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Gross Domestic Product, Carbon Footprint and Sustainability of Agribusiness

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Abstract:
The objective of the study was to measure and compare the agribusiness production chain in 66 countries and the rest of the world considering the variables income (Gross Domestic Product - GDP) and carbon dioxide emissions from burning fossil fuels between the years 1995 and 2018 with methodology based on the input-output matrix. The production chain was divided into Inputs (I), Agriculture (II), Industry (III) and Services (IV). The GDP of world agribusiness in 1995 was around five trillion dollars in current values and accounted for 16.6% of world GDP, rising to about twelve trillion dollars in 2018, decreasing its share to 14.8%. In terms of emissions, agribusiness generated close to 1.8 million tons of carbon dioxide in 1995, accounting for 10.3% of total emissions. Emissions from agribusiness increased by around 400 million tons between 1995 and 2018, however, the share in the total decreased to 7.6%. The aggregates showed changes in the participation values (%) in the total GDP and agribusiness emissions, with (I) Inputs being the aggregate that most increased emissions. The values of the sustainability indicator carbon dioxide emissions from the burning of fossil fuels per unit of income showed that the world productive sector presented in 2018 the generation of 179 tons per million current dollars while agribusiness presented the value of 349. The results of the sustainability indicator calculated as the ratio of emissions per unit of income appreciated that in most countries agribusiness has shown itself capable of increasing income with a lower value of emissions in relation to the average of the economy.
Key Word:poluição atmosférica; dióxido de carbono; meio ambiente; insumo-produto.

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I. Introduction

Climate changes caused by emissions of greenhouse gases into the atmosphere by human activities impact the life cycle and determine events such as droughts, excessive rainfall and sea level rise. Industrialized countries are historically responsible for the accumulation of carbon dioxide in the atmosphere. On the other hand, developing nations are primarily responsible for the increase in emissions in recent history, mainly due to economic growth and increased final demand. Global warming is still ongoing, despite the adoption of new cleaner production technologies and changes in the energy matrix (Pompermayer Sesso et al., 2020).

Negotiations around the problem of global warming evolved towards each country determining its targets for reducing carbon emissions (Paris Agreement). The objective of the nations is to achieve transformations in the production chains, which include new production technologies and energy generation, to meet society's demand for goods and services within the concept of sustainability, that is, the search for a balance between the supply of human needs and preservation of natural resources so as not to compromise the quality of life of future generations (Bueno Rubial, 2016; Okereke & Coventry, 2016; Afionis, 2017). The estimation of the carbon footprint has become important to establish CO2 emission reduction targets, which is the impact on carbon dioxide emissions produced by a sector, product, productive process, nation or person (Thomas & Callan, 2016).

The modern concept of agribusiness dictates that this is the set of activities involved in providing food and fiber to society, in addition to contributing to environmental balance. Agribusiness encompasses the supply of inputs, agriculture, industry and services and estimating its share in the total emissions of countries and establishing its degree of sustainability through indicators is an important step for countries to know the level of pollution and set targets for reduction and adjustment of production systems to achieve sustainability.

Considering the economic importance of agribusiness and its sustainability, the objective of this research was to measure the production chain in 66 countries and the rest of the world, evaluating the variables income and carbon dioxide emissions from burning fossil fuels between the years 1995 and 2018. Specifically,

it is intended to identify the main countries that emit carbon dioxide by burning fossil fuels in the productive sector and analyze the evolution of emissions in the period 1995-2018, sizing agribusiness in terms of income (Gross Domestic Product - GDP) and emissions of carbon dioxide to analyze its evolution, compare results between countries and elaborate sustainability indicators. For the present study, the carbon footprints of agribusiness and the productive sector of each country were calculated as the volume (millions of tons) of carbon dioxide produced during a year. Furthermore, the estimation of sustainability indicators that do not depend on the size of the economy and the total volume of emissions is important, as it makes comparisons between countries possible.

II. Material And Methods

The database prepared by the Organization for Economic Cooperation and Development (OECD, 2020) is the source of the input-output matrices and carbon dioxide (CO_2) emissions. Emissions are related to the productive sectors of countries by burning fossil fuels in millions of tons per year. Therefore, it is important to note that the data used in the survey do not incorporate emissions from factors such as changes in land use and production methods (deforestation, fires, methane and CO_2 emissions from cattle and others). The data are from the period 1995-2018 and have 66 countries and the aggregate Other Countries (rest of the world), which represented more than 90% of world income in the years of the study. The list of countries and their acronyms are:

Australia	AUS	Luxembourg	LUX	Cyprus	CYP
Austria	AUT	Mexico	MEX	India	IND
Belgium	BEL	Netherlands	NLD	Indonesia	IDN
Canada	CAN	New Zealand	NZL	Hong Kong	HKG
Chile	CHL	Norway	NOR	Kazakhstan	KAZ
Colombia	COL	Poland	POL	Lao	LAO
Costa Rica	CRI	Portugal	PRT	Malaysia	MYS
Czech Republic	CZE	Slovak Republic	SVK	Malta	MLT
Denmark	DNK	Slovenia	SVN	Morocco	MAR
Estonia	EST	Spain	ESP	Myanmar	MMR
Finland	FIN	Sweden	SWE	Peru	PER
France	FRA	Switzerland	CHE	Philippines	PHL
Germany	DEU	Turkey	TUR	Romania	ROU
Greece	GRC	United Kingdom	GBR	Russian Federation	RUS
Hungary	HUN	United States	USA		
Iceland	ISL	Argentina	ARG	Saudi Arabia	SAU
Ireland	IRL	Brazil	BRA	Singapore	SGP
Israel	ISR	Brunei Darussalam	BRN	South Africa	ZAF
Italy	ITA			Taipei	TWN
Japan	JPN	Bulgaria	BGR	Thailand	THA
Korea	KOR	Cambodia	KHM	Tunisia	TUN
Latvia	LVA	China	CHN	Viet Nam	VNM
Lithuania	LTU	Croatia	HRV	Rest of the World	ROW

