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Carbon Footprint And Sustainability Indicators In The Automotive Industry Production Chain In Selected Countries

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Abstract:
The objective of the study was to conduct structural and atmospheric emissions analyses for the automotive industry in selected countries. The methodology was based on the multiregional input-output matrix involving 43 countries and the rest of the world. The results showed that there was an 8,841 Gigagram decrease in global CO_2 emissions from the automotive industry during the period 2000-2014, representing a -13% variation. In the year 2014, the sectors with the highest CO_2 emissions were in China, the United States, Germany, and India. The highest growth rate in emissions occurred in India with 383%, followed by Slovakia (332%), Taiwan (210%), Bulgaria (167%), and Russia (158%). The results of the structural decomposition of the variation in CO_2 emissions showed that the intensity effect was the main factor leading to a reduction in CO_2 emissions in the automotive industry. This indicates a decrease in emissions per unit of production. This was the result of increased energy efficiency through new technologies and changes in the energy mix with the use of cleaner sources. On the other hand, the structural and volume effects of final demand contributed to an increase in CO_2 emissions, especially in developing countries. Higher values of the carbon dioxide emissions multiplier indicate less sustainable industries and were obtained for India, Russia, China, Taiwan, and the rest of the world. Conversely, lower values, indicative of more sustainable industries, were obtained for Switzerland, Sweden, Croatia, Germany, and Norway. The spillover of the CO_2 emissions multiplier from the automotive industry exceeded 50% for 29 out of 43 selected countries. Furthermore, most countries (more than 90%) increased spillovers in the period 2000-2014, which indicates that the process of outsourcing emissions from the production chain has deepened.
***Key Word**: carbon dioxide; atmospheric emissions; input-output.*

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I. Introduction

Excess emissions of carbon dioxide and other gases are harmful to the environment and cause an increase in the greenhouse effect, leading to climate change and profound impacts on life on the planet. They are a historical problem arising from human actions. Countries such as the United States, Russia and the European Union bloc are responsible for the accumulated effect of these gases since the industrial revolution. Currently, Brazil, India and China and other developing countries have significantly entered the list of major emitters, but with moral determinations to reduce and adapt economies to solve the problem of climate change.

The increase in the greenhouse effect is not only linked to the emission of carbon dioxide due to the burning of fossil fuels for industry or energy production, but other factors must also be considered to expand the analysis. Activities such as agriculture, forestry, commerce and service provision have their share of responsibility for the emission of greenhouse gases and, therefore, a more comprehensive view of atmospheric emissions is necessary, taking into account the dispersion of production in space. Furthermore, the “outsourcing of emissions” stands out, that is, the dispersion of production processes and atmospheric emissions in space resulting from the globalization of production (global production chains). This leads to the need to analyze and measure the regional (within a country) and interregional (outside the country of origin) effects of gas emissions for different economic sectors.

Considering the problems mentioned, motivation of the present study, the general objective is to carry out structural and atmospheric emissions analyzes for the automobile industry in selected countries. Specifically, (a) countries' participation in carbon dioxide emissions was estimated according to geographic points of view (emissions within the country) and the impact of internal final demand on their global production chains, (b) it was estimated the structural decomposition of the variation in atmospheric emissions (carbon dioxide) into technological effects of final demand and (c) the carbon dioxide emissions multiplier was calculated to evaluate the generation of emissions from the countries' production chains inside and outside their region.

The results make it possible to identify the most polluting production chains with impacts inside and outside the country of origin, to measure the participation of countries in total emissions regardless of geographic delimitation within a vision of global production chains and to measure countries' efforts to adapt production processes (technological innovations) to reduce carbon dioxide emissions in the period 2000 to 2014.

II. Material And Methods

The section presents the methods to be used in the study using the inter-regional input-output system with forty-three countries and the rest of the world in the period 2001-2014. The World Input Output Database [1]. provides the global input-output matrix with 56 sectors and carbon dioxide emissions data [2,3]. Emissions data is detailed in [4,5]. The structural decomposition methodology requires the elimination of the effect of inflation, therefore, there is a need to compare matrices from different years at current prices. The database presents matrices from different years in current values and values from the previous year (Previous Years' Prices – PYP).

