Climate Change and Agricultural Supply in Brasil

Abstract: This paper analyses the potential socioeconomic impacts that climate change projected for 2040 may have on agriculture - in particular on agricultural supply - and the Brazilian economy as a whole and on its different regions. For this purpose, a recursive dynamic interregional CGE model is used, calibrated to the year 2010. Two climate change scenarios are considered: an Intermediate (RCP4.5) - less severe - and a Pessimistic (RCP8.5) - more severe. The main distinction from previous studies is the use of suitable area loss estimates based on projections for the regional pattern of climate change from the 5th and most recent IPCC report. Results show that, although climate change is expected to lead to a reduction in agricultural production and exports in Brazil, this effect would only be relevant for soybean in the Intermediate Scenario. Real GDP reductions appear in both scenarios, but this should be more intense in the Intermediate Scenario. They also signal that those losses will be greater for poorer households and for regions whose economy is more dependent on agriculture and, in particular, on soybean cultivation; and that the real consumption and welfare of households in the Midwest region and part of the Northeast (where soybean crop is more representative) will be more affected than in other regions of Brazil.

Keywords: climate change, food security, agricultural supply, Brazil, CGE model

Classificação JEL: Q54, Q15, R13, D58

1 Introduction

Climate change is one of the greatest challenges facing humanity in the 21st century. The most recent reports of the Intergovernmental Panel on Climate Change (IPCC) presented evidence of rising average temperatures, changes in precipitation patterns, increased frequency of extreme weather events and other meteorological and climatic phenomena arising from the increased atmospheric concentration greenhouse gases (GHGs) (IPCC 2007, 2014). All four GHG concentration and emission scenarios presented in the 5th Assessment Report (AR5) of the IPCC (IPCC, 2014) - known as Representative Concentration Pathways (RCPs) 2.6, 4.5, 6.0, and 8.5 - support projections of rising average surface temperature over this century. The likely increase between years 2081 and 2100 compared to 1986-2005 is expected to be 0.3°C to 1.7°C in the mildest scenario (RCP2.6), and 2.6°C to 4.8°C in the most severe scenario (RCP8.5) (IPCC, 2014, p. 10), which could bring serious economic and social consequences for different populations, productive sectors, and regions around the world.

The agricultural sector, being highly dependent on environmental conditions, especially temperature and precipitation, is often pointed out as the most vulnerable to changes in climate patterns (Zhai et al., 2009). As a result, the potential impacts on agriculture has been one of the most studied topics in the climate change literature in recent years (Chalise et al., 2017).

Some key aspects of the problem are often highlighted in the literature. First, the adverse effects of climate change on agriculture will not be equally distributed around the world, prevailing on tropical and subtropical areas, which predominantly involve developing countries (Darwin et al., 1995; Mendelsohn, 2000; Fischer et al., 2002; Cline, 2007; Quiroga and Iglesias, 2007; Eboli et al., 2010). Second, there are still few studies on climate change and agriculture focusing developing countries, which are regarded as the most vulnerable (Chalise et al., 2017). Third, computable general equilibrium models have been widely used in this field, due to their great capacity to treat the economy as a complete and interdependent system, allowing to address the links between climate change, agriculture and the rest of the economy. Fourth, even less frequent in the literature are studies under the general equilibrium approach devoted to analyzing country-specific implications of the relationship between climate change and agriculture, especially for developing countries (eg, Zhai et al., 2009; Ahmed et al., 2011; Elshennawy et al., 2016; Chalise and Naranpanawa, 2016; Chalise et al., 2017).

As noted by Chalise et al. (2017), computable multiregional general equilibrium models encompassing several countries or groups of countries have often been used in the international literature to address the linkages between climate change, agriculture and the rest of the economy. The high degree of regional aggregation of these models, however, makes them unable to deal with the country-specific implications of climate change (Chalise et al., 2017). Country-specific analyses often require greater regional detailing of national economies, especially in the case of countries with a large territorial extension.

In Brazil, the literature relating climate change and agriculture under a general equilibrium approach has predominantly used static interregional computable models of the bottom-up type and climate scenarios derived from the 4th IPCC report (IPCC, 2007). This category of models allows a explicit treatment of the Brazilian regional and climatic heterogeneity, as well as region-specific shocks, but do not show the evolution path of the economy over time.

In this paper we investigate the potential socioeconomic impacts that climate change projected for 2040 may have on agriculture - in particular on agricultural supply - and the Brazilian economy as a whole and on its different regions. For this, we use the most recent IPCC scenarios and a general equilibrium model with recursive dynamics, calibrated for the 2010 base year, with regional detail in Brazil. The central hypothesis of the study is that rising temperatures and changing precipitation patterns will have net negative effects on agricultural activities, with important consequences for the rest of the economy. Given the regional heterogeneity of crops and production systems that characterize Brazilian agriculture, regionally differentiated impacts are expected.

The main difference between this study and the previous ones for Brazil is the use of “suitable area” changes estimates for 2040, based on projections of the 5th and more recent IPCC report (IPCC, 2014). As far as we know, these scenarios for agriculture have not yet been explored in the Brazilian literature, with the approach and detail proposed here. As we show in the paper, however, this new scenarios are quite different compared to previous ones from the 4th IPCC report.

Brazil is an interesting case study for several reasons. First, as most of its territory is located in tropical and subtropical areas – identified as the most vulnerable – the country will likely face serious setbacks as a result of climate change[1], as highlighted by Ferreira Filho and Moraes (2014). Second, due to the importance of its agriculture and related activities in generating domestic employment and income, the country may suffer serious economic and social consequences resulting from climate changes. Third, due to its great relevance in the international market for agricultural products, climate change may affect Brazil's agricultural supply capacity and the performance of its exports, affecting agricultural international markets. It is worth noting that, according to the World Trade Organization, Brazil recently reached the position of largest net exporter of agricultural products, with a balance of US$ 71.5 billion in 2019 (ahead of the EU, in second, with $35.2 billion).

This paper is composed of 5 sections, in addition to this introduction. Section 2 provides a brief review of the empirical literature on the relationship between climate change and agriculture in Brazil. Section 3 contains a brief description of the empirical model used. Section 4 describes the scenarios and the simulation strategy. Section 5 presents and discusses the main results. The sixth section contains the final remarks of the study.

2 Climate change and agriculture in Brazil

One of the first studies on the relationship between climate change and agriculture for Brazil was Sanghi et al. (1997), who assessed the potential impacts of climate change on land

[1] According to studies by the Center for Advanced Studies in Applied Economics (Cepea), the employed population in Brazilian agribusiness totaled 18.20 million people in 2018, corresponding to 19.82% of the total employed persons in Brazil that year (CEPEA, 2019).

value and the profitability of agriculture. Later, Mendelsohn and Dinar (1999) discussed the effects of global warming on agriculture in Brazil (and also in India). Nobre and Assad (2005) analyzed the effects of increasing temperature on Amazon ecosystems and on Brazilian agriculture. Deconto (2008) investigated the loss of low-risk planting area for eight agricultural crops in different regions of Brazil, generating area loss projections for the years 2010, 2020, 2050 and 2070 based on temperature increase projections from the 4th Assessment Report of IPCC (IPCC, 2007). All these studies used a partial equilibrium approach.

In another line of studies, Domingues et al. (2008) analyzed the impacts on the Northeast region of a shock in the availability of suitable land for agriculture in each state of that region using a static interregional computable general equilibrium (CGE) model. Domingues et al. (2010) used a recursive dynamic general equilibrium model to analyze the impacts of climate change for Brazil distinguishing microregions and eight agricultural activities. Ferreira Filho and Moraes (2014) used a static interregional general equilibrium model, calibrated for the year 2005, to investigate the effects of detailed shocks by agricultural product (eight products) and by region (27 regions). The common element to these studies – besides the general equilibrium approach – is that they depart from the same estimates of suitable area losses made by the Brazilian Agricultural Research Corporation (Embrapa) and partners (Deconto , 2008) derived from the the 4th Assessment Report of IPCC (AR4) (IPCC, 2007) climate scenarios.

