Climate change, water resources and economic impacts in Brazilian hydrographic regions

Ademir Rocha

Department of Economics, University of São Paulo (FEA-USP)

The University of São Paulo Regional and Urban Economics Lab (NEREUS-USP)

E-mail: aamr.eco@gmail.com

Website: www.aderocha.com

Eduardo Haddad

Department of Economics, University of São Paulo (FEA-USP)

The University of São Paulo Regional and Urban Economics Lab (NEREUS-USP)

E-mail: ehaddad@usp.br

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Abstract: In the context of global climate change, one of the biggest challenges is water security. In Brazil, the prospect of water scarcity due to long-run climatic anomalies and the regional disparity between supply and demand for water resources may bring limitations to various socioeconomic activities. We built an economic model named Brazilian Multisectoral and Regional/Interregional Analysis Model with Water Module composed of 67 economic sectors and 12 Brazilian hydrographic regions, all this integrated with hydroclimatic modelling. We evaluated two channels of transmission of the climate change shock. Channel 1 represents the change in the price of treated water and Channel 2 models the possibility of purchasing capital to save raw water. The economic losses resulting from the effect of climate change on water availability are equivalent to a drop in Brazilian GDP (year reference 2015) of US$ 5.2 billion and US$ 12.5 billion under RCP 4.5 and RCP 8.5 (by 2070-2099).

Keywords: Climate change; water; economic impacts; ICGE model; Brazil

JEL code: Q25; Q54; R13

ENABER: 9 (Meio ambiente, recursos naturais e sustentabilidade)

Resumo: No contexto das mudanças climáticas globais, um dos maiores desafios é a segurança hídrica. No Brasil, a perspectiva de escassez hídrica devido a anomalias climáticas de longo prazo e a disparidade regional entre oferta e demanda por recursos hídricos podem trazer limitações a diversas atividades socioeconômicas. Construímos um modelo econômico denominado *Brazilian Multisectoral and Regional/Interregional Analysis Model with Water Module* composto por 67 setores econômicos e 12 regiões hidrográficas brasileiras, integrado a uma modelagem hidro climática. Avaliamos dois canais de transmissão do choque das mudanças climáticas. O Canal 1 representa a variação do preço da água tratada e o Canal 2 modela a possibilidade de aquisição de capital para economizar água bruta. As perdas econômicas decorrentes do efeito das mudanças climáticas sobre a disponibilidade hídrica equivalem a uma queda no PIB brasileiro (ano de referência 2015) de US$ 5,2 bilhões e US$ 12,5 bilhões sob RCP 4.5 e RCP 8.5 (até 2070-2099).

Palavras-chave: Mudanças climáticas; água; impactos econômicos; modelo ICGE; Brasil

1. Introduction

Global climate warming is associated with changes in a series of components in the hydrological cycle. It is very likely that throughout the 21st century, we will see a greater frequency of extreme water events characterized by intense and episodic rains with large amounts of runoff interspersed with long periods of drought and evaporation [1-6].

The irregular water supply resulting from climate change brings limitations and risks to several economic and social activities [7]. The cultivation of irrigated crops, forest production, fishing, hydroelectric power generation, industrial production, transport, tourism, water distribution, and sewage treatment are examples of affected sectors [8-13]. This reality becomes even more severe when considering the increase in global demand for water-intensive goods and services [14].

Given this scenario, studies capable of integrating the topics of climate change, water availability, and economic impacts become necessary, thus seeking ways to guarantee the sustainable maintenance of the water supply and the social and environmental well-being [1,15].

The Brazilian Water Resources Council, through Resolution No. 32/2003, defines a section of the Brazilian territory in 12 hydrographic regions (see Fig. 1a). They are named as Amazon hydrographic region (AMZ), East Atlantic (ALT), West Northeast Atlantic (AOC), East Northeast Atlantic (AOR), Southeast Atlantic (ASD), South Atlantic (ASU), Paraguay (PRG), Paraná (PRN), Parnaíba (PNB), São Francisco (SFO), Tocantins/Araguaia (TOC), and Uruguay (URU). This geographic division guides the planning and management of Brazilian water resources. In Brazil, there is an unequal distribution between the supply and demand of water in its hydrographic regions. Fig. 1b provides some data that goes towards this argument.

In this article, we assess the economic impacts of the change in water availability caused by climate change, focusing on the Brazilian reality. We built an economic model named Multisectoral and Regional/Interregional Analysis Model with Water Module (BMARIA-

H2O), composed of 67 economic sectors and 12 Brazilian hydrographic regions, all this integrated with hydroclimatic modelling. The vulnerabilities identification can lead to better proposals for adaptation and mitigation actions, bringing Brazil closer to the Sustainable Development Goals (SDGs) [16], including those relating to water availability (SDG 6), economic growth (SDG 8), responsible consumption and production (SDG 12), climate action (SDG 13), and life below water (SDG 14).

