Irrigation Policy: Water Use and Socioeconomic Contributions in Brazil

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Abstract:
This study analyzed how the expansion of irrigation would affect water demand and regional socioeconomic impacts, considering two scenarios. The TERM-BR model was used to simulate expansion scenarios in irrigated areas for 2040. The expansion of irrigated areas would increase real wages and household consumption, while leading to a reduction in food prices. The national GDP is projected to increase by 0.30% and 0.36% by 2040, representing an impact of R$ 39,124 ($8,066) billion and R$ 47,417 ($9,776) billion accumulated by 2040, at 2023 prices. Water use would increase by an additional 52% in simulation 1 (24,310 Mm³ or 771 m³/s) and 66% in simulation 2 (30,577 Mm³ or 970 m³/s) by 2040, as an accumulated variation relative to the baseline. Data on household consumption reveal that reductions in food prices would be more significant for lower-income families compared to wealthier families. These results through out from increased agricultural production which would expand food supply, reducing relative prices, with larger effects on crops with higher irrigated productivity compared to rainfed crops.

1. Introduction

The Brazil ranks sixth among countries with the largest irrigated area, reaching approximately 8,2 million hectares (Mha) in 2019, of which 2 Mha are fertirrigated, and 5,3 Mha are irrigated (ANA, 2021). The country presents additional potential of 55 million hectares suitable for irrigation, with 13,6 million hectares having effective potential for immediate actions within the National Irrigation Policy[3], concentrated in the Midwest (45%), South (31%) and Southeast (19%). The average annual growth rate of irrigated areas was 6%[4] from 2005 to 2019. Despite this, the irrigated area remains modest compared with cultivated areas, amounting to 81 million hectares in 2019.

With the expected population growth reaching 9.7 billion by 2050, agriculture will face the challenge of increasing production by 50% compared to 2012 levels (FAO, 2019). In response to this demand, agricultural activities need to intensify production, putting pressure on natural resources. Although, Brazil stands out as a privileged country in food production, with water availability, accounting for 12% of the world's total freshwater, despite regional heterogeneity.

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[3] Law No. 12,787, dated January 11, 2013, and considering the data disclosed in the Irrigation Atlas (2021a).
[4] Irrigated plus fertirrigated areas.

Forecasts regarding the country's water resources[5] reveal a growing water demand[6], notably in irrigated agriculture, which has increased from 640 to 965 m³/s (cubic meters per second) over the past two decades (2000-2020). Recent projections from the National Water Agency estimate a 42% increase in water withdrawals over the next 20 years (until 2040) in Brazil, approximately 26 trillion liters per year as an additional amount (ANA, 2022).

In this paper, we simulate irrigation expansion scenarios proposed by the Brazilian National Water Resources Plan (PNRH) together with the National Irrigation Policy. We analyze how the irritation expansion would affect water demand, as well as the regional socioeconomic impacts, considering two scenarios. In the first simulation, we considered regions with existing irrigated agriculture and available infrastructure, totaling 8 million hectares by 2040. In the second simulation, irrigation expansion would also extend to pasture areas, reaching an additional 10 million hectares.

The main difference between these scenarios occurs with the incorporation of new areas in regions considered as agricultural frontiers in the country, resulting in changes to the regional production structure. This paper contributes to the existing literature on water use in Brazilian agriculture (Ferrarini, 2019; Ferrarini et al. 2020) in two ways. First, we improve water use coefficients, calculating activity in million cubic meters (mm³/year), specifically for irrigated agriculture, considering six systems for irrigation. Second, we detail irrigated areas in municipal level to eight crops groups. Furthermore, the scenarios are based on the effective potential for the new irrigation, according to official reporting.

2. DATABASE AND MODEL

2.1 Database

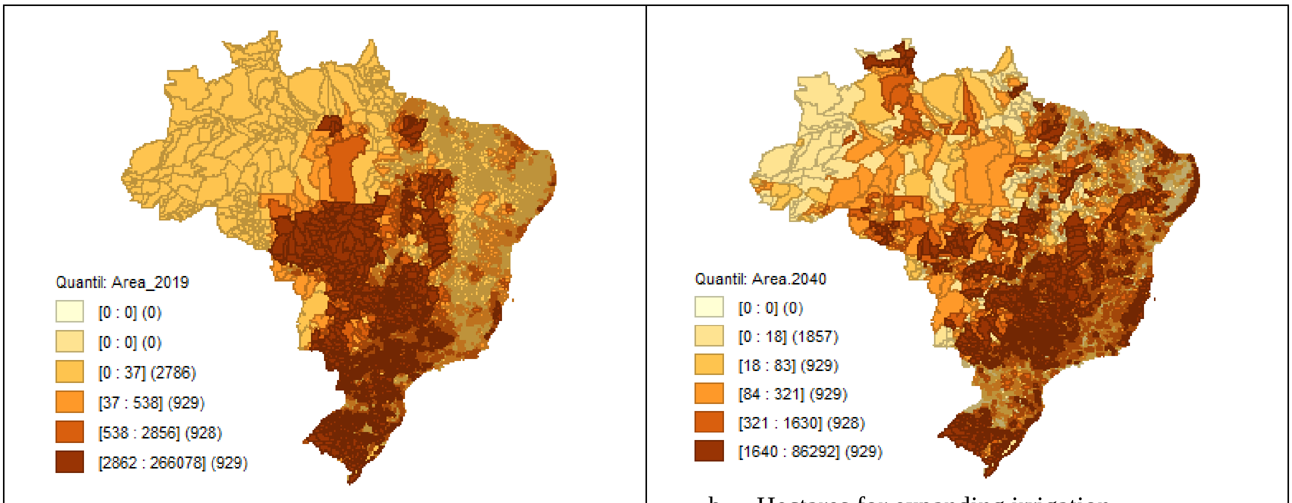
The water database involved different data sources for execution. The main data source for irrigated agriculture from the National Water Agency (ANA). In general, estimates for irrigated agriculture encompass three sets of information: climate, crops, and irrigation systems for 61 different crops. For livestock, technical coefficients for water use per animal were considered, along with factors related to washing, cleaning, and maintenance. The water use matrix for humans was developed considering technical coefficients for regional groups and population, including the losses in the distribution system.

