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ARTICLE

Gross Domestic Product and water footprint of agribusiness: comparative between countries

Produto Interno Bruto e pegada hídrica do agronegócio: comparativo entre países

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Abstract: The objective of this study is to measure the countries' agribusiness in terms of income (Gross Domestic Product - GDP) and water (water footprint), in addition to estimating a sustainability indicator (water per unit of income). The methodology is based on the input-output matrix and was applied to 189 countries with a focus on the twenty largest economies (GDP) in 2015. The GDP of world agribusiness was US$12.3 trillion and the water footprint of 151 trillion cubic meters, the values represented respectively 18% and 97.5% of the total production system. The share of agribusiness income in the total productive system of the countries ranged from 4% to 61%. The highest agribusiness GDP figures were obtained for China (US$ 2.5 trillion), the United States (US$ 1.4 trillion), India (US$ 0.67 trillion), Japan (US$ 0.5 trillion) and Brazil (US$ 0.43 trillion). The environmental cost of agribusiness measured in cubic meters of water per thousand dollars of income generation (m3/US$) ranged from less than one hundred cubic meters for every thousand dollars of income generated to more than 200 thousand, which indicates that there is the possibility of increasing the efficiency of water use and sustainability through the development of new technologies.

Keywords: water, water footprint, agribusiness, sustainability, input-output.

Resumo: O objetivo do presente estudo é dimensionar o agronegócio dos países em termos de renda (Produto Interno Bruto - PIB) e água (pegada hídrica), além de estimar um indicador de sustentabilidade (água por unidade de renda). A metodologia é baseada na matriz insumo-produto e foi aplicada para 189 países com enfoque sobre as vinte maiores economias (PIB) no ano de 2015. O PIB do agronegócio mundial era de US$12,3 trilhões e a pegada hídrica de 151 trilhões de metros cúbicos, os valores representavam respectivamente 18% e 97,5% dos totais do sistema produtivo. A participação da renda do agronegócio no total do sistema produtivo dos países variou entre 4% e 61%. Os maiores valores do PIB do agronegócio foram obtidos para a China (US$ 2,5 trilhões), Estados Unidos (US$ 1,4 trilhão), Índia (US$ 0,67 trilhão), Japão (US$ 0,5 trilhão) e Brasil (US$ 0,43 trilhão). O custo ambiental do agronegócio mensurado em metros cúbicos de água para mil dólares de geração de renda (m^3/US$) variou entre menos de cem metros cúbicos para cada mil dólares de renda gerada para mais de 200 mil, o que indica que existe a possibilidade do aumento da eficiência do uso da água e sustentabilidade por meio do desenvolvimento de novas tecnologias.

Palavras-chave: água, pegada hídrica, agronegócio, sustentabilidade, insumo-produto.

1 Introduction

Water scarcity is a growing problem in many parts of the world. Water demand is increasing due to population growth, industrial development, and the expansion of agriculture. At the same time, the supply of water is decreasing due to pollution, the depletion of aquifers, and changing weather patterns. Climate change is exacerbating water scarcity. Rising global temperatures are leading to changes in rainfall patterns resulting in longer and more intense periods of drought in some areas and flooding in others. In addition, the melting of polar ice caps and glaciers is raising sea levels, which could lead to the salinization of coastal water resources. In this process, the supply of water suitable for the development of human activities will become scarcer, which increases the importance of measuring water use (Hoekstra & Chapagain, 2008).

Considering the greater scarcity of water due to the factors listed above, it is essential to estimate the use of this resource for economic activities. To this end, the concept of the water footprint was developed, which is defined as the volume of freshwater used during the production and consumption of goods and services along the production chain. The estimate of water use drawn up by Hoekstra & Hung (2002) considers the interdependence between sectors of the economy and, therefore, the direct and indirect effects of the water demand. The agricultural sector represents the greatest demand for this resource (approximately 86% of humanity's water footprint) and the supply chain approach is necessary to understand the process of measuring the water footprint (Hoekstra & Chapagain, 2008).

The agricultural sector, which has the highest demand for water among human activities, provides raw materials for different sectors of the economy and participates in various production chains. Within this systemic vision, Davis & Goldberg (1957) developed the concept of agribusiness. For the authors, agribusiness comprises a set of activities that include the supply of inputs, production in the field, industrialization, trade, and services. The division into four aggregates, (I) Inputs, (II) Agriculture, (III) Industry, and (IV) Services. In this way, combining the ideas of Hoekstra & Hung (2002) and Davis & Goldberg (1957), it is possible to estimate the joint water footprint of the various production chains involved in agribusiness.

The general aim of this study is to estimate income (Gross Domestic Product - GDP), the volume of water used (internal water footprint), and an agribusiness sustainability indicator (water per unit of income), the latter of which measures the efficiency of water use and the sustainability of the production process. The methodology is based on the input-output matrix and was applied to 189 countries and the rest of the world, with detailed results for the twenty largest economies in 2015.

The results of the study make it possible to measure the absolute values and participation of agribusiness in the economy in terms of Gross Domestic Product and water use (water footprint). In addition, estimating the water footprint per unit of income generated in agribusiness aggregates as an indicator of efficiency in water use makes it possible to carry out comparative analysis between countries and draw up policies to increase the sustainability of agribusiness. The study advances when compared to previous research because of the relationship established between the water footprint of agribusiness and the respective generation of income, its scope in terms of the number of countries, and the fact that it analyzes agribusiness, including the aggregates of inputs, agriculture, industry, and services.

2 Theoretical backgrounds

Agribusiness can be understood as a process of adding value in which fresh agricultural products are processed and services are added to serve the consumer. Within this process, Davis & Goldberg (1957) divided agribusiness into four aggregates: (I) Inputs, (II) Agriculture,

(III) Industry, and (IV) Services. Inputs correspond to seeds, seedlings, agrochemicals, fuels, financial services, and all the goods and activities that make agricultural production possible. Agriculture involves plant, animal, and extractive production aimed at producing food, fibers, and raw materials for different industries such as textiles, wood, paper and cellulose, food, tobacco, and others. Agro-industry encompasses all types of processing that use agricultural products as their main raw material. Trade, transportation, marketing, and other services that are added to agricultural and agro-industrial products make up the fourth aggregate.

Studies relating agribusiness income generation and environmental variables, such as energy consumption and gas emissions, have been developed to analyze the sustainability of agribusiness or estimate its share of the economy (Gross Domestic Product) and relate it to the level of economic development of countries. Sesso Filho et al. (2019), Bajan & Mrówczyńska-Kamińska (2020) and Pompermayer Sesso et al. (2023) carried out studies on greenhouse gas (GHG) emissions in agribusiness, the authors considering that agribusiness is more sustainable than the economic system because it has a lower ratio of emissions per unit of income than the economy. However, agribusiness has a high share of total emissions, which makes it important to analyze its production structure for GHG mitigation, to contribute to solving the problem of climate change. The relationship between the participation of agribusiness in the economy and development was the subject of studies by Yan et al. (2011), Amarante & Sesso Filho (2020) and Sesso Filho et al. (2022), who concluded that the growth in per capita income leads to a decrease in the participation of agribusiness in the economy, as well as an increase in the participation of industry (aggregate III) and services (aggregate IV) in the income generated by agribusiness in countries and sub-national regions.