More recently, several studies have emerged for Brazil, with an agronomic focus or under a partial equilibrium economic approach, which attempted to estimate the direct impact that climate change projected for the rest of this century will have on the productivity of the main agricultural crops in the country (Féres et al., 2009; Santos et al., 2011; Marin et al., 2013; Araújo et al. 2014; Walter et al., 2014; Assunção and Chein, 2016; Pires et al., 2016; Cruz et al. al.; 2016; Verhage et al.; 2017; Cera et al.; 2017; Tavares et al., 2018). These studies have, in a very incipient way, enabled the first investigations of the impacts of climate change on Brazilian agriculture using a general equilibrium approach.

Along these lines, Nazareth, Cunha and Gurgel (2018) used agricultural productivity projections for different regions of Brazil – obtained from Assunção and Chein (2016) – and for other regions of the world to assess the economic impacts for the country and the rest of the world using a dynamic global CGE model for 5 regions of Brazil and 7 regions in the rest of the world. Tanure et al. (2020) also used the projections of agricultural productivity lossess for the period 2030 to 2049 generated by Assunção and Chein (2016) to analyze the economic impacts of climate change on the Legal Amazon region, using an interregional CGE model with recursive dynamics. It should be noted, however, that there is still a strong limitation for studies of this nature for Brazil, which is the lack of estimates of future agricultural productivity for different agricultural crops covering the entire national territory, as required by the interregional CGE models predominantly used in these types of studies for the country. The "suitable area" variations projections, on the other hand, are generally available by crop and region, for the entire national Brazilian territory, what makes this concept particularly well suited for the study.

Two attempts to overcome the aforementioned limitation, by generating estimates of the direct effects of climate change on agricultural productivity in Brazil for use in CGE models, can be found in Haddad et al. (2013) and Souza (2018). In Haddad et al. (2013) the authors analyzed the impact of climate anomalies observed in 2005 on agriculture and the Brazilian economy using a physical model integrated with an interregional CGE model. The physical model aimed to estimate the direct impact of anomalies on agricultural productivity, while the CGE model aimed to capture the systemic impacts on the rest of the economy. Along the same lines, Souza (2018) also combined a physical model with an interregional CGE model to analyze the direct and indirect impacts of climate change on agricultural productivity and the Brazilian economy as a whole at the end of this century. The physical model sought to estimate the direct impacts of climate change on the productivity of six important agricultural crops in the country (soybean, sugarcane, corn, beans, coffee and orange), taking into account climate change projections and scenarios of the 5th IPCC report. The CGE model used in the study tried to capture the indirect impacts of these productivity changes on agriculture – treated in the model as an aggregate sector, without disaggregation by products – and on the rest of the Brazilian economy.

3 Metodology

The empirical model used in this study is the dynamic TERM-BR, a detailed computable general equilibrium model for the Brazilian economy, interregional, bottom-up, with annual recursive dynamics. Its core theoretical framework comes from the TERM model (The Enormous Regional Model) - a static CGE model developed for the Australian economy (Horridge, Madden and Wittwer, 2005; Horridge, 2012) - and its dynamic extension (Wittwer and Verikios, 2012). A static version of the TERM-BR has been widely used in studies for Brazil (Santos and Ferreira Filho, 2007; Fachinello and Ferreira Filho, 2010; Pavão and Ferreira Filho, 2011; Ferreira Filho and Moraes, 2014; Diniz and Ferreira Filho, 2015; Santos and Ferreira Filho, 2017; Silva and Ferreira Filho, 2018). The dynamic version of the model for the Brazilian economy has also been used in several studies (Ferreira Filho and Horridge, 2014; Ferreira Filho, Ribera and Horridge, 2015; Silva, Ruviaro and Ferreira Filho, 2017).

The dynamic version of TERM-BR used in this study is composed of 136 sectors (industries), 136 commodities and 27 regions. These regions are represented by 27 interdependent models, one for each federation unit (26 states and the Federal District), linked through the goods markets by an interregional trade matrix tracking the regions of origin and destination of goods, and through the production factors market, with labor and capital being treated as mobile among activities and regions. The model is calibrated for the year 2010 – (Diniz, 2019) – using the Brazilian input-output matrix for that year and other official databases that allow a detailed characterization of the Brazilian economy, such as the National Household Sample Survey (PNAD), the Consumer Expenditure Survey (POF), the Municipal Agricultural Production (PAM), all from the Brazilian Institute of Geography and Statistics (IBGE), as well as numerous other sources. For the purpose of this study, the CGE model was aggregated at the level of 15 regions, 34 commodities and 34 sectors, with 12 of these commodities and sectors belonging to agriculture: 8 of them from agriculture itself (set of annual and permanent crops), 3 from livestock, and 1 from forestry and silviculture. The model also distinguishes 3 types of production factors (labour, capital and land), 10 types of occupations in each region (categorized by income classes), 10 types of occupations in each region and 2 types of margins (trade and transport). Annex 1 presents a map with the 15 regions (Figure 1A) and the 34 sectors of the aggregated model (Table 1B).

4 Simulation strategy and scenarios

The model is calibrated for 2010, requiring a historical simulation to update the database. This was done so as to reproduce the path of the Brazilian economy for the period 2011 to 2017.

The baseline simulation (business-as-usual) was built under a few macroecomic assumptions: real GDP (growth of 2.5% per year), demand for exports (3.0% per year), population and labor force (15-69 years) . Population and labor force received shocks at the regional level, as in the historical simulation. The growth of agriculture by region was projected based on the assumptions of agricultural land supply (deforestation) in Brazil in Ferreira Filho et al. (2018).

The policy shock simulation was based on the concept of loss of suitable area - or loss of low risk area - for agriculture. The concept is adapted from the Agricultural Climate Risk Zoning (ZARC) methodology, developed by Embrapa and applied in Brazil since for rural credit and insurance policies. A suitable or low-risk area combines minimal production conditions and a good chance of successful harvesting of the product under consideration (greater than or equal to 80%). If the chance of success is less than 80% the area is considered high risk and, therefore, not suitable for a particular crop.

The climate change projections we used take stock of estimates of suitable or low-risk area losses for eight agricultural crops for all municipalities in Brazil, for 2040, provided by Embrapa and built in accordance with ZARC criteria. These estimates were originally conceived as part of a broad study for the Brazilian economy called “Projeto Brasil 2040: cenários e alternativas de adaptação à mudança do clima” (Project Brazil 2040: scenarios and alternatives for adapting to climate change) (Brasil, 2015).

The low risk area loss estimates made by Embrapa involve several methodological steps, departing from the global climate scenarios. The global models used to generate those estimates were the Hadley Center Global Environmental Model version 2, from the UK, with the so-called Earth System components (HadGEM2-ES); and the Model for Interdisciplinary Research on Climate version 5 (MIROC5), from Japan. The results of the climate projections of these global modelswere refined for the different regions of Brazil by through a dynamic downscaling technique, using the regional climate model ETA, with a spatial resolution of 20 km x 20 km (Brasil, 2016) .[2] As the reference for climate projections, two of the four scenarios of the 5th Assessment Report (AR5) of the IPCC (IPCC, 2014) were used: the RCP4.5 (intermediate or less severe - with some stabilization of greenhouse gas emissions), and RCP8.5 (pessimistic or more severe - with very high emissions of greenhouse gases and no mitigation effort).

Through this procedure, and using the Agricultural Scenario Simulator (SCenAgri), Embrapa estimated, for 2040, the variations (losses or gains) of suitable – or low-risk – areas for eight of the main agricultural crops from Brazil (cotton, rice, sugar cane, beans, corn, soyben, sorghum and wheat), using the planted areas of 2012 as a reference. These eight crops together accounted for 83.41% of the entire area planted with annual and permanent crops in Brazil in 2012, and for 67.81% of the agricultural production value (IBGE, 2018c). Embrapa's projections were made for all Brazilian municipalities for each of the two global models, HadGEM2-ES and MIROC5, as well as for each of the RCP4.5 and RCP8.5 scenarios, thus generating four different projection scenarios, identified in this paper by HadGEM4.5, HadGEM8.5, MIROC.4.5 and MIROC8.5. The variations of suitable area at the municipal level provided by Embrapa were aggregated to 15[3].The eight crops shocks were also aggregated to six, to meet the model´s sectoral definition.