Basic Input-output Theory

The interregional input-output model designed by [6] was based on [7] and has a large volume of intersectoral and interregional data on flows of goods and services. Considering Z the matrix of monetary flows from sector i to sector j, X is the sectoral production vector and A is the matrix of technical coefficients that can be calculated by:

$$A = Z\left(\hat{X}\right)^{-1} \tag{1}$$

According to [8], the input-output system can be expressed by:

$$(I - A)X = Y \tag{2}$$

Where Y is the final demand vector and the other elements were previously defined. The elements of equation (2) can be rearranged as follows:

$$X = (I - A)^{-1}Y \tag{3}$$

The inverse Leontief matrix is given by:

$$S = (I - A)^{-1} \tag{4}$$

And its elements are Sij.

Structural Decomposition Analysis of Emissions Variation

The structural decomposition model (Structural Decomposition Analysis, DAS) adopted in the present research was used by [9] to analyze carbon dioxide emissions from the United States, European Union and BRIC countries (Brazil, Russia, India and China) and is close to that of [10], which can be applied to the job market, emissions and energy. The calculations consider two points in time between which changes in the factor of interest occur. For the present study, the factor of interest is the number of jobs. Variations in the factor of interest (Δc) can be explained by economic growth functions and efficiency changes. The variations of the factor per monetary unit are described by (Δn), which show the efficiency in the use of the factor or intensity of its use. The modification of the factor of interest can also be explained by variations in the economy's technical coefficients (ΔS), changes in the composition of the structure of final demand (Δy^s) and the increase in the volume (absolute value) of final demand (Δy^v). The equation to calculate the factor decomposition can be described by:

$$\Delta c = \Delta n + \Delta s + \Delta y^s + \Delta y^v \tag{5}$$

Considering the element c_j of the column vector c represents the value of the variation of the factor of sector j in the period of analysis. The total factor generated for all sectors of the economy can be determined as a function of sectoral production determined by:

$$c = NX \quad (6)$$

The column vector X contains the sectoral production values, and the elements of N indicate the coefficients of the factor, which represent the amount of the factor of interest generated per monetary unit of production in the sector. The column vector Equation (6) can be rewritten as:

$$c = NX = NSy^s y^v \quad (7)$$

For the present study, we have 43 countries and the rest of the world (44 regions) that have 56 sectors each, and the elements of equation (7) are defined for n sectors of the economy:

N is the vector (1xn) of employment coefficients (jobs per million dollars);
S is the inverse Leontief matrix (nxn);
y^s is the vector (nx1) of final demand coefficients (structure of final demand);
y^v is the vector (nx1) with the absolute values of sectoral final demand.

Assuming the periods t and t-1 and that the data are in current values (eliminating the effect of inflation), the structural decomposition of the employment variation becomes:

$$\Delta c = (\Delta N)S_{(t)}y^s_{(t)}y^v_{(t)} + N_{(t-1)}(\Delta S)y^s_{(t)}y^v_{(t)} + N_{(t-1)}S_{(t-1)}(\Delta y^s)y^v_{(t)} + N_{(t-1)}S_{(t-1)}y^s_{(t-1)}(\Delta y^v)\Delta c = (\Delta N)S_{(t)}y^s_{(t)}y^v_{(t)} + N_{(t-1)}(\Delta S)y^s_{(t)}y^v_{(t)} + N_{(t-1)}S_{(t-1)}(\Delta y^s)y^v_{(t)} + N_{(t-1)}S_{(t-1)}y^s_{(t-1)}(\Delta y^v) \quad (8)$$

According to [11] equation (8) describes one of the polar forms and the other will be:

$$\Delta c = (\Delta N)S_{(t-1)}y^s_{(t-1)}y^v_{(t-1)} + N_{(t)}(\Delta S)y^s_{(t-1)}y^v_{(t-1)} + N_{(t)}S_{(t)}(\Delta y^s)y^v_{(t-1)} + N_{(t)}S_{(t)}y^s_{(t)}(\Delta y^v)\Delta c = (\Delta N)S_{(t-1)}y^s_{(t-1)}y^v_{(t-1)} + N_{(t)}(\Delta S)y^s_{(t-1)}y^v_{(t-1)} + N_{(t)}S_{(t)}(\Delta y^s)y^v_{(t-1)} + N_{(t)}S_{(t)}y^s_{(t)}(\Delta y^v) \quad (9)$$