The methodology used in the present study for dimensioning agribusiness was adapted from Furtuoso et al. (1998) and Bajan & Mrówczynska-Kaminska (2020), who use the input-output matrix. The method is based on the division proposed by Davis and Goldberg (1957) into four parts or aggregates. Thus, aggregate (I) represents inputs, aggregate (II) agriculture, aggregate (III) represents agroindustry and aggregate (IV) services. The adapted methodology was applied to data obtained from the OECD (2020) for 66 countries and Rest of the world (aggregated into Rest of the World) to estimate income generation and carbon dioxide emissions from burning fossil fuels.

Agribusiness is composed of the aggregates (I) Inputs, (II) Agriculture, (III) Industry and (IV) Distribution. The agribusiness GDP measurement method considers that the first aggregate is the inputs for the sector (1) Agriculture, forestry and fishing. The monetary values of these inputs purchased by the agricultural sector are disclosed in the input-output matrices. Aggregate II is the agricultural sector, which covers all activities of animal and vegetable production, extractivism and fishing. The sectors of aggregate III (industry) are Food, beverages and tobacco; Textiles, clothing, leather and related products; Wood and wood products and cork and Paper and printing products. Aggregate IV refers to sectors related to trade and services.

The calculations presented in this section refer to the size of agribusiness in terms of GDP, and the estimates of carbon dioxide emissions from burning fossil fuels follow the same procedure. The measurement of

aggregate I is carried out by Eq. (1), which begins by multiplying the values of the input columns used by the Agriculture sector by the respective added value coefficients (AVC_i), where i = 45 sectors. The GDP of aggregate I is calculated by:

$$GDP_I = \sum_{i=1}^{n} z_i \times AVC_i \quad (1)$$

GDP_I is the GDP of aggregate I (inputs),
z_i is the total value of the input of sector i for agriculture and livestock and
AVCi is the added value coefficients of sector i.

Added Value Coefficients (AVC_i) are obtained by dividing the Value Added at Market Prices for each sector (AV_{MP}) by the respective production (X_i), according to Eq. (2):

$$AVC_i = \frac{AV_{MP\,i}}{X_i} \quad (2)$$

Value Added at market prices (AV_{MP}) is obtained by adding value added at basic prices (AV_{BP}) to net indirect taxes (NIT). Therefore, we have $AV_{MP} = AV_{BP} + NIT$.

The measurement of Aggregate II is carried out in Eq. (3), which considers in the calculation the Added Value of the Agriculture, Forestry and Fishing sector and subtracts the added value of the agricultural inputs used by the sector itself. Then there is that:

$$GDP_{II} = AVA_{PM} - z_1 \times AVC_1 \quad (3)$$

GDP_{II} is the GDP of aggregate II (Agriculture),
AVA_{PM} is the Added Value of Agriculture and the other variables are as previously defined and
z_1 x AVC_1 is the value of the agricultural input used by the sector itself.

Aggregate (III) covers agroindustries identified by factors related to the use of agricultural products as inputs; percentage share of agricultural products in the total inputs of the sector and sectors that carry out the first, second and third transformations of basic agricultural products. The measurement of Aggregate (III) is carried out in Eq. (4) by the sum of the added values of the agro-industrial sectors subtracted from the added values of these sectors that were used as inputs of Aggregate (II). The sectors of aggregate III (industry) are Food, beverages and tobacco; Textiles, clothing, leather and related products; Wood and wood products and cork and Paper and printing products. It must be:

$$GDP_{III} = \sum_{i=1}^{k} \left(AV_{PM\,i} - z_i \times AVC_i\right) \quad (4)$$

$GDP_{II\,I}$ is the GDP of the aggregate (III) of industry and k = 4 agricultural-based industries.

The measurement of the Aggregate (IV) performed by Eq. (5) considers the Added Value of the sectors related to Transport, Commerce and Services. The share related to agribusiness of the total Added Value of these sectors is calculated by the share of agricultural and agroindustrial products in the final demand for products. The process of calculating the Value Added of the IV Aggregate starts with the definition of the Domestic Final Demand (DFD):

$$DFD = GFD - NIT_{DF} - IP_{DF} \quad (5)$$

DFD is the domestic final demand,
GFC is the global final demand,
NIT_{DF} are the net indirect taxes paid by final demand and
PI_{DF} are the imported products for final demand

The trade margin of the transport, commerce and services (MC) sectors is calculated by Eq. (6):

$$MM = AVT_{MP} + AVM_{MP} + AVS_{MP} \quad (6)$$

MM is the market margin,
AVT_{MP} is the added value of the transport sector at market prices,
AVM_{MP} is the added value of the trade sector at market prices and
AVS_{MP} is the added value of the services sector at market prices.

The commercialization margin (MM) and the Domestic Final Demand (DFD) are used in the calculation of the Commerce and Services aggregate (Distribution of agribusiness products) and the added values of the commerce and services sectors that were used as inputs of the Aggregate (II), according to Eq. (7):

$$GDP_{IV} = MM \times \frac{DF_A + \sum_{i=1}^{k} DF_k}{DFD} - \sum_{i=1}^{q} (z_i \times AVC_i) \quad (7)$$

GDP_{IV} is the GDP of aggregate IV,

DFD is the domestic final demand,
DF_A is the final demand of agriculture,
DF_k is the final demand of the agro-industrial sectors (k = 4) and
q = trade and services sectors.