[5] Resolution CNRH Nº 232/2022, dated 22/03/2022, approving the National Water Resources Plan 2022-2040.
[6] Water demand at this point corresponds to the estimated withdrawal flow, meaning the water captured for consumptive uses.

The water use matrix for irrigated agriculture, livestock, and human consumption is estimated at the municipal level (5,570 municipalities). For the industrial sector, approximately 3 thousand products distributed across 247 groups of industrial activities at the national level were considered. The initial agricultural productivity database for irrigated and non-irrigated activities was prepared through an extensive literature survey, which detailed description can be seen Ferrarini (2017). All data was subsequently aggregated and reconciled with the TERM-BR data.

Figure 1 displays details for irrigated agriculture at the municipality level in Brazil, as reported by Irrigation Atlas for the year 2019[7] (Figure 1a), and illustrates areas for potential irrigation expansion, considering water availability and infrastructure (Figure 1b).

Figure 1. Irrigated hectares in Brazil for the year 2019 (1a), and potential hectares for irrigation (1b)



a. Irrigatd hectares (2019)

b. Hectares for expanding irrigation

Prepared by the authors.

The location of irrigated areas and the potential new areas are essential for estimating the volume of water use in irrigated agriculture. To achieve this, data on planted areas annually disclosed in the Municipal Agricultural Production (PAM) report by the Brazilian Institute of Geography and Statistics (IBGE 2023) were employed, representing the historical evolution of production, area, and productivity of non-irrigated crops.

The Irrigation Atlas provided data for 66% of the irrigated areas by crop, requiring disaggregation for 34% of the total irrigated hectares. It which was done considering information on planted area (hectares) for 5,570 municipalities in the country. After it, water use losses by type of irrigation system (Table 1) were added to the technical coefficients to estimate water use by crop and municipality in Brazil.

[7] Latest date reported (ANA, 2021).

Table 1. Crop groups in the TERM-BR model and irrigation system

Crops in Term -BR Model (Aggregated)	Main irrigated crops (Detailed)	Main Irrigation System	Irrigation system efficiency	Water use losses by system (%)
Rice	Rice, Oats, Rye, Triticale	Inundation	60%	40%
Corn	Corn	Central Pivot	85%	15%
Cotton	Cotton	Central Pivot	85%	15%
Sugarcane	Sugar cane	Reel Irrigation	80%	20%
Soy	Soy	Central Pivot	85%	15%
Temporary Crop	Garlic, Peanuts, Potatoes, Onions, Peas, Beans, Tomatoes, Cassava	Localized (Drip, microsprinkler)	95%	5%
Permanent Crop	Citrus, Coffee, Apple, Banana, Coconut	Localized (Drip, microsprinkler)	95%	5%
Forestry and Silviculture	Acai, Palm Heart	Localized (Drip, microsprinkler)	95%	5%

Prepared by the authors.

Through a set of informational considerations, it was possible to estimate water usage for different agricultural groups (Table 2), showing that irrigated agriculture activity represents the highest estimated usage for 2015.

Table 2. Estimated water uses for the year 2015 in each usage from the CGE model

Users	m³/s estimated in 2015	Representative % of consumption
Agriculture	569	62%
Livestock	130	14%
Industry	64	7%
services	130	14%
Household	21	2%

Prepared by the authors.

We distinguish between 'irrigated' and 'fertirrigated' sugarcane areas in the database. When identifying fertirrigated sugarcane areas, we assumed that water resources are not withdrawn from springs; all water used in fertirrigation (80% of areas) comes from the industrial process. For irrigated sugarcane (20% of areas), full irrigation was considered.

2.2 CGE Model

A multi-period computable general equilibrium model of Brazil, based on previous work by de Souza Ferreira Filho and Horridge (2014), is used to analyze water use scenarios in the country. The model includes annual recursive dynamics and a detailed bottom-up regional representation, which, for the simulations reported here, distinguish 14 aggregated Brazilian regions. It also has 36 sectors, 10 household types, and 10 labor types with proxies for qualification. This model version is well-suited for analyzing socioeconomic impacts and includes a water use module that tracks water use in each state. The foundational database is derived from the 2015 Brazilian Input-Output model.