Both the Intermediate Scenario (RCP4.5) and the Pessimistic Scenario (RCP8.5) correspond to the arithmetic mean of the results of Embrapa's suitable area variations for 2040 for the HADGEMand MIROC respective scenarios. Figure 1~~Figure 1~~ summarizes the simulation strategy and the scenarios.

[2] The ETA regionalized climate model is operationalized at the Center for Weather Forecasting and Climate Studies of the National Institute for Space Research (CPTEC/INPE/MCTI) over all of South America in the form of numerical weather forecasting, and has been modified to perform climate simulations (Brasil, 2015).

[3] Annex 2 presents a graph (Figure 2A) with the regional share of each aggregated region of the model (the 15 regions) in the total Brazilian production of each of the eight crops mentioned above (cotton, rice, sugarcane, beans, corn, soybean, sorghum and wheat) in the year 2012. It allows one to have an idea of the relative importance of each region in the national production of each of these crops.

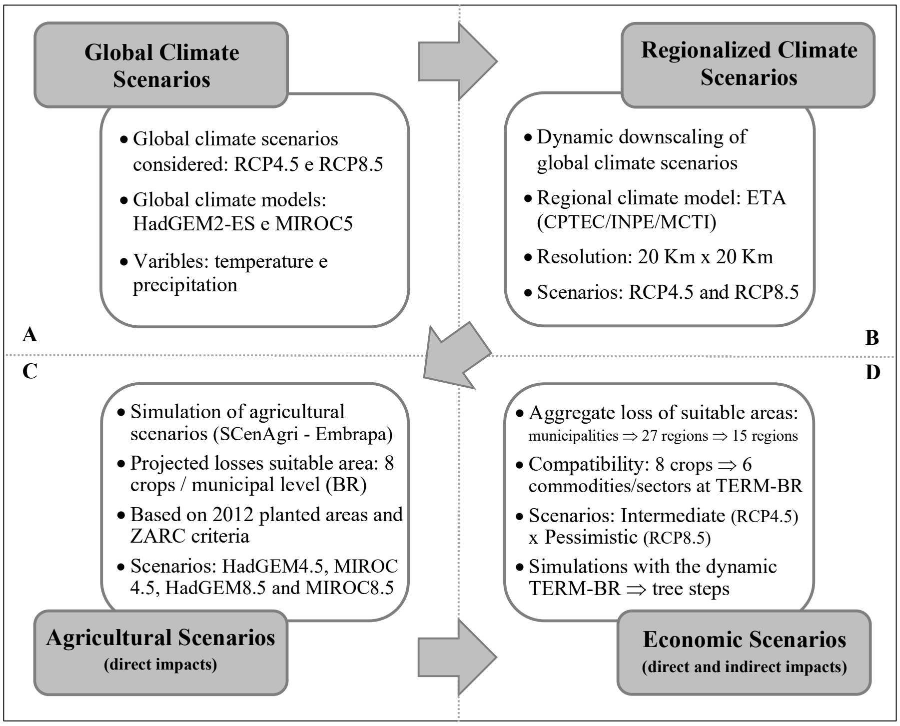

Figure 1. Synthetic schematic representation of the simulation strategy and scenarios.

Note: quadrants A, B and C synthesize the simulation strategies and scenarios from previous studies up to the generation of projections of loss of area suitable for the eight agricultural crops in 2040. Quadrant D properly synthesizes the simulation strategy and scenarios of the present study.

Source: prepared by the authors.

The final scenario results is presented in Table 1~~Table 1~~. The variations in the accumulated suitable areas projected for 2040 were transformed into average annual variations and distributed throughout the 2018-2040 period[4].In our simulation strategy we consider that the total area is the area planted with each crop in each year in the baseline is suitable for the crops, what turns the variations in suitable area in the shocks equivalent to the variations in planted area.

Thus, the causality of the effects of the policy simulation starts with the change in the suitable areas of the different crops, by region. This initial variation in areas leads to a process of competition for land (and substitution among the other primary factors) as determined by CES-type functions. The subsequent productive reallocation and the transmission of its effects in the different markets lead to the final effects upon the economy.

[4] It should be noted that, differently from previous studies, the most recent models adopted by the National Institute for Space Research (INPE) for regional downscaling results include now information on changes in rainfall, besides temperature. This inclusion generates markedly different results in comparison with other scenarios produced by Embrapa in the past.

Table 1. Shocks of variation (%) of suitable area by sector and region - Intermediate and Pessimistic Scenarios - (accumulated values for 2040)

Regions	Intermediate Scenario (RCP4.5)						Pessimistic Scenario (RCP8.5)					
	Sectors						Sectors					
	Rice and other cereals	Corn	Cotton	Sugar cane	Soybeans	Other annual corpos	Rice and other cereals	Corn	Cotton	Sugar cane	Soybeans	Other annual corpos
ParaRond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RestN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MaraToc	0.00	0.00	0.00	0.00	-0.24	0.00	-0.06	0.00	0.00	0.00	-3.88	0.00
Piaui	-19.89	+1.21	-6.20	-3.36	-23.09	-2.45	-44.02	+20.46	-19.55	-19.72	+25.62	-10.30
RestNE	-10.91	-0.69	+1.04	-0.46	-24.97	+0.47	-16.97	+2.74	+0.51	-0.34	+8.99	+3.95
PernAlag	-11.56	-2.77	-1.92	-0.86	0.00	+0.88	-1.00	+16.84	-2.53	-1.99	0.00	+7.81
Bahia	-33.50	-28.56	-25.18	-24.72	-17.71	-14.01	-11.83	+22.85	-19.97	-22.65	+148.66	+5.16
MinasG	-12.02	-15.16	-11.49	1.94	-28.77	-10.83	-9.53	-0.45	-17.35	-4.04	-26.32	-15.61
RestSE	-59.26	-41.36	0.00	-19.38	0.00	-13.95	-66.73	-0.05	0.00	-24.75	0.00	-16.66
SaoPaulo	-31.86	-17.35	-0.99	+1.08	-49.54	-5.09	-29.96	0.00	-0.55	+1.08	-39.97	-3.25
Parana	-19.00	-12.82	0.00	+82.94	-90.50	-6.28	-28.48	0.00	0.00	+82.94	-48.85	-6.97
RestS	0.00	0.00	0.00	+82.94	-64.59	0.00	0.00	0.01	0.00	+82.94	+232.52	0.00
MtGrSul	-26.71	-19.92	-0.01	0.00	-68.97	-5.92	-25.15	-0.01	0.00	0.00	-41.43	-2.83
MtGrosso	0.00	0.00	0.00	0.00	-1.45	0.00	0.00	0.00	0.00	0.00	-1.19	0.00
RestCO	0.00	0.00	0.00	0.00	-0.13	0.00	-0.05	0.00	0.00	0.00	-2.53	0.00

Source: Authors' own calculations.

Note: ParaRond = Pará and Rondônia states; RestN = Rest of North region (Acre, Amapá, Amazonas and Roraima states); MaraToc = Maranhão and Tocantins states; PI = Piauí state; RestNE = Rest of Northeast region (Ceará, Paraíba, Rio Grande do Norte and Sergipe states); PernAlag = Pernambuco and Alagoas states; Bahia = Bahia state; MinasG = Minas Gerais state; RestSE = Rest of Southeast region (Rio de Janeiro and Espírito Santo states); SaoPaulo = São Paulo state; Parana = Paraná state; RestS = Rest of South region (Santa Catarina and Rio Grande do Sul states); MtGrSul = Mato Grosso do Sul state; MtGrosso = Mato Grosso state; RestCO = Rest of Midwest region (Goiás state and Federal District).