The total GDP of Agribusiness is given by the sum of its aggregates in Eq. 8:

$$GDP_{AGRO} = GDP_I + GDP_{II} + GDP_{III} + GDP_{IV} \quad (8)$$

GDP_{AGRO} is the Agribusiness GDP.

The results are divided into three subsections: the first aims to identify the main polluting countries and the evolution of carbon dioxide emissions. In the second subsection, the analysis of GDP values and agribusiness emissions is carried out, and the third presents the discussion on sustainability indicators.

III. Resultand Discussion

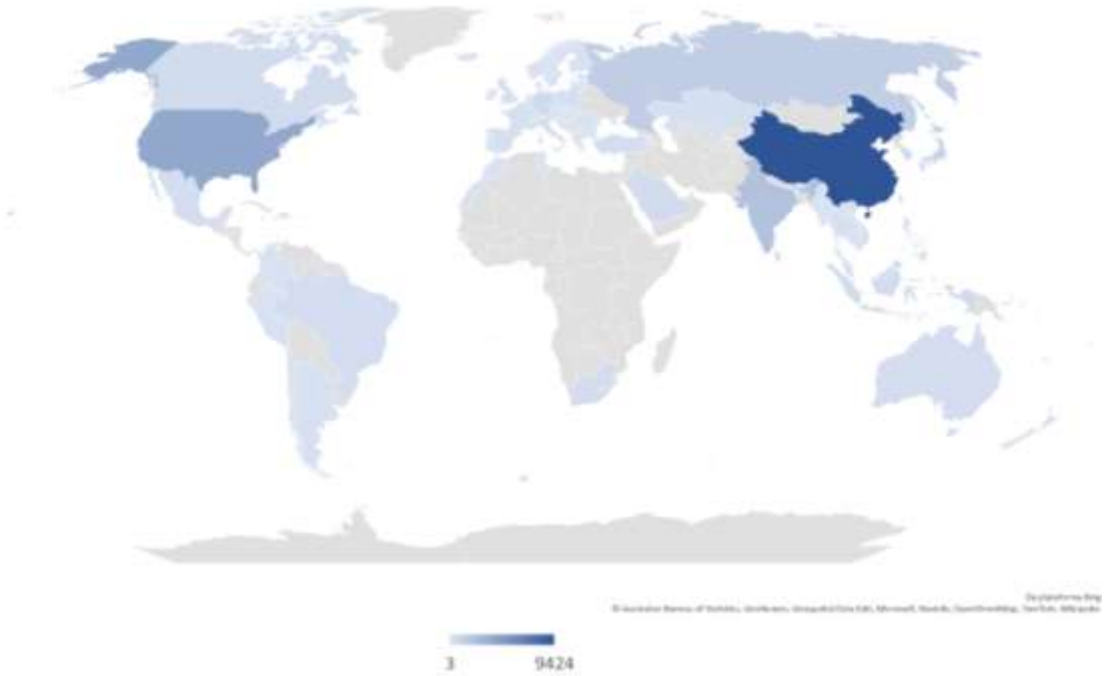
The results are divided into three subsections: the first aims to identify the main polluting countries and the evolution of carbon dioxide emissions. In the second subsection, the analysis of GDP values and agribusiness emissions is carried out, and the third presents the discussion on sustainability indicators.

Major Polluters

Considering the challenges of reducing carbon emissions to control climate change, it is important to identify the main polluters and the growth rates of emissions over time to measure the responsibilities of each country. The maps referring to Figures 1 and 2 were created with Excel 365 through the Bing Platform. Figure 1 shows countries' carbon dioxide emissions from burning fossil fuels in millions of tons annually. The biggest polluters can be identified on the map as China, United States, India, Russia, Japan, South Korea and Germany, respectively. The United States, Japan, Germany and Russia have historical responsibility for the accumulation of emissions from industrialization and, in addition, high total values of current emissions. On the other hand, China, India and South Korea are developing countries with relatively more recent industrialization and which have higher rates of economic growth with the incorporation of people into the consumer market and an increase in industrial production and, consequently, atmospheric emissions.

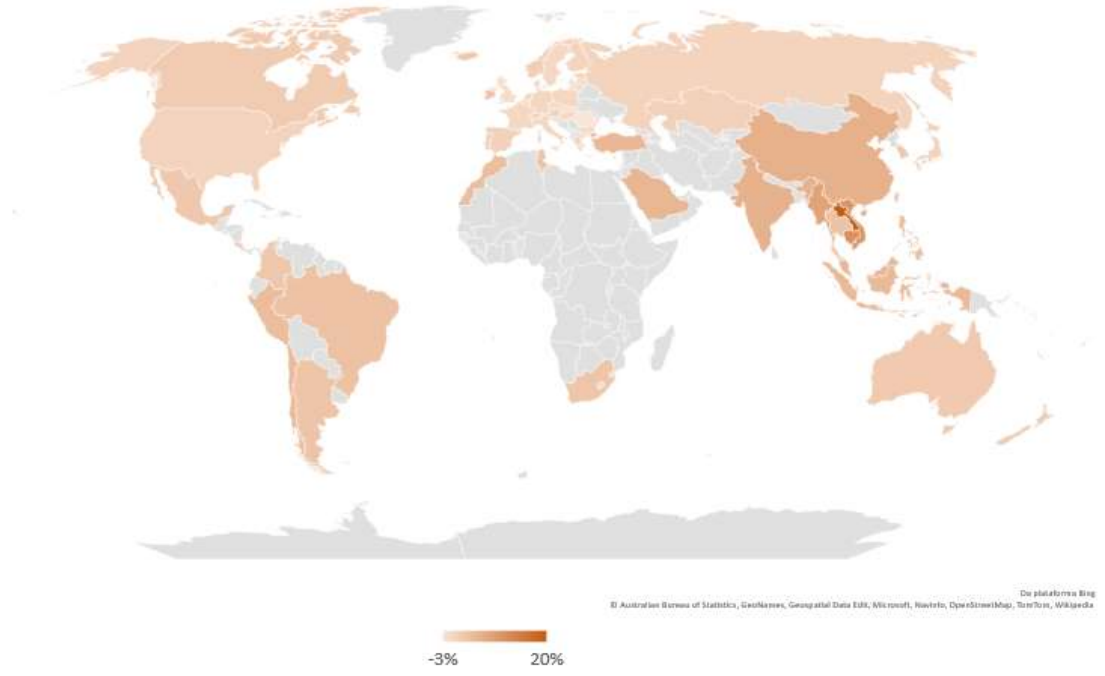
The identification of the biggest polluters in absolute values is important to assess the responsibility of the countries and the need for mitigation, however, there are countries that are not among the main polluters and have growth rates of emissions higher than the average. Figure 2 shows the percentage change in carbon dioxide emissions from burning fossil fuels in the countries' productive sectors. It is observed that most of the increase in emissions is the responsibility of developing countries, we can mention China, India, Colombia, Indonesia, Peru, Saudi Arabia, Malaysia and Vietnam. This is one of the reasons for abandoning the Kyoto Protocol, as the responsibility for reducing emissions fell mainly on developed countries. In the most recent Paris agreement, each country sets its reduction target according to its possibilities.