The evaluation of water use in the TERM-BR model separates agricultural lands into irrigated agriculture and dry farming land. The increase in regional agricultural production depends on both the growth of land areas (irrigated and non-irrigated) and productivity. Average regional land productivity, in turn, depends on the irrigated area, increasing with irrigation. Due to the productivity differential between irrigated and rainfed areas, the supply of food and raw materials (such as sugarcane, soybeans, for example) grows more in irrigated areas than in rainfed areas, resulting in impacts on macroeconomic aggregates.

The water module equations integrated into TERM-BR treat irrigated agricultural land and rainfed land differently, with the former experiencing productivity gains compared to the latter. The growth of regional agricultural production depends on the expansion of cultivated areas (irrigated and non-irrigated) and the productivity of crops in each area described as:

$$K_j = SHRji.Kji + SHRjn.Kjn \tag{1}$$

Equation 1 demonstrates that the total productivity of agriculture (K_j)in activity j[8] depends on the relationship between the share of irrigated agriculture ($SHRji$) and non-irrigated agriculture ($SHRjn$) on the municipality, where Kji is the productivity of irrigated activity and Kjn is the productivity of non-irrigated activity. The elasticity of productivity in activity j with respect to irrigated area is given by the equation.

$$\frac{\partial {K_j}^*}{\partial shrig_j} = \frac{SHRji(1-x)}{(1-x)SHRji + x} \tag{2}$$

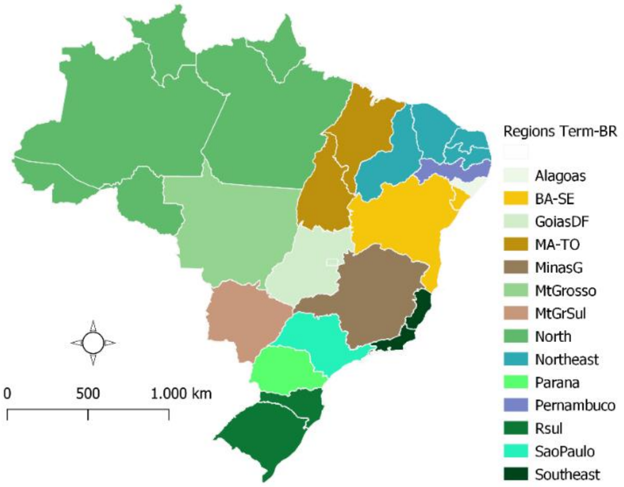
A $shrig_j$ is the variation of the irrigated share, an exogenous element in the model. If we define x (0 < x < 1) as the relative productivity of irrigated and non-irrigated land ($Kjn/$Kji) where Kji > Kjn , ue to the productivity differential between irrigated and non-irrigated areas, the supply of food and raw materials (such as sugarcane, soybeans, for example) grows more in irrigated areas than in non-irrigated areas, resulting in impacts on macroeconomic aggregates. Therefore, the increase in productivity, by crop and region, is one of the impact variables in the model.

The execution of the dynamic inter-regional CGE model requires significant computational effort, and to allow for mathematical adjustment and reduce model processing time, it was necessary

[8] Activity here refers to the type of irrigated crop existing in the municipality, such as rice, cotton, soybeans, corn, and others.

to group certain states while maintaining priority regions for analysis. Map 1 illustrates the aggregated regions (from 27 states to 14 regions) for the policy simulation in the model.

Map 1 - Regional Aggregation - Regional Compatibility of TERM-BR



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A agregação do modelo considerou regiões de maior potencial de expansão da agricultura irrigada e considerou como regiões estratégicas para a ampliação da irrigação o Mato Grosso (MtGrosso), Mato Grosso do Sul (MtGrSul), Paraná (Parana), Minas Gerais (MinasG), São Paulo (SaoPAulo) e Bahia (BA-SE), regiões com polos de irrigação[9].

2.3 Policy simulations for 2020-2040

For the execution of the policy simulation, two situations must be considered in the model: i) the baseline; ii) policy scenario. The reference year of the TERM-BR model used in this research is 2015. The model's baseline includes a period for historical simulation (historical baseline) from 2015 to 2019[10], where irrigated areas (hectares), water use in million cubic meters (Mm^3), population data (IBGE, 2020), and macroeconomic data are adjusted (IBGE, 2023b).

Starting from 2020, the economic behavior (trend baseline) was projected until 2040 using data on the expansion of Gross Domestic Product (GDP) of 1.9% per year, according to the Ten-Year Energy Expansion Plan (PDE) 2031 (Brazil, 2022), and population growth based on estimates from IBGE (2020). The projection of pasture areas was developed using the average observed over the last 5 years, based on remote sensing data from the Image Processing and Geoprocessing Laboratory (LAPIG) at the Federal University of Goiás.