Considering [12] proposal, the average of the two polar forms is taken to calculate the four effects of the structural decomposition of variations in the factor of interest, which in the present study is the number of jobs:

$$\Delta c = {}^1/_2\left((\Delta N)S_{(t)}y^s_{(t)}y^v_{(t)} + (\Delta N)S_{(t-1)}y^s_{(t-1)}y^v_{(t-1)}\right) \text{ (Intensity of emission)}$$
$$+ {}^1/_2\left(N_{(t-1)}(\Delta S)y^s_{(t)}y^v_{(t)} + N_{(t)}(\Delta S)y^s_{(t-1)}y^v_{(t-1)}\right) \text{ (Technology)}$$
$$+ {}^1/_2\left(N_{(t-1)}S_{(t-1)}(\Delta y^s)y^v_{(t)} + N_{(t)}S_{(t)}(\Delta y^s)y^v_{(t-1)}\right) \text{ (Structure of final demand)}$$
$$+ {}^1/_2\left(N_{(t-1)}S_{(t-1)}y^s_{(t-1)}(\Delta y^v) + N_{(t)}S_{(t)}y^s_{(t)}(\Delta y^v)\right) \text{ (Volume of final demand)} \quad (10)$$

To obtain the results for each sector of the economy, N must be taken in diagonalized form:

$$C = \hat{N}X = \hat{N}Sy^s_{(t)}y^v_{(t)} \quad (11)$$

It is noted that positive values of the intensity effect will show a drop in labor productivity. On the other hand, if the results of this effect are negative, this will mean that there has been an increase in labor productivity and a decrease in the number of jobs needed to produce one monetary unit (one million dollars). The technology effect refers to changes in the matrix of technical coefficients, A, which can have positive or negative effects on the variation in jobs. The structure of final demand shows the variation in the proportion of acquisitions of the components of final demand considered as a whole. The elements of final demand are Households, Government, Exports and Investment. Changing the participation of each sector in the acquisition of products and services in demand can have positive or negative effects on the generation of jobs. The volume effect of final demand can be interpreted as economic growth and positive values indicate an increase in the number of people employed due to growth in final demand. It is possible to obtain negative values, which would indicate recession and job losses.

Carbon Dioxide Emissions Multiplier

Using the inverse Leontief matrix, it is possible to estimate for each sector of the economy how much emissions are generated directly and indirectly for each monetary unit produced for final demand (Miller and Blair, 2009):

$$G_j = \sum_{i=1}^{n} s_{ij}v_i \quad (12)$$

Where:
G_j is the total impact, direct and indirect, on emissions.
s_{ij} is the ij-eth element of the inverse Leontief matrix and
v_i is the direct emissions coefficient.

The spillover effect is the impact of the generation of emissions outside the region of origin of the sector, thus, the regional impact occurs within the country of origin of the sector and the inter-regional effect (spillover) is the inter-regional impact were of its origin which can be calculated as a percentage of the total value of emissions.

III. Result

Table 1 presents the values and rates of variation of carbon dioxide emissions for energy generation in the automobile industry in selected countries. Emission values for the period 2000-2014 and rate of change are in annual Gigagrams. It is observed that the automotive industries with the highest carbon emissions in 2014 were China, the United States, the Rest of the World, Germany and India. The countries with the lowest absolute values were Greece, Cyprus, Luxembourg, Lithuania and Malta. The classification of the biggest polluters was modified during the period of analysis, as China was in second place in the year 2000 and the United States in first, subsequently reversing the positions. Other countries also changed their position, like Brazil, which moved from 17th place to 9th place in the ranking, while Canada dropped from 5th place in the year 2000 to 14th place.

Despite the importance of identifying the biggest polluting automotive industries in absolute values, efforts to reduce carbon dioxide emissions must be considered. Therefore, the variation rates presented in Table 1 indicate the commitment of the countries and their sectors under analysis to seek alternatives to mitigate the generation of CO2. The total values show that there was a decrease of 8,841 Gigagrams in global emissions from the automobile industry, which represented a variation of -13%. The highest rate of growth in emissions from the automobile industry occurred in India, with an increase of 383% in the period 2000-2014, followed by the Slovak Republic with a growth of 332%, then Taiwan, with 210%, Bulgaria with 167% and Russia with 158%. %. On the other hand, the highest rates of decrease were observed for Greece (-100%), in other words, the production of automotive vehicles practically went to zero; Cyprus (-97%); Lithuania (-88%), Romania (-86%); and Finland (-82%).