Figure 1. Carbon dioxide emissions from burning fossil fuels in the productive sector of countries in 2018. Values in millions of tons per year.



Source: Survey calculations based on OECD data (2020).

Figure 2. Average annual rate of change in carbon dioxide emissions from burning fossil fuels in countries, from 1995 to 2018. Values in annual percentages.



Source: Survey calculations based on OECD data (2020).

Table 1 shows carbon dioxide emissions from burning fossil fuels in the productive sector in total values (millions of annual tons), share (%) and variations of the top twenty polluters in absolute values for the year 2018. The five biggest polluters are responsible for approximately 90% of the 26 billion tons emitted in 2018. Data on variations in absolute and relative values of carbon dioxide indicate whether the country is increasing emissions and following a path contrary to the international consensus on the need to reduce climate change risks caused by air pollution. The biggest increases in emissions share are from Vietnam (827%), China

(259%), India (243%), Saudi Arabia (189%), Indonesia (157%), Turkey (171%) and Brazil (89%). On the other hand, the largest percentage declines in emissions occurred for the United Kingdom (-32%), Italy (-20%), Germany (-14%), Poland (-13%) and the United States (-3%). These countries sought new production processes and energy generation to reduce emissions.

The estimated values of participation and variation of emissions and conclusions are in accordance with França et al. (2018) and Esteves (2017), who stated that the European Union and the United States are major world emitters. However, countries are adopting new, cleaner production technologies and modifying the energy matrix with a greater share of renewable energy sources. On the other hand, investigations carried out by Souza et al. (2015), Perdigão et al. (2017) and Zapparoli et al. (2018) showed that developing countries, and in particular the Brazil-Russia-India-China (BRIC) countries, despite efforts to adopt fewer polluting technologies and renewable energy sources, have increased carbon dioxide emissions mainly due to the increase in final demand. This is shown in the present study by the increase in emissions from China, India and Brazil and similar behavior in other developing economies.

The results indicated the need to adopt cleaner production technologies and modify the energy matrix of the countries, mainly the biggest polluters with historical responsibility and the emerging ones with increased current emissions to achieve the reduction targets established by the countries in the Paris Agreement voluntarily.

Table 1. Main emitters of carbon dioxide by burning fossil fuels in the productive sector.

Country		Total emissions from the productive sector (millions of tons)				Participation in world emissions (%)			HDI 2018	Emissions Rank 2018
		1995	2018	Variation	Variation (%)	1995	2018	Variation		
1	China	2624	9424	6800	259%	16.5%	35.9%	19.4%	0.76	1
2	United States	4047	3912	-135	-3%	25.4%	14.9%	-10.5%	0.93	2
3	India	628	2151	1523	243%	3.9%	8.2%	4.3%	0.64	3
4	Russia	1401	1372	-29	-2%	8.8%	5.2%	-3.6%	0.82	4
5	Japan	1004	998	-6	-1%	6.3%	3.8%	-2.5%	0.92	5
6	Korea	387	586	199	52%	2.4%	2.2%	-0.2%	0.91	6
7	Germany	645	555	-90	-14%	4.0%	2.1%	-1.9%	0.95	7
8	Indonesia	187	482	295	157%	1.2%	1.8%	0.7%	0.71	8
9	Canada	362	478	115	32%	2.3%	1.8%	-0.5%	0.93	9
10	Saudi Arabia	162	468	306	189%	1.0%	1.8%	0.8%	0.85	10
11	South Africa	240	392	152	63%	1.5%	1.5%	0.0%	0.71	11
12	Australia	249	351	102	41%	1.6%	1.3%	-0.2%	0.94	12
13	Turkey	129	350	221	171%	0.8%	1.3%	0.5%	0.82	13
14	Mexico	224	341	118	53%	1.4%	1.3%	-0.1%	0.78	14
15	Brazil	165	310	146	89%	1.0%	1.2%	0.1%	0.76	15
16	United Kingdom	391	266	-125	-32%	2.5%	1.0%	-1.4%	0.93	16
17	Taipei	150	266	116	77%	0.9%	1.0%	0.1%	0.91	17
18	Poland	284	247	-37	-13%	1.8%	0.9%	-0.8%	0.88	18
19	Viet Nam	26	238	212	827%	0.2%	0.9%	0.7%	0.70	19
20	Italy	297	237	-60	-20%	1.9%	0.9%	-1.0%	0.89	20

Source: Survey calculations based on OECD data (2020).