[9] Ordinance MDR No. 1,082, dated April 25, 2019.
[10] Latest information on irrigated areas provided in official documents through the Irrigation Atlas (ANA, 2021).

Potential areas for expanding irrigation are outlined in the document 'Territorial Analysis for the Development of Irrigated Agriculture in Brazil' reported by The Ministry of Regional Development (MDR/GPP, 2020). These classifications offer essential information to identify potential new irrigable areas for immediate action.

Scenarios were established based on official documents that are part of the National Water Resources Plan (PNRH) (ANA, 2022) and the Irrigation Atlas (ANA, 2021). Table 3 summarizes the scenarios (Scen 1 and Scen 2) for expanding irrigation in each region of the TERM-BR model, presenting the percentage magnitude of the expansion in relation to the regional additional potential considered effective for short and medium-term actions.

Table 3. Scenarios for expanding irrigation - Areas and percentage expansion in each region of the model

n	Regions TERM-BR	Scen 1 (hectares)	Scen 2 (hectares)	% of the additional regional potential Scen 1	% of the additional regional potential Scen 2
1	North	34,635	223,079	4	23
2	MaTo	122,765	366,030	13	39
3	Rnordeste	50,452	50,452	57	57
4	Pernambuco	25,093	25,093	90	90
5	Alagoas	24,203	24,203	84	84
6	BahSerg	189,280	495,888	38	100
7	MinasG	382,160	382,160	91	91
8	SaoPaulo	1,255,755	1,477,600	53	62
9	Rsudeste	1,215,408	1,267,615	96	100
10	Parana	458,587	625,860	35	48
11	Rsul	1,467,319	1,900,113	40	52
12	MtGrSul	1,032,352	1,262,205	47	58
13	MtGrosso	510,094	561,093	91	100
14	GoiasDF	1,315,493	1,343,988	98	100
	Total	**8,083,596**	**10,005.379**		

Prepared by the authors.

Scenario 1 refers to local areas with is a tradition of irrigation (presence of irrigated agriculture) along with high or medium available infrastructure and an average projection of 404 thousand hectares per year, above the historical average of the last 13 years, which is 280 thousand hectares per year. The second scenario further expands irrigated agriculture by an additional 2 million hectares under the current condition of pasture as described in the MDR/GPP document (2020). This scenario corresponding to an average expansion of 500 thousand hectares per year.

3. Results

3.1 The national and regional socioeconomic results

The irrigated areas expansion would increase real wages and household consumption, while simultaneously leading to a reduction in food prices. In the same way, the national GDP increasing by 0.30% and 0.36% by 2040. This represents an impact of R$ 39,124 ($8,066) billion and R$ 47,417 ($9,776) billion accumulated by 2040, at 2023 prices, in SCEN 1 and SCEN 2, relative to the baseline. Similarly, irrigation would impact real household consumption by 0.43% and 0.52% or R$ 24,756 ($5,104) billion and R$ 29,812 ($6,146) billion, at December 2023 prices, by 2040 (Table 4).

These results are highly relevant and more pronounced when compared to those presented in Ferrarini et al. (2019). Such discrepancies can be explained by various factors, such as differences in the simulation strategy, including expansion regions, crops, and a timeframe used. Before that, the scale of irrigated area expansion and the methods employed for productivity calculation are different between studies. In addition, the presented study demonstrates three times higher expansion than Ferrarini et al. (2019).

Table 4. National Impacts. SCEN 1 e SCEN 2, Cumulative % variation in macroeconomic aggregates by 2040.

	Real Household Consumtion	Real Government Consumption	Real Export	Real GDP	Real Wage
SCEN 1	0.43	0.43	-0.14	0.30	0.51
SCEN 2	0.52	0.52	-0.11	0.36	0.61

Results.

The national results show a significant expansion in household consumption, government spending, wages, and GDP in real terms. However, it is important to note that the expansion of irrigation and the consequent increase in domestic consumption, driven by real income growth, may impact the reduction of aggregate exports of the national economy in both scenarios, despite the increase in food exports (Table 6).

With the advancement of national income, an expansion of domestic consumption is expected for the set of goods produced and exported by the national economy, in real terms. Additionally, in both scenarios analyzed, irrigation would have a positive effect on real household consumption across all income brackets (as described according to POF classes 1 to 10), both for the total household consumption basket and the food consumption basket (Table 5). This could contribute to a more equitable distribution of income and consumption among different family classes.

Indeed, the technological pattern adopted per unit area plays a crucial role in determining the level of productivity. The technical production coefficients, in turn, establish the quantities of inputs consumed per hectare and per crop, through a production function specific to each crop, which naturally varies in each region under study. Therefore, by employing irrigation techniques, it is possible to enhance crop yield gains, resulting in significant impacts on regional production and economic aggregates with price and consumption (Table 5).