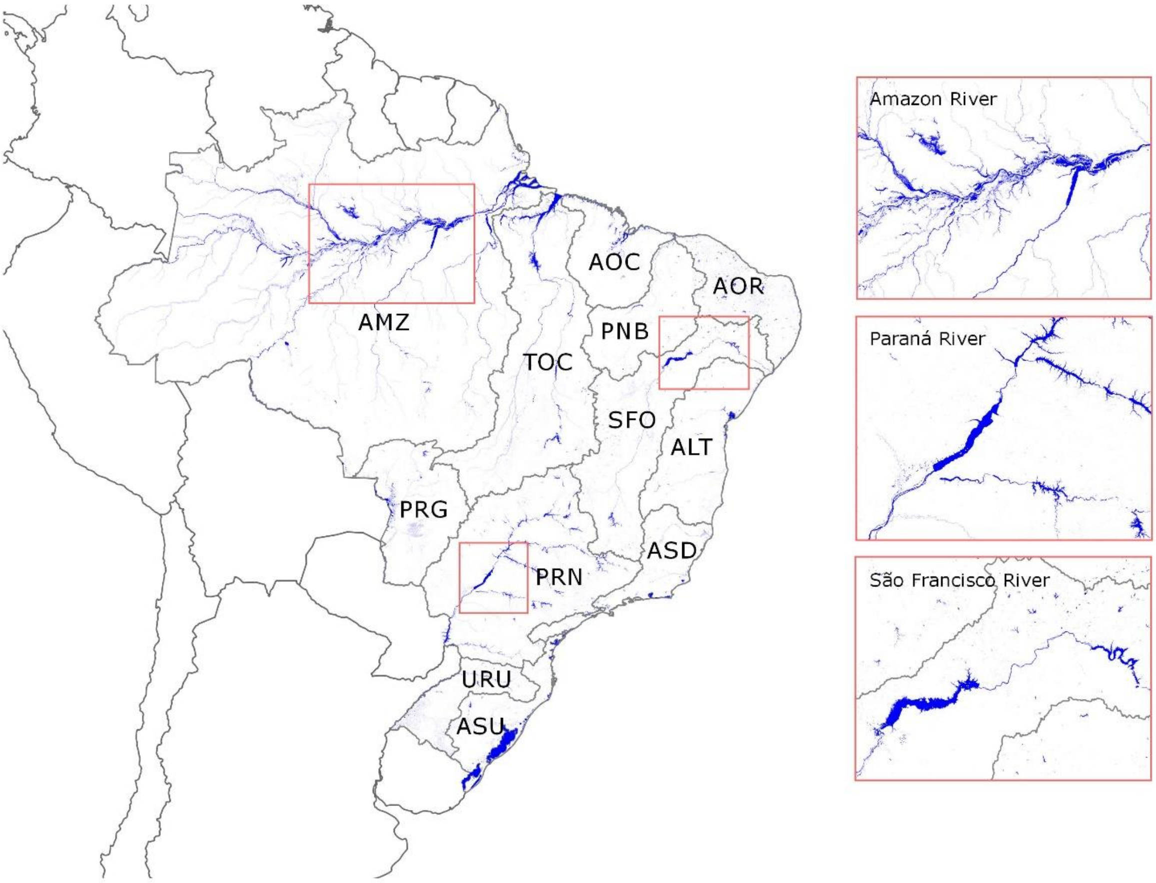

Fig. 1. Brazilian hydrographic information.

(a) Brazilian hydrographic regions and main rivers. AMZ - Amazon, ALT - East Atlantic, AOC - West Northeast Atlantic, AOR - East Northeast Atlantic, ASD - Southeast Atlantic, ASU - South Atlantic, PRG - Paraguay, PRN - Paraná, PNB - Parnaíba, SFO - São Francisco, TOC - Tocantins/Araguaia and URU - Uruguay.

Water availability

AMZ	💧	**x 301.0**	65,617 m³/s	83.48%	*PRG*	💧	**x 4.7**	1,023 m³/s	1.30%
ALT	💧	**x 1.2**	271 m³/s	0.35%	*PRN*	💧	**x 20.1**	4,390 m³/s	5.59%
AOC	💧	**x 1.8**	397 m³/s	0.51%	*PNB*	💧	**x 1.5**	325 m³/s	0.41%
AOR	💧	**x 1.0**	218 m³/s	0.28%	*SFO*	💧	**x 4.0**	875 m³/s	1.11%
ASD	💧	**x 6.1**	1,325 m³/s	1.69%	*TOC*	💧	**x 14.2**	3,098 m³/s	3.94%
ASU	💧	**x 2.4**	513 m³/s	0.65%	*URU*	💧	**x 2.5**	550 m³/s	0.70%

Water consumption

AMZ	🚰	**x 7.2**	35,871 hm³	10.53%	*PRG*	🚰	**x 2.8**	14,169 hm³	4.16%
ALT	🚰	**x 3.4**	16,809 hm³	4.94%	*PRN*	🚰	**x 28.7**	143,568 hm³	42.15%
AOC	🚰	**x 1.0**	5,003 hm³	1.47%	*PNB*	🚰	**x 1.1**	5,595 hm³	1.64%
AOR	🚰	**x 2.5**	12,738 hm³	3.74%	*SFO*	🚰	**x 4.7**	23,524 hm³	6.91%
ASD	🚰	**x 3.8**	19,034 hm³	5.59%	*TOC*	🚰	**x 3.4**	17,246 hm³	5.06%
ASU	🚰	**x 5.2**	25,914 hm³	7.61%	*URU*	🚰	**x 4.2**	21,117 hm³	6.20%