The ranking of the world's biggest polluters in terms of emissions in absolute values indicates the size of each country's responsibility. However, comparing these values does not allow measuring and comparing the sustainability of their production systems. Sustainability indicators can be obtained by the ratio between carbon dioxide emissions per capita or Gross Domestic Product unit, this makes it possible to compare countries with different demographic and economic dimensions. For the present study, the second indicator was used.

Agribusiness and carbon dioxide emissions

Table 2 presents the aggregate results of the sizing in terms of GDP generation and carbon dioxide emissions from burning fossil fuels in the productive sector. It can be noted that the GDP of agribusiness in 1995 was about five trillion dollars in current values and participated in 16.6% of the world GDP, rising to about twelve trillion dollars in 2018, decreasing its participation to 14, 8%. In terms of emissions, agribusiness generated close to 1.8 million tons of carbon dioxide in 1995, accounting for 10.3% of total emissions. Emissions from agribusiness increased by around 400 million tons between 1995 and 2018, however, the share in the total decreased to 7.6%. The inputs (I), Agriculture (II), Industry (III) and Services (IV) showed changes

in their participation in the total GDP and agribusiness emissions, with (I) Inputs being the aggregate that most increased emissions.

The results in Table 4 show that aggregate (I) increased its share in the Agribusiness GDP from 6.8% to 9.8% while its share in agribusiness emissions from 15.5% to 26.1% in the period. Aggregate (II) increased the participation in the Agribusiness GDP from 20% to 24% and decreased the participation in emissions from 25.5% to 24%. Aggregates (III) and (IV) together decreased the participation in the GDP of Agribusiness from 73.2% to 66.1% and the joint participation in emissions from 59% to 49.9%. Estimates indicate a change in the composition of agribusiness income with benefits for agricultural inputs and rural producers. Inputs were the aggregate that showed the greatest relative (percentage share) and absolute increase in carbon dioxide emissions. On the other hand, the aggregate (III) that represents the agroindustry, reduced its participation in agribusiness income by around 5.7% and in emissions by 12.2%.

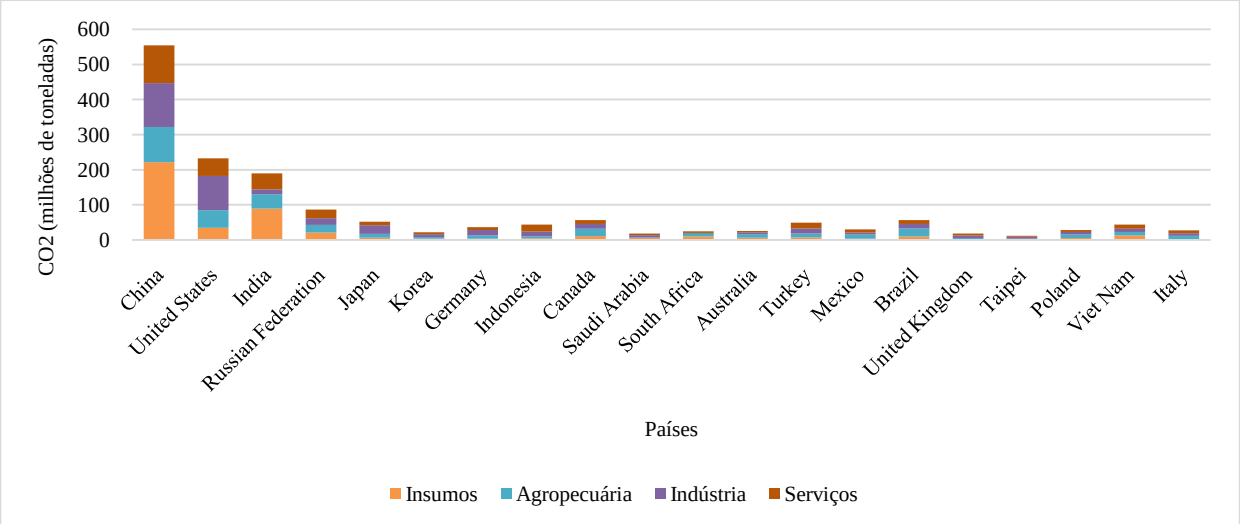
Table 2. Gross Domestic Product (GDP) and carbon dioxide emissions from burning fossil fuels in agribusiness and the global productive sector. Aggregates: Inputs (I), Agriculture (II), Industry (III) and Services (IV). GDP values in billions of current dollars and emissions in millions of tons per year.

Year	Variable	Aggregates (Absolute values and participation in agribusiness)				Agribusiness Totals	Production sector totals	Share of agribusiness in the world (%)
		I	II	III	IV			
1995	GDP	336	992	1602	2026	4957	29895	16.6%
		6.8%	20.0%	32.3%	40.9%	100.0%		
	Emissions	282	462	655	414	1814	17559	10.3%
		15.5%	25.5%	36.1%	22.9%	100.0%		
2018	GDP	1208	2960	3278	4860	12306	82962	14.8%
		9.8%	24.0%	26.6%	39.5%	100.0%		
	Emissions	573	527	526	572	2198	28945	7.6%
		26.1%	24.0%	23.9%	26.0%	100.0%		

Source: Survey calculations based on OECD data (2020).

Figure 3 presents data on carbon dioxide emissions from agribusiness in the main polluting countries. The list of the top twenty polluters presents developed and developing countries with a predominance of the second group. The highlights are China and the United States, which are also the biggest polluters in total terms (productive sector). The classification of the biggest polluters in total values of the productive sector was used for the order of presentation of the countries in Figure 6, however, it is noted that the classification for the biggest polluters of agribusiness is not the same. Brazil and Indonesia have agribusiness with higher values of carbon emissions than Germany, although the latter has a higher total value (productive sector).