The results of the rate of variation in CO_2 emissions from the countries' automotive industry indicate that developing countries showed growth in emissions while developed countries showed a drop in values (negative rates). Developing countries have population growth, increased per capita income and other factors that drive final demand, which results in increased emissions.

It is important to note that the results of the variation in emissions from the production of motor vehicles in different countries only show the indicators, but do not present the causes of the changes. In this way, the use of the structural decomposition methodology based on the input-output matrix makes it possible to measure the factors of variations and disaggregate them into emission intensity, technology, structure and volume of final demand effects.

Table 1: Carbon dioxide emissions in Gigagrams per year from the automobile industry in selected countries and the rest of the world in the years 2000 and 2014. Values in Gigagrams (Gg).

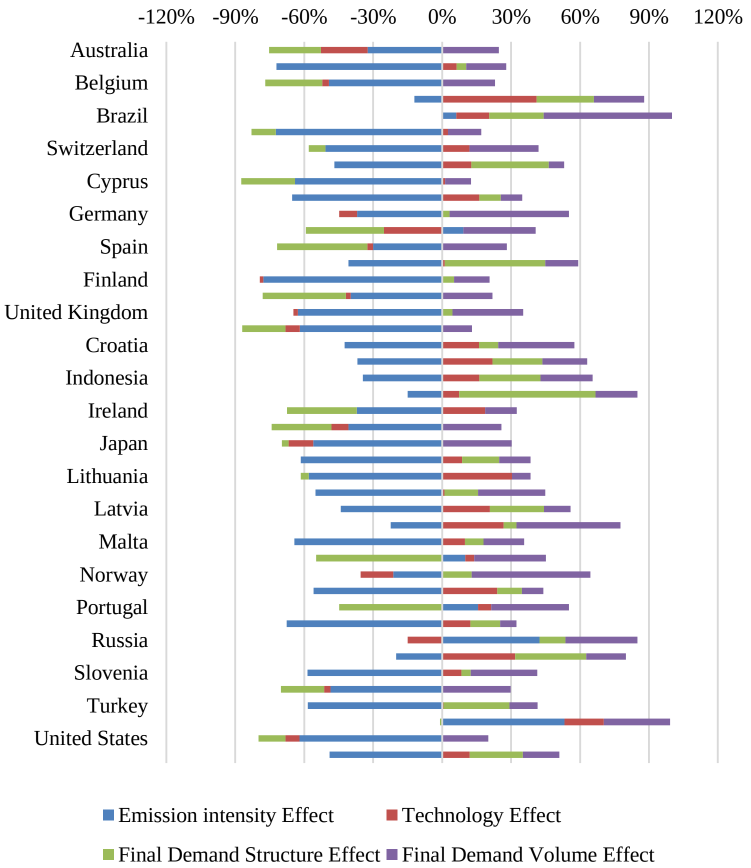
Country		2000		2014		Variation 2000-2014	Variation 2000-2014 (%)
		Emissions	Rank	Emissions	Rank		
1	Australia	251	21	126	24	-125	-50%
2	Austria	143	25	33	27	-110	-77%
3	Belgium	187	23	73	26	-114	-61%
4	Bulgaria	8	39	22	31	13	167%
5	Brazil	885	17	1838	9	953	108%
6	Canada	4068	5	887	14	-3180	-78%
7	Switzerland	21	34	17	33	-4	-19%
8	China	12161	2	17147	1	4986	41%
9	Cyprus	6	40	0	43	-6	-97%
10	Czech Republic	768	18	226	22	-542	-71%
11	Germany	4364	4	4675	4	311	7%
12	Denmark	24	32	19	32	-5	-22%
13	Spain	1690	11	884	15	-805	-48%
14	Estonia	10	38	15	34	6	58%
15	Finland	58	28	11	36	-48	-82%
16	France	1993	9	715	17	-1278	-64%
17	United Kingdom	2175	8	1587	10	-588	-27%
18	Greece	51	30	0	44	-51	-100%
19	Croatia	3	41	5	38	1	35%
20	Hungary	133	26	226	21	93	70%
21	Indonesia	942	15	1474	11	532	56%
22	India	953	14	4601	5	3648	383%
23	Ireland	15	35	6	37	-10	-63%