Population

AMZ	👥	**x 5.1**	11.0 M	5.38%	*PRG*	👥	**x 1.0**	2.1 M	1.05%
ALT	👥	**x 7.5**	16.1 M	7.90%	*PRN*	👥	**x 30.8**	66.3 M	32.44%
AOC	👥	**x 3.1**	6.7 M	3.27%	*PNB*	👥	**x 1.9**	4.2 M	2.05%
AOR	👥	**x 11.9**	25.5 M	12.50%	*SFO*	👥	**x 7.1**	15.3 M	7.49%
ASD	👥	**x 13.8**	29.7 M	14.52%	*TOC*	👥	**x 4.3**	9.2 M	4.52%
ASU	👥	**x 6.6**	14.2 M	6.97%	*URU*	👥	**x 1.8**	3.9 M	1.92%

Gross value product

AMZ	💵	**x 5.7**	$ 177 B	4.05%	*PRG*	💵	**x 1.7**	$ 52 B	1.19%
ALT	💵	**x 6.6**	$ 203 B	4.65%	*PRN*	💵	**x 64.3**	$ 1,976 B	45.37%
AOC	💵	**x 1.4**	$ 44 B	1.02%	*PNB*	💵	**x 1.0**	$ 31 B	0.71%
AOR	💵	**x 8.8**	$ 270 B	6.19%	*SFO*	💵	**x 7.7**	$ 238 B	5.46%
ASD	💵	**x 24.7**	$ 761 B	17.46%	*TOC*	💵	**x 4.0**	$ 122 B	2.80%
ASU	💵	**x 12.6**	$ 388 B	8.90%	*URU*	💵	**x 3.1**	$ 95 B	2.19%

Fig. 1. Brazilian hydrographic information.

(b) Water availability and consumption data (2015).

In this article, we assess the economic impacts of the change in water availability caused by climate change, focusing on the Brazilian reality. We built an economic model named Multisectoral and Regional/Interregional Analysis Model with Water Module (BMARIA-H2O), composed of 67 economic sectors and 12 Brazilian hydrographic regions, all this integrated with hydroclimatic modelling. The vulnerabilities identification can lead to better proposals for adaptation and mitigation actions, bringing Brazil closer to the Sustainable Development Goals (SDGs) [16], including those relating to water availability (SDG 6), economic growth (SDG 8), responsible consumption and production (SDG 12), climate action (SDG 13), and life below water (SDG 14).

2. Climate change, water resources and economic impacts

Climate change has a direct influence on water events. Most economies, including Brazil, are conditioned by the hydrological regimes of their hydrographic regions. The activities of agriculture, livestock, forestry and mineral extraction, aquaculture, water-intensive industries, and hydro-energy are potentially vulnerable [1].

Interregional computable general equilibrium (ICGE) models are particularly suitable for assessing the systemic effects of climate change and water availability on economic variables. ICGE models consider the economy as a system of interdependent markets, in which the numerical values of equilibrium of all variables must be determined simultaneously [17]. Any exogenous disturbance (e.g., climate change) can be measured through the set of endogenous variables in the economy.

The BMARIA-H2O model is an ICGE model with a water module capable of assessing the economic impacts of changes in water availability caused by climate change (for more details, see Additional Information section). The structure of our model represents a variant of the ORANI-G model [18-21] and BMARIA model [22], both well documented and widely used. Furthermore, it takes advantage of insights from the UPGEM model [23]. With a bottom-up structure (where national results are obtained from regional aggregations), the model recognizes the economy of the 12 Brazilian hydrographic regions. The model identifies 67 economic sectors. Economic sectors can interact with domestic or foreign economic agents through the purchase of input and the sale of final goods. The sectors can use two types of water in production: treated water from the water and sewage sector and raw water abstracted from the environment. The sectors are divided into four categories of water use: A are large users of water and with low charges, where: A1 - agriculture, A2 - livestock and A3 - forestry and aquaculture; B indicates users of non-potable water with a relative volumetric charge; C are users of clean water (mainly treated) with good volumetric charge; and D represents the public utility sectors that use water as an input, where: D1 - electricity, gas and other utilities and D2 water, sewage and drainage services. Labor and capital are also used as primary factors of production. In demand, five groups of users are considered - producers, investors, households, foreign demand, and government. Furthermore, we consider the payment of taxes.

3. Method

3.1. Production structure

Fig. 2, shows the nested production structure (= index of industry activity) of the BMARIA-H2O model. To produce a final good (top-level), it is necessary to combine intermediate inputs, primary factors, and other costs using a Leontief type function (equivalent to a constant elasticity of substitution (CES) production function with the substitution elasticity set to zero).