Agribusiness is important in analyzing the sustainability of countries, both in terms of carbon dioxide emissions and water use. Water footprint studies usually focus on agriculture, because approximately 86% of humanity's water footprint is in the agricultural sector (Hoekstra & Chapagain, 2008). Normally, the water footprint is counted in cubic meters within a given period (month, year) and product weight (kilograms or tons). Sustainability indicators can be developed by dividing the water footprint by the number of inhabitants in the region or production unit to analyze regions comparatively.

The water footprint is a measure of the appropriation of fresh water through its use for human activities (blue and green water footprint) and the effect of water pollution from these activities is the gray water footprint (Hoekstra, 2008). Blue water refers to surface and groundwater in lakes, rivers, and aquifers. Green water is precipitation on land that does not run off or recharge aquifers, but is stored temporarily on soil or vegetation and is then evaporated or transpired by plants (Aldaya & Hoekstra, 2010; Mekonnen & Hoekstra, 2010). The differentiation and measurement of blue and green water footprints are important because the environmental, economic, and social impacts and opportunity costs of using surface and groundwater differ greatly from those of using rainwater for human activities (Falkenmark & Rockström, 2004; Hoekstra & Chapagain, 2008). Greywater is the volume of freshwater required for the dissolution of pollutants to reach natural concentrations and water quality standards. The concept of the gray water footprint is that the measurement of pollution can be defined in terms of the volume of water needed to dilute pollutants so that they become harmless (Hoekstra et al., 2009).

The first water footprint studies were primarily aimed at assessing the water trade of products on a global scale. Later research aimed to rigorously quantify the three components (blue, green, and gray water) for specific crops and geographical areas. More recent studies are concerned with establishing methodologies and tools for measuring the water footprint (Lovarelli et al., 2016). Databases on water use have been developed to aid analysis on the subject, such as the work by

Tamea et al. (2021), in which the authors created a database representing the amount of water needed to produce a good and virtually exchanged with international trade in the period 1986-2016.

The average annual global water footprint in the period 1996-2005 was 9,087 Gm^3/year (74% green, 11% blue, 15% gray), with agriculture contributing 92%. In 2011, the global water footprint of agricultural production was 8,362 Gm^3/year, 80% green, 11% blue, and 9% gray (Hoekstra & Mekonnen, 2012). Global water demand is expected to increase by between 20% and 30% between 2010 and 2050 (Burek et al., 2016). Agricultural production is the main consumer of water and population growth, income growth, and dietary changes are expected to increase the water demand. The water footprint is expected to increase by up to 22% due to climate change and land use by 2090. Current agricultural production is unsustainable from the point of view of water use, especially about the blue water footprint. This calls for action to improve water sustainability and protect the ecosystems that depend on it (Mekonnen & Gerbens-Leenes, 2020).

Considering that the demand for natural resources is growing and these resources are expected to become scarcer in the future, the development of efficient water management in agriculture is necessary to meet the growing demand for food and sustainably reduce poverty and hunger. The discussion is about how the world will feed the global population without further impacting freshwater and ecosystems. The solution indicated by scientific studies is the sustainable intensification of agricultural production, which implies the use and adaptation of technologies to increase productivity, especially on land with low yields in agricultural production. This would lead to less need for deforestation to increase total production (Tilman et al., 2011; Cassman & Grassini, 2020; Drechsel et al., 2015; Garnett et al., 2013; Godfray et al., 2010). In addition, there is the possibility of stimulating changes in the human diet by replacing foods that require a large volume of water in production with others with a smaller water footprint, as well as reducing food waste and loss (Foley et al., 2011; Jalava et al., 2016; Kummu et al., 2012).

To understand the impacts of human diet variation and food waste on water consumption, it is important to know water use efficiency differs between agricultural products. The average water footprint per calorie of beef is 20 times higher than that of cereals and starchy roots. The water footprint per gram of protein of milk, eggs, and chicken meat is 1.5 times higher than that of legumes (Mekonnen & Hoekstra, 2011). In addition, there is variation in water consumption in livestock production, with the water footprint of beef meat (15,400 m^3/ton corresponds to the global average) being much greater than the footprints of sheep meat (10,400 m^3/ton), pigs (6,000 m^3/ton), goats (5,500 m^3/ton), or chicken (4,300 m^3/ton). The global average water footprint of chicken eggs is 3,300 m^3/ton, while the water footprint of cow's milk is 1,000 m^3/ton (Mekonnen & Hoekstra, 2011).

The lower feed conversion efficiency for animal products is largely responsible for the relatively high water footprint of these products compared to plant products. Animal products from industrial systems (feedlots) generally consume and pollute more groundwater and surface water resources than animal products from grazing or mixed systems. The increase in global meat consumption and the intensification of animal production systems will put even more pressure on global freshwater resources in the coming decades (Mekonnen & Hoekstra, 2012).

Many nations save domestic water resources by importing water-intensive products and exporting less water-intensive products, this strategy is defined in the literature as virtual water trade (Yang et al., 2006). National water savings through international trade can imply a reduction in global water stress if the flow of virtual water is from places with high water productivity to places with low water productivity.

Estimates have shown that the total amount of water that would have been needed in importing countries if all imported agricultural products had been produced domestically is 1605 Gm^3/year. These products are, however, produced with only 1253 Gm^3/year in the exporting countries, saving global water resources by 352 Gm^3/year. This saving represents 28% of international water flows related to trade in agricultural products and 6% of global water use in agriculture (Chapagain et al., 2006).

However, the virtual water trade is dominated by green virtual water, which constitutes a low opportunity cost of use, as opposed to blue virtual water (Yang et al., 2006). Around 52% of the blue water footprint of global consumption and 43% of international flows of blue virtual water come from places where sustainable environmental flows are violated. Approximately 22% of the violation of the sustainability of the environmental flow of the blue water footprint of global consumption occurs outside the specific countries of consumption, indicating that several of them have externalized their impacts (Mekonnen & Hoekstra, 2020).

Considering international trade and its impacts on water use, there are uncertainties in accounting for and estimating the scale of water savings, as there are negative implications for global water savings in terms of the efficiency of its use and food security in importing countries, and for the environment in exporting countries. The solutions to the scarcity of this resource are to expand rainfed agriculture to improve global food security and to gain efficiency in the use of water for greater environmental sustainability (Yang et al., 2006).

The importance of the agricultural sector in the total water footprint and the need to measure water use efficiency in agribusiness are the motivation for this study, which advances previous research by measuring the water footprint and income generation in agribusiness for a range of countries (database of 189 countries) within a comprehensive view of four aggregates (inputs, agriculture, industry, and services) estimating the need for water per unit of income generated. The systemic view helps to estimate the cost of generating income in environmental terms, in which case the water footprint has been divided into blue, green, and gray water.

