Water and Global Value Chain: A subsystem application to Brazil

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The deindustrialization of developed countries has led to a shift in water use activities to developing countries without a similar reduction in consumption of manufactured goods in developed countries. The location of different stages of production in other countries with the objective of reducing costs (including environmental ones) has led to an increase in international trade regarding final goods and, in particular, intermediate inputs.

The objective of this paper is to analyse the use of water by production and consumption in Brazil from 1995 to 2009, using a multiregional input-output matrix in order to consider all water uses (blue, green and grey water) associated to value chains. Estimates were made using the World Input-Output Database (WIOD).

The methodology of the subsystems or vertically integrated sectors is used to quantify the total (direct and indirect) use of the different types of water by the Brazilian sectors and subsystems from 1995 to 2009, including the uses avoided/caused by the final and intermediate imports/exports. Next, structural decomposition analysis is applied to investigate the role of international trade in the evolution of total water use and the extent to which the change in composition of domestic production by industry (and the consequent change in water use) is due to changes in production and in consumption. In conclusion, it is shown how comparison between the use of the different types of water by sector and corresponding subsystem provides can be useful for evaluating the impacts of public policies on production and consumption in the management of water resources.

Keywords: water consumption; input-output matrix; vertically integrated sectors (subsystems); international trade

Subject classification codes: include these here if the journal requires them

1. Introduction

Human economy is embedded in nature, and exchanges matter and energy with the larger system of the earth. It is an open system inside the framework of a closed system in the thermodynamic sense. The both ideas imply that there are limits to the material growth of the economy. Considering the interests of future generations, the scale of the economy has to be limited, and therefore, the issue of equity and distribution comes to the fore (Røpke, 2005). Each generation would have the right to enjoy the services from natural assets, but the assets themselves must be passed on to the next generation. It is necessary to thinking of sustainability as a matter of intergenerational equity (Norgaard, 1992).

At the global level, there is a clear flow of primary commodities from poorer to wealthy countries. Developed countries dictating the terms of trade with less-developed ones, which environmental and natural resources tend to be undervalued under free trade. As a result, poor countries specialised in polluting products tend to have fewer opportunities to internalise environmental costs into prices (Muradian and Martinez-Alier, 2001), and industrialized countries are increasingly appropriating both global natural resources and the sink capacity of ecological systems (Mózner, 2013).

The deindustrialization of developed countries has led to a shift water use activities to developing countries without a similar reduction in consumption of manufactured goods in developed countries because developed countries import biocapacity from developing countries and consume more biomass and sink-capacity then what is produced within their own boundaries nations (Mózner, 2013; Baker, 2017).

It happens because acquiring a ‘comparative advantage’ in water-intensive goods is a strategy pursued by economic agents in developing countries, which environmental regulations tend to be less stringent than in developed ones. This kind of regulations discouraging local agents from investing in more efficient technologies, while they simultaneously encouraging developed nations to externalize water-intensive manufacturing to these less-regulated regions (Prell and Feng, 2016). The result of international competition is a “race to the bottom” of social and environmental standards leading to inequality, poverty, and environmental destruction (Haberl, 2015). Consequently, the location of different stages of production in other countries with the objective of reducing costs (including environmental ones) has led to an increase in international trade regarding final goods and, in particular, intermediate inputs.

There would be fewer incentives to reduce total material throughput in developed countries because the environmental costs of their increasing material consumption are not suffered by them, these environmental costs are suffered by developing countries where extraction, purification and processing of materials (and energy) are done (Muradian and Martinez-Alier, 2001). In a globalized world, this growing demand for resources is increasingly being satisfied through international trade which is contributing to detaching people spatially and socially from the ecosystems that support them. (McKinney, 2014; Garmendia et al, 2016). Therefore, international trade blurs the responsibility for the ecological effects of production and consumption because it lengthens the link between consumption and its consequences (Mózner, 2013).

Studies of global value chains (GVCs) - the combined set of production stages that are needed to produce a final good - are needed in situations where production is highly fragmented across firms and geographical borders. As such GVC can be viewed as a special case of vertically integrated production, characterized by the fact that production stages are carried out in at least two countries. In this paper, the concept of subsystems or vertically integrated sectors developed by Pasinetti (1973) from Sraffa (1960) is used to quantify the total (direct and indirect) use of the different types of water by the Brazilian sectors and subsystems from 1995 to 2009, including the uses avoided/caused by the final and intermediate imports/exports.

Our objective is to analyse the use of water by production and consumption in Brazil from 1995 to 2009, using a multiregional input-output matrix in order to consider all water uses (blue, green and grey water) associated to value chains and applying ecological pricing (or more generally Sraffa pricing). We argue that ecological pricing values biosphere processes, on the basis of biophysical interdependencies between all parts of the ecosystem. This method essentially measures the 'efficiency ratios' of transforming energy and mass to each other in the system.

Next, structural decomposition analysis is applied to investigate the role of international trade in the evolution of total water use and the extent to which the change in composition of domestic production by industry (and the consequent change in water use) is due to changes in production and in consumption.

In conclusion, it is shown how comparison between the use of the different types of water by sector and corresponding subsystem provides can be useful for evaluating the impacts of public policies on production and consumption in the management of water resources.

A water trade imbalance refers to the extent to which the different types of water uses embodied in a country's exports exceeds the water uses embodied in its imports (Prell and Feng, 2016). Exchange is 'ecologically unequal' if there is an imbalance between imports and exports (Mózner, 2013). In this sense, embodied water uses can therefore be considered a form of ecological, social and economic surplus extraction from developing countries where developed countries are increasingly appropriating both global natural resources and the sink capacity of ecological systems in order to maintain their consumption by paying developing countries 'a pittance' (Liverman, 2009; Baker, 2017). Free trade is expected to exacerbate global water uses because reduced water use are global public goods, so member countries have an incentive to become free-riders and reductions in water uses are likely to be under-supplied. (Moon, 2011).