Table 1~~Table 1~~ shows that the shocks applied are predominantly negative (indicating loss of suitable area) in both scenarios, but especially in the Intermediate (RCP4.5). In this scenario, the most severe negative shocks – in terms of absolute magnitudes – are for soybean, followed by rice and other cereals, and corn, in several regions. The most negative shocks occur in almost the entire Northeast region, in the entire Southeast region, in practically the entire South region, and in part of the Midwest region (particularly Mato Grossso do Sul) . Relevant positive shocks (gain of suitable area) appear only for sugar cane in the southern region of Brazil (Paraná and RestS).

In the Pessimistic Scenario (RCP8.5), although negative shocks also predominate, there is a higher frequency of positive shocks than in the Intermediate. In this scenario the most severe negative shocks are for rice and other cereals, and in some cases, for soybean. In regional terms, the most frequent and intense negative shocks appear in the Southeast region, part of the Northeast region (Piauí and Bahia), part of the South (Paraná) and part of the Midwest region (particularly Mato Grosso do Sul). For corn, positive shocks predominate (gain of suitable area); however, the most significant positive shocks occur for soybean in the Rest of the South, Bahia and Piauí. The shocks for sugarcane in Paraná and RestS are also positive in both scenarios, and this is mainly due to the good response of this crop to increases in temperature and CO_2 concentration during a certain period. In a longer time horizon – beyond 2040 – the crop would react poorly to the continued rise in temperature and CO_2 concentrations, which would exceed the optimal levels, implying a reduction in the suitable area.

It is important to stress that, in addition to the absolute magnitudes of these suitable area shocks, the structure of the sectoral composition of economic activities in each region plays a decisive role in the expected final impact of the shocks on different Brazilian regions. In particular, it is important to know in advance the shares of each agricultural activity in the production value of each regional economy in the base year (2010). Table 2~~Table 2~~ provides this information for the eight agricultural sectors in the regional production value in the base year (2010) for each of the 15 aggregated regions of the model.

Table 2. Share of the agricultural sectors in the value of regional production of all activities in the base year (2010).

Regions	Sectors								
	Rice and ohter cereals	Corn	Cotton	Sugar cane	Soybeans	Ohter annual crops	Coffee	Other Permanent crops	Agriculture*
ParaRond	0.0017	0.0027	0.0001	0.0005	0.0034	0.0155	0.0031	0.0091	0.0361
RestN	0.0008	0.0007	0.0003	0.0019	0.0015	0.0109	0.0005	0.0023	0.0189
MaraToc	0.0064	0.0037	0.0014	0.0060	0.0206	0.0111	0.0003	0.0016	0.0511
Piaui	0.0021	0.0048	0.0009	0.0011	0.0158	0.0068	0.0005	0.0016	0.0336
RestNE	0.0003	0.0015	0.0001	0.0040	0.0007	0.0081	0.0002	0.0056	0.0205
PernAlag	0.0001	0.0003	0.0001	0.0176	0.0005	0.0047	0.0002	0.0057	0.0292
Bahia	0.0001	0.0034	0.0056	0.0021	0.0082	0.0133	0.0031	0.0173	0.0531
MinasG	0.0002	0.0036	0.0002	0.0050	0.0032	0.0076	0.0145	0.0022	0.0365
RestSE	0.0000	0.0000	0.0000	0.0005	0.0001	0.0006	0.0019	0.0008	0.0039
SaoPaulo	0.0000	0.0005	0.0000	0.0074	0.0004	0.0010	0.0005	0.0028	0.0126
Parana	0.0037	0.0084	0.0000	0.0053	0.0208	0.0119	0.0017	0.0021	0.0539
RestS	0.0070	0.0038	0.0000	0.0003	0.0112	0.0125	0.0000	0.0033	0.0381
MtGrSul	0.0016	0.0132	0.0042	0.0293	0.0471	0.0046	0.0002	0.0003	0.1005
MtGrosso	0.0035	0.0144	0.0327	0.0086	0.1178	0.0107	0.0003	0.0020	0.1900
RestCO	0.0004	0.0035	0.0023	0.0051	0.0126	0.0063	0.0002	0.0008	0.0312

Source: Model database.
Note: (*) Annual crops + Permanent crops.

The importance of agriculture for the economies of Mato Grosso and Mato Grosso do Sul is noteworthy, with shares of 19% and 10% in the total of regional production value, respectively. These regional economies are, for this reason, heavily dependent on the performance of agricultural activities to regional GDP. It is also important to note the relevant role of soybean cultivation in these regions: the soybean sector alone accounts for 11.8% of Mato Grosso's and 4.7% of Mato Grosso do Sul's production value in the base year (2010) . Although these activities – soybean cultivation and agriculture as a whole – are also quite traditional in Paraná and the Rest of the South, these regions (especially the state of Paraná) have a more diversified economy and, therefore, are less dependent on these activities, compared to Mato Grosso and Mato Grosso do Sul.

Finally, it is important to note that in the policy simulations substitution among agricultural crops and among activities (sectors) using land, which involves 11 sectors of the model, are allowed. This means that even agricultural activities that were not subject to shock in the simulation (coffee and other permanent crops) and other land-using activities (livestock, milk productions and forestry) may vary - for more or for less - as a result of resource allocation process after the policy shock.

5 Results

The results presented throughout this section refer to deviations of policy shocks (climate change shocks) from the baseline, accumulated up to 2040.

Table 3 shows the changes in production, land use and exports , by agricultural activity, for each of the two climate change scenarios: Intermediate (RCP4.5) and Pessimistic (RCP8.5). Interestingly, the negative impacts are higher for the Intermediate Scenario than for the Pessimistic one, for all activities listed in the table. Changes in production are mainly due to regional variations in the suitable areas (losses or gains).

In the Intermediate Scenario, only two of the twelve agricultural activities would have their production negatively affected by climate change, soybean (-30.26%) and cotton (-1.47%). For other agricultural activities there would be an increase in production compared to the baseline scenario, with emphasis on rice and other cereals (6.77%). In the case of rice and other cereals, even having originally suffered loss of suitable area in the simulation implemented in the Intermediate Scenario, the combination of direct and indirect effects from the allocation of resources in response to climate change and the change in the relative prices of inputs and products would lead to a net expansion of production in Brazil, although in different regions[5]. In the case of sugarcane, the increase in production in Brazil is due to the improvement in the performance of the crop under conditions of increased temperature and CO_2 concentration in the timeframe of the study. Over a longer time horizon, with continuing increases in temperatures and CO_2 emissions, this trend of growth in production is expected to reverse. Table 3~~Table 3~~shows that in all cases land use and production variation moves in the same direction.

Table 3. Percentage change in production, land use and exports, by agricultural activities - Brazil - (accumulated in 2040)

Agricultural Activity	Intermediate Scenario (RCP4.5)			Pessimistic Scenario (RCP8.5)		
	Production	Land Use	Export	Production	Land Use	Export
Rice and other cereals	6.77	9.49	18.06	-10.48	-14.01	-19.52
Corn	2.28	2.65	9.39	-0.45	-0.65	-0.74
Cotton	-1.47	-2.65	-2.24	-3.05	-4.60	-6.97
Sugar cane	3.89	3.99	0.00	2.01	1.99	0.00
Soybeans	-30.26	-39.90	-51.19	0.24	-2.63	2.65
Other annual crops	2.29	4.88	9.37	-1.54	-2.98	-6.85
Coffee	2.42	2.96	4.20	0.83	0.98	1.40
Other permanent crops	1.02	2.10	8.87	-1.02	-1.73	-5.79
Livestock	2.14	3.09	2.78	-0.92	-1.44	-0.42
Milk production	1.95	3.85	0.00	-0.92	-1.80	0.00
Hogs and poultry	0.71	0.00	1.90	-0.33	0.00	0.07

[5] Maratoc, Parana and RestS are the relevant regions of productions for the Rice and other cereals aggregate. Parana´s share in total production is 18.4%. Although Parana gets a negative shock, RestS (60%) and Paratoc (6.5%) are not affected in this scenario.

