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Research article

Brazilian Environmental-Economic Accounting for Water: A structural decomposition analysis

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ABSTRACT

The UN Sustainable Development Goals constitute a bench of directives with a universal scope to establish actions to mitigate poverty and protect the environment. Benefiting from the Environmental-Economic Accounting for Water recently published in Brazil, it is possible to harmonize the demand of water and the economic sectors. To this end, this study conducted an input-output analysis and structural decomposition analysis to explore the water consumption of the Brazilian Economy and its driving forces during an unprecedented drought and economic recession between 2013 and 2015. The results indicate that the total variation of the water consumption in the period is 15%. Between 2013 and 2014, the total effect was positive, causing an increase of 45% in the embodied water consumption, having as main driver the final demand and the intensity effect. In the second period, the total intensity effect was negative, provoking a decrease of −10% in the total water consumption. The "Agriculture, livestock, forestry and fishing" is the main sector responsible for these positive and negative results, while the "Energy and gas natural supply" sector has a strategic position to avoid a structural increase on the economic water demand.

1. Introduction

1.1. Background and motivation

Although Brazil is endowed with some of the world's largest freshwater resources, they are distributed unequally in terms of territory, space and time. Even though the distribution is uneven, it is an absolute advantage for non-substitutable natural resources which allows the development of economic sectors considered intensive in water resources (IBGE, 2018).

Water scarcity situation are increasingly occurring in certain regions in Brazil in recent years. According to the latest report by the National Water Agency (NWA), of the 5,570 Brazilian municipalities, 51% (2,839) declared a State of Emergency or State of Calamity due to drought at least once between 2003 and 2017 (ANA, 2018). Regarding the demand factor for water use in Brazil, it is estimated that it has grown by approximately 80% in the last two decades. According to NWA, the forecast is that by 2030 the withdrawal will increase 24%. The history of the evolution of water uses is directly related to the economic development and the urbanization process of the country. The main use of water in the country, in terms of quantity used, is irrigation (52%), followed by human supply (23.8%) and industry (9.1%). Together these uses represent about 85% of total withdrawal and consumption (ANA, 2018).

In recent years, Brazil faced instability concerning economic indicators, especially in terms of economic activity. Brazil's GDP increased 3% in 2013, with R$ 5.33 trillion. In 2014 GDP increased only 0,5%, accounting for R$ 5.77 trillion, and in 2015, the same indicator decreased 3,5% in volume, accounting R$ 5.99 trillion (IBGE, 2016).

During this period, water flow units were also instable. In the Northeast of Brazil, in São Francisco watershed, between 2014 and 2016, the lowest annual average natural flows were recorded in the Sobradinho reservoir since 1931 (ANA, 2018). In the Southeast of Brazil, in Paraíba do Sul watershed, in 2014 and 2015, rainfall and flow rates were well below the average, significantly reducing the water stocks accumulated in the reservoirs. In February 2015, the equivalent

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reservoir reached a useful volume of 0.33%, the lowest value recorded in all history. The Paraibuna and Santa Branca reservoirs came to operate below their minimum operating levels, using the so called “dead volume” (ANA, 2018).[1]

At the Cantareira Reservoir System in São Paulo State, between October 2013 and November 2015 there was a significant reduction in the volume of precipitation, which reduces as affluent leaks to the reservoirs. The average flow in 2014 was 8.70 m^3/s, the lowest value since 1930, corresponding to about 22% of the historical average and 40% of the average of 1953, until then the lowest recorded value. In 2015, an average flow was 19.67 m^3/s, the second lowest value ever recorded (ANA, 2018).

In order to prevent risks and respective economic costs caused by potential water drought, it is essential to monitor indicators of water intensity and productivity. In this case, quantitative and qualitative water resources indicators could be considered in the decision-making processes. Therefore, the first Environmental-Economic Accounting for Water (EEA-W) for Brazil was published in 2018 by the Brazilian Institute of Geography and Statistics and the National Water Agency (IBGE, 2018), considering the period from 2013 to 2015. The EEA-W presents results analysis for the Asset Account, Physical and Hybrid Supply and Use Tables, as well as Indicators.

Based on the data provided by the Brazilian EEA-W and on the economic data provided by the Brazilian System of National Accounts (SNA) it is possible to estimate the “virtual water” content of the Brazilian economy, as proposed by Allan (1998). The “virtual water” is defined as the direct and indirect water embodied in products and it is frequently used to evaluate the growing international trade and its impact on water flow demand (Allan, 1998).

Several authors perform an analysis of the exported, imported and net virtual water flow, globally or regionally. Duarte et al. (2016) provides an overview of the evolution of virtual water flows in the world between 1965 and 2010, analysing the main determining economic factors through a Decomposition Analysis. The overview points out that America stands out as the main exporter of virtual water, and Europe and Asia as dependent on foreign water resources, as they appear as net importers of virtual water. For the three of the top five marketed agricultural products, namely cotton, soybeans and wheat, the main exporting countries are the United States, Brazil and Argentina (Duarte et al., 2016).

Zhang et al. (2016) analysed the virtual water flow in China between 2001 and 2013 and demonstrated the country has an imported virtual water flow (155.55 billion m^3/year) much higher than the volume exported (29.94 billion m^3/year). Imported products are concentrated in water-intensive agricultural products, such as soybeans, cotton and palm oil. The virtual export of water is destined mainly to the Republic of Korea, Hong Kong and Japan, while the imported water is mainly from the United States, Brazil and Argentina. In America, the first exporter of virtual water to China is the United States with 35.51 billion m^3/year, followed by Brazil and Argentina, with 32.08 billion m^3/year and 18.48 billion m^3/year, respectively (Zhang et al., 2016).

Niemeyer and Garrido (2011) conducted a study to analyse the importance of Latin American countries in the global virtual water flow through international agricultural trade, highlighting the objectives of food security. The results show that Argentina and Brazil are progressively becoming part of the world’s food basket, in the commercialization of products such as corn and soybeans (Niemeyer and Garrido, 2011).