Table 5. National Impact. SCEN 1 and SCEN 2, cumulative % variation in food prices and household consumption by 2040

household	Food prices		Total consumption		Food consumption	
	scen 1	scen 2	scen 1	scen 2	scen 1	scen 2
POF1	-0.19	-0.22	0.14	0.23	0.18	0.28
POF2	-0.17	-0.20	0.30	0.42	0.30	0.41
POF3	-0.15	-0.18	0.36	0.46	0.33	0.44
POF4	-0.15	-0.17	0.38	0.47	0.34	0.43
POF5	-0.15	-0.18	0.42	0.50	0.38	0.46
POF6	-0.15	-0.17	0.43	0.50	0.37	0.44
POF7	-0.17	-0.20	0.49	0.57	0.40	0.48
POF8	-0.14	-0.17	0.47	0.55	0.38	0.45
POF9	-0.15	-0.17	0.49	0.57	0.41	0.49
POF10	-0.10	-0.11	0.47	0.55	0.41	0.48

Results.

The data on household's consumption reveal that reductions in food prices would be more significant for lower-income families (POF1) compared to wealthier families (POF10). These results through out from increased agricultural production which would expand food supply, reducing relative prices, with larger effects on crops with higher irrigated productivity compared to rainfed crops. This is a general equilibrium effect with environmental consequences in water use, which is discussed further ahead.

The dynamics caused by increased production in irrigated agriculture and lower food prices would stimulate the growth of commodity exports, including rice, corn, soybeans, temporary and perennial crops (Table 6). The policy implementation would contributed to the reduction of social inequality and the provision to ensure food security for the Brazilian and global populations.

Table 6. National impact. Prices, production and exports for selected economic activities, SCEN 1 and SCEN 2, accumulated % change in 2040

economic activities	Prices Accumulated % Change		Production Accumulated % change		Exportation Accumulated % Change	
	SCEN 1	SCEN 2	SCEN 1	SCEN 2	SCEN 1	SCEN 2
Rice	-19.72	-22.04	44.03	49.58	164.45	178.33
Corn	-1.81	-2.26	2.77	3.49	4.26	5.36
Cotton	-3.08	-4.08	6.67	9.19	11.49	15.76
Sugarcane	-22.20	-25.45	12.22	14.08	0.00	0.00
Soy	-1.17	-1.49	2.06	2.74	2.67	3.56
Temporary Crop	-5.81	-6.86	1.51	1.81	12.23	15.21
Permanent Crop	-3.22	-4.39	5.48	7.35	11.38	15.04
Forestry and Silviculture	-0.24	-0.45	-0.33	-0.26	-0.97	-0.22
Cattle and other animals	0.00	-0.23	-0.55	-0.71	-1.06	-1.66
Milk, cow and others	0.00	0.00	0.10	0.10	0.00	0.00
Sugar	-9.03	-10.36	20.58	23.89	38.89	45.22
Ethanol	-9.01	-10.34	5.70	6.57	26.90	30.64

Results.

Sugarcane is a not exported crop in its natural form. However, the products derived from it are exported, such as sugar and ethanol. Sugar could export 38.89% in SCEN 1 and 45.22% in SCEN 2. Additionally, domestic ethanol increases diversification of the national energy matrix and increases the use of organic material in the context of biomass, which leads to a reduction in the emissions of gases that cause the greenhouse effect in the atmosphere. Plant and forestry exploitation, (açaí and heart of palm), there will be a decrease in production and exports. This is due to the potential decrease in pasture areas in response to the expansion of irrigation areas. Consequently, exports would decrease to attend domestic demand.

The regional results highlighted an increase in economic aggregates, in real terms, across all analyzed regions. However, the expansion of irrigation would impact regions with a higher relative participation of agriculture in regional production, such as Mato Grosso do Sul (MS: 15.3%) and Mato Grosso (MT: 29%), compared to states where other productive activities (industry, commerce, etc.) have more significant roles in regional production, such as São Paulo, where agriculture represents 1.6% of regional production and other activities represent 98.4% (Annex 1).

The greatest impacts on the regional GDP would occur in the states of Mato Grosso, Mato Grosso do Sul, and Goiás, belonging to the Brazilian Midwest, registering cumulative growth of 3.33%, 1.77%, and 1.38% respectively compared to the baseline in 2040 in SCEN 2 (Table 7). The expansion of the regional GDP is associated with the local productive dynamics, driven in the economic model by the magnitude of the simulated policy shock in the scenarios, which is higher in this region. The Midwest region of the country presents a large volume of freshwater, numerous rivers, aquifers, and springs, as well as being one of the main grain-producing regions, allowing for the advancement of irrigation.

It is still possible to observe an increase in GDP in the North and MaTo (Maranhão and Tocantins) regions in SCEN2 due to the additional expansion of 188,444 hectares in the North and 243,265 hectares in MaTo. The MaTo region represents part of the regional structure of Brazilian states considered as agricultural frontier areas with high potential for the expansion of intensive agriculture (Bolfe et al, 2016; de Araújo et al, 2019).

Both scenarios would promote impacts on the real household consumption and GDP. However, the response of the economic model presents the possibility of a reduction in consumption for the region of Alagoas. It would occur due to the mobility of production factors (labor, capital) through the relocating between regions in the model, as would be the case with a greater expansion of irrigated agriculture in Bahia and other states in the Northeast region that could attract more labor (Map 1).

Table 7. Regional Economic Impacts. SCEN 1 and SCEN 2 as cumulative % relative to the baseline in 2040.