The intermediate input nest (goods 1 to $n+1$) is a CES-type combination of domestic (hydrographic regions) and imported goods. Here, we adopt the Armington hypothesis, in which there is an imperfect substitution between domestic and imported goods. Industries (= set of firms) minimize the total cost of purchasing domestic and imported goods subject to a production function. The substitution between goods will depend on their price relative to the average and the value of the Armington elasticity. This reasoning is repeated in the choice of purchase of domestic goods; in this case, the purchase substitution occurs between the hydrographic regions. The demand for water produced by the water and sewage sector follows this logic. Thus (i) water consumption will depend on its price - hence climate change comes as an exogenous cost shock and (ii) as essential water input is for a given industry in a region - this will depend on the elasticity of substitution.

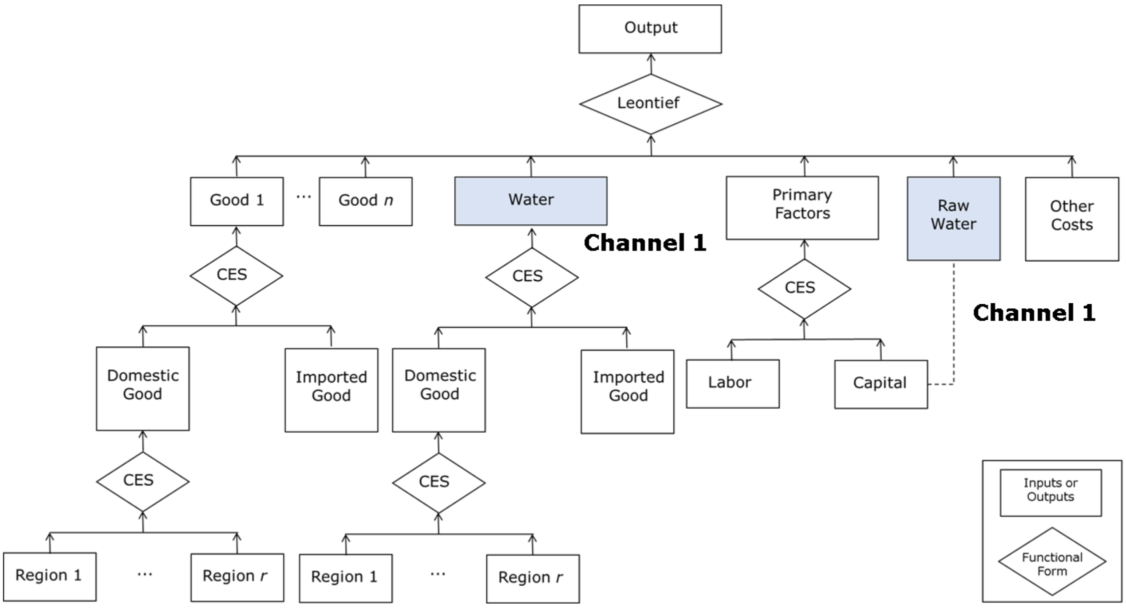

Fig. 2. Production structure.

Each industry's demand for labor, capital, and raw water is determined in the nest of primary factors. Labor and capital are chosen through a problem of cost minimization subject to the production function. The model structure allows the substitution between these factors depending on their relative price and the elasticity present in the CES function. In addition, technical changes that alter the productivity of factors can affect their demand. Raw water is also used as a primary factor by industries. Some modelling mechanisms should be highlighted: (i) raw water has no price defined by the market, so its use does not follow an optimization problem; (ii) we assume that the activity level in the industry positively determines the demand for raw water; (iii) we consider that the cost of access to water resources is affected by climate change. Thus, an economical cost related to this type of natural resource is inserted in the modelling framework. The demand for raw water will depend on its elasticity (a parameter of resistance to changing demand and indicates how essential the factor is) and of the cost shock related to the change in water availability (scarcity or not) caused by climate change; and (iv) the substitution between raw water and capital is possible, i.e., with the shock of climatic cost, industries can adopt a greater or lesser amount of capital in the production process. For example, this is particularly relevant in the agriculture sector, where a possible increase in the cost of access to water can lead the user to adopt more efficient irrigation pivots, invest in new forms of storage or water reuse tools. The same can occur in industrial or service sectors where water-saving or reuse technologies can be purchased.

3.2. Shock description

Our model classifies water in two ways: treated water from the water and sewage sector and raw water extracted directly from the environment. Therefore, water cost shocks resulting from the greater/lower difficulty of water abstraction will be imputed in the model differently.

The first shock, related to the effects of climate change on the availability of treated water, will be introduced into basic water prices, described in equation (1):

$$p_j^r = \lambda_j^r + \varepsilon_j^r \tag{1}$$

where the basic prices (p_j^r) of the good j of the hydrographic region r are formed from a unit cost index (λ_j^r). The exogenous shock ε_j^r represents the change in the cost of water due to climate change. The shock was attributed to the water, sewage and drainage services ($j = 39$) located in the hydrographic regions ($r = 1, \dots, 12$). The economic effects resulting from this disturbance are referred to as Channel 1.