Among the studies of international trade of virtual water, one for the specific case of Brazil should be presented. da Silva et al. (2016) evaluated the international trade in virtual water of federal states of Brazil, as well as estimated water scarcity dependence and self-sufficiency by state. For this, they considered the international trade in agricultural commodities and some livestock products in the period between 1997 and 2012. To meet the proposed objectives, the authors estimated the water footprint (blue and green water) of national consumption and the commercial balance of virtual water.

Its main results corroborate those predicted by the literature already mentioned. That is, Brazil was a net exporter of virtual water in the international trade of agricultural commodities and some livestock products between 1997 and 2012, as its exports of virtual water accounts 67.1 billion m^3 per year, against imports of 12.3 billion m^3 per year (da Silva et al., 2016).

The relevant position of Brazil in the virtual water trade chain, the economic instability in the past years in addition to the increasing water scarcity situation in a country with huge disposal of water resources highlight the importance of analyse the main drivers of the water consumption variation between 2013 and 2015.

1.2. Literature survey

Many authors developed multi-regional and interregional environmentally extended input-output models (IOM) to quantify direct and indirect water withdrawal, optimize virtual water trade between different geographic regions or different economic agents, and also calculate regional water footprint. Some of the objectives of these studies are to show the optimal strategy of economic production activities in a water-scarce region to produce less water-intensive crops, by quantifying the direct and indirect water withdrawal of each economic sector. For these studies, the authors gathered water resources information with economic data.

Aviso et al. (2018) developed a multi-regional environmentally extended input-output models to optimize virtual water trade between different geographic regions in Philippines in consideration of local environmental resource constraints, product demands and economic productivity. Based on a case study on agriculture crop production and trade in different regions, the results show that the optimal strategy does not necessarily limit a water-scarce region to produce less water-intensive crops (Aviso et al., 2018).

Deng et al. (2016) uses an interregional input-output model to calculate the regional water footprint of China in 2002 and 2007 and analyse the changing trend of the water footprint (Deng et al., 2016). Bogra et al. (2016), transforms the economic input−output table from 2003 to 2004 of India into a water withdrawal IOM to quantify direct and indirect flows to estimates the direct and indirect water withdrawal of all economic sectors (Bogra et al., 2016). Cazcarro et al. (2013a) construct a multiregional IOM for Spain, in order to evaluate the pressures on the water resources, virtual water flows, and water footprints of the regions, and the water impact of trade relationships within Spain and abroad. Results show an important imbalance between origin of water resources and final destination, with significant water pressures in the South, Mediterranean, and some central regions (Cazcarro et al., 2013a).

Regarding the identification of the main drivers of the water demand change, the Structural Decomposition Analysis (SDA) has been widely used in the literature as its robust results are useful to orient policy implications. In order to evaluate the effectiveness of the water-saving policy in Heihe River Basin in China, a basin-scale hydroeconomic IOM and the SDA analysis revealed that decreased water consumption intensity played an important role in reducing water consumption even though this effect was largely offset by the final demand increase, mostly by virtual water exportation in goods and services (Liu et al., 2018). In a China’s urban analysis, for Zhangye city, the results showed that the main for the decreased water footprint was the technological effect stemmed from the growth on the water consumption intensity and partly offset by the structural effect induced by the change of final demand structure (Feng et al., 2017).

[1] The “dead volume” or technical reserve represents the volume of water stored below the gates of a reservoir, which requires pumping for use. In critical situations of low storage level, it can be used as a water reserve for emergency use.

The SDA for the Spanish economy, from 1980 to 2007, shows that the household demand and the increase of exports appear as key explicative factors of the increase in water consumption almost three times the growth, the demand effect being largely offset by technological effect mainly in the agricultural crops (Cazcarro et al., 2013b).

To support the construction of "national water-saving cities",[2] Shang et al. (2017) adopted a decomposition method to quantitatively analyse changing industrial water use in Tianjin. The authors decomposed the data changes associated with industrial restructuring using a refined Laspeyres model, in two period, ie, before 2008, when industrial water use decreased, driven predominantly by technological advances, and after 2008, when higher industrial output led to greater industrial water use that overshadowed the water savings achieved by technological development. The results demonstrate that water efficiency showed limited improvement, despite the increasing industrial scale and output of certain industrial sectors in Tianjin. Changes in industrial water use in Tianjin are not caused by a single factor, but result from a combination of industrial scale expansion, water-saving technologies, industrial restructuring, and shortages of water (Zhang et al., 2016).

Although the literature can provide some studies with interesting results about the drivers that most influence the water demand in different countries, it was not found any study that evaluates the economic and technological driving forces of water demand in Brazil's economy. Furthermore, it is not possible to find one that links the change in water demand patters during a water crises and economic recession, like the case of Brazil.

By investigating the economic sectors response between 2013 and 2015, this study proposes to empirically evaluate the main drivers of the water consumption variation by the economic sectors. In addition, the relevance of the Brazilian exports of virtual water on the global trade has great significance in socio-economic impact since water consumption is critical for societal sustainability and development discussion.

1.3. Scope of the study

Due to the exposed, the main objective of this study is to identify the main driver of the increase of the water consumption between 2013 and 2015 and to highlight the discussion in terms of policy implications to the water intensity of the economy in the case of Brazil. In order to answer this question, this study aims to investigate the main economic driving forces, from both supply and demand side, in the national context.

Once the EEA-W integrates the physical and monetary flows of water resources provision into the economic sectors from 2013 to 2015, emblematic questions should be addressed, which are: How the evolution of macroeconomic indicators, as Final Demand, in National Accounts interferes in physical demand of water resources uses? How changes in the availability of water resources may interfere in the sectoral water demand evolution of the economy? Considering the water consumption intensity by economic activity, and the final demand change during 2013 and 2015, which is the embodied water of the economy and by sector? Which are the main economic and technological drivers that influences the most the embodied water changes by sector? This paper aims to address which economic effects mostly interferes in the water demand.

To this end, the methodological approach chosen in this paper permitted to estimate the virtual water embodied in products by economic sectors with an extended input-out model (IOM). Then the main drivers of the water consumption by economic sectors are analysed through a SDA.