Our proposal is to use the concept of subsystems or vertically integrated sectors developed by Pasinetti (1973) from Sraffa (1960) since it permits to estimate the amount of water directly and indirectly necessary to the economic system as a whole to obtain a physical unit of commodity.

4. Methodology

4.1. Data

We use the environmental inter-regional Input- Output accounts reported as part of the World Input- Output Database (WIOD) project (Timmer et al., 2015). The objective of the whole WIOD database is to have a fully integrated worldwide dataset consisting of harmonized Supply and Use Tables (SUTs), bilateral trade matrices and inter-country input-output tables completed by socioeconomic and environmental accounts (Lenzen et al., 2004). This version of the WIOD database is reported for 35 industries[1] in 41

1 Agriculture, Hunting, Forestry and Fishing (AtB), Mining and Quarrying (C), Food, Beverages and Tobacco (15t16), Textiles and Textile Products (17t18), Leather, Leather Products and Footwear (19), Wood and Products of Wood and Cork (20), Pulp, Paper, Printing and Publishing (21t22), Coke, Refined Petroleum and Nuclear Fuel (23), Chemicals and Chemical Products (24), Rubber and Plastics (25), Other Non-Metallic Mineral (26), Basic Metals and Fabricated Metal (27t28), Machinery, Not elsewhere classified (29), Electrical and Optical Equipment (30t33), Transport Equipment (34t35), Manufacturing, Not elsewhere classified; Recycling (36t37), Electricity, Gas and Water Supply (E), Construction (F), Sale and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel (50), Wholesale Trade, Except of Motor Vehicles and Motorcycles (51), Retail Trade and Repair, Except of Motor Vehicles and Motorcycles; (52), Hotels and Restaurants (H), Inland Transport (60), Water Transport (61), Air Transport (62), Other Supporting Transport Activities (63), Post and Telecommunications (64), Financial

regions/countries (40 countries[2] plus a composite 'Rest of the World', RoW region) from 1995 to 2009.

Environmental satellites are environmental variables of relevance for analysis, expressed mainly in physical units, which are juxtaposed to the monetary SUT framework. The environmental satellites are defined such as to cover the broadest range of environmental themes as reasonably achievable while maintaining a data quality that is well grounded in the empirical availability of primary data.

The WIOD covers the use of water (measured in 1000 m^3), distinguishing three different types of water (blue, green, and grey), based on the concepts of the water footprint approach (Hoekstra et al., 2011). Conventional national water use accounts are restricted to statistics on water withdrawals in its own territory. This includes the use of surface and groundwater by different economic activities and end users (the so-called blue water). The approach proposed by Hoekstra et al., extends these statistics, including data on the use of rainwater (green water) and volumes of water use for the absorption of waste (grey water), giving a broader perspective of appropriation of freshwater humans.

Intermediation (J), Real Estate Activities (70), Renting of Machinery & Equipment and Other Business Activities (71t74), Public Administration and Defence; Compulsory Social Security (L), Education (M), Health and Social Work (N), Other Community, Social and Personal Services (O), and Private Households with Employed Persons (P).

2 Australia (AUS), Austria (AUT), Belgium (BEL), Brazil (BRA), Bulgaria (BGR), Canada (CAN), China (CHN), Cyprus (CYP), Czech Republic (CZE), Denmark (DNK), Estonia (EST), Finland (FIN), France (FRA), Germany (DEU), Greece (GRC), Hungary (HUN), India (IND), Indonesia (IDN), Ireland (IRL), Italy (ITA), Japan (JPN), South Korea (KOR), Latvia (LVA), Lithuania (LTU), Luxembourg (LUX), Malta (MLT), Mexico (MEX), The Netherlands (NLD), Poland (POL), Portugal (PRT), Romania (ROU), Russia (RUS), Slovak Republic (SVK), Slovenia (SVN), Spain (ESP), Sweden (SWE), Taiwan (TWN), Turkey (TUR), UK (GBR), and USA (USA).

At the time of the WIOD compilation, there were no international datasets which met the geographic and temporal requirements of the database. Consequently, water accounts were estimated following different methods, depending on the available data. The main source of data for water accounts is the series of studies on water footprint calculations conducted by Mekonnen and Hoekstra (2010a, b and 2011a, b). The data, for reasons of homogeneity with the national accounting principles of the SUTs, is organised in compliance with the accounting principles of NAMEA.

4.2. Methodology

The economic activities of production and consumption are not independent or neutral in relation to the global ecosystem, which makes the divorce of the economic analysis of its "biophysical foundations" more and more worrying (Proops, 1989). One possibility is to reconstruct the biophysical foundations of economic activity by broadening the classical approach to include energy and low entropy materials extracted from environmental systems and eventually returned as waste (Christensen, 1989).

The theoretical implications of a biophysical approach to production require a reformulation of the theory of interactions within the economy, which includes a sectoral price model and a short-term macro model of price and quantity dynamics. Without a theory of value (price) in the ecological economy, valuation of the ecosystem and economic resources cannot be rigorously defended (Patterson, 1998).

According to Judson (1989), neo-Ricardian theorists assert that the value of any commodity can be expressed not only in terms of labour, but also in terms of any "standard" or "basic" commodity. As the energy theory of value is also based on physical accounting and the "cost of production" approach, Sraffa's classic model

(1960) can serve as a methodological basis for valuing the ecosystem and economic resources.

However, the Sraffian pricing model has little or no biophysical meaning because it does not map physical flows of energy and mass, does not explicitly conform to the principles of mass and energy conservation (First Law of Thermodynamics) and is based on the circular flow of exchange value instead of the ecological economical model of linear mass and energy transfer (Patterson, 1998). As the continuous flow of necessary materials and energy from natural systems was taken as given in the Sraffian system, it is necessary to extend the concept of commodity prices for environmental resources and services (Christensen, 1989).