3 Methodology

The input-output matrix is an economic model that shows the relationships between sectors of the economy through the flow of goods and services. Therefore, the data shows the intersectoral relationships within a region's economic system. The data contained in the input-output matrix provides a detailed view of the production structure and makes it possible to measure the level of sectoral interconnection in the economy. It is possible to estimate the impact of variations in final demand on the various sectors for economic, demographic, and environmental variables (Leontief, 1951; Miller & Blair, 2009).

Chart 1 shows a schematic example of an input-output table for an economy with two sectors, showing the various flows of goods and services between the two sectors (intermediate consumption) which are used as inputs in the production process. The components of final demand purchase final goods and services from the respective sectors. Various satellite accounts can be obtained with environmental (atmospheric emissions and water), material (minerals), and demographic (employed people, age and qualifications) variables.

For this study, the agribusiness sizing methodology uses data from the input-output matrices of 189 countries. The data source used in this article was the Global Supply Chain Database (EORA, 2023), which provides input-output matrices for 190 regions (189 countries and the rest of the world) with twenty-six sectors. The database also provides the water footprint of the sectors (blue, green, and gray). The monetary values are in millions of current 2015 dollars and the water footprint is in millions of cubic meters per year.

Chart 1. Input-output matrix for an economy with 2 sectors.

Component	*Sector 1*	*Sector 2*	*Household Consumption*	*Government*	*Investment*	*Exports*	*Total*
Sector 1	z_{11}	z_{12}	c_1	g_1	i_1	e_1	x_1
Sector 2	z_{21}	z_{22}	c_2	g_2	i_2	e_2	x_2
Imports	m_1	m_2	m_c	m_g	m_i		m
Taxes	t_1	t_2	t_c	t_g	t_i	t_e	t
Added Value	w_1	w_2					w
Total	x_1	x_2	c	g	i	e	

Where: z_{ij} is the monetary flow between sectors *i* and *j*; c_i is household consumption of products from sector *i*; g_i is government spending on sector *i*; i_i is the demand for investment goods produced in sector *i*; e_i is the total exports of sector *i*; x_i is the total output of sector *i*; t_i is the total net indirect taxes paid by *i*; m_i is the imports made by sector *i*; w_i is the value added generated by sector *i*. Source: adapted from Miller & Blair (2009).

The construction of the matrices and environmental satellite accounts of the database used is described in Lenzen et al. (2012, 2013). The sectors in the EORA (2023) input-output matrices are shown in Chart 2. The primary sectors belonging to agribusiness are (1) Farming and (2) Fishing and aquaculture, which form aggregate II and provide raw materials for the agro-industrial sectors; (4) Food and beverages; (5) Textiles and clothing; and (6) Wood and paper, which belong to aggregate III. Aggregate I is made up of inputs, goods, and services, which are consumed by the sectors in aggregate II. The services added along the way (transportation, marketing, and others) make up aggregate IV.

Chart 2. Sectors in the input-output matrices of the countries in the EORA database, 2015.

Sector4
(1) Agriculture
(2) Fishing and aquaculture
(3) Mineral extraction
(4) Food and beverages
(5) Textiles and clothing
(6) Wood and paper
(7) Chemical and non-metallic mineral products
(8) Metal products
(9) Machinery and equipment
(10) Transportation equipment
(11) Other manufacturing
(12) Recycling
(13) Electricity, gas and water
(14) Construction
(15) Maintenance and repair of machinery and equipment
(16) Wholesale trade
(17) Retail trade
(18) Accommodation and food
(19) Transportation
(20) Post and telecommunications
(21) Financial intermediation
(22) Public Administration
(23) Education, health, and other services
(24) Domestic services
(25) Other services
(26) Re-export and re-import

Source: EORA (2023).

The calculations for sizing agribusiness in terms of Gross Domestic Product and water footprint were adapted from Furtuoso & Guilhoto (2003) and Bajan & Mrówczyńska-Kamińska (2020), both based on the input-output matrix. The estimates are based on the division proposed by Davis & Goldberg (1957) into four agribusiness aggregates: (I) Inputs; (II) Agriculture; (III) Industry; and (IV) Services. Aggregate (I) is made up of the inputs used in sectors (1) Agriculture and (2) Fishing and aquaculture. Initially, to calculate Aggregate I, two components are identified in Equation 1:

$$GDP_I = GDP_{I1} + GDP_{I2} \tag{1}$$

Equation 1 shows:
GDPI= GDP of aggregate I, agricultural production inputs,
$GDP_{I\,1}$= GDP of aggregate I, agricultural inputs (*k=1*), and
$GDP_{I\,2}$ = GDP of aggregate I, inputs from Fishing and aquaculture (*k=2*).

The input values for sectors (1) Agriculture and livestock and (2) Fishing and aquaculture are in the respective intermediate consumption columns, which are multiplied by the value-added coefficients at sectoral market prices (CVA_i), where $i = 26$ sectors. To obtain the sectors' Value Added Coefficients (*CVAi*), the Value Added at Market Prices (VA_{PMi}) must be divided by the Sector's Production (*Xi*) d according to Equation 2,

$$CVA_i = \frac{VA_{PM_i}}{X_i} \tag{2}$$

Value added at market prices (VA_{PM}) r Gross Domestic Product is calculated by adding the value added at basic prices (VA_{PB}) to the Net Indirect Taxes *(IIL)* on products, thus $VA_{PM} = VA_{PB} + IIL$.

A The aggregate Gross Domestic Product (GDP) for each sector (GDP_{Ik}) is measured using Equation 3, in which the values of the inputs for the (1) Agriculture and (2) Fishing and aquaculture sectors are multiplied by the respective value-added coefficients and then added together:

$$GDP_{Ik} = \sum_{i=1}^{n} z_{ik} \times CVA_i \tag{3}$$

Equation 3 shows:
GDP_{Ik} is the GDP of aggregate I (inputs) for Agriculture *(k=1)* and Fishing and aquaculture (*k=2*),
z_{ik} is the total input value of sector i for Agriculture (*k=1*) and Fishing and aquaculture (*k=2*),
CVA_i is the value-added coefficient of sector *i,*
i = 1, 2, ..., 26 sectors of the economy.

The measurement of the Gross Domestic Product of Aggregate II (GDP_{IIk}) a presented in Equation 4 considers the Value Added at market prices of the sectors (1) Agriculture and livestock and (2) Fishing and aquaculture and subtracts the value added referring to the inputs of the sector itself.

$$GDP_{IIk} = VA_{PMk} - z_{kk} \times CVA_k \tag{4}$$

Equation 4 shows:
$GDP_{II\,k}$ s the GDP of aggregate II for Agriculture *k=1* e Pesca and Fishing and aquaculture *k=2*,
$VA_{PM\,k}$ is the Value Added at market prices for sectors (1) Agriculture and livestock and (2) Fishing and aquaculture.