Usually SDA are carried out with long series time of data, but no longer time series of water demand by economic sectors are available to Brazil. However, the period of available data of Brazilian EEA-W is quite interesting. The economic activity decelerated in the country: while the GDP in 2013 recorded 3% of growth, in 2014 it did 0.5% and decreased to −3.5% in 2015 (IBGE, 2016). This phenomenon can induce changes in the interdependences between economic sectors. Also, the country faced a huge water crisis during this period, as discussed in the begging of this section.

The paper is organized as follows: after this introduction, the next session describes the methodological aspects of the IOM and SDA applied. The third section presents the results and, the last one, discusses the main conclusions and directions to further developments.

2. Materials and methods

Input-Output Analysis is a useful approach to quantify sectoral water footprint. The water footprint is an indicator that take to account not only the direct water demand of a consumer or producer, but also all the indirect water requirement. The water footprint method is based on Leontief model and considers the total interdependence of the economic demand and supply chain (Hoekstra et al., 2011).

The recent publication of the Brazilian EEA-W allows the estimation of an IOM for Brazil. It represents the water flows required by the economic activities with the same SNA structure, which allows the linkage between the environmental and economic data without hypotheses assumption, providing more robustness to the results.

The Brazilian EEA-W provides information for six economic activities, according to International Standard Industrial Classification of all Economic Activities (IBGE, 2018)[3] - The correct reference is (IBGE, 2018).

i) Agriculture, livestock, forestry and fishing (ALFF);
ii) Extractive industry (EI);
iii) Manufacturing and Construction (MC);
iv) Electricity and natural gas supply (ENGS);
v) Water and sewage (except for "remediation activities" (WS); and
vi) Other activities ("remediation" and all the service activities) (OA).

The Physical Supply-Use Table (Physical SUT) presents a compilation of the water resources flow assessment. It represents the interactions between the environment with the economy, flows between the economic sectors and also the return from economy to the environment. The Hybrid Supply-Use Table (Hybrid SUT) is a combination of the Physical SUT with production, intermediate consumption and final consumption economic data, adding to the monetary aggregates of the SNA (IBGE, 2018).

In order to implement the extended IOM and the SDA, we combined information of the Physical SUT between 2013, 2014 and 2015 and the SUT for the Brazilian economy to the same period. More specifically, the starting point is the SUT for the Brazilian economy to the period 2013-2014-2015 that resulted from an annual estimation series of SUT to 2000–2015 (Passoni, 2019).

There was a rearrangement of SUT aggregation sectors due to the sector aggregation of the Physical and Hybrid SUT. As the Imports are not part of the scope of this study, the National Use Table was used to applied the symmetric tables, assuming the industry-technology hypothesis.

[2] The Chinese Government recognized Tianjin as a "Water-Saving Society Construction Demonstration City" and create a task force, commissioned by the Chinese Ministry of Water Resources (MWR) and the Tianjin Municipal Water Authority, to conducts consultancy studies of "change in Tianjin's industrial water use and attribution analysis". The research findings are expected to provide a theoretical and data basis for creating more "national water-saving cities".

[3] It is important to highlight that the EEA-W considers the blue water from both surface and groundwater, a share of sea water and a small share of green water (or rain water) for households use only (IBGE, 2018).

$$x \doteq A * x + f \doteq (I - A)^{-1} * f \doteq L * f \quad (1)$$

where, **x** is the vector (6 × 1) of the gross production output by 6 industry sectors; **A** is the matrix (6 × 6) of the technical coefficients ($a_{ij} = x_{ij}/x_j$) relating monetary flows from industry *i* to industry *j* to total output of industry *j*; **L** is the Leontief matrix (6 × 6) representing structural interdependencies; **f** is the vector (6 × 1) of final demand. Now, with an IOM defined by industry technology hypothesis, it is possible to extend the model to the embodied water consumption estimation of the Final Demand by economic activities.

We first developed an extended IOM with water resources variables to estimate the direct and indirect technical coefficient for water consumption. Second, with those coefficients, we developed a SDA to isolate the three potential drivers of water demand: the water intensity, the structural and the final demand effect.

This study considers **water consumption (WC)** as the physical indicator because it is the part of water withdrawal used by the economic sector which is not returned to the activity responsible for sewage collection nor to the environment. In other words, this is the water that has been incorporated into products, or consumed by households or livestock (IBGE, 2018).

2.1. Estimation of the water embodied in Brazilian economic activities

The Satellite account framework is an effective way to introduce environmental variables in the IOM, using industry technology or commodity technology hypothesis. The environmental variables are incorporated to the SUT as external vectors. This method requires the same product and industry breakdown as the SUT they accompany, and allows to keep the system balanced (Genty et al., 2012).

The external environmental vector to be analysed in this study is the embodied water consumption by economic sectors, as displayed in the Physical SUT of Brazilian EEA-W. In this sense, it is possible to define the matrix $\hat{\mathbf{W}}$ as the diagonal matrix representing the embodied water consumption per monetary unit of the six economic activities output by $w_{ij} = w_j/x_j$. Finally, it is possible to quantify the total embodied water consumption (w_c) in the Final Demand as follows:

$$w_C = \widehat{W} * L * f \quad (2)$$

Indeed, the Final Demand can be represented in its aggregated form or by a matrix which records the sales by each sector to final markets for their production. Final Demand is composed by Exports, Government consumption, Households,[4] Gross fixed capital formation and Changes in inventories.

2.2. Structural decomposition analysis

The SDA has been developed in order to deepen the understanding of the main drivers of water consumption pattern of the economic activities. In other words, SDA method is a comparative-static tool to break down the observed changes in physical variables into the changes in their physical and economic determinants. The method depends on a well-constructed input-output monetary and physical table which indicates a detailed structure of production, final demand and the complex interaction between the environment, in this case, the water embodied in the economy transactions.

The objective is to determine the influence of each physical and economic determinants, also called as drivers, in the water embodied consumption changes. In this sense, the SDA method chosen considers three main drivers that explains the water consumption changes, which are:

i) The intensity changes, *eg.* the water resource direct demand of the economic activities;
ii) The economy structural changes, *eg.* an increase or decrease of economic activities production and its intermediate consumption structure, and;
iii) The final demand change, *eg.* the households, government or exports consumption demand.