The second shock, related to climate change on the availability of raw water, will be introduced indirectly through capital expenditures to substitute or save water. This modelling trick was used because most of the raw water used in Brazil is not linked to any economic mechanism (e.g., collection, taxation, etc.). Following [23], we used (2):

$$x(k)_j^r = V(k)_j^{r^{-1}} \, \psi_j^r \varepsilon_j^r \tag{2}$$

where $x(k)_j^r$ indicates the amount of capital to substitute or save water adopted by sector j in the hydrographic region r, $V(k)_j^r$ is the current level of capital used, ψ_j^r is a price semi-elasticity of demand for water and ε_j^r represents the shock of water cost access from climate change. In this case, shocks were imputed to agriculture, including support ($j = 1$), livestock, including support ($j = 2$), forestry, fisheries and aquaculture ($j = 3$), and beverage ($j = 11$) present in the hydrographic regions ($r = 1, \dots, 12$). These goods/sectors correspond to more than 95% of the raw water consumed in the Brazilian economy. The economic effects of this disorder are named Channel 2.

These two channels represent endogenous forms of economic adaptation to climate change. Channel 1 is an adaptation by increasing the water price. In other words, with the changes in water availability, it will be necessary to adjust the price of water in order to adapt demand to the new reality. Channel 2 represents a productive adaptation in which the primary factors raw water and capital can be replaced (this is limited by the dependence of the economic sector on the water input).

The shock values were obtained by the following procedure: first, we analyze changes in water availability using a basic hydroclimatic model (precipitation minus potential evapotranspiration) for the Brazilian hydrographic regions. At this point, we use climatic data processed by the Eta-MIROC5 model for the years 2070-2099 (average of the period), considering the scenarios RCP 4.5 and RCP 8.5 and compare them with historic data from 1960-2005 (average of the period) [24-26]; second, we translate these changes in water availability into percentage changes in the cost of water access for each region. In this case, financial reports from a Brazilian water company were used.

Fig. 3 shows changes in the cost of water due to climate change (including confidence interval). Under RCP 4.5 scenario, the PNB, PRG, and AOR regions have the most significant cost shocks, with 428.9%, 144.5%, and 98.8%, respectively. These regions already have problems related to water availability. Thus, with the imposition of adverse effects of climate change they would have an even higher cost to access water resources. The AMZ, AOC, ASD, PRN, SFO, and TOC regions have intermediate cost impacts, values around 5.9% to 42.0%. On the other hand, the cost of water abstraction in the regions ASU and URU is expected to fall, with -13.5% and -22.2%, respectively. This cost reduction is consistent with the expectation of greater water availability for these regions. For the other regions, moderate increases in the cost of water are expected. Under RCP 8.5 scenario the analyses remain the same. In this case, only the size of the shocks tend to be larger. For the PNB, PRG, and AOR regions an increase in the water cost of 873.2%, 295.9%, and 271.4%, respectively is expected.