By incorporating environmental resources and services, the ecological price (or Sraffian price) evaluates the processes of the biosphere, based on biophysical interdependencies between all parts of the ecosystem (Patterson, 2002). This method essentially measures the "efficiency ratios" of energy and mass transformation in the system. It can be shown mathematically that the choice of the cash is entirely arbitrary and the ecological prices are transitive, reflexive and symmetric (Patterson, McDonald and Hardy, 2017).

A subsystem is defined by Sraffa in Appendix A of his book (1960: 111):

> Such a system can be subdivided into as many parts as the commodities in their liquid product, so that each part forms a minor auto-replenishment system, whose liquid product consists of a single class of commodity. These parts will be called "subsystems".

Pasinetti (1973) theoretically investigated the logical properties of the subsystems, connecting the amount of direct and indirect work of Sraffa with the direct and indirect requirements of the Leontief inverse matrix. To do this, Pasinetti developed the concept of a vertically integrated sector, a compact form of representing a subsystem, which synthesizes each of them into a single working coefficient v_i. and in a single composite commodity h_i.

The vertically integrated labour coefficient for commodity *i*, v_i, $i = 1, 2, ..., m$, expresses the amount of labour directly and indirectly necessary to the economic system as a whole to obtain a physical unit of commodity *i* as well Last. It is defined as $v' = l'\left(I - A^{\Theta}\right)^{-1}$, where v' is the line-vector of vertically integrated labour coefficients, and l' is the line-vector of the direct labour coefficients [i.e. the direct labour ratio (L_j) by the final product (Yj) in each industry: $l_j = \frac{L_j}{Y_j}$ and $\left(I - A^{\Theta}\right)^{-1}$ is the inverse matrix of Leontief.[3]

The composite commodity h_i, $i = 1, 2, ..., m$, called the unit of vertically integrated productive capacity, expresses in a consolidated manner the series of physical quantities of the heterogeneous commodities *1, 2, ..., m* directly and indirectly necessary to the economic system as a whole to obtain a physical unit of commodity i as final good. It is defined as: $A\left(I - A^{\Theta}\right)^{-1} \equiv H \equiv \left[h_1 \quad h_2 \quad \dots \quad h_m\right]$.

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3 The matrix of direct coefficients (A) summarizes the coefficients of interdependence among the sectors, indicating the inputs that are needed from each of them to generate each product unit. Notice that the matrix of direct coefficients (A^{Θ}) is modified because the original matrix of direct coefficients was decomposed as the sum of the matrix of circulating capital ($A^{(C)}$) and fixed capital ($A^{(F)}$), so that $A \equiv A^{(C)} + A^{(F)}$. Thus, A^{Θ} was defined as $A^{\Theta} \equiv A^{(C)} + \hat{\delta}A^{(F)}$, in which $\hat{\delta}$ is a diagonal matrix in which each δ_j represents a fraction of all fixed capital goods that the economic system has to replace. Of course, the matrix A^{Θ} is indecomposable, and it is assumed that Hawkins-Simons conditions are satisfied. See Morishima (1964).

Therefore, the vertically integrated sectors are not empirical constructs, but are calculated from input-output model data, organized in such a way that for each final product (consumption or investment good), a single vertically integrated sector (or subsystem) is built. To do this, all components of the final demand (except those of the sector to be built) are set to zero. Then all the inputs that are directly and indirectly required to produce a given quantity of the final product demanded are calculated.

To measure the real weight of water use in the economic system, we will follow the approach proposed by Momigliano and Siniscalco (1982a, 1982b) to investigate structural change in the Italian economy from the mid-1960s to the mid-1970s, we will use the subsystem concept by constructing a matrix:

$$R = \hat{x}^{-1}(I - A)^{-1}\hat{y} \tag{1}$$

Where $\hat{x}$ it is the diagonalized vector of gross output, A it is the matrix of domestic input-output coefficients and $\hat{y}$ is the diagonalized vector of final demand.

Each row of **R** is equal to 1 and shows "the proportion of the activity of each branch that comes under the various subsystems" (Momigliano and Siniscalco, 1982a: 281). **R** can therefore be used as an operator to reclassify any variable from an industry base to a subsystem base.

Using **R**, we define the matrix $\mathbf{W_h}$ as:

$$W_h = \hat{w}_h R \tag{2}$$

where, h = *blue, green, grey*

Where $\hat{w}_h$ it is the diagonalized vector of different kinds of water (blue, green, grey) used by sector. The generic element W_{hij} of $\mathbf{W_h}$ is the amount of water used, directly and indirectly, by sector i to satisfy the final demand in subsystem j.

It should be noted that, as demonstrated by Rampa (1982), all previous matrices are invariant to relative prices. A comparative analysis of the changes occurring over time in the matrices defined above is useful for unravelling the determinants of structural change. In fact, while $\mathbf{W_h}$ calculates levels, **R** calculates the quotas of each subsystem in each relevant sector in terms of the use of the different types of water.

4.3. Structural decomposition analysis

As we said before, the generic element w_{hij} of $\mathbf{W_h}$ is the amount of water used, directly and indirectly, by sector *i* to satisfy the final demand in subsystem *j*. Each element could be decomposed as:

$$w_{h_{ij}} = \alpha_{ij} S_i V_j W_h \qquad (3)$$

where W_h is the amount of each type of water used, directly and indirectly; V_j is the proportion of each type of water used, directly and indirectly, by subsystem *j*; (i. e., $V_j \equiv \sum_{i=1}^{m} w_{h_{ij}} / W_h$, $j = 1, \dots, m$); S_i is the proportion of each type of water used, directly and indirectly, by sector *i*; (i. e., $S_i \equiv \sum_{j=1}^{m} w_{h_{ij}} / W_h$, $i = 1, \dots, m$); and α_{ij} is the intensity which each type of water used, directly and indirectly, by sector *i* to satisfy the final demand in subsystem *j* (i. e., $\alpha_{ij} \equiv w_{h_{ij}} / S_i V_j W_h$, $i = 1, \dots, m$ and $j = 1, \dots, m$).