The total value of the Gross Domestic Product of Aggregate II is calculated by adding up the values added by the primary sectors, according to Equation 5:

$$GDP_{II} = GDP_{II1} + GDP_{II2} \tag{5}$$

Na Equação (5), tem-se:
GDP_{II} = GDP of aggregate II, Gross Domestic Product of the Agricultural sector.
$GDP_{II\,1}$ = GDP of aggregate II, (1) Agriculture,
$GDP_{II\,2}$ = GDP of aggregate II, (2) Fishing and aquaculture.

Aggregate (III) comprises the industrial sectors whose main raw material comes from Aggregate (II): (4) Food and Beverages, (5) Textiles and Clothing, and (6) Wood and Paper. The calculation of the Gross Domestic Product of Aggregate III is the sum of the added values at market prices of the agribusiness industrial sectors subtracted from the added values of these referring sectors that were used as inputs in Aggregate II. Equation 6 performs this calculation:

$$GDP_{III\,k} = \sum_{q=4}^{6} \left(VA_{PM_q} - z_{kq} \times CVA_q \right) \tag{6}$$

Equation 6 shows:
$GDP_{III\,k}$ s the Gross Domestic Product of the agro-industry aggregate (III),
k = 1,2. Agriculture *k=1* e and Fishing and aquaculture *k=2,*
q = sectors belonging to agro-industry (4, 5 and 6).
The total value of the Gross Domestic Product of Aggregate III is calculated using Equation 7:

$$GDP_{III} = GDP_{III1} + GDP_{III2} \tag{7}$$

Equation 7 shows:
GDP_{III} = GDP of aggregate III, Gross Domestic Product of the Agricultural sector.
$GDP_{III\,1}$ = GDP of aggregate III, (1) Agriculture,
$GDP_{III\,2}$ = GDP of aggregate III, (2) Fishing and aquaculture.

Aggregate (IV) includes the trade and services sectors within agribusiness, which correspond to sectors 15 to 25 of the twenty-six existing in the countries' input-output matrix. The Gross Domestic Product of the services aggregate (IV) will be proportional to the share of agricultural and agro-industrial products, trade and services and is estimated by the share of agricultural and agro-industrial products in domestic final demand (DFD), which is the value of overall final demand (DFD), subtracting net taxes (IIL_{DF}) and imports (IM_{DF}), it follows that $DFD = DFG - IIL_{DF} - PI_{DF}$. The Value Added at market prices of the service sectors is added together:

$$VA_{PMS} = \sum_{s=1}^{m} VA_{PMs} \tag{8}$$

Equation 8 shows:
VA_{PMS} é is the Value Added at Market Prices of the service sectors,
m is the number of service sectors (sectors 15 to 25 of the twenty-six sectors in the input-output matrix).
VA_{PMs} is the value added at market prices of each service sector.

The Gross Domestic Product of the aggregate (IV) for agribusiness will be given by the share of agribusiness sectors in domestic final demand times the total Gross Domestic Product of the service sectors, estimated in Equation 9:

$$GDP_{IV} = VA_{PMS} \times \frac{\sum_{k=1}^{n} DF_k + \sum_{q=1}^{m} DF_q}{DFD} - \sum_{k=1}^{n}\sum_{s=1}^{m} z_{ks} \times CVA_{ks} \quad (9)$$

Equation 9 shows:
GDP_{IV} is the Gross Domestic Product of aggregate IV,
VA_{PMS} is the Value Added at Market Prices of the service sectors,
n is the number of basic sectors, which are Agriculture k=1 and Fishing k=2,
q is the number of agro-industrial sectors, of which there are three: Food and Beverages, Textiles and Clothing, and Wood and Paper,
DF_k = final demand from Agriculture (k=1) and Fishing (k=2)
DF_q = final demand from agro-industrial sectors
m is the number of service sectors (sectors 15 to 25 of the twenty-six sectors in the input-output matrix).

The total GDP of Agribusiness is the sum of its aggregates, i.e:

$$GDP_{AGRO} = GDP1 + GDP_{II} + GDP_{III} + GDP_{IV} \quad (10)$$

Equation 10 shows:
GDP $_{AGRO}$ s the Gross Domestic Product of Agribusiness and the other elements of the equation have been calculated and defined previously.

To calculate the water footprint, Equation 2 would be modified to become the water footprint coefficient, as in Equation 11, in which the Value added at market prices coefficient would be exchanged for the blue (W_a), green (W_v) or gray (W_c) water footprint volume for each sector:

$$CW_i = \frac{W_i}{X_i} \quad (11)$$

Equation 11 shows that:
CW_i is the coefficient of the water footprint of each sector,
W_i is the water footprint of sector i, where i = 1, 2, ..., 26 which can be blue (W_a), green (W_v), or gray (W_c) water,
X_i is the sector's production,

The water footprint estimated for agribusiness is internal, i.e. it refers to the appropriation of water within the country and does not take into account water from imported inputs or exported products.

4 Results and discussion

The results of agribusiness sizing for the world (189 countries) in 2015, considering two variables, Gross Domestic Product and Water Footprint, were aggregated in tables to find out the total values and then used to draw up maps. The detailed results for the twenty largest economies in the world were summarized in tables and graphs for analysis. These countries account for most of the world's income, more than 80%, and are important in decision-making regarding environmental policies and the development of new technologies.

4.1 Agribusiness Gross Domestic Product of the Countries

The aggregate results for the 189 countries and the rest of the world showed that the GDP of world agribusiness in 2015 was approximately 12 trillion dollars, around 18% of world GDP. Aggregates (III) Industry and (IV) Services had the largest shares in income generation, both with around 35%, with 22% of income remaining with rural producers (Agriculture - aggregate II) and 7% in aggregate I (Inputs).

Figures 1 and 2 illustrate the individual results for the 189 countries in the EORA database (2023). Figure 1 shows the absolute values of the Gross Domestic Product of Agribusiness in billions of dollars in 2015. Figure 2 illustrates the results of agribusiness' share of the countries' income (GDP) in percentage terms. The results of Figure 1 show that the largest agribusiness Gross Domestic Product in 2015 was China, with around 2.5 trillion dollars, other countries with higher values that visually stand out are the United States (US$ 1.4 trillion), India (US$ 0.67 trillion), Japan (US$ 0.51 trillion) and Brazil (US$ 0.43 trillion). The high figures indicate the importance of agribusiness in the world, considering all the aggregates.