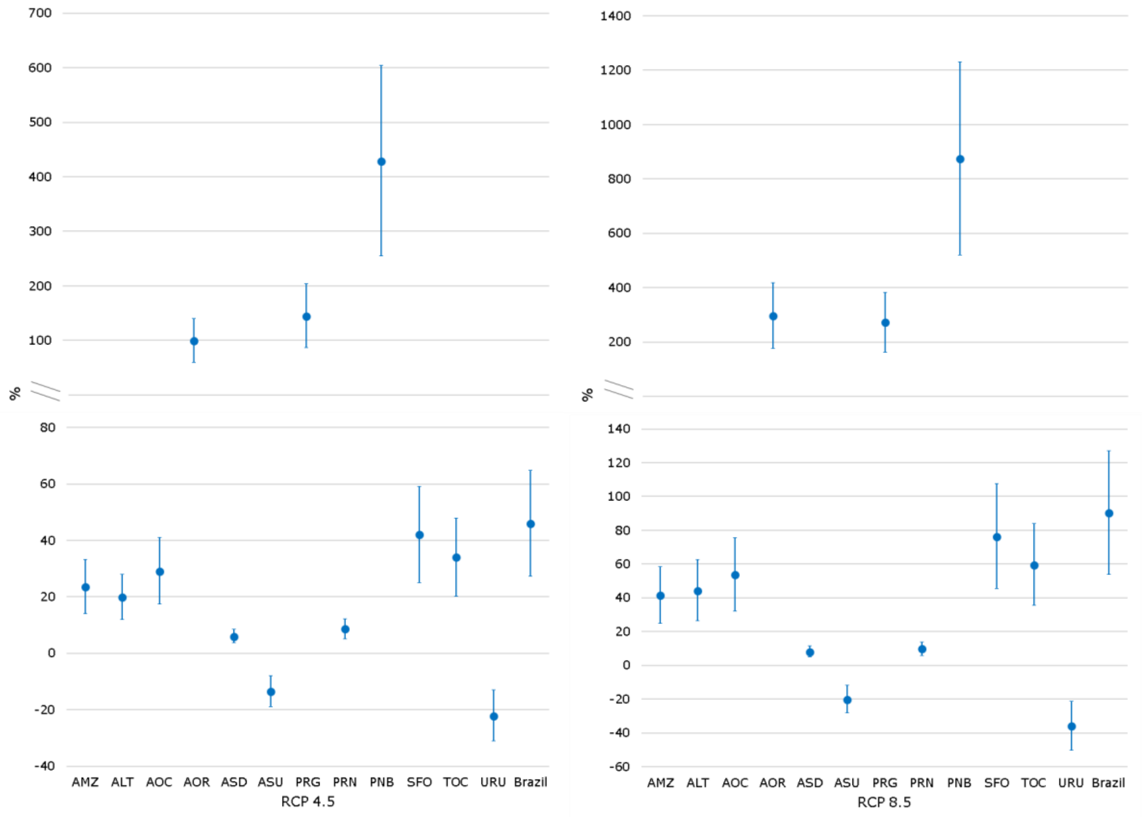

Fig. 3. Water cost changes in the Brazilian hydrographic regions.

4. Results

4.1. Macro aggregates results

Fig. 4 shows the results of the simulations for the macro aggregates. The total effects are decomposed into Channel 1 (climate change shock on water prices in the water and sewage services sector) and Channel 2 (climate change shock on access to raw water that leads to capital demand to substitute or save water). We conclude that the economic losses resulting from the effect of climate change on water availability are considerable and are equivalent to a reduction in GDP (reference year 2015) of US$ 5.2 billion under RCP 4.5 (by 2070-2099) and US$ 12.5 billion under RCP 8.5 (by 2070-2099). In terms of percentage change this represents a drop in GDP of -0.23% under RCP 4.5 and -0.56% under RCP 8.5. In both cases, Channel 1 has a more significant contribution to these results. The low substitutability of water in most user sectors turns price increases into direct shocks to the economy.

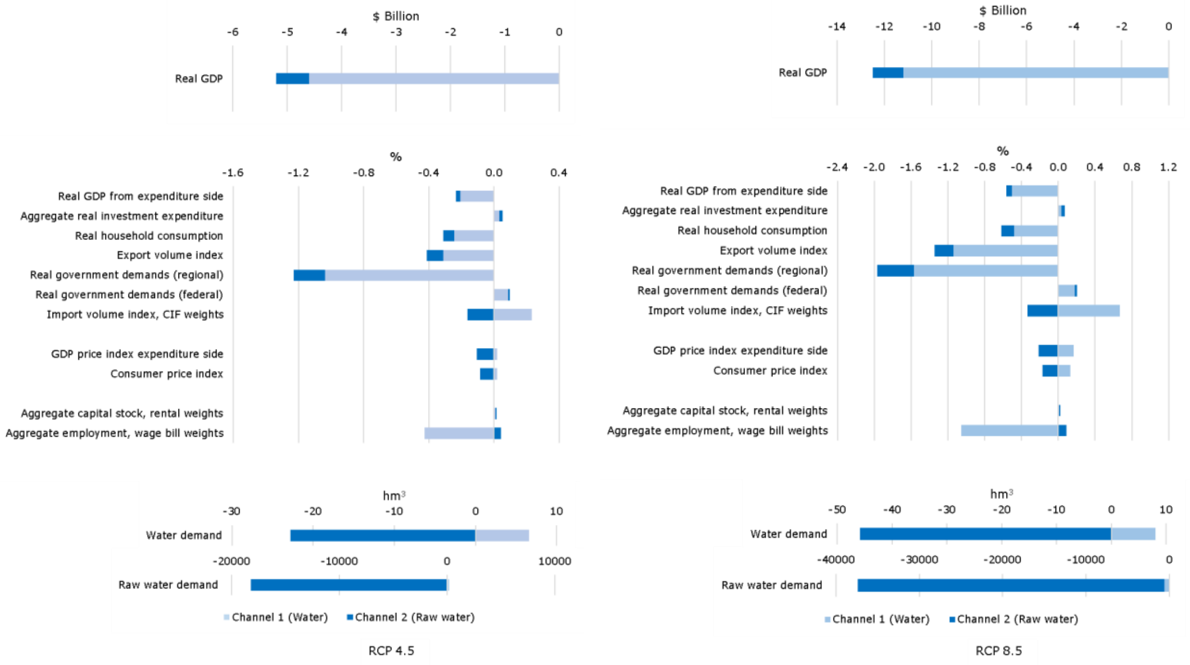

Fig. 4. Impacts on selected macro variables.

4.2. Regional and sectoral results

Fig. 5a shows the drop in real GDP in each Brazilian hydrographic region. It is possible to see that the hydrographic regions located in the semi-arid Northeast and its neighbors, PNB, AOR, ALT, and AOC, are mainly affected. From the point of view of economic development, this result is worrying because these regions are currently vulnerable, so that climate change and its impacts on water availability may be another limiting factor. On the other hand, some regions are little or not affected by the change in water availability. This is the case for ASU, PRG and URU. For ASU and URU, it is in line with the projections of higher water supply, which results in lower economic losses. Interestingly, despite having one of the highest water cost change values, the PRG region is expected to perform positively. This result is related to its productive structure focused on livestock activity. However, hydrographic regions that are little or not affected by water availability/climate change are also moderately affected. This is the case for PRN and ASD. This result shows us that the impacts of climate change are not restricted directly to affected regions alone. In other words, economic interdependence spreads damage to most regions of the system.