Forestry	3.02	5.31	9.32	-0.93	-1.65	-2.36

Source: Model results.

The impacts of climate change on Brazilian agricultural exports in the Intermediate Scenario reveal that, in the case of soybean, there would be a 50% drop in the volume exported in 2040. There would also be a drop in cotton exports, but in a much lower magnitude (2.24%), following the behavior of production and land use. The other agricultural activities shown in Table 3 would register expansion in exports under the conditions simulated in the Intermediate Scenario.

An important aspect to highlight regarding these simulated results for agriculture in Brazil is that, in general, they do not seem to jeopardize Brazil's role in supply of food, fiber and energy for the domestic and the rest of the country markets, under the conditions simulated for the Intermediate Scenario, but soybeans is an exception. The reduction of Brazilian production in the magnitude projected for this scenario may is significant. The simulation indicates that the price of soybean in Brazil would increase by more than 20% (21.56%) in the accumulated for 2040 in the Intermediate Scenario.

In the Pessimistic Scenario, negative impacts of climate change on Brazilian agricultural production predominate, but it would be more accentuated only in the case of rice and other cereals, and cotton (the latter to a lesser extent). The exceptions would be sugarcane, coffee and soybean, which would register a small increase in production in relation to the baseline. The three variables – production, land use and exports – are also strongly associated in this scenario, with exports showing more intense declines than those projected for production, similarly to the Intermediate Scenario. Therefore, out of all the food crops analyzed, in the Pessimistic Scenario only the case of rice and other cereals would present a supply risk in the domestic market.

Table 4~~Table 4~~ complements the analysis at the national level. It shows changes in employment by activity for both scenarios. In general, the results are in line with the behavior of the production, land use and exports variables in Table 3~~Table 3~~. For the Intermediate Scenario, soybean loses more than 22% of jobs for Brazil as a whole, while rice and other cereals, and sugar cane are the ones employment grows. In the Pessimistic Scenario, the behavior changes substantially and soybean, as it adapts better to the climatic conditions of this scenario, would present a slight increase in employment, while rice and other cereals lost almost 9% of their occupations.

Table 4. Percentage change in employment, by agricultural activities - Brazil - (accumulated for 2040)

Agricultural Activity	Employ	
	Intermediate Scenario (RCP4.5)	Pessimistic Scenario (RCP8.5)
Rice and other cereals	5.41	-8.65
Corn	1.83	-0.37
Cotton	-0.60	-1.98
Sugar cane	3.58	1.97
Soybeans	-22.32	1.79
Other annual crops	0.68	-0.60
Coffee	2.05	0.73
Other permanent crops	0.19	-0.48
Livestock	1.26	-0.60

Milk production	0.50	-0.29
Hogs and poultry	0.60	-0.33
Forestry	1.46	-0.47

Source: Model results.

Table 5~~Table 5~~ and Table 6~~Table 6~~ show the regional variations in the production of agricultural activities for the 15 Brazilian regions specified in the aggregation adopted in the TERM-BR model.

In the Intermediate Scenario, as shown in Table 5~~Table 5~~, soybean would present a reduction in production in all 15 regions, with great variability in these results (between -0.27% in the Rest of the North to -59.73% in Paraná). Besides Paraná, a sharp drop in soybean production would also be seen in Mato Grosso do Sul, RestS, São Paulo, as well as Rest of Northeast, Minas Gerais, RestSE, Bahia, Mato Grosso, Piauí and RestCO. Paraná and RestS would be the only regions that would show growth in the production of all analyzed agricultural activities, except for soybean, with sugarcane production expanding the most (52% in Paraná and almost 20% in RestS).

Table 5. Production variation, by agricultural activities – Brazil and 15 Brazilian regions – Intermediate Scenario (RCP4.5) – (Percentage change, accumulated for 2040)

Region	Agricultural Activity											
	Rice and Others	Corn	Cotton	Sugar cane	Soybeans	Other A. Crops	Coffee	Other P. Crops	Livestock	Milk production	Hogs and Poultry	Forestry
ParaRond	1.24	0.36	0.50	-0.27	-2.39	-0.15	1.05	0.00	0.08	-0.86	0.06	-0.16
RestN	1.67	0.50	0.17	-0.27	-0.27	-0.37	0.95	-0.05	0.04	-0.78	0.24	-0.27
MaraToc	1.90	0.42	0.57	0.20	-2.50	-0.04	0.85	-0.12	0.01	-0.78	-0.05	-0.10
Piaui	-3.08	0.91	0.11	-0.15	-6.71	0.28	0.97	0.17	0.92	-0.16	0.21	0.82
RestNE	-2.85	0.18	1.43	-0.20	-12.06	0.27	0.39	0.18	-0.04	-0.59	0.22	0.59
PernAlag	-3.20	-0.46	0.43	-0.14	-0.97	0.17	0.47	0.15	0.02	-0.51	0.20	0.39
Bahia	-9.29	-10.21	-8.40	-10.58	-8.35	1.00	2.34	0.97	1.27	0.26	0.05	1.02
MinasG	0.29	-3.17	-2.98	1.69	-11.88	0.33	2.22	0.32	0.40	-0.03	0.05	0.38
RestSE	-23.66	-16.06	0.69	-6.84	-8.62	0.34	1.92	0.24	0.25	-0.10	0.21	0.28
SaoPaulo	-8.31	-5.09	0.46	1.96	-28.90	0.10	2.24	0.12	1.08	0.11	0.34	0.40
Parana	10.26	11.45	15.51	52.78	-59.73	9.16	9.59	9.53	15.76	11.07	1.83	14.07
RestS	8.26	8.11	5.64	19.77	-35.62	3.62	6.55	3.70	6.48	4.62	1.89	4.92
MtGrSul	-5.88	-4.63	3.31	5.13	-43.92	1.76	3.76	2.21	3.55	1.49	0.36	1.17
MtGrosso	3.62	1.20	0.92	1.76	-7.80	0.29	2.60	0.95	1.26	0.38	0.78	0.06
RestCO	3.42	1.18	0.43	0.69	-6.08	0.02	2.04	0.73	0.49	-0.29	0.54	-0.09
Brazil	6.77	2.28	-1.47	3.89	-30.26	2.29	2.42	1.02	2.14	1.95	0.71	3.02

Source: Model results.

In the Pessimistic Scenario(Table 6~~Table 6~~), the simulation points to a drop in the production of rice and other cereals for all 15 Brazilian regions. The highest fall would be registered for the RestSE (-34.26%), Piauí (-14.22%), São Paulo (-13.81%) and RestS (-13.07%). In this scenario, the projected expansion of soybean production in three regions also stands out: Bahia (42.79%), RestS (38.08%) and Piauí (5.18%). In contrast, there would be a sharp drop in other regions, such as Mato Grosso do Sul (-21.29%), São Paulo (-18.69%) and

Paraná (-18.20%). At the national level, as already mentioned, soybean production would change little in this scenario as a result of climate change (increase of 0.24%), contrasting with the performance projected for the Intermediate Scenario. In general, RestS, Paraná and Bahia would be the regions with the greatest variability in production for the set of agricultural activities analysed in this study.