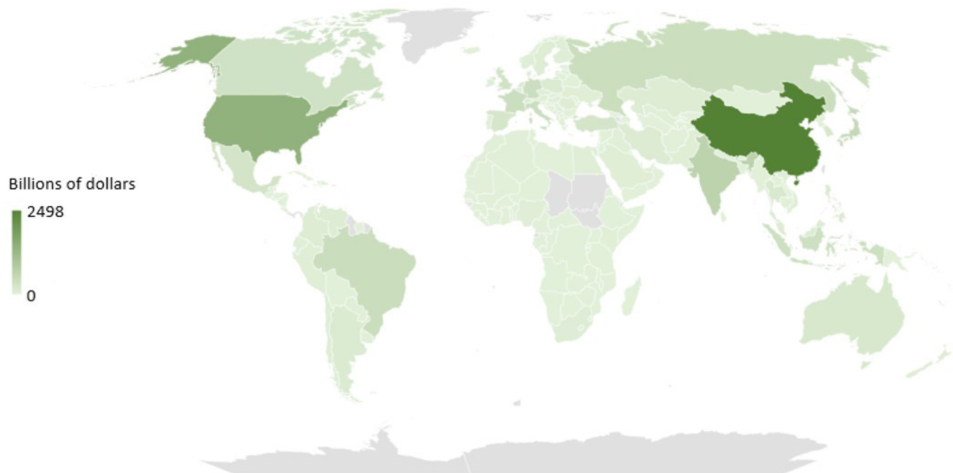

Figure 1. Agribusiness Gross Domestic Product of countries in 2015. Values in billions of dollars.
Source: prepared by the authors based on the research results

Figure 2 shows the importance of agribusiness among the countries analyzed, with a share of Gross Domestic Product varying between 4% and 61%. The highest figures for the share of agribusiness in the GDP of the production system were obtained for Kyrgyzstan (61%), Paraguay (61%), Uzbekistan (52%), Kenya (50%) and Ethiopia (47%). Brazil had a 23% share of agribusiness in the economy. Developing countries had a higher share of agribusiness in the economy, especially in Latin America (such as Paraguay with 61%) and Asia (such as Indonesia with 40% and India with 38%). On the other hand, developed countries such as the United States (10%), Canada (16%), and Germany (11%) had figures for agribusiness' share of the economy that did not exceed 20%. The results are in line with the assessment of Yan et al. (2011), Amarante & Sesso Filho (2020), and Sesso Filho et al. (2022), as the authors stated that the growth in per capita income is accompanied by a decrease in the share of agribusiness in the economy (Gross Domestic Product).

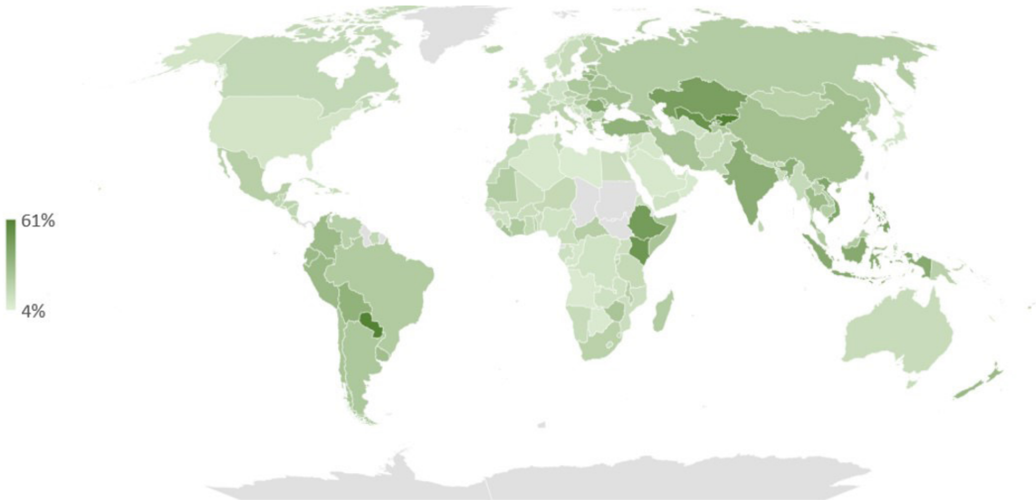

Figure 2. Agribusiness' share of countries' Gross Domestic Product - in percent - 2015.
Source: prepared by the authors based on the research results

Table 1 shows the results of agribusiness sizing for the twenty largest economies in the world, considering the Gross Domestic Product for 2015. It is important to note that the dollar values calculated consider the exchange rate used by the Eora Global Supply Chain Database (EORA, 2023). The data in Table 1 was used to draw up Figure 3, which illustrates the share of aggregates in countries' agribusiness GDP. Looking at Table 1, it can be seen that China had the highest agribusiness GDP, with around 2.5 trillion dollars and a 28% share of the national economy, followed by the United States, with 1.4 trillion dollars, which corresponded to 10% of the national total, India (0.67 trillion dollars and 38% of the total), Japan (0.5 trillion dollars and 10% of the total) and Brazil (0.43 trillion dollars and 23% of the total).

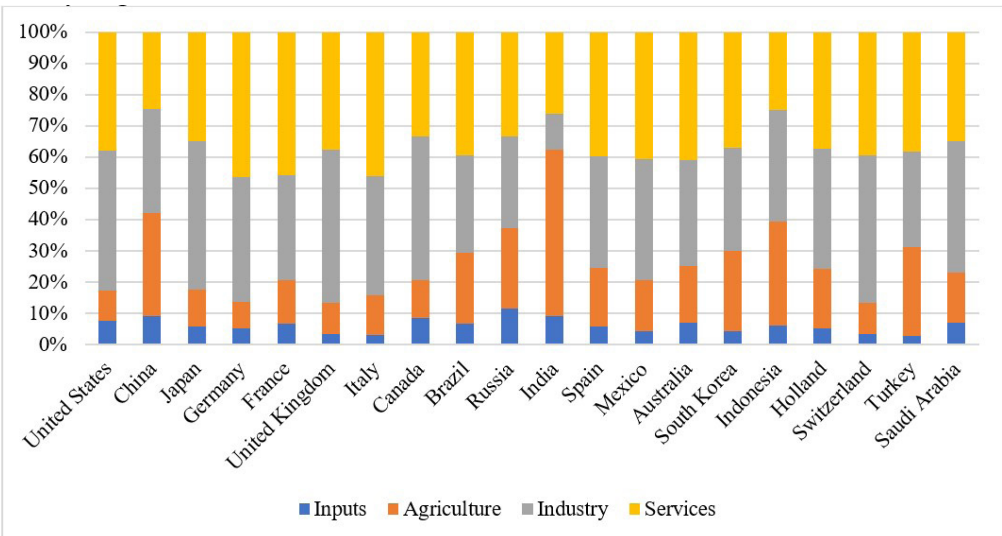

Figure 3. Share of aggregates in the Gross Domestic Product of agribusiness in the twenty largest economies in 2015.
Source: prepared by the authors based on the research results.

The twenty largest economies in the world showed a share of agribusiness in national GDP ranging from 8% (Saudi Arabia) to 40% (Indonesia). The importance of agribusiness for each country varies, as does the share of aggregates in the composition of income. It should be noted that some of the countries showed a combined share of industry and services (aggregates III and IV) greater than 80%, especially the United States, Japan, Germany, France, the United Kingdom, Italy, Canada, Mexico, and Switzerland. China, the largest agribusiness GDP, showed a share of industry and services of around 60%. Brazil, Russia, India, Spain, Australia, South Korea, Indonesia, the Netherlands, Turkey, and Saudi Arabia showed a result of less than 80% of value added through industrialization and the addition of services.