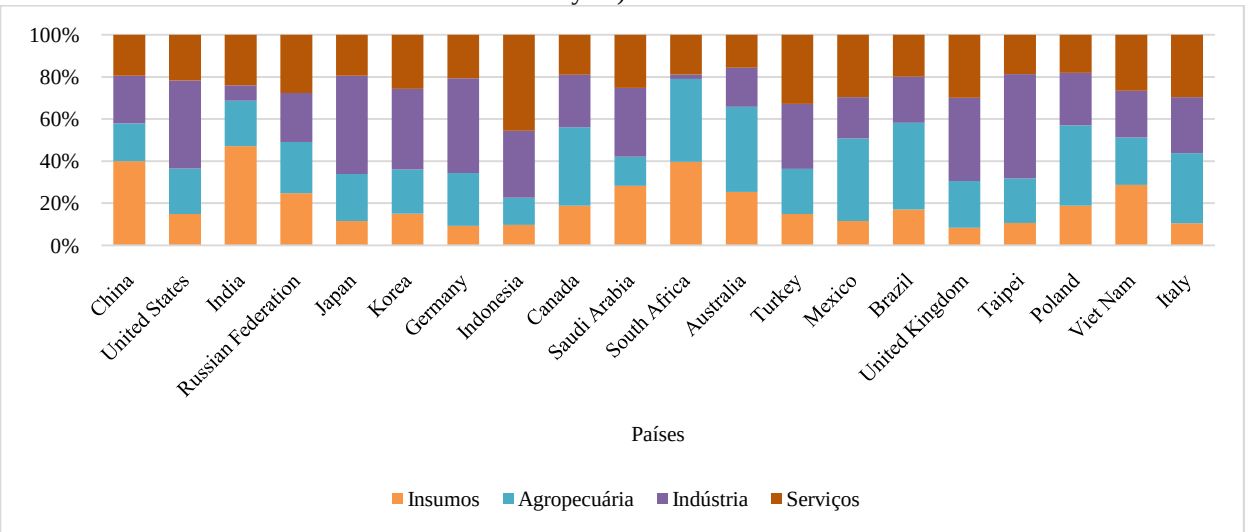
Figure 3. Largest agribusiness polluters in 2015 in carbon dioxide emissions (millions of annual tons)



Source: Survey calculations based on OECD data (2020)

Figure 4 shows the participation of households in carbon dioxide emissions from agribusiness in the main polluting countries. The results indicate variations in the participation of households in emissions across countries. United States, Japan, South Korea, Germany, Indonesia, Turkey, United Kingdom and Taipei account for around 60% of agribusiness emissions originating from industry and services. Canada, Australia, Mexico, Brazil, Poland and Italy presented agriculture as the aggregate with the greatest participation in agribusiness emissions. China, India, South Africa and Vietnam had aggregate (I) of inputs as the main polluter of agribusiness. This shows that the countries' productive structures, which include intersectoral relations and energy generation, are different and generate different impacts on emissions. Furthermore, it is important to take into account the different level of industrialization between them. The results are important for each country to identify which agribusiness aggregate is primarily responsible for most emissions and encourage the adoption of cleaner production technologies to reduce emissions.

Figure 4. Share of agribusiness aggregates in emissions in 2015 in carbon dioxide emissions (million tons per year).



Source: Survey calculations based on OECD data (2020).

Sustainability indicator

The identification of the biggest polluters establishes differentiated responsibilities for their greater participation in agribusiness emissions, however, the tendency is for them to be proportional to the size of the economy. However, the dynamics of emissions over time and the capacity to generate carbon dioxide per unit of GDP of countries are indicators of sustainability. The two estimated sustainability indicators refer to the generation of carbon dioxide per unit of agribusiness GDP and the comparison of the rate of change in emissions from this and the productive sector of the country under analysis.

Table 3 presents the sustainability indicator estimated as the value of carbon emissions per unit of income (Gross Domestic Product) of agribusiness aggregates and the world economy. Considering that income data are in current values for each year, it is not possible to compare indicators between years. In 1995, the global productive sector presented a generation of 14,030 tons per one million current dollars, while agribusiness presented a value of 4,532. In 2018, the value was 179 for agribusiness and 349 for the world productive sector. Therefore, it can be said that agribusiness is more sustainable from the point of view of this indicator than the economy as a whole. Observing the values for the agribusiness aggregates, we have that in the year 1995 the aggregate (III) presented the highest value of carbon dioxide generation for a nominal million dollars of income, around 7987, thus being the most polluting. On the other hand, the aggregate (IV) was the most sustainable with a value of 2942 tons of CO_2 per million dollars. For the year 2018, the aggregate (IV) is still the least polluting, however, the aggregate (I) of inputs has become the least sustainable with 474 tons of carbon dioxide per one million dollars of income, in contrast, the industry (aggregate (III)) improved its environmental performance, with a value of 161 and becoming more sustainable even than the aggregate (II), that presented a value of 178.

Table 3. Sustainability indicator, ratio of carbon dioxide emissions from burning fossil fuels per Gross Domestic Product (GDP), agribusiness aggregates and world productive sector. Aggregates: Inputs (I), Agriculture (II), Industry (III) and Services (IV). Values in tons of carbon per million current dollars.

Year	Aggregates				Agribusiness	Productive sector
	I	II	III	IV		
1995	6301	3486	7987	2942	4532	14030
2018	474	178	161	118	179	349

Source: Survey calculations based on OECD data (2020).