Region Term-BR	Real GDP		Real wage		Real Households		Real investment	
	SCEN 1	SCEN 2	SCEN 1	SCEN 2	SCEN 1	SCEN 2	SCEN 1	SCEN 2
North	0.04	0.38	0.33	0.63	0.21	0.51	-0.09	0.04
MaTo	0.16	0.53	0.35	0.64	0.20	0.48	-0.14	-0.04
Rnordeste	0.04	0.07	0.42	0.55	0.31	0.41	-0.05	0.01
Pernambuco	0.05	0.07	0.38	0.49	0.28	0.35	-0.13	-0.10
Alagoas	0.06	0.05	0.08	0.10	-0.29	-0.37	-0.19	-0.23
BahSerg	0.14	0.35	0.45	0.70	0.34	0.60	-0.12	-0.02
MinasG	0.50	0.58	0.65	0.76	0.59	0.69	-0.01	-0.01
SaoPaulo	0.14	0.13	0.45	0.50	0.39	0.41	-0.10	-0.15
Rsudeste	0.16	0.16	0.48	0.54	0.40	0.45	0.10	0.13
Parana	0.31	0.32	0.54	0.60	0.51	0.56	0.05	0.02
Rsul	0.34	0.34	0.51	0.55	0.46	0.49	-0.16	-0.22
MtGrSul	1.36	1.77	0.89	1.17	0.99	1.32	1.31	1.74
MtGrosso	2.62	3.33	1.45	1.84	1.38	1.75	0.53	0.69
GoiasDF	1.15	1.38	0.97	1.20	0.94	1.15	1.64	2.05

Results.

The investment is an endogenous variable in the model and constrained, reductions in it would occur due to the reallocation of financial resources between sectors and regions. Besides, the expansion of irrigation would impact the dynamics of the labor market, real wages, and food consumption by family groups in all regions. However, in Alagoas region, the local government could adopt other policies capable of maintaining demand for labor and avoid losses in real households.

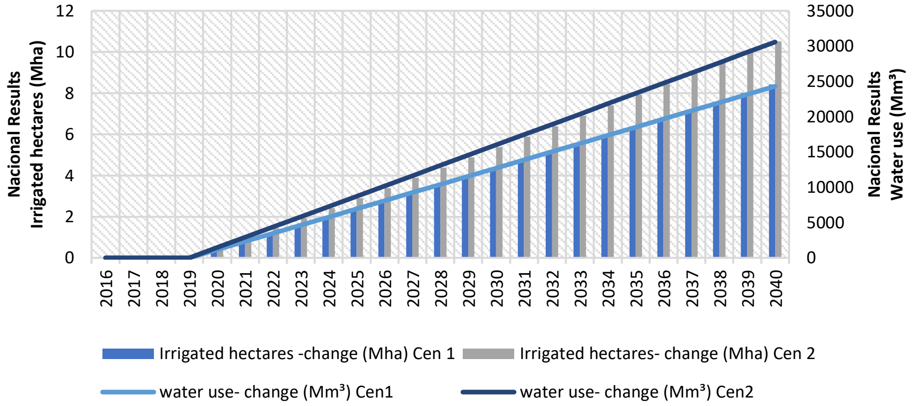
3.2 Water use impacts

In Brazil, crops such as rice, sugarcane, and coffee have the largest irrigated areas. However, the volume of water used for irrigation depends on factors associated with regional climate, irrigation systems, and the crop's water needs throughout its cycle. The potential for irrigation installation (both total and effective), as described in the Irrigation Atlas (ANA, 2021), should be carefully considered due to local specificities, infrastructure expansion, and hydraulic infrastructure projects that can over time alter the estimate of additional irrigable area. With increased irrigation, the water supply is affected through transfers from other basins (Zhuang, 2016), while climatic factors also impact the water balance of water sources (Woolway et al., 2020; Mello et al., 2020), requiring monitoring of usage and management of both quality and quantity.

The simulated scenarios show a percentage change in water use of an additional 52% in CEN 1 (24,310 Mm^3 or 771 m^3/s) and 66% in CEN 2 (30,577 Mm^3 or 970 m^3/s) by 2040 as an accumulated variation relative to the baseline (Graph 1). Incorporating these results with the baseline of the model, the irrigated area by 2040 could reach 17.6 Mha in CEN 1 (8 Mha from policy plus trend growth) and

19.5 Mha in CEN 2 (10 Mha from policy plus trend growth). These simulated results are higher when compared to the projected 12.4 Mha of irrigated areas for 2040 described in the Irrigation Atlas (ANA, 2021) for the same period.

Graph 1. National Results, Irrigated Area (Mha), and Water Volume (Mm³) in Irrigated Agriculture up to 2040 - Accumulated Variation Relative to Baseline.



Results.

Brazil has the largest volume of freshwater compared to other nations in the world. However, with an unequal distribution of this resource (Melo et al, 2020) and an increase in irrigated areas in regions with limited water availability and frequent long periods of drought (ANA, 2019), this could contribute to the escalation of conflicts over water usage. Although the data used in the simulations consider regions with both surface and groundwater availability, such information is quantitative and does not provide insights into water quality or its impacts on the hydrological cycle due to the effects of anthropogenic activities.