24 Italy	1908	10	941	13	-967	-51%
25 Japan	3502	7	2184	7	-1318	-38%
26 Republic of Korea	3673	6	2077	8	-1597	-43%
27 Lithuania	11	36	1	41	-10	-88%
28 Luxembourg	1	44	1	42	0	-15%
29 Latvia	2	43	3	39	1	62%
30 Mexico	939	16	1381	12	442	47%
31 Malta	3	42	2	40	-1	-44%
32 Netherlands	119	27	108	25	-11	-10%
33 Norway	11	37	14	35	3	29%
34 Poland	474	19	292	19	-182	-38%
35 Portugal	21	33	23	30	2	10%
36 Romania	217	22	30	28	-187	-86%
37 Russia	1142	13	2947	6	1805	158%
38 Slovakia	57	29	247	20	190	332%
39 Slovenia	37	31	29	29	-8	-21%
40 Sweden	308	20	170	23	-139	-45%
41 Turkey	1482	12	782	16	-699	-47%
42 Taiwan	185	24	574	18	389	210%
43 United States	15934	1	5498	2	-10436	-65%
44 Rest of the world	4757	3	4961	3	204	4%
Totals	65692	-	56852	-	-8841	-13%

Source: research results.

Figure 1 illustrates the results for the calculations of the structural decomposition of the variation in CO_2 emissions from the automobile industry in the selected countries in the period 2000-2014. Therefore, the variation in absolute value presented in Table 1 was decomposed into four effects: emissions intensity, technology, structure of final demand and volume of final demand. The graph in Figure 1 shows percentage values of the contribution of each effect to the variation in CO_2 emissions in each country.

Figure 1: Structural decomposition of the variation in carbon dioxide emissions from the automobile industry in the selected countries and the rest of the world in the period 2000-2014. Values in percentages of the effects in relation to the balance in absolute value.



Source: research results.

The intensity effect was negative for most of the countries analyzed. This shows that the ratio of CO_2 emissions per unit of production (one million dollars) decreased in the period 2000-2014, this result is directly related to changes in the countries' energy generation matrix and greater efficiency in the use of energy in the automotive sector and its production chain. The intensity effect was the most important factor in mitigating emissions for the automobile industry, but with important exceptions such as Taiwan and Russia.

The technology effect refers to the variation in the combination of inputs and monetary flows used by the automotive industry and its impact on sectoral carbon dioxide emissions. The results were variable, negative for Australia, Denmark and Russia and positive for Bulgaria, Hungary and Indonesia. However, the contribution of the technology effect is relatively smaller than the emissions intensity effect for most countries.

The structure of final demand shows the impacts on CO_2 emissions resulting from the comparative analysis of the composition of consumption between the years 2000 and 2014. The components of this final consumption are families, government, exports and investment. The structure effect of final demand contributed to the increase in emissions in most countries, being an important factor regardless of the level of development.