It was considered two break-down intervals: 2014–2013 and 2015–2014, in order to investigate the short-term response of the economic sectors to the water crises and the economic recession in the period. The variation of w_C between two periods is given by Miller and Blair (2009):

$$\Delta_C^{0-1} = \Delta w_C^1 - \Delta w_C^0 = \widehat{W}^1 * L^{*1} * f^1 - \widehat{W}^0 * L^{*0} * f^0 \quad (3)$$

$$\begin{aligned} \Delta w_C{}^{0-1} = & \frac{1}{2} \Delta \widehat{W} \left(L^{*0} * f^0 + L^{*1} * f^1 \right)_{intensity\ effect} \\ & + \frac{1}{2} \left(\widehat{W}^1 * \Delta L^* * f^0 + \widehat{W}^0 * \Delta L^* * f^1 \right)_{structural\ effect} \\ & + \frac{1}{2} \left(\widehat{W}^0 * L^{*0} + \widehat{W}^1 * L^{*1} \right) \Delta f_{final\ demand\ effect} \end{aligned} \quad (4)$$

The "intensity effect" considers the change of the direct water consumption coefficient among the period. It is also called "direct effect". It represents the direct requirement of water consumption of the one monetary unit in the sector production. It may reflect various aspects of technology change, such as changes in production recipes, substitutions caused by relative price changes, economies of scale, and, in this case, the reduction of the water consumption demand by the economic sectors.

The "structural effect" shows how changes in the structure of the economy have contributed to changes in total water consumption. It is also called "total effect", since represents the total impact on water demand (direct and indirect) pushed by the production of a sector and its interdependences economy-wide, representing an increase (decrease) in intermediate consumption due to production change.

The "final demand effect" represents the impact of the economy level of activity. As pointed by Miller and Blair (2009), changes in final demands may be the result of changes in the overall level of final demand or changes in the relative proportions of expenditure on the various goods and services in the final-demand vector. Also, this effect allows to evaluate the economic system in trends of economic growth and recession (Miller and Blair, 2009).

Even this kind of three effects SDA has been widely used in the scientific literature, Nagashima (2018) pointed out the importance of addressing uncertainties in decomposition results. Particularly, the simulations reveal instabilities for the intensity and structural effects. In other words, it arises wariness in interpreting and transferring conclusions to suggest the potential of economic restructuring for reducing the environmental burden of the economic system.

In contrast, the decomposition effect of the final demand is relatively insusceptible in this regard, indicating a good source of basement to orient environmental policies in terms of economic activity. The sign reversal of the unstable structural effect arises from estimation of the technical coefficient matrix (A) which includes many sources of measurement error. Importantly, these errors accumulate in the process of complex calculations for Leontief's multiplier and structural decomposition (Nagashima, 2018).

Considering that Brazil faced a water crisis and an economic recession in the analysed period, the SDA method has been chosen because it permits to measure the physical impact of each determinant (structural, intensity and final demand) in the water demand changes. Using the SDA, the authors quantify in physical unit the changes in water demand caused by each analysed driver, which permits to indicates some evidences of the water resources and economic context. As an example, the SDA permits to indicates if the decrease in the intensity effect due to the

[4] Including non-profit organizations.

water crisis had a bigger or lower impact in water consumption comparative to the final demand due to exports changes, per sector of the Brazilian economy.

3. Results and discussion

3.1. Total water consumption

Table 1 presents the main results of the total water consumption (w_c) embodied in the Final Demand from 2013 to 2015, disaggregated to each economic sector. It is also presented the correspondent final demand in monetary values in the period analysed, in order to clearer the comparation of the results.

According to Table 1, the ALFF sector has the highest w_c, 23,704 hm^3, in 2015. This value represents 78% of the total economy water consumption. Nevertheless, this sector does not have the same importance in the final demand value, representing only an average of 3% of the total final demand of the economy during the period.

In order to illustrates the variation of the total water consumption w_c and the final demand, Table 2 presents the percentage changes of the embodied water consumption w_c and the final demand, by economic sector, for each period.

Considering that the w_c for the "Agriculture, livestock, forestry and fishing" sector increased only 9% and the final demand increased 25% along 2013–2015 (Table 2), the SDA results should demonstrate if there is a direct intensity effect, and if so, how does the final demand influences in total water consumption.

The MC sector which has the second higher volume of water consumption, with 3,806 hm^3 on 2013, perceives a decrease in w_c of −9%, although the positive change in the final demand of 4% along 2013–2015, resulting in total w_c of 3,450 hm^3 in 2015 (Table 2). For this sector, the SDA should point out if this represents an efficiency gain by a reduction in intensity, by a structural effect, or by the unchanged in final demand during 2014–2015. The WS sector had a decrease in w_c of −5%, while the final demand increased 5% along 2013–2015.

It is important to notice that in the second period, between 2014 and 2015, all sectors, except EI sector faced a decrease in w_c (Table 2). Those facts could be related to a water constraint caused by the water crisis on the same period. Nevertheless, this event and its consequence could be better evaluated by the SDA. Considering that in this period Brazil faces together an economic recession and water crisis, the SDA should explain which are the drivers, for example, if intensity effect or a structural effect, that justifies the bigger parcel of the w_c. negative change. Considering the relevant points highlighted from the total water consumption, to better comprehend the drivers and economic mechanisms of these changes, the next item presents the SDA results.

Table 2
Variation of the total water consumption and final demand.

Economic sectors	Δ2013-2015		Δ2013-2014		Δ2014-2015	
	w_c	Final demand	w_c	Final demand	w_c	Final demand
Agriculture, livestock, forestry and fishing	9%	25%	10%	8%	−1%	16%
Extractive Industry	9%	−6%	5%	7%	4%	−12%
Manufacturing and Construction	−9%	4%	−4%	4%	−5%	0%
Electricity and natural gas supply	19%	46%	20%	16%	−1%	27%
Water and sewage	−5%	5%	−2%	−1%	−3%	6%
Other activities	−8%	18%	−4%	11%	−4%	6%

Source: Own elaboration.