The data from the Irrigation Atlas highlight 1,1 million hectares under irrigation in the irrigation hub municipalities in Brazil (122 municipalities out of 5,570). The effective potential for expanding irrigation in these municipalities is an additional 3,1 million hectares, representing a 179% increase in these regions. The region with the highest potential for irrigation expansion is the state of Mato Grosso (MtGrosso), which could reach up to 3,6 million hectares under a medium-term policy plan, with approximately 2,2 million hectares suitable for expansion across 33 of the state's 141 municipalities. Additionally, Brazil has suitable areas in other regions of the country not classified as irrigation hubs, which could contribute to changes in regional production dynamics.

Part of this existing potential in the country was simulated in SCEN1 and SCEN2, and the regional impacts on water use considered the group of main crops existing in the base year of the model. Therefore, some regions with significant expansion in irrigated areas may not result in high quantities of water usage, which is due to the specificity of the crops practiced in the region. An example of this is the Goiás region (Goiás/DF), which is the fifth largest region for expansion of areas and the ninth region for increased water usage. Regionally, the Midwest would present the greatest potential for advancing irrigation (Table 8). This region has a semi-humid tropical climate, with hot and rainy summers and cold and dry winters, and is drained by important basins such as the Araguaia River, Tocantins River, and Paraná River, which allows for good regional water availability.

Table 8. Regional Impacts on Water Use. SCEN 1 and SCEN 2 - Results in Mm³, m³, and % Change - Accumulated for 2040

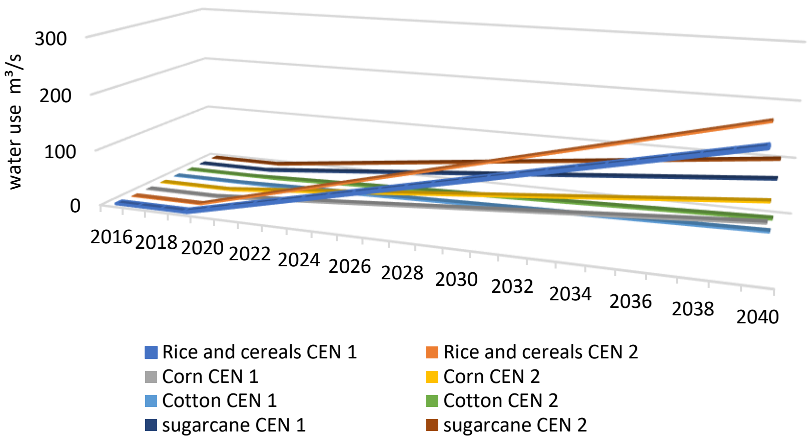
TERM-BR	Brazil Region	m³/s SCEN 1	m³/s SCEN 2	% change SCEN 1	% change SCEN 2
North	North	6	40	7	47
MaTo	Northeast/North	13	37	23	68
Rnordeste	Northeast	8	8	12	12
Pernambuco	Northeast	4	4	12	12
Alagoas	Northeast	2	3	10	10
BahSerg	Northeast	26	68	22	58
MinasG	Southeast	260	306	67	79
SaoPaulo	Southeast	32	33	20	21
Rsudeste	Southeast	49	49	64	64
Parana	South	29	32	68	75
Rsul	South	182	186	76	78
MtGrSul	Midwest	11	15	39	53
MtGrosso	Midwest	87	113	172	222
GoiasDF	Midwest	63	77	70	85
Total		771	970		

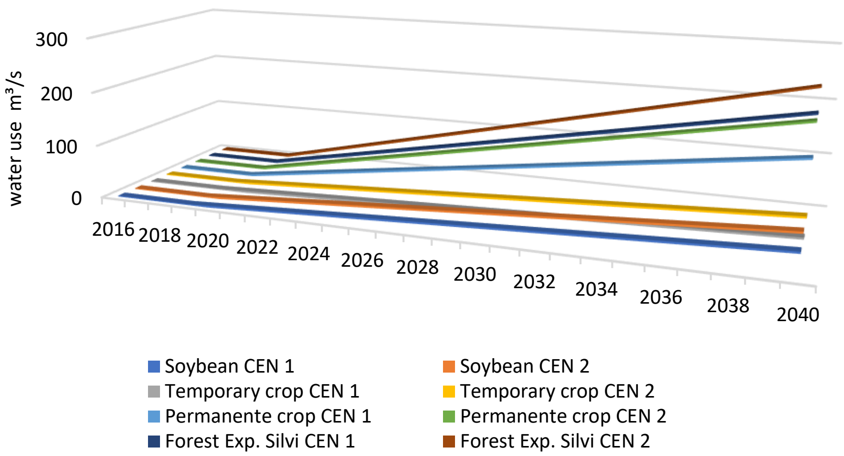
Results

*MA: Maranhão state located in Northeast; TO: Tocantins state located in North

When comparing the necessary water demand for expanding regional irrigation with water availability, it is possible to draw some inferences. According to the Water Resources Outlook Report of Brazil (ANA, 2023), out of the 255,000 m³/s of water that flows on average through Brazilian territory, nearly 80% is located in the Amazon Basin, which supplies the North and part of the Midwest regions of the country. Additionally, the low-flow rate (Q95) corresponds to approximately 58,000 m³/s of surface water and an additional 13,000 m³/s of groundwater, which would allow for the expansion of irrigated areas in terms of water volume as simulated. Given that water restriction is limiting in some regions of the country, the results highlight the Midwest, Maranhão, and Tocantins as having the most potential for expansion.