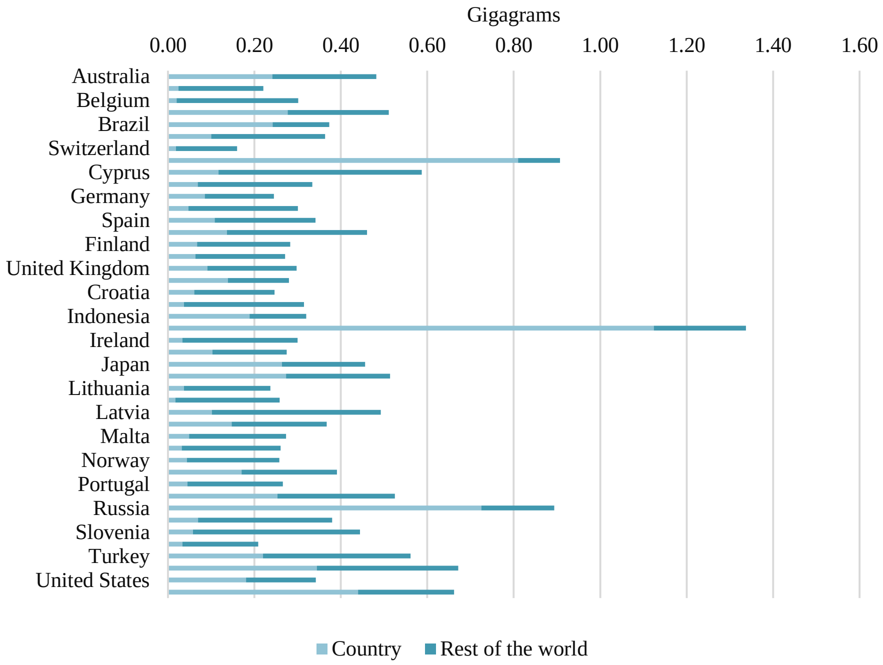
Economic growth, called the final demand volume effect, refers to the increase in consumption and its impact on the generation of carbon dioxide from the automobile industry in selected countries, notably developing countries such as Brazil, China, India, Turkey and Indonesia. For some developed countries the effect was negative, such as Belgium, France, Ireland and the Netherlands.

The analysis of the results of the structural decomposition of the variation in CO_2 emissions showed that the global automotive industry was successful in reducing emissions mainly by reducing the ratio of emissions per unit of production, which implies greater efficiency in the use of energy through new technologies and changes in the energy matrix to cleaner sources.

Figure 2 illustrates the multiplier of carbon dioxide emissions from the automobile industry in the selected countries for the year 2014, the values have units of Gigagrams per increase of one million dollars in final demand and are decomposed into intra-regional effects (within the country) and inter-regional (outside the sector's country of origin). The highest values indicate less sustainable industries and were obtained for India, Russia, China, Taiwan and the rest of the world. On the other hand, the lowest values and those with more sustainable industries were obtained for Switzerland, Sweden, Croatia, Germany and Norway.

For India, the results showed that the increase of one million dollars in final demand in motor vehicles resulted in 1.12 Gigagrams in CO_2 emissions within the country and 0.21 Gigagrams in the production chain outside the country (world). In the case of Brazil, the same increase in demand presented values of 0.24 and 0.13 Gigagrams for the effects within the country and in the world, in relative terms it represented less than a third of India's total emissions in the industrial production chain.

Figure 2: Generation of carbon dioxide emissions for the one-million-dollar variation of the countries automobile industry, 2014. Values in Gigagrams (Gg).