3.2. Structural decomposition analysis of embodied water consumption in Brazil

The following figures present the results of the SDA. Fig. 1 presents the results to the 2013–2014 period and Fig. 2 to the 2014–2015 one. The decomposition illustrates the changes in the total water consumption in three effects (intensity, structural and final demand). It is possible to analyse the main drivers which influence the change in the total water consumption by each economic sector.

Analysis by Effect. Table 3 presents the SDA results by intensity, structural and final demand effect, for both periods, demonstrating the drivers of the total effect for each economic activity.

Between 2013 and 2014, the economy faced an increase in the embodied water consumption, being the final demand the main driver (1,968 hm3) of the positive total effect (1,962 hm^3). The intensity effect shows a loss in efficiency (249 hm^3), contributing for the increase in w_c, while the structural effect contributes a little for a w_c reduction (−254 hm^3). The three sectors that faced an increase in the embodied water consumption, ALFF, EI and EGNS (2,185 hm^3, 12 hm^3 and 18 $hm^{3,}$ respectively), have the final demand as the most important driver that influences such increases (1,533 hm^3, 15 hm^3 and 10 hm^3, respectively).

The intensity effect also justifies an increase in the w_c for the ALFF and the EGNS sectors, indicating that a loss in water efficiency provokes a higher consumption (805 hm^3 and 3 hm,^{3} respectively). In this period, the intensity effect was the driver of a reduction in w_c only for the MC, WS and OA sectors (−161 hm^3, -58 hm^3 and -33 hm^3, respectively).

Between 2014 and 2015, the total effect in the embodied w_c was negative for almost all the economic activities, except for the EI sector. In mostly all sectors, the main driver of this reduction in water consumption was the intensity effect, and in some sector in both intensity and structural effect. The ALFF sector perceives an important intensity effect (−2,476) that was overwhelmed by the final demand and

Table 1
Total water consumption embodied in the final demand.

Economic sectors	2013				2014				2015			
	w_c		Final demand		w_c		Final demand		w_c		Final demand	
	hm^3	%	billions of BRL	%	hm^3	%	billions of BRL	%	hm^3	%	billions of BRL	%
Agriculture, livestock, forestry and fishing	21,715	75%	179	3%	23,900	77%	194	3%	23,704	78%	224	4%
Extractive Industry	258	1%	121	2%	270	1%	129	2%	282	1%	114	2%
Manufacturing and Construction	3,806	13%	1,866	34%	3,646	12%	1,947	33%	3,450	11%	1,938	32%
Electricity and natural gas supply	85	0%	56	1%	102	0%	65	1%	101	0%	82	1%
Water and sewage	2,395	8%	13	0%	2,337	8%	12	0%	2,270	7%	13	0%
Other activities	812	3%	3,193	59%	778	3%	3,547	60%	748	2%	3,775	61%
Total	29,071	100%	5,427	100%	31,033	100%	5,895	100%	30,554	100%	6,147	100%

Source: IOM results based on EEA-W and SNA data.

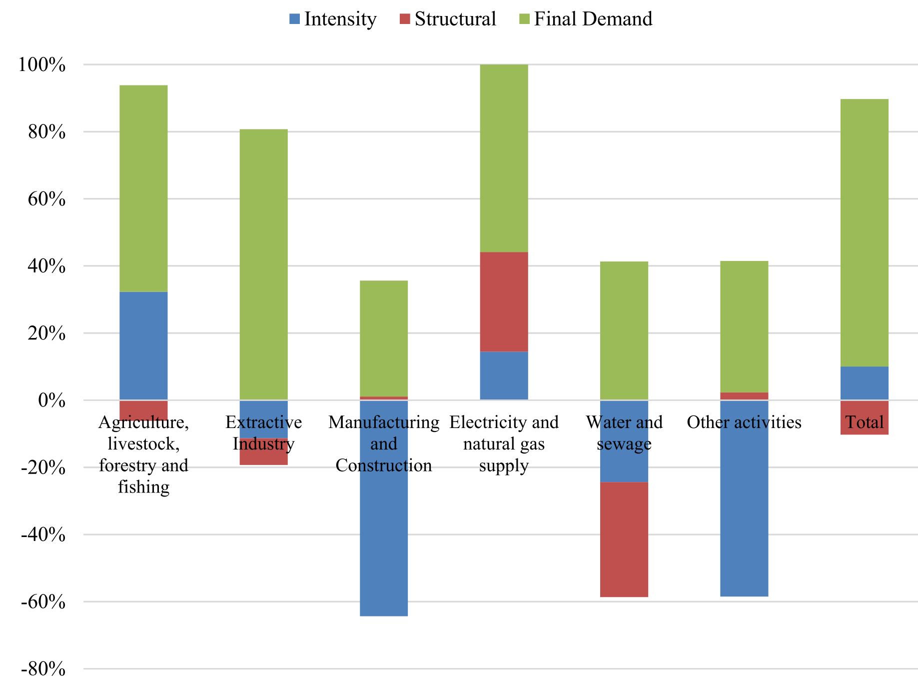

Fig. 1. SDA of the water consumption between 2013 and 2014.

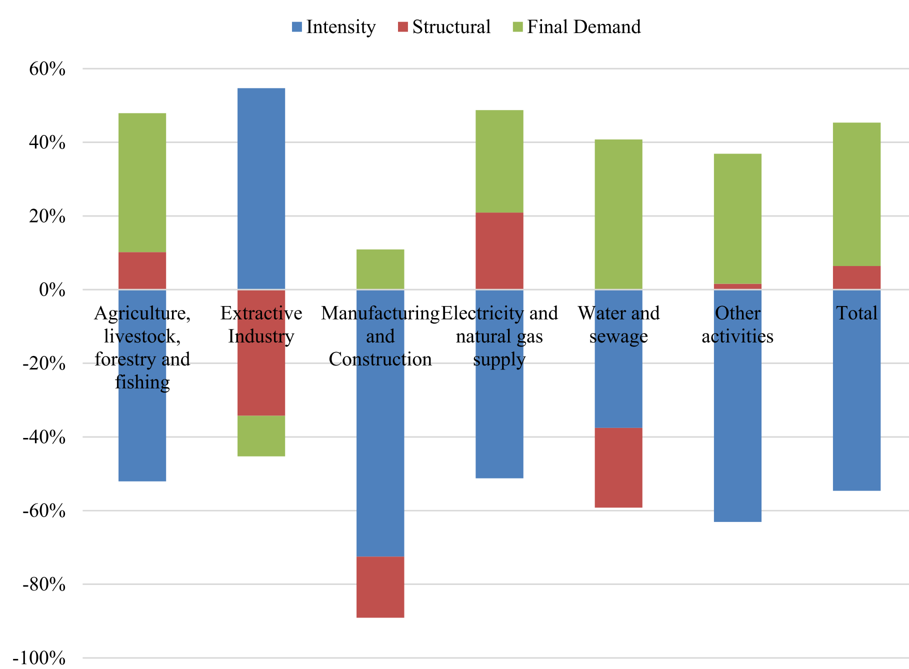

Fig. 2. SDA of the water consumption between 2014 and 2015.