In order to study the contribution of each component from 1995 to 2009, the following decomposition is proposed:

(1) Intensity component: $I(\alpha_{ij}) = \Delta\alpha_{ij} S_i V_j W_h$

(2) Sector component: $I(S_i) = \alpha_{ij} \Delta S_i V_j W_h$

(3) Subsystem (Vertically integrated sector) component: $I(V_j) = \alpha_{ij} S_i \Delta V_j W_h$

(4) Volume component: $I(W_h) = \alpha_{ij} S_i V_j \Delta W_h$

(5) Intensity-Sector component: $I(\alpha_{ij} S_i) = \Delta\alpha_{ij} \Delta S_i V_j W_h$

(6) Intensity-Subsystem component: $I(\alpha_{ij} V_j) = \Delta\alpha_{ij} S_i \Delta V_j W_h$

(7) Intensity-Volume component: $I(\alpha_{ij} W_h) = \Delta\alpha_{ij} S_i V_j \Delta W_h$

(8) Sector-Subsystem component: $I(S_i V_j) = \alpha_{ij} \Delta S_i \Delta V_j W_h$

(9) Sector-Volume component: $I(S_i W_h) = \alpha_{ij} \Delta S_i V_j \Delta W_h$

(10) Subsystem-Volume component: $I(V_j W_h) = \alpha_{ij} S_i \Delta V_j \Delta W_h$

(11) Intensity-Sector-Subsystem component: $I(\alpha_{ij} S_i V_j) = \Delta\alpha_{ij} \Delta S_i \Delta V_j W_h$

(12) Intensity-Sector-Volume component: $I(\alpha_{ij} S_i W_h) = \Delta\alpha_{ij} \Delta S_i V_j \Delta W_h$

(13) Intensity-Subsystem-Volume component: $I(\alpha_{ij} V_j W_h) = \Delta\alpha_{ij} S_i \Delta V_j \Delta W_h$

(14) Sector-Subsystem-Volume component: $I(V_j S_i W_h) = \alpha_{ij} \Delta S_i \Delta V_j \Delta W_h$

(15) Overall (Intensity-Sector-Subsystem-Volume) component: $I(\alpha_{ij} V_j S_i W_h) = \Delta\alpha_{ij} \Delta S_i \Delta V_j \Delta W_h$

As these components are too disaggregated, the follow aggregation is proposed:

(1) Intensity aggregated component: $J(\alpha_{ij}) = I(\alpha_{ij}) + {}^1\!/_2\, I(\alpha_{ij} S_i) + {}^1\!/_2\, I(\alpha_{ij} V_j) + {}^1\!/_2\, I(\alpha_{ij} W_h) + {}^1\!/_3\, I(\alpha_{ij} S_i V_j) + {}^1\!/_3\, I(\alpha_{ij} S_i W_h) + {}^1\!/_3\, I(\alpha_{ij} V_j W_h) + {}^1\!/_4\, I(\alpha_{ij} V_j S_i W_h)$

(2) Sector aggregated component: $J(S_i) = I(S_i) + {}^1\!/_2\, I(\alpha_{ij} S_i) + {}^1\!/_2\, I(S_i V_j) + {}^1\!/_2\, I(S_i W_h) + {}^1\!/_3\, I(\alpha_{ij} S_i V_j) + {}^1\!/_3\, I(\alpha_{ij} S_i W_h) + {}^1\!/_3\, I(V_j S_i W_h) + {}^1\!/_4\, I(\alpha_{ij} V_j S_i W_h)$

(3) Subsystem aggregated component: $J(V_j) = I(V_j) + {}^1/_2\, I(\alpha_{ij}V_j) +$

${}^1/_2\, I(S_iV_j) + {}^1/_2\, I(V_jW_h) + {}^1/_3\, I(\alpha_{ij}S_iV_j) + {}^1/_3\, I(\alpha_{ij}V_jW_h) +$

${}^1/_3\, I(V_jS_iW_h) + {}^1/_4\, I(\alpha_{ij}V_jS_iW_h)$

(4) Volume aggregated component: $\mathrm{J}(W_h) = I(W_h) + {}^1/_2\, I(\alpha_{ij}W_h) +$

${}^1/_2\, I(S_iW_h) + {}^1/_2\, I(V_jW_h) + {}^1/_3\, I(\alpha_{ij}S_iW_h) + {}^1/_3\, I(\alpha_{ij}V_jW_h) +$

${}^1/_3\, I(V_jS_iW_h) + {}^1/_4\, I(\alpha_{ij}V_jS_iW_h)$

5. Results

We concentrated our analysis on total water use considering the consumption of all countries. In order to make the decomposition clear, the members of BRIC (Brazil, Russia, India and China) and the three biggest generators (Rest of the World, the United States, and Indonesia) are outlined. We aggregate all 27 members of the European Union (as of 1 January 2007) and remain countries which data available in WIOD as "Others".

5.1. The use of water in the world

The water use in the world between 1995 and 2009, from the sectors' perspective, increased from 8.4 trillion to 11.5 trillion cubic meters of water, an increase of 2.26% per year. In 2009, the Rest of the World consumed 4.0 trillion cubic meters of water, followed by China (1.7 trillion), India (1.3 trillion) and the United States (1.2 trillion). Brazil occupies the 5th place with 0.7 trillion m^3 of water consumed. Three countries had a growth rate of more than 4% per year in water use: Lithuania (4.55%), Latvia (4.36%), and Estonia (4.03%), and only two countries, which consume very little water, showed significant decreases, Cyprus (-4.15%), and Malta (-2.13%). The concern factor is that three large water users showed significant growth in this period, China (3.45%), Brazil (3.21%), and Indonesia (3.55%).