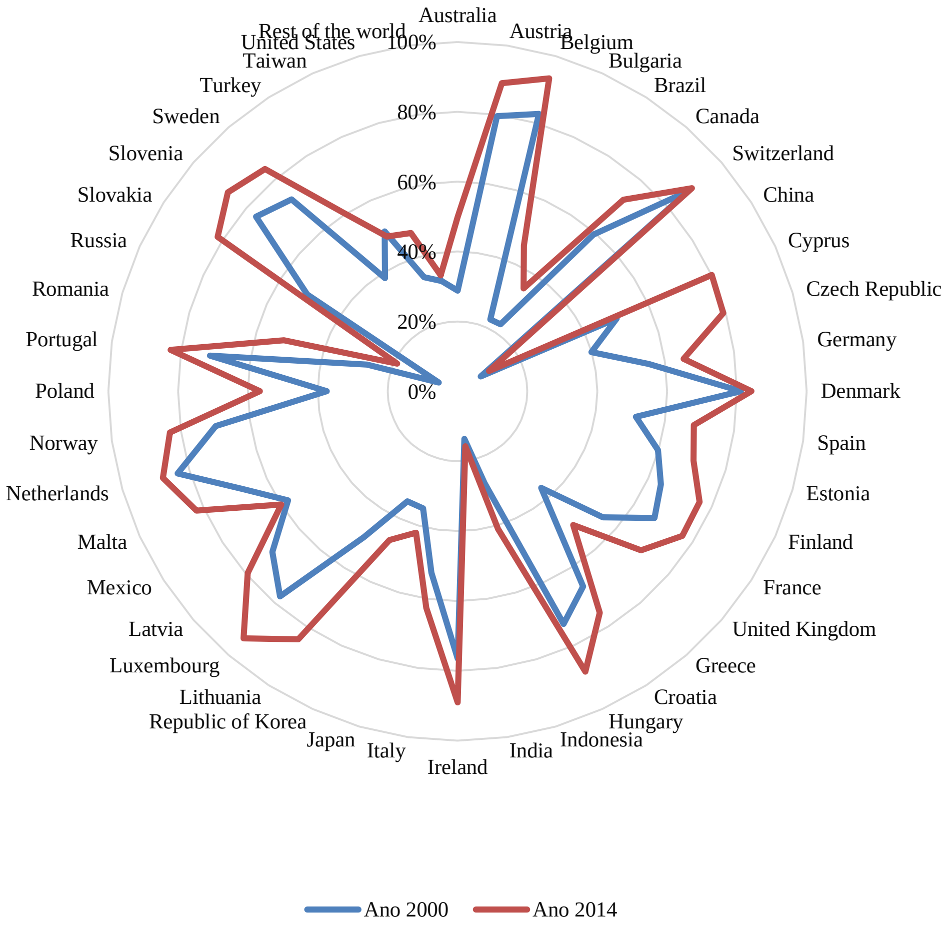


Source: research results.

The visual analysis of Figure 2 indicates that the majority of CO_2 generation in the countries' automotive industry occurs in the production chain and, mainly, outside the sector's country of origin for most countries. Considering this characteristic, the results were used to prepare Figure 3 illustrates the spillover of the multiplier of CO_2 emissions from the automobile industry in the selected countries in the years 2000 and 2014. The values are in percentage of the inter-regional effect in relation to the total effect. The values are greater than 50% for 29 out of 43 selected countries. The highest spillover values were identified in Luxembourg with 94%, Belgium with 93%, Switzerland and Ireland with 89% and Hungary and the Netherlands with 88%.

It is noted that for most countries (more than 90%) spillover increased in the period 2000-2014, which indicates that the process of outsourcing emissions from the production chain has become more important. In this way, a country's automobile industry can reduce its CO_2 emissions internally by purchasing components (inputs) from other regions that generate air pollution outside its geographic area. This is a limitation for international agreements to mitigate carbon dioxide emissions, in which targets are determined based on the geographic limits of countries and do not consider indirect pollution from production chains.

Figure 3: Spillover of carbon dioxide emissions generation into the one-million-dollar change of countries' automobile industry, 2000-2014.



Source: research results.

IV. Conclusion

The total values show that there was a decrease of 8,841 Gigagrams in global emissions from the automobile industry in the period 2000-2014 with a variation of -13%. The automotive industries with the highest carbon emissions in 2014 belonged to China, the United States, the Rest of the World, Germany and India. The highest rate of growth in emissions occurred in India, with an increase of 383%, followed by the Slovak Republic with growth of 332%, then Taiwan, with 210%, Bulgaria with 167% and Russia with 158%. On the other hand, the highest rates of decrease were observed in Greece (-100%), that is, production of automotive vehicles practically went to zero; Cyprus (-97%); Lithuania (-88%), Romania (-86%); and Finland (-82%).

The analysis of the results of the structural decomposition of the variation in CO2 emissions showed that the global automotive industry was successful in reducing emissions mainly by reducing the ratio of emissions per unit of production (intensity effect), which implies greater efficiency in the use of energy through new technologies and changes in the energy matrix to cleaner sources. On the other hand, the structure and volume effects of final demand contributed to the increase in CO_2 emissions, notably in developing countries.

Higher values of the carbon dioxide emissions multiplier indicate less sustainable industries and were obtained for India, Russia, China, Taiwan and the rest of the world. On the other hand, the lowest values and those with more sustainable industries were obtained for Switzerland, Sweden, Croatia, Germany and Norway.

The spillover multiplier of CO2 emissions from the automobile industry was greater than 50% for 29 out of 43 selected countries. The highest spillover values were identified in Luxembourg with 94%, Belgium with 93%, Switzerland and Ireland with 89% and Hungary and the Netherlands with 88%. Furthermore, most countries (more than 90%) increased spillovers in the period 2000-2014, which indicates that the process of outsourcing emissions from the production chain has deepened.

New studies on the automobile industry can be developed with environmental variables such as water and materials to identify changes in technology and efficiency in the use of resources.

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