The values obtained indicated that there was an increase in world emissions, but despite the drop in the participation of agribusiness in the economy (-1.8%), its participation in emissions decreased in percentage terms in a more important way (-2.7%). In addition, the sustainability indicator showed that it is less polluting than the economy average (productive sector). However, the analysis and conclusions about the aggregated results for the world may not indicate generalizations for the 66 countries in the study, as they may have different characteristics of agribusiness and their evolution may have a specific trajectory. Therefore, it is important to evaluate the disaggregated results to identify the evolution of countries and the sustainability of agribusiness in each of them.

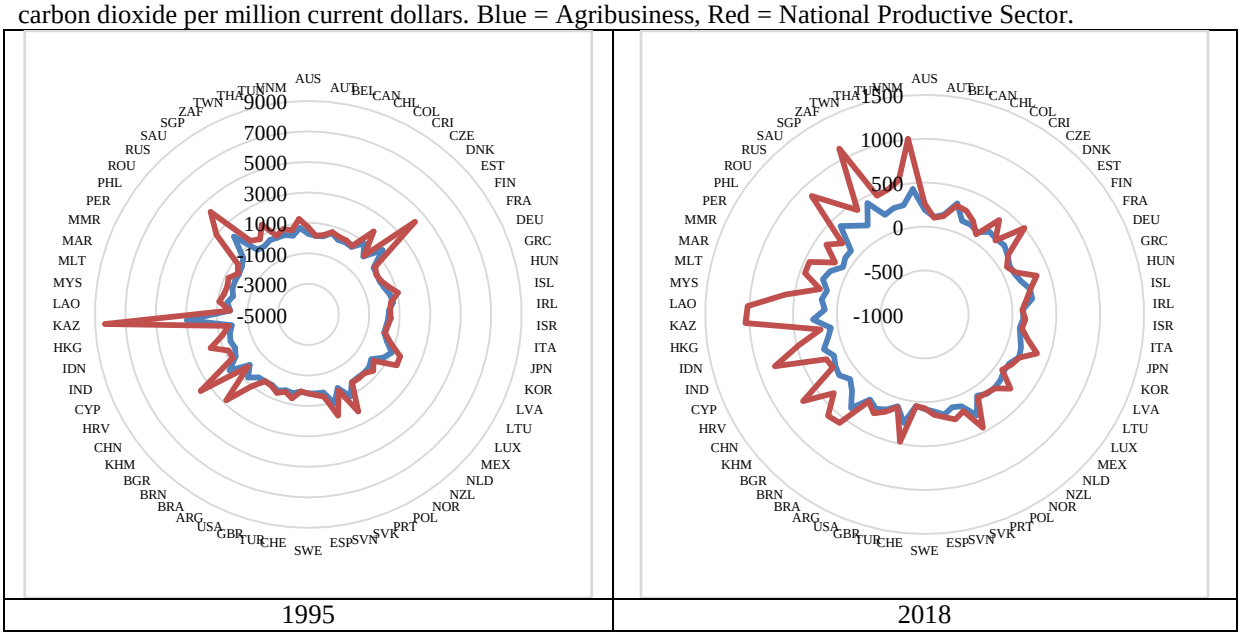
The generation of carbon dioxide by burning fossil fuels by agribusiness and the productive sector of the countries in tons per million current dollars in the analysis period is illustrated in Figure 5. The results of the sustainability indicator of the agribusiness and productive sector of the countries of the study, the value refers to the ratio of carbon dioxide emissions from the burning of fossil fuels per unit of income, in this case tons per million current dollars for each year: 1995 and 2018. A great variance in values can be noticed, with emphasis on Vietnam (VNM), South Africa (ZAF) and Russia (RUS). Agribusiness in these countries generated more than 380 tons of carbon dioxide per one million current dollars of GDP in 2018, however, the same countries presented values above 800 for the productive sector.

In 1995, 63 of the 66 countries showed greater sustainability in agribusiness, as the indicator was lower than in the productive sector. France (FRA), Iceland (ISL) and Sweden (SWE) showed higher generation of carbon dioxide per unit of income for agribusiness compared to the productive sector. In 2018, 56 countries had lower values for agribusiness than for the productive sector, the exceptions were Austria (AUT), Belgium (BEL), Canada (CAN), Costa Rica (CRI), Denmark (DNK), France (FRA), Iceland (ISL), Ireland (IRL), New Zealand (NZL), Sweden (SWE).

The results of the sustainability indicator for the countries indicate that it is possible to state that in most of them, agribusiness is more sustainable than the productive sector. Furthermore, differences in the indicator values calculated for agribusiness and the productive sector increased for some of them, notably for non-OECD countries (in the graph, countries starting from Argentina-ARG). The generation of carbon dioxide is directly related to the technological level and origin of the energy supplied to the production processes. Therefore, high values of emissions per unit of income show that countries must strive to develop cleaner production technologies and changes in the energy matrix. Figure 5 makes the visual comparative analysis of emissions per unit of income between agribusiness and the productive sector of the countries possible, and the results showed that most countries present agribusiness with relatively smaller values when compared to the productive system (greater sustainability).

The results for estimating the GDP of Agribusiness worldwide and of the selected countries, as well as the percentages of participation in the global economy are close to those obtained by Sesso Filho et al. (2022). Considering the sustainability of agribusiness, in most countries it proved capable of increasing production with lower emissions per unit of income compared to the economy average. Sesso Filho et al. (2019) and Bajan & Mrówczynska-Kaminska (2020) analyzed carbon dioxide emissions from agribusiness, but with different measurement methods. The present study obtained a 13.6% share of agribusiness in the world economy and 15.3% in 2015, values close to the 15% obtained by Sesso Filho et al. (2019) for the year 2009. The conclusions of the present study agree with Bajan & Mrówczynska-Kaminska (2020), as agribusiness can increase its participation with an emissions per unit of income (GDP) indicator lower than the average for the economy. In addition, the carried-out study showed that there is a downward trend in its share in total emissions, concomitantly with an increase in its share in the country's GDP, a characteristic found even in developing countries such as China, India, Brazil and Mexico.

