chemical products	12,106,511	8%	72,515	167
Coke and refined petroleum products	17,801,734	12%	13,310	1,337
Computer, electronic and optical products	27,494	0%	25,476	1
Construction	17,389,108	11%	1,109,713	16
Electrical equipment	2,108,818	1%	75,451	28
Electricity, gas, steam and air conditioning	34,612,812	23%	23,273	1,487
Food products, beverages and tobacco	12,628,448	8%	519,220	24
Machinery and equipment	2,476,234	2%	112,677	22
Metal products	7,060,732	5%	274,819	26
Motor vehicles	5,629,701	4%	143,087	39
Other nonmetallic products	10,369,551	7%	44,177	235
Other transport equipment	377,918	0%	43,187	9
Paper products and printing	4,176,070	3%	83,207	50
Pharmaceutical products	1,710,931	1%	58,584	29
Repair and instal. of machines equipment	1,245,060	1%	207,868	6
Rubber and plastic products	2,649,689	2%	104,857	25
Textiles, apparel and leather products	997,382	1%	120,821	8
Water supply and waste management	9,448,896	6%	98,502	96
Wood products	406,373	0%	52,473	8

As can be seen in Table 2, the three value chains with the highest emissions per job are basic metals, chemical products and other nonmetallic products.
It is interesting to note that some value chains that are high emitters of GHG also integrate a significant number of jobs within their activities. For example, construction accounts for 11% of total emissions but, due to the high number of jobs generated in this sector, has an emissions ratio of just 16 TCO2-eq/job. Similarly, the value chain of food products, beverages and tobacco accounts for 8% of total emissions but produces only 24 TCO2-eq/job.
Table 3 presents the emissions related to the activities of each value chain, distributed according to their position in terms of proximity to the final demand. First, it can be observed that value chains vary considerably in terms of their length. For some value chains, there are up to six levels of precedent intersectoral relationships, representing a significant level of GHG emissions (e.g. construction, electrical equipment, machinery and equipment, metal products, motor vehicles, and repair and installation of machinery and equipment), while other value chains are short or their precedent activities do not produce a high number of emissions (computer, electronic and optical products; electricity, gas, steam and air conditioning; other nonmetallic mineral products; other transport equipment; and wood products). The length of value chains impacts the feasibility of establishing circular loops and, consequently, affects the potential for differential effects based on the level at which these loops are implemented within the value chain.

Table 3: Emissions per value chain, intersectoral link position and corresponding emissions (E_{jk})

Value chains	Link 6	Link 5	Link 4	Link 3	Link 2	Link 1	Final Demand
Basic metals		0.1	145	7,963	194,560	3,404,068	4,644,204
Chemical products					54,720	2.287.565	9,764,226
Coke and refined petroleum prod.			21	1,121	19,777	3,700,885	14,079,951
Computer/electronic/optical products							27,494
Construction	0.01	22	1,286	37,813	1,733,327	12,475,771	3,140,911
Electrical equipment	0.01	18	1,001	24,455	475,954	1,448,187	159,221
Electric, gas, steam & air cond.							34,612,812
Food products, beverages and tobacco		6	643	21,879	672,730	5,622,519	6,310 ,677
Machinery and equipment	0.01	21	1,176	28,745	526,485	1,161,360	758,468
Metal products	0.04	83	4,635	116,141	2,092,988	4,680,801	166,167
Motor vehicles	0.01	29	1,598	42,257	942,145	4,134,416	509,285
Other nonmetallic products						933,424	9,43,127
Other transport equipment						228,478	149,440
Paper products and printing			18	1,865	55,091	1,235,754	2,883,360
Pharmaceutical products				2,624	109,693	760,019	838,595
Rep. install. of machin. & equip.	0.003	6	390	10,034	206,908	85,933	173,795
Rubber and plastic products		0	39	5,609	235,965	2,208,003	200,112
Textile and leather products				825	34,510	524,012	438,035
Water and waste management				1,051	55,373	976,808	8,415,664
Wood products						268,834	137,539
TOTAL	**0.1**	**185**	**10,952**	**302,382**	**7,410,226**	**46,904,837**	**96,846,083**
% TOTAL	**0.00%**	**0.00%**	**0.01%**	**0.20%**	**4.89%**	**30.9%**	**63.94%**

Second, overall, the percentage of emissions produced in the final phase of value chains and in the immediately preceding phase by another sector accounts for 94.90% of total emissions. Of the remaining percentage (5.1%), 4.89% is emitted in the intersector relations of link 2. Thus, 99.79% of the emissions included in the model are emitted in the immediate response to final demand and in the two preceding phases.
Third, value chains can be assigned to two differentiated categories: those that concentrate most of the emissions in the last stage of response to final demand and those that induce upstream emissions in other sectors. In the first category, it is worth mentioning electricity, gas, steam and air conditioning; other nonmetallic mineral products; paper products and printing; coke and refined petroleum products; chemicals and chemical products; water supply and waste management; basic metals; and computer, electronic and optical products. The rest of the value chains can be placed in the second category.

4. CONCLUSIONS

As part of a research stream with the ultimate goal of defining a methodology to assess the impact that the circular economy can have on the productive fabric of a region, the objective of this paper is to propose a framework to assess the susceptibility of sectors and value chains to be affected by the implementation of the circular economy. For this purpose, a quantitative method based on EEIOT was used and expanded to incorporate the employment variable. Data processing was used to construct a three-dimensional space based on three axes: value chains, productive sectors, and the position of each sector according to its distance from the final demand of intersectoral relations. In this space, emissions and employment corresponding to the activities retained in the model developed by Retegi et al. (2023) have been identified.