structural effect (1,796 hm^3 and 484 hm^3, respectively), but still has a negative total effect (−196 hm^3).

The MC and WS sectors also faced a decrease in the embodied w_c (−196 hm^3 and -67 hm^3, respectively), with the intensity and the structural effect as the main driver. The EGNS sector has small negative total effect (−1 hm^3). For this sector, even though the intensity effect was important (−23 hm^3), the final demand and the structural effect (12 hm^3 and 9 hm^3, respectively) almost turn the total effect unchanged.

It is important to highlight that in both periods the final demand effect was strongly positive. Even between 2014 and 2015, when the country faced a strong economic recession. Already in 2014 the GDP had stagnated and the final demand driver did not accompanied the economic slowdown. In the last period, even with the reduction of the economic activity, the final demand effect shows inertia and still pushed up the increase in the total water consumption.

Analysis by Sector. In the first period, from 2013 to 2014, the increase of the embodied water consumption by the ALFF sector was pushed mostly by the increase of the final demand, being responsible for more than 70% of the total increase (1,533 hm^3). The second driver is caused by the intensity effect, responsible for 37% of the change (805 hm^3). On the other hand, the structural effect contributes to a reduction of the water consumption (−153 hm^3), as it is presented in Table 3 and

Table 3
SDA by intensity, structural and final demand effects (hm^3).

Economic sectors	2013–2014 effects				2014–2015 effects			
	Total	Intensity	Structural	Final demand	Total	Intensity	Structural	Final demand
Agriculture, livestock, forestry and fishing	2,185	805	−153	1,533	−196	−2,476	484	1,796
Extractive Industry	12	−2	−2	15	12	68	−43	−14
Manufacturing and Construction	−161	−360	6	193	−196	−182	−42	27
Electricity and natural gas supply	18	3	5	10	−1	−23	9	12
Water and sewage	−58	−82	−115	139	−67	−138	−79	150
Other activities	−33	−115	5	77	−31	−74	2	41
Total	1,962	249	−254	1,968	−479	−2,824	332	2,013

Source: Own elaboration

illustrated in Fig. 1.

In the second period, from 2014 to 2015, this sector verified a decrease in the total water consumption, caused mostly by a strong negative change of the intensity effect (−2,476 hm^3). Although the importance of this effect, this was neutralized by the opposite influence of the final demand effect (1,796 hm^3) and the structural effect (484 hm^3), as presented in Table 3 and illustrated in Fig. 2. The main final demand component that pushed positively the increasing in water consumption was the Exports (2,180). Those opposite effects caused a little reduction in water consumption, of only −196 hm^3.

The results of the main drivers of the embodied water consumption change in this period for the ALFF sector raise two important reflections on the subject that contributes to subsidize public policies.

Firstly, it is relevant to highlight that a small change of the water consumption intensity in this sector from 2014 to 2015 has a strong influence in the reduction of the total water consumption of the activity. Nevertheless, the opposite force caused by the final demand and the structural effects provokes a small net result reduction in water consumption.

This fact indicates that the implementation of an efficient public policy needs to encourage the reduction of the water consumption intensity, but also has to consider mechanisms to induce the reduction of intermediate and final demand of its products. ALFF is an export-oriented sector which has an intensive water consumption demand to comply its total gross production due to the irrigation activity.

The ALFF sector has a small fraction (less than 5%) of the value added at final demand in monetary values in comparison to the share of the embodied water consumption in the sector's final demand (around 75%), as showed on Table 1. This fact shows the burden that the increase in the economic activity of the sector may put over the water resources of the country.

A second point of discussion consists on the factor that caused the reduction in water consumption intensity. It could have happened by technological improvement of the sector's production. Or, in other words, to the capacity of increase the sectoral gross output demanding less water per unit of production. On the other hand, the reduction in water consumption intensity could also have happened due to the change in the rainfall regime.

A reduction in rainfall should represent a short-term change in the agriculture irrigation, passing from an irrigation system to a dry farming that uses soil water. As an example, in the period of the water crisis between 2014 and 2015, there was a reduction of the harvested irrigated area in 2.8%, which indicates that the decrease in water consumption intensity should be a short-term effect (ANA, 2015).

The ENGS sector has an increase in the total w_c between 2013 and 2014 (18 hm^3), which the main driver was the final demand, pushed by the Households. It is also possible to note a strong structural effect in both period, that can be attributed to the increasing in the use of thermal power plants instead of hydroelectricity. Between 2014 and 2015 there was a small decrease in the total w_c (−1 hm^3) provoked by the intensity effect (−23 hm^3).

The EGNS sector also depends on the water availability to become operationally viable, as hydroelectricity is principal source of power generation, constituting 69% (EPE, 2014), 63% (EPE, 2015) and 62% (EPE, 2016) of the energy matrix of the country, respectively. With the decrease of the hydropower generation due to the lack of rainfall and the lower volume of water in the reservoirs, the increase in thermo power generation pushed up the demand of water consumption in the sector (ANA, 2015). In 2013, the thermo power generation (including natural gas, petroleum products, coal, nuclear and biomass sources) represented 28% of the energy matrix and faced an increase of 15% in this share until the end of 2015 (EPE, 2016).