Table 6. Production variation, by agricultural activities – Brazil and 15 Brazilian regions – Intermediate Scenario (RCP8.5) – (Percentage change, accumulated for 2040)

Region	Agricultural Activity											
	Rice and Others	Corn	Cotton	Sugar cane	Soybeans	Other A. Crops	Coffee	Other P. Crops	Livestock	Milk production	Hogs and Poultry	Forestry
ParaRond	-0.76	0.15	0.22	-0.20	-0.14	0.17	0.38	0.07	-0.12	0.51	0.03	0.00
RestN	-1.58	0.20	-0.14	-0.09	-0.12	0.30	0.36	0.16	-0.18	0.52	-0.15	0.00
MaraToc	-2.46	0.22	0.25	0.00	-1.41	0.19	0.46	0.24	0.01	0.60	0.11	0.01
Piaui	-14.22	2.14	-4.56	-6.57	5.18	0.00	0.33	-0.02	-0.79	0.18	0.01	-0.48
RestNE	-7.92	0.96	0.87	-0.51	4.71	-0.08	0.52	-0.01	-0.05	0.30	-0.08	-0.35
PernAlag	-2.43	5.60	-0.46	-1.61	1.33	-0.01	0.39	-0.13	-0.12	0.19	-0.08	-0.32
Bahia	-7.93	4.69	-10.67	-14.45	42.79	-1.73	-2.70	-2.29	-3.22	-1.94	-0.12	-2.21
MinasG	-6.81	0.36	-5.98	-1.30	-8.85	0.54	0.91	0.40	0.48	0.51	0.00	0.44
RestSE	-34.26	0.72	-0.07	-9.19	-2.05	0.81	0.96	0.44	0.57	0.68	-0.12	0.52
SaoPaulo	-13.81	0.69	-0.47	1.09	-18.69	0.79	0.85	0.39	0.37	0.84	-0.07	0.46
Parana	-8.81	5.57	5.30	37.43	-18.20	4.41	4.08	4.39	5.08	4.65	0.20	5.28
RestS	-13.07	-12.00	-10.83	7.01	38.08	-7.94	-10.03	-8.19	-10.54	-8.49	-1.85	-9.38
MtGrSul	-11.03	1.94	0.96	2.29	-21.29	1.50	1.63	1.34	1.57	1.37	0.19	0.78
MtGrosso	-2.06	0.40	-0.36	0.32	-1.50	0.45	0.72	0.43	0.13	0.76	0.06	0.14
RestCO	-2.61	0.34	-0.41	0.12	-2.04	0.40	0.48	0.35	0.24	0.56	0.04	0.11
Brazil	-10.48	-0.45	-3.05	2.01	0.24	-1.54	0.83	-1.02	-0.92	-0.92	-0.33	-0.93

Source: Model results.

Other selected macroeconomic results are shown in Table 7. Real GDP for Brazil would contract in both scenarios, and the same would happen in most Brazilian regions. Interestingly enough, the reduction in real GDP for Brazil as a whole would be greater in the Intermediate Scenario than in the Pessimist, and the same happens for most regions. This result is basically linked to the behavior of the soybean, which presented a large drop in production in the Intermediate Scenario (-30.30%), compared to a slight production gain (0.24%) in the pessimistic scenario, affecting relatively more important soybean-producing states, such as Mato Grosso and Mato Grosso do Sul in the Intermediate Scenario. These results shed light on the role of precipitation in predicting climate change for agriculture. Previous results with scenarios from the 4th IPCC Report - AR4 (Ferreira Filho and Moraes, 2014) found a greater drop in GDP for both Brazil and soybean-producing regions. Those scenarios, however, did not take into account precipitation, only temperature changes. The inclusion of AR5 precipitation information in the crop models is crucial to the soybean response, which is actually better in the Pessimistic Scenario than in the Intermediate one.

The main agricultural producing regions in Brazil show the biggest drops in real GDP in both scenarios, an expected result due to the nature of the shocks. In some cases, these results on GDP differ significantly from results found in other studies for Brazil, but direct comparisons among different studies require caution, as the set of criteria used in the simulations (scenarios, closures, databases, model, time horizons, etc.) are usually quite different from each other. For example, Domingues et al. (2010), when analyzing the impacts of climate change on the Brazilian economy for the year 2050, estimated losses of around 0.5% in real GDP in one of the scenarios (scenario A2, from the 4th Assessment Report of the IPCC) and 2.3% in another scenario (B2). Ferreira Filho and Moraes (2014), on the other hand, found real GDP reductions for Brazil of 0.28% in one of the simulated scenarios (A2) for the year 2020, and a drop of 1.12% in another less severe scenario (B2) for 2070. In this study, however, the authors additionally imposed a reduction in the total agricultural area in each region equivalent to the total loss of suitable (or low-risk) area of the region with the crops, under the hypothesis that those areas would not be occupied by another crop. This may have, to some extent, overestimated the negative impacts on the agricultural sector and on GDP. In contrast, in the simulations implemented in this study, the possibility of replacing one crop by another was allowed, and this replacement was treated endogenously. In particular, livestock and forestry play a prominent role in this process in the Intermediate Scenario, occupying a significant part of the areas lost by agriculture. In the Pessimistic Scenario, the areas lost by some crops are completely replaced by other agricultural crops.

The results shown in Table 7 reveal large differences in the behavior of real GDP among Brazilian regions as a consequence of projected climate change for 2040. They suggest that in the Intermediate Scenario (RCP4.5) there will be a decline in real GDP for 13 of the 15 regions specified, and that the states of Mato Grosso do Sul, Paraná, Mato Grosso and Bahia will be the regions that would bear the worse effects. It is noteworthy that these four states, in addition to having agriculture as a very important part of their economies - especially Mato Grosso and Mato Grosso do Sul - are also important producers of soybean, and which also stands out in the form of bran, oil and as raw material for the chicken meat exported by the country. Therefore, the intersector resource allocation process driven by climate change in the Intermediate Scenario would not be enough to offset the GDP losses resulting from the retraction in the area suitable for soybean cultivation in these four regions. In all of them, real GDP should decline more than at the national level.

For regions where soybean cultivation is non-existent or not relevant in the overall regional agricultural production, or where it is relevant but the process of allocating resources to other activities almost compensates for the losses arising from the retraction of the area with soybean, the impacts on regional GDP are smaller.

Table 7 – Results of climate change shocks on the main macroeconomic variables – Brazil and 15 Brazilian regions – Intermediate and Pessimist Scenarios (% change accumulated in 2040)

Region	Scenario	Macroeconomic Variables							
		Real GDP	Real household consumption	Real investment	Exports (vol.)	Imports (vol.)	Employment	Real wage	Capital stock
Brazil	RCP4.5	-0.15	-0.12	-0.18	-0.42	-0.30	0.00	-0.05	-0.08
	RCP8.5	-0.04	-0.07	-0.10	0.15	0.10	0.00	-0.09	-0.03
ParaRond	RCP4.5	-0.01	-0.04	-0.01	0.82	-0.12	0.01	0.02	-0.02
	RCP8.5	0.02	0.05	0.04	0.13	0.04	0.01	0.02	0.01
RestN	RCP4.5	0.00	-0.04	0.02	0.68	-0.14	0.00	0.02	0.01
	RCP8.5	0.01	0.03	0.04	0.03	0.00	0.00	0.00	0.01