In 2009, from subsystems' perspective, the Rest of the World consumed 3.9 trillion cubic meters of water, followed by China (1.7 trillion), India (1.3 trillion) and the United States (1.2 trillion). Brazil occupies the 5th place with 0.6 trillion m^3 of water consumed. Two countries had a growth rate of more than 4% a year in total water use, Latvia (4.47%), and Estonia (4.25%). Japan (-2.36%), Bulgaria (-1.97%), Cyprus (-1.96%), and Luxembourg (-1.92%) showed significant decreases.

Comparing the total water use in the world between 1995 and 2009, using the relation between sectors and subsystems optics, we emphasize that the greatest relationships are observed in countries where there is a great water availability or that use these resources in a less intense way, such as Canada (1.27), Australia (1.27), Bulgaria (1.18), Brazil (1.16), Estonia (1.13), and Lithuania (1.13). On the other hand, the lowest relationships are observed in countries with low availability of water resources or that use these resources very intensively, such as the Netherlands (0.15), Malta (0.19), South Korea (0.33) , Belgium (0.34), and Japan (0.35).

The relation between sectors and subsystems in the United States (0.94) shows that 94% the water used in that are generated there, 6% are extracted elsewhere. These relations are 0.87 for France, 0.80 for Spain, 0.66 for Italy, 0.51 for Germany, 0.45 for United Kingdom, and 0.35 for Japan. All these countries are great importers of water.

Table 1. Total use of water in the world (in billions cubic meters).

Countries	**Sectors**		**Δ (%)**	**Subsystems**		**Δ (%)**	**SEC/VIS**
	1995	**2009**	**2009/1995**	**1995**	**2009**	**2009/1995**	**average**
RoW	2,816.1	4,071.8	2.67%	2,620.0	3,852.0	2,79%	1,07
CHN	1,050.9	1,688.9	3.45%	1,029.8	1,740.8	3,82%	1,00
IND	1,089.2	1,344.9	1.52%	1,053.9	1,319.9	1,62%	1,04
USA	986.9	1,180.5	1.29%	1,010.4	1,200.2	1,24%	0,94
BRA	470.4	731.8	3.21%	432.2	612.2	2,52%	1,16
RUS	402.2	543.3	2.17%	378.7	526.3	2,38%	1,07
IDN	290.4	473.0	3.55%	277.4	446.8	3,46%	1,06

Countries	Sectors		Δ (%)	Subsystems		Δ (%)	SEC/VIS
	1995	2009	2009/1995	1995	2009	2009/1995	average
CAN	231.9	278.9	1.33%	171.5	227.8	2,05%	1,27
MEX	136.5	148.3	0.59%	137.1	170.3	1,57%	0,89
AUS	118.0	133.5	0.89%	88.0	116.7	2,04%	1,27
TUR	110.2	125.5	0.93%	114.1	144.1	1,68%	0,90
FRA	94.1	108.1	0.99%	110.3	123.1	0,79%	0,87
ESP	53.1	89.3	3.78%	74.8	112.7	2,97%	0,80
ITA	74.3	71.3	-0.30%	109.0	107.0	-0,13%	0,66
DEU	55.7	65.7	1.19%	113.4	128.4	0,89%	0,51
POL	57.9	65.4	0.87%	57.1	66.9	1,13%	0,97
JPN	54.5	47.4	-0.99%	176.8	126.6	-2,36%	0,35
TWN	45.2	56.5	1.60%	64.0	65.1	0,12%	0,78
ROU	51.6	48.0	-0.52%	50.4	47.9	-0,37%	1,01
GBR	28.7	29.1	0.10%	56.3	64.1	0,93%	0,45
HUN	26.5	29.3	0.74%	24.7	23.7	-0,29%	1,08
SWE	25.3	25.5	0.06%	26.7	26.9	0,05%	0,93
BGR	24.7	24.1	-0.19%	22.8	17.3	-1,97%	1,18
GRC	18.6	16.0	-1.05%	21.7	22.6	0,29%	0,78
KOR	17.5	18.8	0.53%	55.8	54.5	-0,17%	0,33
PRT	16.8	13.9	-1.36%	23.1	19.6	-1,16%	0,70
AUT	15.3	16.3	0.48%	19.0	20.1	0,40%	0,80
CZE	13.6	15.5	0.91%	14.1	16.0	0,94%	0,93
LTU	7.3	13.6	4.55%	6.3	10.8	3,96%	1,11
DNK	9.6	10.8	0.86%	15.5	14.9	-0,29%	0,66
FIN	9.1	10.2	0.76%	10.0	12.6	1,64%	0,81
SVK	8.0	7.9	-0.07%	7.7	8.8	0,99%	0,94
BEL	5.7	6.1	0.59%	16.5	20.8	1,65%	0,34
NLD	5.9	5.9	0.01%	29.7	43.6	2,78%	0,15
LVA	3.9	7.1	4.36%	3.4	6.3	4,47%	1,07
IRL	4.5	4.7	0.30%	6.3	8.2	1,87%	0,62
EST	2.7	4.7	4.03%	2.0	3.7	4,25%	1,13
SVN	2.7	3.1	1.17%	3.7	4.0	0,55%	0,74
CYP	1.1	0.6	-4.15%	1.6	1.2	-1,96%	0,54
LUX	0.3	0.4	1.14%	0.7	0.9	1,92%	0,42
MLT	0.1	0.0	-2.13%	0.3	0.2	-1,05%	0,19
Total	**8,436.9**	**11,535.6**	**2.26%**	**8,436.9**	**11,535.6**	**2,26%**	**1,00**

Source: author calculations from WIOD.