The BRIC countries (Brazil, Russia, India, and China), South Korea, Australia, and Indonesia have the greatest potential for agro-industrialization, considering the low share of value added by this aggregate and the fact that they are emerging countries with large populations and/or exporters of basic products.

Table 1. Gross Domestic Product of agribusiness aggregates and shares in the national total of the twenty largest economies (Gross Domestic Product) in 2015. (I) Inputs, (II) Agriculture, (III) Industry, (IV) Services. (US$ billion)

Country	Agribusiness					Rank (Total)	Share of agribusiness in the country's GDP
	I	II	III	IV	Total		
United States	105.05	133.40	627.97	534.80	1401.22	2	10%
China	226.43	820.72	832.88	617.50	2497.53	1	28%
Japan	28.85	60.19	245.68	179.21	513.94	4	10%
Germany	20.16	33.74	160.79	185.63	400.32	6	11%
France	26.18	55.53	134.24	182.26	398.21	7	15%
United Kingdom	9.84	29.60	147.56	113.62	300.61	12	12%
Italy	11.86	50.14	151.56	182.97	396.52	8	19%
Canada	25.40	37.76	142.04	102.81	308.01	11	16%
Brazil	28.36	97.76	133.77	169.46	429.34	5	23%
Russia	45.65	101.36	116.13	133.05	396.20	9	22%
India	59.56	355.16	77.94	173.95	666.62	3	38%
Spain	12.63	43.46	82.12	92.07	230.27	15	17%
Mexico	10.72	43.46	102.77	107.25	264.20	13	21%
Australia	11.93	32.52	60.79	72.87	178.11	17	14%
South Korea	8.04	51.08	65.58	74.04	198.75	16	19%
Indonesia	22.40	123.32	133.56	92.45	371.72	10	40%
Netherlands	7.98	29.22	59.34	57.88	154.42	18	19%
Switzerland	2.97	9.31	43.44	36.47	92.20	19	13%
Turkey	6.81	70.29	75.18	95.09	247.37	14	36%
Saudi Arabia	3.67	8.80	22.73	18.98	54.17	20	8%

Source: prepared by the authors based on the research results.

4.2 Agribusiness water footprint of the countries

The sum of the agribusiness water footprint results for 189 countries and the rest of the world in 2015 was around 151 trillion cubic meters, of which 83% was green water, 14% blue water, and 3% grey water. Aggregate II (agriculture) was the main water user with 83.49% of the total, followed by aggregate I (inputs) with 14.23%, aggregate III (industry) with 2.26%, and aggregate IV (services) with 0.01%.

The results of the agribusiness water footprint estimate for the countries were used to create Figures 4 and 5. The estimated water footprint is internal and does not consider the part of agribusiness outside the country, such as imported and exported inputs. Figure 4 shows the total water footprint of agribusiness in billions of cubic meters per year in 2015 and Figure 5 illustrates the share of agribusiness' water footprint in the total national water footprint of the countries' production systems.

Figure 4 shows that there is a wide variation in the water footprint of agribusiness, which depends on the characteristics of each country, with the highest values being over one trillion cubic meters for the countries with the largest areas, such as the United States, China, Russia, Brazil, and India. Considering the importance of agribusiness in supplying food and fiber for the population itself and for meeting external demand, the availability of water is a fundamental point for the continued operation of agribusiness.

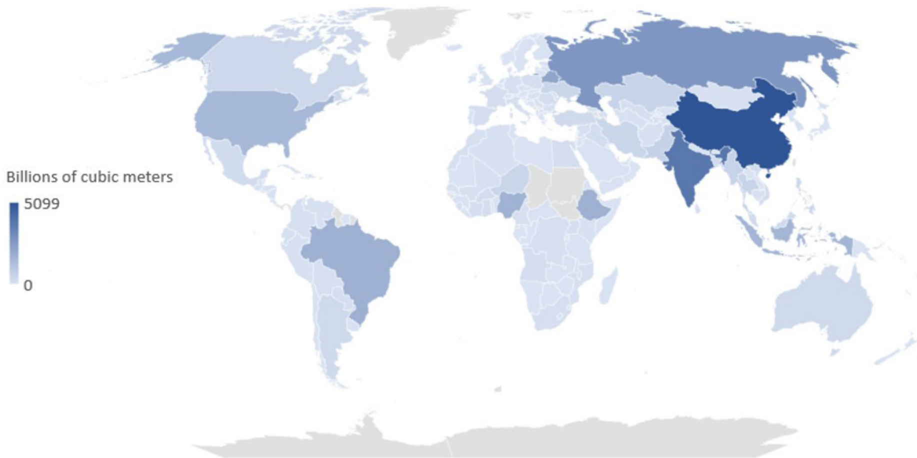

Figure 4. Total water footprint (blue, green, and gray water) of agribusiness in countries in 2015. Values in billions of cubic meters per year.
Source: prepared by the authors based on the research results.

Figure 5 shows that the share of agribusiness' water footprint in the total water footprint of the production system in the countries ranges from 46% to approximately 100% of the available blue, green, and gray water. Agribusiness therefore has a high impact and depends on the continuous supply of water resources for its operation. The growing scarcity of water as a result of climate change could limit the development of agricultural activity with consequences such as food shortages and price increases, mainly with impacts on the poorest populations.

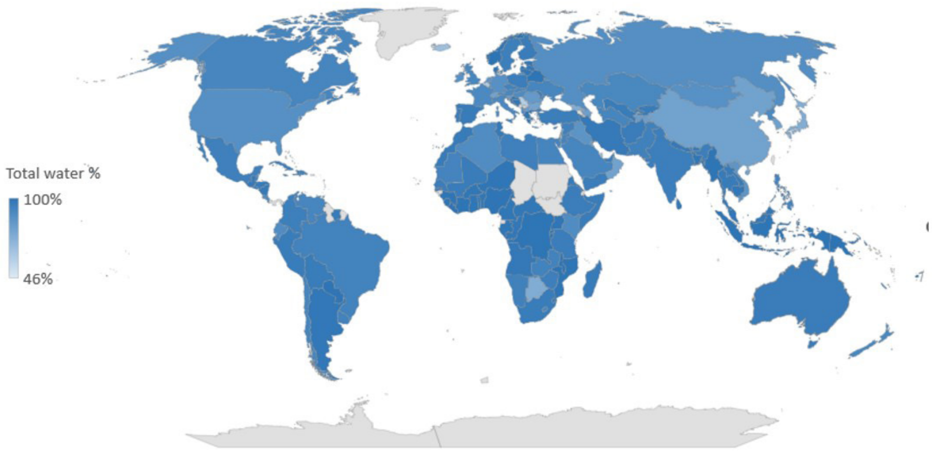

Figure 5. Share of agribusiness's internal water footprint in the water footprint of countries' production systems in 2015.
Source: prepared by the authors based on the research results.