Figure 5. Indicator of sustainability of agribusiness and productive sector of the countries. Values in tons of carbon dioxide per million current dollars. Blue = Agribusiness, Red = National Productive Sector.



Source: Survey calculations based on OECD data (2020).

Table 4 presents the sustainability indicators for agribusiness carbon dioxide emissions per unit of income (GDP) and the average annual rate of change in emissions for agribusiness and the productive sector of the largest polluting countries. The pollution generating capacity of countries ranges from 99 tons of carbon dioxide per one million current 2018 dollars (UK) to 1125 tons (South Africa).

The lower the value of emissions per unit of GDP, the greater the sustainability of the country's agribusiness. Considering the world's biggest polluters, agribusiness is most sustainable in Italy, the United Kingdom, Germany, Japan, Indonesia, Mexico, Brazil, South Korea and the United States, all countries with less than 170 tons of emissions per unit of income (million dollars) in 2018. On the other hand, Vietnam, South Africa, Russia and Canada have a high environmental cost of their agribusiness with more than 300 tons of carbon dioxide for every one million dollars of income in the year 2018. Note- This classification is highly variable, since in 1995 Russia and Poland had the relatively most polluting agribusiness in the group of the twenty largest emitters in the productive sector.

The comparison between the rates of change in emissions from agribusiness and the countries' productive sector allows measuring and identifying whether agribusiness is a productive system that evolves differently from total emissions. In the case of China, the productive sector increased carbon dioxide emissions by 5.72% per year in the period 1995-2018, but its agribusiness increased emissions by 1.92% per year in the same period. The United States reduced emissions from the productive sector by 0.15% per year during the study period and agribusiness -1.27% per year. The same occurred for 17 of the 20 largest polluters, except for South Africa, Australia and the United Kingdom. This indicates a downward trend in the participation of agribusiness in total emissions in most of the main polluting countries. The highest average annual negative rates of variation in carbon emissions in agribusiness occurred in South Korea (-3.48%), Japan (-1.90%), United Kingdom (-1.66%) and Poland (-1.54%) and the largest increases occurred in Vietnam (8.58%), India (5.19%), Saudi Arabia (4%) and Turkey (3.79%).

Table 4. Carbon dioxide emissions by agribusiness GDP and variation in carbon dioxide emissions from burning fossil fuels in agribusiness and the productive sector.

Country	**1995**		**2018**		**Average annual rate of variation in emissions**	
	Agribusiness	Productive sector	Agribusiness	Productive sector	Agribusiness	Productive sector

1	China	1334	3650	195	699	1,92%	5,72%
2	United States	377	542	169	194	-1,27%	-0,15%
3	India	396	1774	215	802	5,19%	5,50%
4	Russian Federation	2042	4284	389	862	-1,30%	-0,09%
5	Japan	124	188	120	207	-1,90%	-0,03%
6	Korea	478	721	159	353	-3,48%	1,82%
7	Germany	167	265	119	147	-1,10%	-0,65%
8	Indonesia	298	794	131	474	2,44%	4,19%
9	Canada	545	627	316	291	0,09%	1,21%
10	Saudi Arabia	390	1135	285	600	4,00%	4,72%
11	South Africa	475	1611	424	1125	2,58%	2,15%
12	Australia	284	696	192	261	1,53%	1,50%
13	Turkey	256	593	259	476	3,79%	4,44%
14	Mexico	292	638	142	291	1,17%	1,86%
15	Brazil	229	231	153	179	1,97%	2,80%
16	United Kingdom	181	308	92	99	-1,66%	-1,66%
17	Taipei	424	553	221	458	-1,17%	2,51%
18	Poland	1039	2149	293	449	-1,54%	-0,61%
19	Viet Nam	690	1288	430	1007	8,58%	10,16%
20	Italy	169	266	92	121	-1,26%	-0,97%

Source: Survey calculations based on OECD data (2020).

IV. Conclusion

The survey results indicated that the five largest polluters in the world are China, the United States, India, Russia and Japan, in that order. The biggest increases in emissions share are from Vietnam (827%), China (259%), India (243%), Saudi Arabia (189%), Indonesia (157%), Turkey (171%) and Brazil (89%). On the other hand, the largest percentage declines in emissions occurred for the United Kingdom (-32%), Italy (-20%), Germany (-14%), Poland (-13%) and the United States (-3%).

The agribusiness GDP in 1995 was around five trillion dollars in current values and accounted for 16.6% of the world's GDP, rising to around twelve trillion dollars in 2018, decreasing its share to 14.8%. In terms of emissions, agribusiness generated close to 1.8 million tons of carbon dioxide in 1995, accounting for 10.3% of total emissions. Emissions from agribusiness increased by around 400 million tons between 1995 and 2018, however, the share in the total decreased to 7.6%. The Inputs (I), Agriculture (II), Industry (III) and Services (IV) aggregates showed changes in their participation in the total GDP and agribusiness emissions, with (I) Inputs being the aggregate that most increased emissions.

The values of the sustainability indicator carbon dioxide emissions from the burning of fossil fuels per unit of income showed that the world productive sector presented in 2018 the generation of 179 tons per one million current dollars for agribusiness and 349 for the world production sector. Therefore, it can be said that agribusiness is more sustainable from the point of view of this indicator than the economy.

The results of the study are important for directing agricultural policies and the management of agribusiness production chains, helping in the pursuit of economic, social and environmental sustainability. New surveys may cover a greater number of countries and variables, such as jobs and energy use, to develop new agribusiness sustainability indicators and enable comparative analyzes without the influence of absolute emission values.

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