Graph 2. Water Use Impacts. Change in m³/s across the eight crop groups of the economic model, CEN 1 and CEN 2, cumulative policy results for 2040





Results.

The projections show that permanent crops and rice are the crop groups that would demand the most water resources. Rice cultivation is the largest water consumer, being the primary demand within the irrigated crop group of the economic model. The rice crop cycle, although concentrated on average over 120 days per year, is intensive in terms of water demand due to flooding irrigation systems used in Brazil. On the other hand, semi-perennial crops such as soybeans, wheat, and corn (for example) require supplemental irrigation, especially in regions with lower environmental water availability or more adverse climates. Because of this water requirement, the regional impacts of expanding irrigated agriculture are varied.

Final remarks

The Term-BR model was designed to address changes in a general equilibrium framework at the regional level. Furthermore, the aggregate outcome does not reflect the heterogeneity of agricultural production systems within farms. Edaphoclimatic conditions, soil type, and crop type (monoculture or crop rotation) in Brazil's 5,572 municipalities can diverge in magnitude the identified socioeconomic results and water use. However, in the data elaboration, it was possible to spatialize relevant information on irrigated areas and water use by type of crop and municipality, allowing for better refinement of the information. Expanding information on productivity differentials was essential to estimate the magnitude of gains generated by the activity and its impacts on economic aggregates.

These points are important because Brazil holds the largest volume of freshwater compared to other nations in the world. However, with an unequal distribution of this resource and an increase in irrigated areas in regions with limited water availability and frequent long periods of drought, this could contribute to the amplification of conflicts in water usage. Although the data used in the simulations consider regions with both surface and groundwater availability, such information is quantitative and does not provide insights into water quality or its impacts on the hydrological cycle due to the effects of anthropogenic activities.

The irrigation expansion policy should consider improvements in the water distribution system across Brazilian territory to minimize losses and enable a lesser impact on water resources. Policies outlined in the National Water Resources Plan (PNRH) 2022-2040 regarding technological, logistical, and energy transition improvements need to be considered in water resource management. The differences in the expansion of new irrigated areas described in simulated scenarios could be achieved through a regional irrigation incentive public policy in the country.

Among the challenges for advancing irrigation, one can mention the need for credit, climate variability, water resource management, investments, and research for expanding irrigation hubs. In parallel with the expansion of irrigated areas, other effects could positively impact productivity increases, such as investments in technology and water use efficiency, use of fertilizers, soil management improvements, and others. A relevant point in the study is that, for the first time, to the best of our knowledge, it manages to address socioeconomic results with the level of detail presented in this study, contributing to discussions on the impacts of irrigation policies (private and/or public investments).

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Annex I. Baseline. Regional production share (%) for the group of agricultural activities, in the year 2015.

Parcela de Produção Regional	Rice	Corn	Cotton	Sugarcane	Soybeans	Temp. Crops	Permanent Crops	Livestock	Forestry	Other sectors
North	0.1	0.2	0.0	0.0	0.4	1.3	1.5	3.0	0.7	92.7
MaTo	0.4	0.6	0.1	0.3	3.0	0.8	0.1	3.8	0.6	90.5
Rnordeste	0.0	0.1	0.0	0.2	0.4	0.6	0.3	1.5	0.1	96.7
Pernambuco	0.0	0.0	0.0	0.5	0.0	0.3	0.4	1.5	0.0	97.3
Alagoas	0.0	0.0	0.0	2.7	0.0	0.5	0.2	1.6	0.0	94.9
BahSerg	0.0	0.3	0.4	0.1	1.1	0.9	1.2	1.6	0.4	93.8
MinasG	0.0	0.3	0.0	0.4	0.4	0.7	1.5	1.7	0.4	94.6
SaoPaulo	0.0	0.1	0.0	0.7	0.1	0.2	0.3	0.3	0.1	98.4
Rsudeste	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.2	0.0	99.2
Parana	0.2	0.7	0.0	0.4	2.7	1.0	0.2	1.8	0.5	92.4
Rsul	0.6	0.3	0.0	0.0	1.8	1.1	0.3	1.7	0.3	94.0
MtGrSul	0.1	2.0	0.2	2.0	5.3	0.3	0.0	4.8	0.6	84.7
MtGrosso	0.2	3.0	2.7	0.7	15.4	0.8	0.1	5.6	0.5	71.0
GoiasDF	0.1	0.7	0.1	1.0	1.9	0.6	0.1	2.1	0.1	93.4

Input data for the model.