Table 2 shows the results of the total water footprint (blue, green, and gray water) of agribusiness, its aggregates, and participation in the total national production system of the world's largest economies (Gross Domestic Product) in 2015. The figures refer to billions of cubic meters per year. Looking at the results in Table 2, the share of agribusiness' water footprint in the total national production system ranges from 74% (Japan) to approximately 100% (Indonesia). The absolute values range from 7 billion cubic meters (Switzerland) to more than 5 trillion cubic meters (China). The large variation in figures is explained by the fact that the water footprint depends on various factors, such as the territorial extension, climate, soil, and agribusiness production systems of each country.

The values obtained for the water footprint of agribusiness show that, among the aggregates, Agriculture (aggregate II) has the largest share in the total water footprint of agribusiness, followed by Industry (aggregate III), Inputs (aggregate I) and Services (aggregate IV). There are countries with a higher water footprint for Inputs, such as the United States and China, and others with a higher value for Industry, such as the United Kingdom, Italy, and Brazil. Furthermore, in all the cases of the world's largest economies, the water footprint of the Services sectors (aggregate IV) is the smallest.

The largest agribusiness water footprint was in China, with around five trillion cubic meters, more than 80% of which was in agriculture (aggregate II). The second highest value was obtained by India, with approximately 3.8 trillion cubic meters in 2015, followed by Russia (2.7 trillion m^3), Brazil (1.8 trillion m^3), Indonesia (1.6 trillion m^3) and the United States (1.5 trillion m^3).

Table 2. Total internal water footprint (blue, green, and gray water) of agribusiness aggregates and participation in the water footprint of the production system of the twenty largest economies (Gross Domestic Product) in 2015. The aggregates: (I) Inputs, (II) Agriculture, (III) Industry, (IV) Services. (billion m^3).

Country	*Agribusiness*					*Rank (Total)*	*Share of agribusiness in the production system's water footprint*
	I	II	III	IV	Total		
United States	292.05	984.51	230.87	0.27	1507.70	6	87.51%
China	388.81	4349.41	344.90	16.27	5099.39	1	78.89%
Japan	2.03	19.21	1.79	0.04	23.07	18	73.96%
Germany	16.95	78.76	8.37	0.08	104.16	14	86.98%
France	25.36	127.44	10.73	0.39	163.92	12	90.25%
United Kingdom	1.23	40.02	5.35	0.01	46.60	15	91.59%
Italy	9.46	75.80	23.54	0.37	109.18	13	90.58%
Canada	89.61	286.72	21.73	0.60	398.66	7	92.02%
Brazil	185.04	1116.88	490.22	0.63	1792.77	4	93.48%
Russia	417.49	2056.17	233.43	9.67	2716.75	3	88.09%
India	345.95	3287.86	222.71	1.58	3858.11	2	95.34%
Spain	11.17	119.42	55.16	0.05	185.81	11	96.84%
Mexico	17.52	171.63	54.67	0.16	243.99	10	94.47%
Australia	34.00	201.91	75.68	0.01	311.60	9	96.42%
South Korea	1.43	26.22	4.72	0.02	32.40	17	79.66%
Indonesia	109.46	1368.31	127.01	0.04	1604.82	5	99.74%
Netherlands	0.73	6.69	3.87	0.03	11.32	19	84.98%
Switzerland	0.70	4.99	1.40	0.02	7.11	20	78.68%
Turkey	13.34	259.28	44.04	0.38	317.05	8	95.55%
Saudi Arabia	1.05	28.02	4.01	0.02	33.10	16	91.94%

Source: Prepared by the authors based on the survey results.

Figure 6 illustrates the composition of the agribusiness water footprint of the twenty countries with the highest Gross Domestic Product values in terms of blue, green, and gray water. The largest share was green water, with approximately 70% or more in nineteen of the twenty countries analyzed, except Saudi Arabia, where blue water predominated (more than 70%). This indicates that most of the water footprint of agribusiness products, whether fresh or processed food or even fibers (textiles and clothing), comes from the process of evapotranspiration and the use of water in the soil. The share of blue and gray water varies between countries, with China, Germany, and the United Kingdom having the largest share of the gray water footprint, with approximately 20% of the total water footprint of agribusiness. On the other hand, Brazil, Russia, Australia, and Indonesia make relatively less use of blue and gray water sources, which together account for around 10% or less of the estimated agribusiness water footprint.

The joint analysis of the results indicates that countries with a higher share of Services (aggregate IV) in agribusiness income generation also showed a higher share of the gray water footprint, with the United States, Germany, France, the United Kingdom, the Netherlands, and Switzerland showing these characteristics. The industrial and service sectors usually have a greater share of the grey water footprint, so the greater the degree of industrialization and addition of services to agricultural products will lead to a greater share of the grey water footprint.

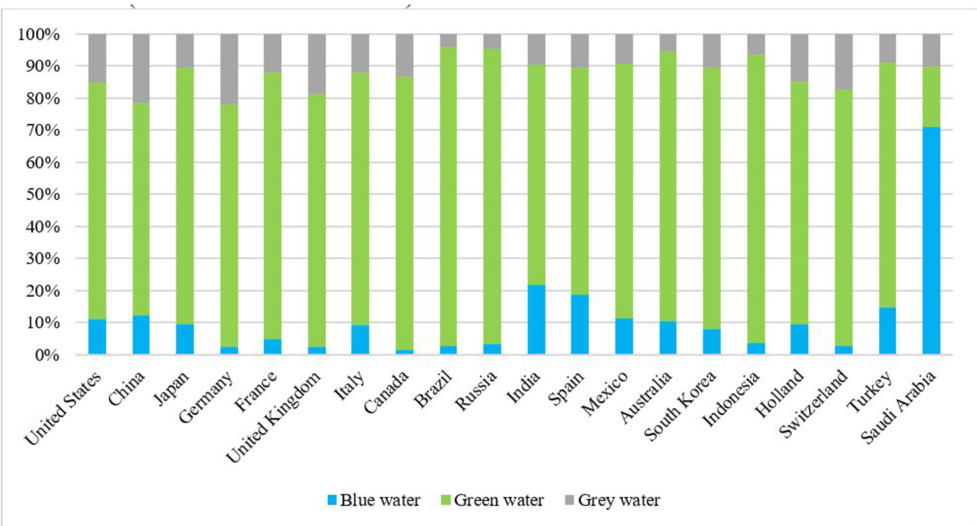

Figure 6. Share of water types in the agribusiness water footprint of the twenty largest economies (Gross Domestic Product) in 2015.

Source: Prepared by the authors based on the survey results.

4.3 Water use efficiency

The estimated water footprint values per unit of income for the countries showed such large differences that it is difficult to draw up maps and graphs. The highest values are above one hundred thousand cubic meters of water used in the production process for every thousand dollars of income generated (m^3/US$) in 2015 and were obtained for Ethiopia, Sudan, and Zimbabwe. This is due to the low added value of the products and the high evaporation (green water footprint) characteristic of production and the climate in these countries. On the other hand, countries such as Switzerland and Japan showed values below one hundred cubic meters of water used for every thousand dollars of income generated, due to the efficiency of water use and the high added value of production.