Evaluating the activity level of the sectoral groups (Fig. 5a) it is possible to notice that the type A sectors are severely affected in the AOC and PNB regions, especially livestock (group A2) and forestry production (group A3). This also happens with sectors of group B (includes some extractive and industrial activities) and C (includes some industries and services). In addition, we have as a result that the AOR and PNB regions may have difficulties in their water and sewage sectors (group D2). This evidence alerts us to the need for improvements in water management instruments that consider the construction of infrastructure aimed at reducing waste and water reuse. Furthermore, it is necessary to form a social conscience around the efficient consumption of water. In the PRG region, a reduction in the level of activity in the agricultural sector (group A1) and forestry (group A3) is expected. However, for the livestock activity (group A2) water restriction does not seem to be something of concern. In the ASU and URU regions, economic benefits are expected for the forest extraction activity (group A3). Still, it is possible to see that the water and sewage sector (group D2) is privileged by the greater water availability. In the rest of the country, moderate negative impacts are expected in most economic activities included in the model.

4.3. Water demand and capital to save raw water

The changes observed in the economy directly impact the amount of water (treated and raw) used/required by economic activities. Some sectors will require more water while others will substitute or save the resource. Changes in the water price, the use of capital that saves water, the level of sectoral activity, and water's essentiality as an input (= price elasticity of demand) determine these results. In general, considering a long-run scenario, sectors tend to save or substitute water (Fig. 5b). PRN, PRG and PNB have a high capacity to reduce water demand, whether due to economic scale (PRN case) or due to the impact of climate change that increases the water cost access (PNB and PRG). The agriculture, livestock, and forestry sectors play an important role in this change. On the other hand, in the ASU and URU regions, where an increase in water availability is expected, there is a low response capacity to reduce water demand, especially raw water. The other regions have a moderate reduction in water demand.

Still on the possibility of saving water through economic adaptation reactions, Fig. 5b provides information related to the use of capital for this purpose. In general, it is possible to note that climate change and its effects on water availability can lead to capital demand to compensate for possible water scarcity. In practice, this demand for capital may involve the purchase of irrigation pivots, water reuse equipment, construction of water extraction/storage places, and others. The sectors of agriculture, livestock, and forest production are the sectors that will tend to make higher capital investments. Regionally, PNB and PRG are expected to see the biggest changes in these inversions. On the other hand, ASU and URU are expected to spend less on this adaptation (because climate scenarios indicate greater water security for these regions). The other regions indicate a significant purchase of capital to save water.

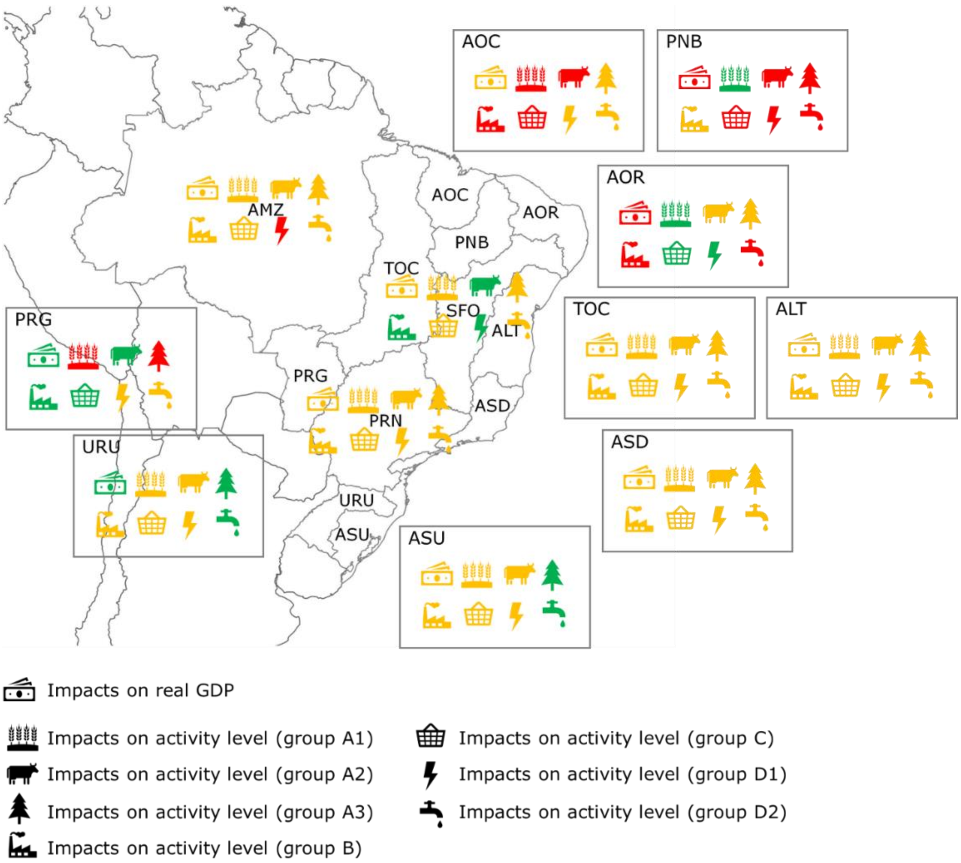

Fig. 5. Impacts on hydrographic regions (both RCP scenarios).