According to the data analysis, it can be observed that, in 10 of the 20 value chains analysed, most of the emissions are generated in the last phase of providing the final demand. For other value chains, most of the emissions are carried out in the immediately preceding phase (link 1). The outcomes of this study enable the classification and qualification of production sectors based on the following criteria:

- Number of value chains in which they are present
- The intensity of emissions per job
- The proximity or distance of the participation in value chains from the final demand

Sectors with participation concentrated in a limited number of value chains, coupled with a high level of emissions per job and a considerable distance from the final demand will be more vulnerable to the implementation of circular economy principles. Furthermore, considering the findings, value chains can be classified based on the following:

- The number of sectors involved and the length of the chain
- The phase during which emissions occur
- The level of emissions and the induced employment

These classifications of sectors and value chains will offer valuable insights that can inform conclusions regarding circular economy policies and, ultimately, their regional impact. For instance, the value chain of electricity, gas, steam and air conditioning exhibits the characteristics of a short chain, a high emission intensity per job, and a significant proportion of total emissions. In this case, the circular economy strategies to emphasise would range from the R0 refuse strategy to the R2 reduce strategy (Kirchherr et al., 2017). Another example is the construction value chain, which accounts for a substantial number of emissions, with fewer emissions in the final phase and many jobs. Considering the challenges associated with recycling construction materials, achieving effective emission reductions would necessitate demand reduction strategies or technological approaches involving material substitutions that facilitate recycling and reuse.

This research is part of a broader line of inquiry aimed at assessing the vulnerability of the productive fabric within a geographical context to the implementation of circular economy strategies. To achieve this objective, further research is needed in areas such as sector qualification that takes into consideration all the above-mentioned factors, incorporates the value added of activities as a key variable alongside employment, conducts qualitative analysis that integrates the specific characteristics and the trends of each value chain (e.g. technological, local vs. global) and assesses vulnerability from a geographic industrial fabric perspective.

As mentioned in the introduction, the use of environmentally extended input–output tables (EEIOTs) inherently presents limitations associated with a certain level of imprecision. However, it provides a more comprehensive perspective compared to tools based on life-cycle analysis. The level of detail in the available information and the use of sector averages do not allow for precise differentiation within the same sector. Nonetheless, the validity of the conclusions may be sufficient to identify priorities among sectors as well as areas requiring further investigation.

REFERENCES

European Commission. 2019. The European green deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. COM (2019) 640 final. Retrieved June 2023 from: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN[1].

INE. (2020). Cuentas medioambientales. Cuenta de emisiones a la Atmósfera [Environmental accounts. Emission to atmosphere accounts] – Año 2020. Retrieved January 2023 from: https://datos.gob.es/es/catalogo/ea0010587-cuentas-de-emisiones-a-la-atmosfera-por-agregacion-de-ramas-de-actividad-cnae-2009-y-hogares-como-consumidores-finales-problematica-ambiental-y-periodo-identificador-api-t26-p084-base_2010-serie-l0-01006-px[2]

INE (2023) DIRCE. Directorio Central de Empresas. Empresas por CCAA, actividad principal (grupos CNAE 2009) y estrato de asalariados. Retrieved June 2023 from: https://www.ine.es/jaxiT3/Tabla.htm?t=39372 [2]

Kirchherr, J., Reike, D., & Hekkert, M. (2017) Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation & Recycling, 127*, 221–232. http://dx.doi.org/10.1016/j.resconrec.2017.09.005[3]

Mies, A., & Gold, S. (2021). Mapping the social dimension of the circular economy. *Journal of Cleaner Production*, *321*, 128960. https://doi.org/10.1016/j.jclepro.2021.128960[3]

OECD (2021) Input–output tables (IOTs) 2021 ed. Retrieved January 2023 from https://stats.oecd.org/Index.aspx?DataSetCode=IOTS_2021[2]

Park, Y., Kim, J., Kyung, D., Park, H. Characterization of Greenhouse Gases Emissions by Economic Sectors Using Environmentally Extended Input-Output Analysis (EEIOA). September 2022. Journal of Korean Society of Environmental Engineers 44(9):308-335. https://doi.org/10.4491/KSEE.2022.44.9.308

Peters, G. P, Minx, J. C., Weber, C. L., & Edenhofer, O. (2010). Growth in emission transfers via international trade from 1990 to 2008. *Proceedings of the National Academy of Sciences of the United States of America 2010, 108*(21), 8903–8908. https://doi.org/10.1073/pnas.1006388108[3]

Potting, J., Hekkert, M., Worrell, E. & Hanemaaijer, A. (2017). Circular economy: Measuring innovation in the product chain. Retrieved January 2023 from: https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf[3]

Ranganathan, J. A., Moorcroft, D. M., Koch, J., & Bhatia, P. (2001). The greenhouse gas protocol: A corporate accounting and reporting standard. Retrieved January 2023 from: https://ghgprotocol.org/corporate-standard[1]

Retegi, J., Ibarra, D., & Igartua, J. I. (2023) Linear representation of greenhouse gas emissions along industrial value chains using environmentally extended input–output tables. 17th International Conference on Industrial Engineering and Industrial Management XXVII Congreso de Ingeniería de Organización Barcelona, Spain, July 6-7, 2023.[4]

[1] Document obtained from web
[2] Database from web page
[3] Article
[4] Conference paper