MaraToc	RCP4.5	-0.03	-0.15	-0.05	0.56	-0.23	0.00	-0.08	-0.06
	RCP8.5	-0.02	0.02	-0.02	0.06	0.00	0.00	-0.01	-0.02
Piaui	RCP4.5	-0.11	-0.23	0.07	0.35	-0.38	-0.01	-0.15	-0.08
	RCP8.5	0.02	0.02	-0.09	0.68	0.21	0.00	-0.01	-0.03
RestNE	RCP4.5	-0.04	-0.09	-0.11	0.36	-0.22	0.00	-0.02	-0.07
	RCP8.5	-0.01	-0.04	-0.03	0.43	0.13	0.00	-0.07	-0.01
PernAlag	RCP4.5	-0.02	-0.07	-0.04	1.11	-0.21	0.00	-0.01	-0.04
	RCP8.5	-0.07	-0.09	-0.12	0.50	0.05	0.00	-0.12	-0.06
Bahia	RCP4.5	-0.20	-0.33	-0.38	0.56	-0.36	-0.01	-0.25	-0.21
	RCP8.5	0.03	0.04	0.17	1.85	0.27	0.00	0.01	0.13
MinasG	RCP4.5	-0.03	-0.10	-0.06	-0.62	-0.17	0.00	-0.03	-0.05
	RCP8.5	-0.04	-0.09	-0.09	-0.96	0.04	0.00	-0.12	-0.04
RestSE	RCP4.5	-0.09	-0.13	-0.19	0.18	-0.45	0.00	-0.06	-0.10
	RCP8.5	-0.06	-0.11	-0.17	0.06	-0.11	0.00	-0.13	-0.08
SaoPaulo	RCP4.5	-0.04	-0.10	-0.15	-0.94	-0.31	0.00	-0.04	-0.07
	RCP8.5	-0.01	-0.04	-0.05	-0.39	0.12	0.00	-0.07	-0.02
Parana	RCP4.5	-1.24	-0.16	-0.68	-0.57	0.27	0.03	-0.12	-0.09
	RCP8.5	0.07	0.48	0.38	-0.51	0.12	0.05	0.40	0.19
RestS	RCP4.5	-0.09	0.07	0.03	-0.78	-0.41	0.01	0.12	0.02
	RCP8.5	-0.23	-0.44	-0.58	1.21	0.58	-0.03	-0.43	-0.14
MtGrSul	RCP4.5	-1.98	-1.24	-1.89	-2.65	-1.31	-0.06	-1.12	-0.81
	RCP8.5	-0.83	-0.53	-0.89	-1.77	-0.46	-0.02	-0.53	-0.41
MtGrosso	RCP4.5	-0.37	-1.11	-1.03	3.08	-1.35	-0.07	-0.98	-0.93
	RCP8.5	-0.09	-0.15	-0.28	0.51	-0.21	-0.01	-0.18	-0.20
RestCO	RCP4.5	0.00	-0.03	-0.07	1.66	-0.28	0.01	0.02	-0.09
	RCP8.5	-0.01	-0.01	-0.04	0.33	0.04	0.00	-0.04	-0.02

Source: Model results.

In the Intermediate Scenario (RCP4.5), for Brazil as a whole, all GDP components show a decline, including net exports. In terms of trade flows, the impacts of climate change in the Intermediate Scenario were more heterogeneous across the six regions. For exports, Mato Grosso do Sul (-2.65%), São Paulo (-0.94%), RestS (-0.78%) would present the worse results. The drop of more than 2.65% in exports from Mato Grosso do Sul is the largest percentage change among all the values shown in Table 7. Some regions, such as Mato Grosso, RestCO, Pernambuco/Alagoas, Pará/Rondônia, RestN, Maranhão/Tocantins, show a notable increase in exports. For Brazil as a whole, climate change would cause a drop of 0.42% in aggregated exports in the Intermediate Scenario, as a consequence of the high share of agricultural products. In the case of imports, results point to a drop both for Brazil as a whole and for all regions represented in Table 7, generally following the behavior of the real GDP.

The national employment was kept fixed at baseline levels throughout the simulations. However, regional and sectoral employment vary endogenously. In the Intermediate Scenario, employment would change little in relation to the baseline for the different regions of Brazil.[6] However, real wages would show a modest decline for Brazil as a whole, especially in Mato Grosso do Sul, Mato Grosso, and Bahia. The impacts on GDP would be smaller for the Pessimistic Scenario (RCP8.5), as shown in Table 7. GDP falls are more accentuated in Mato Grosso do Sul, RestS and Mato Grosso, contrasting with increases in Paraná, both for consumption and for the real investment. It is worth mentioning the increases in exports by Bahia, RestSRestS and Piauí, and the falls in Mato Grosso do Sul and RestS. Real wage would

[6] Small variations for this variable were also found in Silva, Ruviaro and Ferreira Filho (2017). The authors present the results obtained for employment in six Brazilian regions. All values found in that study were between -0.03% and +0.18% in the accumulated in 2035 (final year of analysis of that study).

also show a greater downward trend, especially in regions with a higher volume of agricultural production.

A sensitivity analysis was carried out with the values of a central parameter in this study, the elasticity of substitution among primary production factors for agricultural activities. The analysis was carried out for the Intermediate Scenario, varying by 10% more or less the value of that elasticity. As can be seen from Table 8, regional GDP results are stable for most regions. The exception is the state of Mato Grosso, which has a greater variation between these simulations. Again, this result is associated with the importance of soybean in the region. Although the magnitude of variation is different, however, its direction is the same in all three cases.[7]

Table 8 – Sensitivity analysis for regional real GDP for the Intermediate Scenario – Percentage change - (accumulated in 2040)

Region	Real GDP (Intermediate Scenario - RCP4.5)		
	Using Elasticity Substitution 10% lower	Using Original Elasticity Substitution	Using Elasticity Substitution 10% higher
ParaRond	-0.01	-0.01	-0.01
RestN	0.01	0.00	0.00
MaraToc	-0.01	-0.03	-0.04
Piaui	-0.10	-0.11	-0.11
RestNE	-0.04	-0.04	-0.04
PernAlag	-0.02	-0.02	-0.02
Bahia	-0.21	-0.20	-0.19
MinasG	-0.03	-0.03	-0.03
RestSE	-0.09	-0.09	-0.09
SaoPaulo	-0.04	-0.04	-0.04
Parana	-1.26	-1.24	-1.22
RestS	-0.08	-0.09	-0.10
MtGrSul	-2.00	-1.98	-1.95
MtGrosso	-0.17	-0.37	-0.47
RestCO	0.01	0.00	-0.01

Source: Model results.

Table 9 shows the results of the same sensitivity analysis as before, but now for production of each of the 12 agricultural activities in the model, at the national level, for the Intermediate Scenario. As in the previous case, the results varied little for most activities, and the direction of variations is the same in all three situations.

Table 9 – Sensitivity analysis of variation in agricultural production by activity for the Intermediate Scenario – Percentage change - (accumulated to 2040)

	Production Variation

[7] The national GDP, however, practically does not vary in the sensitivity analysis. Variations are -0.150 for the original analysis, -0.146 when the elasticity of substitution is 10% lower, and -0.150 when that parameter has a value 10% higher.

Agricultural Activity	(Intermediate Scenario - RCP4.5) Using Elasticity Substitution 10% lower	Using Original Elasticity Substitution	Using Elasticity Substitution 10% higher
Rice and other cereals	7.09	6.77	6.47
Corn	2.32	2.28	2.24
Cotton	-1.52	-1.47	-1.28
Sugar cane	4.09	3.89	3.70
Soybeans	-30.87	-30.26	-29.64
Other annual crops	2.48	2.29	2.11
Coffee	2.47	2.42	2.37
Other permanent crops	1.11	1.02	0.94
Livestock	2.21	2.14	1.97
Milk production	2.08	1.95	1.84
Hogs and poultry	0.72	0.71	0.70
Forestry	3.10	3.02	2.97

Source: Model results.

In what follows we present some welfare effects. Table 10 shows, overall, a reduction in real household consumption in the Intermediate Scenario (RCP4.5) for all income categories in all regions of Brazil, with the exception of the RestS. The decline would be more intense in Mato Grosso do Sul and Mato Grosso, for all income classes (POF1 to POF10)[8], and lower in Bahia, Piauí and Maranhão/Tocantins. All these regions, in addition to having a large share of agriculture in their economies, are also important soybean producers (especially Mato Grosso and Mato Grosso do Sul). The reduction in household consumption then strongly influenced by the contracton in the suitable area of soybeans, followed by a drop in production and exports of oilseeds, with a consequent drop in real wages and real GDP. Additionally, simulation results for Brazil as a whole – not shown in the tables – suggest that the decline in real household consumption in this Intermediate Scenario is likely to occur slightly more intensely for lower-income groups.