5.2. The use of water in Brazil

The water use in Brazil between 1995 and 2009, from the sectors' perspective, increased from 470.4 billion to 731.8 billion cubic meters of water, an increase of 3.21% per year. In 2009, the Rest of the World consumed 41.4 billion cubic meters of water from Brazil, followed by China (33.4 billion), Germany (10.3 billion) and the United States (7.6 billion). Four countries had a growth rate of more than 10% per year in water use: China (27.74%), Taiwan (14.80%), India (14.73%), and Estonia (12.12%). Only two countries showed significant decreases, Hungary (-8.71%), and Malta (-6.71%). Besides China, other three large water users showed significant growth in this period, the Rest of the World (9.30%), Germany (7.16%), and South Korea (9.64%).

The water use in Brazil between 1995 and 2009, from the subsystems' perspective, increased from 432.2 billion to 612,2 billion cubic meters of water, an increase of 2.52% per year. In 2009, Brazil consumed 11.8 billion cubic meters of water from the Rest of the World, 2.1 billion from China, and 1.1 billion from the United Staes. Four countries had a growth rate of more than 10% per year in water use: China (13.08%), United Kingdom (10.44%), Taiwan (10.58%), and Indonesia (12.49%). Only one country, Latvia, showed significant decreases, -7.11%.

Comparing the total water use in Brazil between 1995 and 2009, using the relation between sectors and subsystems optics, showed that Brazil is a exporter of water to all the regions of the world. This relation indicates that Germany uses 82.41 times more water from Brazil than Brazil uses water from Germany. Among the greatest user of water from Brazil, the biggest relations between sectors and subsystems are Germany (82.41), Japan (130.79), Spain (97.23), the Netherlands (524,13), United Kingdom (110.28), and South Korea (180.20).

Table 2. Total use of water in Brazil (in millions cubic meters).

Countries	**Sectors**		**Δ (%)**	**Subsystems**		**Δ (%)**	**SEC/VIS**
	1995	**2009**	**2009/1995**	**1995**	**2009**	**2009/1995**	**average**
BRA	419,915.5	593,696.7	2.50%	419,915.5	593,696.7	2,50%	1,00
RoW	11,914.9	41,377.6	9.30%	8,351.2	11,838.0	2,52%	2,23
CHN	1,084.4	33,384.0	27.74%	378.7	2,117.0	13,08%	11,99
USA	6,564.4	7,582.0	1.03%	1,367.8	1,144.5	-1,27%	7,64
DEU	3,905.8	10,284.2	7.16%	76.7	140.2	4,40%	82,41
JPN	3,732.7	4,039.7	0.57%	20.2	34.2	3,85%	130,79
ESP	2,922.4	4,881.5	3.73%	19.9	44.8	5,97%	97,23
NLD	2,395.0	4,088.9	3.89%	11.2	9.7	-1,07%	524,13
ITA	2,501.2	4,044.8	3.49%	60.6	56.7	-0,48%	68,24
FRA	3,358.5	3,565.6	0.43%	148.3	132.3	-0,82%	25,30
GBR	1,766.1	3,112.5	4.13%	15.9	64.0	10,44%	110,28
KOR	969.5	3,517.8	9.64%	17.9	17.6	-0,11%	180,20
RUS	652.8	1,089.3	3.73%	273.5	503.3	4,45%	4,49
PRT	1,402.5	1,598.9	0.94%	31.0	33.8	0,61%	39,62

Countries	Sectors		Δ (%)	Subsystems		Δ (%)	SEC/VIS
	1995	2009	2009/1995	1995	2009	2009/1995	average
CAN	587.9	1,638.2	7.59%	743.4	691.3	-0,52%	2,14
BEL	977.4	1,565.8	3.42%	25.6	19.7	-1,86%	76,46
MEX	238.8	729.4	8.30%	46.0	54.8	1,26%	27,98
TWN	285.5	1,971.5	14.80%	15.7	64.0	10,58%	35,04
IDN	493.7	1,469.5	8.10%	107.7	559.6	12,49%	2,61
IND	318.5	2,179.5	14.73%	263.4	625.7	6,38%	1,68
TUR	338.3	1,055.7	8.47%	18.2	49.4	7,42%	24,11
SWE	565.0	571.5	0.08%	31.8	38.0	1,29%	16,51
DNK	987.8	373.4	-6.71%	14.7	11.0	-2,08%	53,62
GRC	269.6	569.9	5.49%	6.0	3.5	-3,78%	80,63
POL	259.1	603.1	6.22%	22.1	53.0	6,45%	9,64
AUT	274.2	410.2	2.92%	10.0	29.9	8,18%	24,63
ROU	135.1	507.3	9.91%	16.0	19.5	1,42%	27,59
AUS	214.3	490.7	6.09%	119.5	72.6	-3,50%	3,56
HUN	374.9	104.7	-8.71%	10.8	22.9	5,55%	21,52
FIN	200.1	409.9	5.26%	20.1	23.5	1,13%	14,49
BGR	165.9	137.8	-1.32%	12.4	23.6	4,71%	8,82
CZE	223.2	201.1	-0.74%	17.9	11.8	-2,91%	12,76
IRL	124.1	188.5	3.03%	2.7	4.7	3,97%	57,84
SVN	159.3	132.7	-1.30%	1.7	3.9	6,18%	83,65
CYP	42.9	33.3	-1.79%	0.1	0.1	-2,51%	710,50
SVK	27.3	62.1	6.04%	4.0	4.9	1,37%	11,03
LTU	21.8	48.6	5.90%	2.7	5.9	5,77%	9,71
LUX	9.8	32.6	8.94%	0.6	0.3	-4,37%	54,58
LVA	16.2	13.8	-1.12%	9.8	3.5	-7,11%	5,37
MLT	4.8	5.1	0.43%	0.1	0.0	-3,35%	332,75
EST	4.6	23.0	12.12%	1.7	4.6	7,51%	4,16
Total	**470,405.8**	**731,792.7**	**3.21%**	**432,213.2**	**612,234.6**	**2,52%**	**1,16**

Source: author calculations from WIOD.