It is difficult to expand the Brazilian power generation without increasing the water consumption demand because there is no longer expansion of large hydroelectric projects due to their socio-environmental unsustainability. As the EGNS have been expanded with thermal power plants, it implies an expressive increase in the water consumption demand. Or, in other words, the increase in energy production becomes increasingly inefficient in relation to the demand of water.

Even though the ALFF sector has the highest water consumption in absolute numbers, the consumption coefficient (the demand for water per unit of total production) in the ENGS sector is the highest among all sectors (approximately 12 hm^3 of water consumption per unit of production). For the ALFF sector this number is of the order of 0.02 of water consumption per unit of production (BIGS, 2018). In this sense, the policy of expanding the power generation should consider the construction of new thermal power plants in areas where there is no competition for the water allocation.

The second most important activity in terms of direct water consumption, the MC sector, presents a decrease in the embodied water consumption along both period, −161 hm^3 between 2013 and 2014, and -196 hm^3 from 2014 to 2015. In the first period, the intensity effect was the only driver that brings down the water consumption, being responsible for −360 hm^3, while the final demand plays the opposite role bringing up the water consumption by 193 hm^3. In the second period, the intensity and structural effect plays both an important role for the water consumption reduction, representing −182 hm^3 and −42 hm^3, respectively, and the final demand having an opposite effect of only 27 hm^3 (as shown in Table 3).

The third most important activity in terms of direct water consumption, the WS sector, has a decrease in the embodied w_c between 2013 and 2014 (−58 hm^3), and also between 2014 e 2015 (−67 hm^3), as shown in Table 3. In both periods, the driver that brings down the total water consumption was from the intensity and the structural effect.

It is important to notice that the water consumption of OA sector, which includes all the services activities, influences on the water consumption of the WS sector, as the first one depends on the water distribution and sewage services. As the WS sector, OA sector faces a decrease in embodied water consumption of −33 hm^3 and -74 hm^3, in both period, 2013 to 2014 and 2014 to 2015, respectively.

The total water consumption of this sector was negatively pushed by the intensity effect, that operates with a reduction of −115 hm^3 and -74 hm^3, in each period, respectively. The structural effect had a positive impact during both periods, but lower than the positive impact of the final demand effect which caused an increase of 77 hm^3 and 41 hm^3 from 2013 to 2014 and 2014 to 2015, respectively. In 2015, the services sector had a decrease of 7.3% influenced by the retraction in sales of industrial products (IBGE, 2016). The difference of the contribution in the increasing of water consumption due to the final demand, between one period to another, should be due to the economic recession that contributes to reduce services related to the distribution of industrial products.

The total w_c of the EI sector increases in 12 hm^3 in both periods, nevertheless between 2014 and 2015 this sector was the only one that faces an increase in total w_c. The drivers of this increase are different from one period to another. In the first period the main driver was the final demand, and the responsible for this effect were mainly Households, Change in inventories and Exports (40%, 35% and 10%, respectively). In the second period, the increasing in the total negative effect was caused by the positive intensity effect (68 hm^3), which compensate the negative structural and the demand effect that was lower (-43 hm^3 and -14 hm^3), this last effect influenced by a reduction in the Gross fixed capital formation, Change in inventories and Exports. This sector was also the only one that had negative final demand effect, which could be related or contributed, to Samarco's dam mining waste collapse, which took place in November 2015.

4. Conclusion

The results of the SDA show that in both periods the final demand effect stays positive in almost all activities, having the ALFF sector as the most important parcel of the final demand driver. This result can be explained by exports increasing, which demonstrate that domestic and international market can impact the national water consumption.

Furthermore, considering 2014 to 2015 the results show in almost all sectors the structural effect was less important than the intensity effect. This result shows that the water crisis could have generated a greater influence on the intensity effect reducing embodied water consumption, comparatively to the economic structural recession. It is necessary to monitor future water variation induced by natural and economic driving forces in order to evaluate if this response will be incorporated as technological improvement.

Two important reflections on this subject could contributes to subsidize public policies. Even with a small change on water consumption intensity and a strong influence in the reduction of the total water consumption in the ALFF sector, the opposite force caused by the final demand and the structural effects provokes a small net result reduction in water consumption by this sector.

This fact indicates that the implementation of an efficient public policy needs to encourage the reduction of the water consumption intensity, but also has to consider mechanisms to induce the reduction of intermediate and final demand of its products. ALFF sector is an export-oriented sector which has an intensive water consumption demand to comply its total gross production due to the irrigation activity.

In terms of the holistic approach on the integration of energy, water and environment policies, it is necessary considering the strategic position of the ENGS sector. As the power generation has been expanded with thermal power plants, it implies an expressive increase in the inefficient on water consumption intensity. As the ENGS is a supplier economywide, it would be expected a possible structural increase of the water consumption demand.

It was verified that in the second period the total water consumption decreased due to the negative intensity effect, reflecting the water crisis. However, the final demand effect stayed positive. As mentioned above, this fact indicates that, in some cases, the public policy needs to encourage not only the most efficient water technology, but they have to management the scale effect, as the final demand increasing or its composition.

In view of a bibliography gap on the analysis of water use in the Brazilian economy, this work is pioneering in the use of data from the Brazilian EEA-W for the development of the SDA method. From the application of the SDA method, the greatest contribution of the present work is to record in physical unit the determinants of water consumption in the Brazilian sectors, which could subsidize public policies on water savings and economic instruments for water management.

Considering the weakness of the economy structure aggregation in only six sectors, we highlight the importance of carrying out an analysis with a greater breakdown of economic activities, so it will be possible to distinguish inside each sector, the prevalence of determined economic activity in water embodied consumption. To disaggregate the sectors in different economic activities will be necessary a more detailed estimation in physical water consumption.

Furthermore, since the time period analysis was short, a future improvement should consider a longer time series. To better understand the fact that drives the intensity effect, as well as the final demand driver considering the economic changes, would also require a longer series. Another important improvement is to develop the analysis based on a constant price monetary data in relation to a base year, in order to avoid the price effect over time and exclude any nominal change in output.