Table 3 shows the relationship between the water footprint of agribusiness, its aggregates, and income (Gross Domestic Product) in 2015, in cubic meters per thousand dollars. The results show the environmental cost in terms of water footprint (cubic meters) to generate one unit of income (one thousand dollars) in each agribusiness aggregate. Looking at the total values, the figures range from approximately 45 cubic meters per thousand dollars of income generated (Japan) to around 6,857 m^3/US$ (Russia).

Considering the calculated sustainability indicator, the most efficient countries in the use of water resources are Japan, the Netherlands, Switzerland, and South Korea, which use between 45 and 163 cubic meters of water for every thousand dollars generated in agribusiness income. Looking at the estimated values for the aggregates, aggregate II (Agriculture) is the one with the highest estimated indicator value, followed by aggregate I (Inputs) and lastly, aggregate III (Industry). Services (aggregate IV) have the lowest water use in cubic meters per thousand dollars of income generated in agribusiness. The highest water footprint values per unit of income generated in agricultural production (Aggregate II) were obtained for Russia (20 thousand m^3 per thousand dollars), Brazil (11.4 thousand m^3/US$), Indonesia (11 thousand m^3/US$), India (9.3 thousand m^3/US$), Canada (7.6 thousand m^3/US$) and the United States (7.4 thousand m^3/US$).

Table 3. Relationship between water footprint and income (Gross Domestic Product) of the twenty largest economies in 2015. Aggregates: (I) Inputs, (II) Agriculture, (III) Industry, (IV) Services. Values in m^3/US$1,000.

Country	*Agribusiness*					*Rank (Total)*
	I	II	III	IV	Total	
United States	2780.22	7379.92	367.64	0.51	1076.00	9
China	1717.09	5299.52	414.11	26.35	2041.77	5
Japan	70.24	319.07	7.30	0.24	44.89	20
Germany	841.02	2334.25	52.05	0.42	260.19	15
France	968.68	2294.94	79.92	2.13	411.64	13
United Kingdom	125.19	1351.97	36.23	0.05	155.01	17
Italy	798.17	1511.87	155.32	2.02	275.33	14
Canada	3527.91	7593.86	152.95	5.86	1294.32	7
Brazil	6525.55	11425.04	3664.72	3.69	4175.59	4
Russia	9145.68	20285.63	2010.00	72.70	6857.11	1
India	5808.00	9257.39	2857.56	9.11	5787.60	2
Spain	884.40	2748.00	671.79	0.58	806.91	11
Mexico	1634.96	3949.41	531.96	1.51	923.50	10
Australia	2849.84	6209.47	1244.92	0.12	1749.46	6
South Korea	178.54	513.30	71.98	0.27	163.01	16
Indonesia	4887.17	11095.80	950.95	0.41	4317.24	3
Netherlands	91.15	228.94	65.28	0.57	73.33	19
Switzerland	235.91	536.00	32.18	0.51	77.12	18
Turkey	1960.38	3688.55	585.77	4.04	1281.69	8
Saudi Arabia	285.10	3186.24	176.22	1.27	611.03	12

Source: Prepared by the authors based on the survey results.

The large difference between the estimated values of the sustainability indicator in the world's largest economies and the water footprint per unit of income indicates that there is scope for increasing efficiency in the use of water, especially in the production of inputs and in the field, as in Japan, the Netherlands and Switzerland. This is an opportunity to develop public policies to develop new water-saving technologies, especially in Russia, India, Indonesia, Brazil, China, Australia, Turkey, Canada, and the United States, countries with values above 1,000 cubic meters per 1,000 dollars of agribusiness Gross Domestic Product. New varieties of plants that are more efficient in their use of water, resistant to drought and production processes in agriculture that reduce the use of blue water, are less polluting (lower gray footprint), and reduce the evaporation of water from the soil (green water).

In the case of agricultural production, the possible solutions for increasing the efficiency of water use and reducing the water footprint are the development of drought-resistant varieties (better use of soil water - green), more efficient irrigation systems (less use of blue water) and production systems that reduce soil water evaporation (lower green water footprint). Therefore, the implementation of public policies to encourage research into the genetic improvement of plants and the development of new technologies in the field that use relatively less water can contribute to the efficient use of water and mitigate the effects of climate change. From the point of view of the demand for agricultural products (fresh or processed), changes in the human diet can contribute to reducing the water footprint of agribusiness.

In the industrial and service sectors, there are efficient strategies for reducing water consumption, such as training workers in water consumption practices and raising awareness of the importance of avoiding waste; monitoring and maintaining the production process to identify situations with higher consumption and adopt corrective measures; developing water recycling systems, such as the installation of treatment plants for reuse in secondary processes or systems for using rainwater for non-potable purposes. In addition, investing in modern and efficient equipment, such as dry running systems, automatic taps with motion sensors, and low-consumption toilets (Mierzwa & Hespanhol, 2005; Rocha et al., 2018). The development of tax exemption policies for companies that increase the sustainability of the production process and incentives for the development of production technologies that use less water will contribute to a lower water footprint per unit of production (or income).

The results showed that the environmental cost of adding value to agribusiness aggregates is greatest in the initial stages, Inputs (Aggregate I) and Agricultural Production (Aggregate II), followed by industry and services. The service sectors demand relatively less water per unit of income generated than the other aggregates. In addition, there is a wide range of water use sustainability indicators between countries. Therefore, there is a possibility that countries with a restricted water supply will use international trade strategically to save scarce resources by importing raw materials (fresh agricultural products) and processing them domestically, allowing them to generate income at a lower environmental cost in terms of their water footprint. However, as was seen in the literature review, the use of international trade to increase efficiency in the use of water can transfer the problem and cause scarcity of the resource in poorer commodity-exporting countries.

5 Conclusions

The adaptation of the agribusiness sizing methodology based on the input-output matrix to be applied to economic and environmental variables and databases for many countries is one of the contributions of this research. The results of the water use efficiency indicator, measured as the ratio of water footprint per unit of income, showed that there is great variation in the level of sustainability of agribusiness between countries. This indicates that there is scope for using new technologies to improve water use efficiency, especially in clusters I (Inputs) and II (Agriculture), which are the main users of this natural resource.

The research results can guide policies to increase water use efficiency and sustainability through investments in research and development of products and processes that save this natural resource.

In agriculture, drought-resistant varieties and production systems that reduce the blue water footprint and protect the soil to reduce evapotranspiration (green water) will contribute to greater sustainability. In the industrial and service sectors, production processes with less use of blue water and fewer pollutants (gray water) will have an impact on input aggregates, industry, and services.

Further research could involve sizing up countries' agribusiness for more recent periods and economic, environmental, and social variables. The joint analysis of carbon, water, and social footprints is important because sustainability involves various aspects of the production process and its impacts on society.

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