5.3. Structural decomposition of the use of water in Brazil

From the sectors' perspective, the water use in Brazil increased from 470.4 billion to 731.8 billion cubic meters of water between 1995 and 2009. Intensity and Subsystem aggregated component compensate each other. The variation of 261.4 billion cubic meters of water is explained by Sector aggregated component (76.7 billion cubic meters of water), and Water aggregated component (184.6 billion).

Besides Brazil, China (32.3 billion cubic meters of water), the Rest of the World (29.5 billion), and European Union (14.5 billion) had the greatest contribution on the increase of total use of water from Brazil. Intensity aggregate component are the most important explanation of these increase of use of water for China (23.3 billion) and the

Rest of the World (16.9 billion). In the case of the European Union, the most important component is the Water aggregate one (9.3 billion), followed by Intensity aggregate component (7.2 billion). Call attention the negative contribution of Subsystem aggregate component (-5.9 billion), which are the greatest of all of these components, including the case of Brazil.

Table 3. Decomposition of the variation of use of water in Brazil from 1995 to 2009 (sector point of view, in millions cubic meters).

Countries	Intensity	Sector	Subsystem	Water	Total
CHN	23,275.21	1,819.60	2,945.36	4,259.42	32,299.59
RoW	16,932.01	3,176.01	1,796.20	7,558.52	29,462.74
USA	-1,126.28	922.14	-1,008.17	2,229.90	1,017.60
IDN	428.72	117.69	148.77	280.65	975.83
IND	1,468.03	147.54	-103.32	348.75	1,860.99
RUS	46.20	110.51	14.10	265.75	436.56
EU	7,136.52	3,886.51	-5,896.40	9,349.79	14,476.42
BRA	-66,692.28	65,247.29	17,928.32	157,297.81	173,781.14
Other	4,783.13	1,253.76	-1,965.56	3,004.70	7,076.02
Total	**-13,748.74**	**76,681.05**	**13,859.30**	**184,595.29**	**261,386.90**

Source: author calculations from WIOD.

From the subsystems' perspective, the water use in Brazil increased from 432.2 billion to 621.2 billion cubic meters of water between 1995 and 2009. Intensity and Sector aggregated component compensate each other. The variation of 180.0 billion cubic meters of water is explained by Subsystem aggregated component (18.5 billion cubic meters of water), and Water aggregated component (180.0 billion).

Besides Brazil, the Rest of the World (3.5 billion cubic meters of water), and China (1.7 billion) had the greatest contribution on the increase of total use of water of Brazil. Intensity aggregate component are the most important explanation of these increase of use of water for China (1.2 billion). In the case of the Rest of the World, the most important component is the Water aggregate one (3.1 billion).

Table 4. Decomposition of the variation of use of water in Brazil from 1995 to 2009 (subsystem point of view, millions of cubic meters).

Countries	Intensity	Sector	Subsystem	Water	Total
CHN	1,176.67	179.97	40.03	341.65	1,738.32
RoW	-557.56	562.93	356.22	3,125.20	3,486.79
USA	-500.29	-171.06	45.35	402.68	-223.32
IDN	297.29	52.21	10.73	91.65	451.88
IND	258.33	-44.77	15.38	133.38	362.32
RUS	103.18	-4.57	13.50	117.70	229.80
EU	91.81	-133.70	23.83	209.39	191.34
BRA	-66,692.28	65,247.29	17,928.32	157,297.81	173,781.14
Other	-156.44	-187.00	35.21	311.38	3.15
Total	**-65,979.29**	**65,501.29**	**18,468.57**	**162,030.84**	**180,021.41**

Source: author calculations from WIOD.

6. Conclusion

The methodology of the subsystems or vertically integrated sectors was used to quantify the total (direct and indirect) use of the different types of water by the Brazilian sectors and subsystems from 1995 to 2009, including the uses avoided/caused by the final and intermediate imports/exports.

The deindustrialization of developed countries has led to a shift in water use activities to developing countries. The relation between sectors and subsystems showed this water trade imbalance. Some countries like Brazil, Canada, and Australia are great exports of water, and the great majority of European Union countries (France, Spain, Italy, and Germany), and Japan are great importers of water.

Our analysis of the use of water by production and consumption in Brazil from 1995 to 2009 showed that Brazil is an export of water for all countries. The Rest of the World, China, Germany, and the United States are the greatest importers of water from Brazil. The greatest exporters of water to Brazil are the Rest of the World, China, and United States.

Structural decomposition analysis was applied to investigate the role of international trade in the evolution of total water use and the extent to which the change in composition of domestic production by industry (and the consequent change in water use) is due to changes in production and in consumption. Four aggregate components were proposed: intensity, sector, subsystem, and volume. The role of China and the Rest of the World as the greatest exporters of water from Brazil is due to intensification of the use of water.

In conclusion, the use of the different types of water by sector and corresponding subsystem is useful for evaluating the impacts of public policies on production and consumption in the management of water resources. Finally, a very interesting extension of this article is the analysis of water use using the methodology proposed in other countries and periods, or even the application of the methodology proposed to analyze other inputs with environmental impact, such as the generation of energy.

References

Baker, Lucy. 2017. Of embodied emissions and inequality: Rethinking energy consumption. Energy Research & Social Science vvv:ppp-ppp. ISSN 2214-6296, https://doi.org/10.1016/j.erss.2017.09.027.