Other limitation of this kind of approach is the intensity and structural effect sensitivity to support environmental policies. However, the final demand effect is strongly reliable, as pointed by Nagashima (2018). It is important to highlight that in both periods the final demand effect was strongly positive. Even between 2014 and 2015, when the country faced a strong economic recession. Already in 2014, the GDP had stagnated and the final demand driver did not accompany the economic slowdown. In the last period, even with the reduction of the economic activity, the final demand effect shows inertia and still pushed up the increase in the total water consumption.

Otherwise, the results contribute to understand the economic drivers that influences the water resources demand from economic activities. The analysis permits also to show the dependence of the economy on water resources public policies, which can be improved in terms of regulation and economic instruments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Giovanna Ferrazzo Naspolini: Conceptualization, Methodology, Investigation, Writing - original draft. **Bruna Stein Ciasca:** Investigation, Writing - original draft. **Emilio Lèbre La Rovere:** Supervision. **Amaro Olimpio Pereira Jr:** Conceptualization, Methodology, Supervision.

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References

Allan, J.A., 1998. Virtual water: a strategic resource. Ground Water 36, 545+.
ANA, 2015. Conjuntura dos recursos hídricos: informe 2015. Agência Nacional de Águas.
ANA, 2018. ANA_informe_conjuntura_2018.pdf, Conjuntura Dos Recursos Hídricos No Brasil 2018: Informe Anual. Agência Nacional de Águas, Brasília.

Aviso, K.B., Holaysan, S.A.K., Promentilla, B., M A, Yu, S., K D, R Tan, R., 2018. A multi-region input-output model for optimizing virtual water trade flows in agricultural crop production. Management of Env Quality 29, 63–75. https://doi.org/10.1108/MEQ-01-2017-0012.

Bogra, S., Bakshi, B.R., Mathur, R., 2016. A water-withdrawal input–output model of the Indian economy. Environ. Sci. Technol. 50, 1313–1321. https://doi.org/10.1021/acs.est.5b03492.

Cazcarro, I., Duarte, R., Sánchez Chóliz, J., 2013a. Multiregional input–output model for the evaluation of Spanish water flows. Environ. Sci. Technol. 47, 12275–12283. https://doi.org/10.1021/es4019964.

Cazcarro, I., Duarte, R., Sánchez-Chóliz, J., 2013b. Economic growth and the evolution of water consumption in Spain: a structural decomposition analysis. Ecol. Econ. 96, 51–61. https://doi.org/10.1016/j.ecolecon.2013.09.010.

da Silva, V., de Oliveira, S., Hoekstra, A., Dantas Neto, J., Campos, J., Braga, C., de Araújo, L., Aleixo, D., de Brito, J., de Souza, M., de Holanda, R., 2016. Water footprint and virtual water trade of Brazil. Water 8, 517. https://doi.org/10.3390/w8110517.

Deng, G., Ma, Y., Li, X., 2016. Regional water footprint evaluation and trend analysis of China—based on interregional input–output model. J. Clean. Prod. 112, 4674–4682. https://doi.org/10.1016/j.jclepro.2015.07.129.

Duarte, R., Pinilla, V., Serrano, A., 2016. Understanding agricultural virtual water flows in the world from an economic perspective: a long term study. Ecol. Indicat. 61, 980–990. https://doi.org/10.1016/j.ecolind.2015.10.056.

EPE, 2014. Statistical Yearbook of electricity. Empresa de Pesquisa Energética.

EPE, 2015. Statistical Yearbook of electricity. Empresa de Pesquisa Energética.

EPE, 2016. Statistical Yearbook of electricity. Empresa de Pesquisa Energética.

Feng, L., Chen, B., Hayat, T., Alsaedi, A., Ahmad, B., 2017. The driving force of water footprint under the rapid urbanization process: a structural decomposition analysis for Zhangye city in China. J. Clean. Prod. 163, S322–S328. https://doi.org/10.1016/j.jclepro.2015.09.047.

Genty, A., Arto, I., Neuwahl, F., 2012. Final Database Of Environmental Satellite Accounts. TECHNICAL REPORT ON THEIR COMPILATION 69.

Hoekstra, A.Y., Chapagain, Ashok K., Aldaya, M.M., Mekonnen, M.M., 2011. The Water Footprint Assessment Manual: Setting the Global Standard, first ed. Routledge. https://doi.org/10.4324/9781849775526.

IBGE, 2018. Contas econômicas ambientais da água : Brasil : 2013 - 2015 (Notas técnicas No. Instituto Brasileiro de Geiografia e Estatística, Rio de Janeiro, ISBN 9788524044526. Contas Econômicas e Ambientais da Água.

IBGE, 2016. Contas Nacionais (No. ISSN 1415-9813), Sistema de Contas Nacionais. Instituto Brasileiro de Geiografia e Estatística, Rio de Janeiro.

Liu, J., Zhao, X., Yang, H., Liu, Q., Xiao, H., Cheng, G., 2018. Assessing China's "developing a water-saving society" policy at a river basin level: a structural decomposition analysis approach. J. Clean. Prod. 190, 799–808. https://doi.org/10.1016/j.jclepro.2018.04.194.

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

Nagashima, F., 2018. The sign reversal problem in structural decomposition analysis. Energy Econ. 72, 307–312. https://doi.org/10.1016/j.eneco.2018.04.027.

Niemeyer, I., Garrido, A., 2011. Latin American agricultural trade: the role of the WTO in sustainable virtual water flows. EAAE 2011 Congress 12.

Passoni, P.A., 2019. Deindustrialization and regressive specialization in the brazilian economy between 2000 and 2014: a critical assessment based on the input-output analysis (Tese de Doutorado). Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Shang, Y., Lu, S., Li, X., Sun, G., Shang, L., Shi, H., Lei, X., Ye, Y., Sang, X., Wang, H., 2017. Drivers of industrial water use during 2003–2012 in Tianjin, China: a structural decomposition analysis. J. Clean. Prod. 140, 1136–1147. https://doi.org/10.1016/j.jclepro.2016.10.051.

Zhang, Y., Zhang, J., Tang, G., Chen, M., Wang, L., 2016. Virtual water flows in the international trade of agricultural products of China. Sci. Total Environ. 557–558, 1–11. https://doi.org/10.1016/j.scitotenv.2016.02.166.