(a) Impacts on regional GDP and sectoral activity level. Green icons represent low impact of climate change (positive or small negative values), yellow icons represent medium impact (negative values) and red icons represent high impacts (negative values).

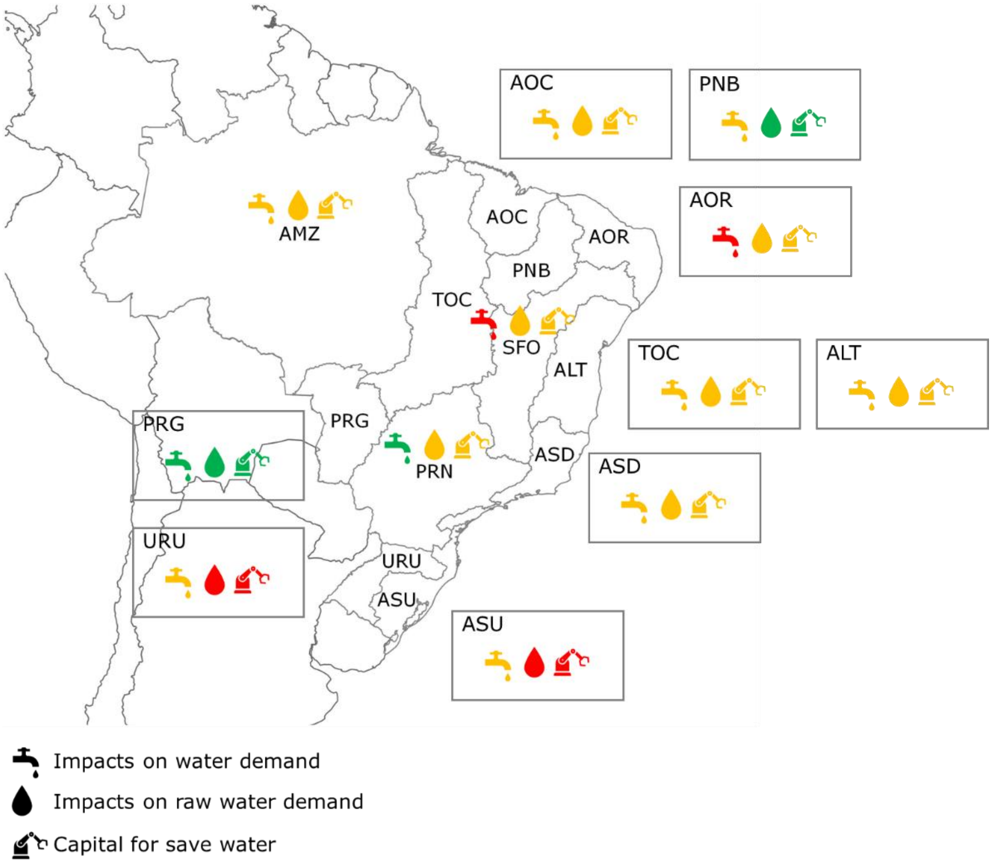

Fig. 5. Impacts on hydrographic regions (both RCP scenarios).

(b) Impacts on water demand and capital used for saving water. Green icons indicate large reduction in water demand due to climate change and increased use of capital to save water, yellow icons indicate medium impact on water demand reduction and capital purchase to save water, and red icons indicate low capacity to reduce demand (sometimes even increases water consumption) and purchase of capital.

5. Conclusion

Some lessons can be learned from our analyses. First, integrated models are robust tools capable of evaluating the economic impacts of changes in water availability resulting from climate change. Second, economic sectors and regions respond differently to water availability shocks. Their individual productive structures and economic interactions can determine the economic effects. This interdependence also determines virtual water flows. Third, the water and sewage sector can be highly affected by climate change. Given this, it is necessary to reduce water losses. In the long run, this implies (i) improvements in water distribution infrastructure, sewage collection and treatment (avoiding water leaks) [27]; (ii) implementation of reuse water systems [28]; (iii) changes in production processes seeking greater efficiency in water use [29]; and (iv) increased awareness aimed at a voluntary water saving [30]. Fourth, it is necessary to reduce administrative conflicts around water management [31-32]. In this case, political and social agents must seek agreements on their responsibilities in shared territories. Finally, it is necessary to create economic instruments aimed at paying for water resources [33]. In other words, it is necessary to charge economic agents/sectors that use large amounts of water in their production process and later use the amounts collected in infrastructure actions and water bodies preservation.

Additional information

For more details, see https://doi.org/10.11606/T.12.2022.tde-28062022-153417.

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