Christensen, P. P., 1989. Historical roots for ecological economics - Biophysical versus allocative approaches. Ecological Economics 1 (1): 17-36.

Garmendia, Eneko; Urkidi, Leire; Arto, Iñaki; Barcena, Iñaki; Bermejo, Roberto; Hoyos, David; Lago, Rosa. 2016. Tracing the impacts of a northern open economy on the global environment, Ecological Economics, 126: 169-181, ISSN 0921-8009, https://doi.org/10.1016/j.ecolecon.2016.02.011.

Haberl, Helmut. 2015. Competition for land: A sociometabolic perspective. Ecological Economics 119: 424-431, ISSN 0921-8009, https://doi.org/10.1016/j.ecolecon.2014.10.002.

Hoekstra, A., Chapagain, A., Aldaya, M., Mekonnen, M. 2011. The Water Footprint assessment manual. Setting the global standard. Earthscan, London & Washington.

Judson, D. H. 1989. The convergence of Neo-Ricardian and embodied energy theories of value and price. Ecological Economics 1 (3): 261-282.

Lenzen, M., Pade and L., Munksgaard, J. 2004. CO2 multipliers in multi-region input-output models. Economic System Research 16 (4): 391–412.

Liverman, Diana M. 2009. Conventions of climate change: constructions of danger and the dispossession of the atmosphere. Journal of Historical Geography 35 (2): 279-296. ISSN 0305-7488, https://doi.org/10.1016/j.jhg.2008.08.008.

McKinney, Laura A. 2014. Foreign direct investment, development, and overshoot. Social Science Research 47: 121-133, ISSN 0049-089X, https://doi.org/10.1016/j.ssresearch.2014.04.003.

Mekonnen, M. and Hoekstra, A. 2010a. The green, blue and grey water footprint of farm animals and animal products. Value of Water Research Report Series, No.48, Volume I and II. UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M. and Hoekstra, A. 2010b. The green, blue and grey water footprint of crops and derived crop products. Value of Water Research Report Series, No.47, Volume I and II. UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M., Hoekstra, A. 2011a. National water footprint accounts: the green, blue and grey water footprint of production and consumption. Value of Water Research Report Series, No.50, Volume I and II. UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M., Hoekstra, A. 2011b. The water footprint of electricity from hydropower. Value of Water Research Report Series, No.51. UNESCO-IHE, Delft, the Netherlands.

Momigliano, F. and Siniscalco, D. 1982a. The growth of service employment: a reappraisal. BNL Quarterly Review 142: 269–306.

Momigliano, F. and Siniscalco, D. 1982b. Note in tema di terziarizzazione e deindustrializzazione. Moneta e Credito 138: 143–181.

Moon, Wanki 2011. Is agriculture compatible with free trade? Ecological Economics 71 (15): 13-24, ISSN 0921-8009, https://doi.org/10.1016/j.ecolecon.2011.09.004, https://www.sciencedirect.com/science/article/pii/S0921800911003661

Morishima, Michio. 1964. Equilibrium, stability and growth: a multi-sectoral analysis. London: Oxford University Press.

Mózner, Zsófia Vetőné 2013. A consumption-based approach to carbon emission accounting – sectoral differences and environmental benefits. Journal of Cleaner Production 42: 83-95, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2012.10.014.

Muradian, Roldan and Martinez-Alier, Joan. 2001. Joan. Trade and the environment: from a 'Southern' perspective. Ecological Economics 36 (2): 281-297, ISSN 0921-8009, https://doi.org/10.1016/S0921-8009(00)00229-9.

Norgaard, Richard B. 1992. Sustainability as intergenerational equity: Economic theory and environmental planning, Environmental Impact Assessment Review 12 (1–2): 85-124, ISSN 0195-9255, https://doi.org/10.1016/0195-9255(92)90007-K.

Pasinetti, Luigi L. 1973. The Notion of Vertical Integration Economic Analysis. Metroeconomica 25 (1): 1-29.

Patterson, Murray. 1998. Commensuration and theories of value in ecological economics. Ecological Economics 25(1): 105–125.

Patterson, Murray G. 2002. Ecological production based pricing of biosphere processes. Ecological Economics 41 (3): 457–478.

Patterson, Murray; McDonald, Garry and Hardy, Derrylea. 2017. Is there more in common than we think? Convergence of ecological footprinting, emergy analysis, life cycle assessment and other methods of environmental accounting. Ecological Modelling 362: 19–36. https://doi.org/10.1016/j.ecolmodel.2017.07.022

Prell, Christina and Feng, Kuishuang. 2016.. The evolution of global trade and impacts on countries' carbon trade imbalances. Social Networks 46: 87-100, ISSN 0378-8733, https://doi.org/10.1016/j.socnet.2016.03.001.

Proops, J. L. R. 1989. Ecological economics: Rationale and problem areas. Ecological Economics 1 (1): 59-76

Rampa, G. 1982. "Commento a Momigliano e Siniscalco". Moneta e Credito 139: 475–479.

Røpke, Inge. 2005. Trends in the development of ecological economics from the late 1980s to the early 2000s. Ecological Economics 55 (2): 262-290, ISSN 0921-8009, https://doi.org/10.1016/j.ecolecon.2004.10.010.

Sraffa, Piero. 1960 [1985]. Produção de Mercadorias por meio de Mercadorias: Prelúdio a uma Crítica da Teoria Econômica. Apresentação de Mario Luiz Possas.

Tradução de Elizabeth Machado de Oliveira. 2ª edição. São Paulo: Abril Cultural.

Timmer, M.P., Dietzenbacher, E., Los, B., Stehrer, R. and de Vries, G.J. 2015. An illustrated user guide to the world input–output database: the case of global automotive production. Review of International Economics 23: 575–605.