Table 10 – Variation (%) in real household consumption by region and by income categories (accumulated values for 2040) - Intermediate Scenario (RCP4.5)

Region	POF1 (poorest)	POF2	POF3	POF4	POF5	POF6	POF7	POF8	POF9	POF10 (richest)
ParaRond	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.04	-0.04
RestN	-0.05	-0.04	-0.04	-0.05	-0.04	-0.05	-0.04	-0.06	-0.04	-0.04
MaraToc	-0.17	-0.17	-0.16	-0.15	-0.16	-0.16	-0.14	-0.15	-0.15	-0.13
Piaui	-0.22	-0.23	-0.23	-0.23	-0.23	-0.22	-0.24	-0.23	-0.23	-0.22
RestNE	-0.08	-0.08	-0.08	-0.08	-0.09	-0.09	-0.10	-0.09	-0.09	-0.09
PernAlag	-0.05	-0.06	-0.07	-0.06	-0.07	-0.08	-0.07	-0.08	-0.08	-0.08
Bahia	-0.33	-0.33	-0.34	-0.32	-0.32	-0.33	-0.32	-0.32	-0.32	-0.32
MinasG	-0.12	-0.09	-0.10	-0.10	-0.06	-0.11	-0.10	-0.10	-0.10	-0.09

[8] POF1, ranges from 0 to 2 minimum wages; POF2, more than 2 to 3; POF3, more than 3 to 5; POF4, from more than 5 to 6; POF5, more than 6 to 8; POF6, from more than 8 to 10; POF7, from more than 10 to 15; POF8, from more than 15 to 20; POF9, from more than 20 to 30; and POF10, above 30 minimum wages. The minimum wage in Brazil in 2010 was R$ 510.00 per month (approximately US$ 290.00 dollars, considering the average rate of the American currency in 2010, US$ 1.00 = R$ 1.76).

RestSE	-0.13	-0.12	-0.12	-0.12	-0.12	-0.13	-0.12	-0.11	-0.13	-0.13
SaoPaulo	-0.10	-0.09	-0.08	-0.06	-0.11	-0.11	-0.11	-0.10	-0.11	-0.10
Parana	0.12	-0.18	-0.14	-0.14	-0.22	-0.18	-0.22	-0.26	-0.13	-0.14
RestS	0.10	0.09	0.09	0.07	0.07	0.06	0.10	0.10	0.04	0.07
MtGrSul	-1.29	-1.32	-1.28	-1.27	-1.31	-1.25	-1.30	-1.14	-1.25	-1.20
MtGrosso	-1.12	-1.11	-1.11	-1.11	-1.10	-1.11	-1.15	-1.14	-1.15	-1.09
RestCO	-0.01	-0.01	-0.02	-0.03	-0.04	-0.03	-0.02	-0.04	-0.03	-0.04

Source: Model results.

Table 11 shows the variation in real household consumption in 2040 in the Pessimistic Scenario (RCP8.5). Household consumption drops in this scenario for most income classes and in almost all regions of Brazil, with the exception of Pará/Rondônia, RestN, Maranhão/Tocantins, Piauí, Bahia and Paraná. In these regions, increases in real household consumption for the different income categories prevail, compared to the baseline scenario. For the regions that registered a decrease, real households consumption decline more for the lower-income classes, compromising more the welfare of these groups of poorer households. In cases where there is an increase in real household consumption, climate change causes greater welfare gains for the higher-income classes than for the lower-income classes, with the exception of Paraná. In other words, in the Pessimistic Scenario (RCP8.5) climate change, in general, worsens the welfare of lower-income groups more than those of higher-income groups.

Table 11 – Variation (%) in real household consumption by region and by income categories (accumulated values for 2040) - Pessimistic Scenario (RCP8.5)

Region	POF1	POF2	POF3	POF4	POF5	POF6	POF7	POF8	POF9	POF10
ParaRond	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.07
RestN	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04
MaraToc	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03
Piaui	0.00	0.01	0.01	0.02	0.01	0.02	0.01	0.03	0.02	0.04
RestNE	-0.05	-0.05	-0.05	-0.04	-0.04	-0.03	-0.03	-0.03	-0.03	-0.02
PernAlag	-0.12	-0.11	-0.10	-0.10	-0.09	-0.09	-0.09	-0.07	-0.09	-0.08
Bahia	-0.01	0.00	0.03	0.02	0.03	0.05	0.05	0.06	0.06	0.08
MinasG	-0.12	-0.11	-0.11	-0.10	-0.09	-0.10	-0.09	-0.09	-0.09	-0.07
RestSE	-0.12	-0.14	-0.14	-0.12	-0.12	-0.12	-0.11	-0.11	-0.10	-0.09
SaoPaulo	-0.06	-0.07	-0.06	-0.07	-0.06	-0.05	-0.04	-0.04	-0.03	-0.02
Parana	0.60	0.47	0.49	0.49	0.46	0.47	0.47	0.46	0.49	0.49
RestS	-0.60	-0.49	-0.49	-0.49	-0.48	-0.43	-0.47	-0.49	-0.39	-0.40
MtGrSul	-0.60	-0.57	-0.56	-0.56	-0.57	-0.54	-0.56	-0.50	-0.52	-0.50
MtGrosso	-0.16	-0.16	-0.15	-0.16	-0.15	-0.15	-0.16	-0.15	-0.16	-0.14
RestCO	-0.02	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	0.00	0.00	0.00

Source: Model results.

6 Final remarks

In this paper we analyze the potential socioeconomic impacts that climate change may have on Brazilian agriculture - in particular on agricultural supply - and the economy as a whole, and on its different regions. The main conclusion is that climate change – by leading to a loss of suitable area for several important agricultural crops in Brazil – should lead to a reduction in production and exports for most of the agricultural activities analyzed, especially in the case of soybean in the Intermediate Scenario. Although for most agricultural activities this should not significantly affect supply, in the case of soybean there may be risks for the commodity markets, due to Brazil's relevance in the global supply.

As a consequence of the impacts on agriculture, a retraction in the Brazilian real GDP is expected, in both scenarios, but the negative effect is bigger in the Intermediate (RCP4.5), which involves a larger loss of agricultural suitable area , as calculated by the climate models used in this study. In other words, in the absence of adaptation or mitigation measures for the potential losses of suitable (low-risk) area in Brazil caused by climate change, there is a tendency for a contraction – albeit moderate – in the level of economic activity in the country.

The results at regional level suggest that the losses will be greater for those regions whose economies are more dependent on agriculture, especially in those more dependent on soybeans. This confirms the existing view in the literature about the importance of regionally disaggregated analyses when addressing the impacts of climate change, especially in the case of countries with a large territorial extension such as Brazil. They show that the impacts of climate change on agriculture, in addition to being unevenly distributed around the world, also tend to be unevenly distributed even among different regions of the same country. Therefore, besides the continued need for new country-specific studies on this important topic, especially for developing economies, it is also highly recommended to pay greater attention to regional differences within the national economies in future research efforts.

Results also lead to the conclusion that the negative impacts of climate change will be more intense on poorer workers and households, especially in the Midwest (RestCO) regions and part of the Northeast Brazil (in the part where soybean cultivation is more representative), which should have their consumption and welfare more intensely affected than workers and households in other regions of Brazil. These have been dynamic regions in terms of the recent development of Brazilian agriculture, but the results presented here suggest that this dynamic may change under climate change scenarios, bringing to the debate new considerations about the need for regional development policies.

This study point to the importance of maintaining and strengthening the institutional apparatus for dealing with the problem of climate change in Brazil, aiming to minimize its negative impacts in the coming decades, including the impact on the production and supply of soybean and its consequences. It stresses, for example, the importance of initiatives such as the ABC Plan (Low Carbon Agriculture) led by the Brazilian federal government, aimed at reducing greenhouse gas emissions (GHG). In the field of adaptation, the importance of continuing and strengthening support for agricultural research in Brazil through the National Agricultural Research System (SNPA) is an important strategy for adapting to the effects of climate change, with a view on the development of agricultural varieties that are more resistant and more adapted to the new climatic conditions projected for each region of Brazil in the coming decades.

Finally, it´s important to stress the high level of uncertainty involved in this kind of study, introduced in the analysis by the the climate change impacts upon agriculture suitable areas. As mentioned before, previous studies with the AR4 projections reported much higher negative results than we found here. The inclusion of precipitation in the crop models probably increased their forecasting capability, but this is still a contentious issue. This is an important research line to keep in the agenda.

References

Ahmed, S. A., Diffenbaugh, N. S., Hertel, T. W., Lobell, D. B., Ramankutty, N., Rios, A. R., & Rowhani, P. (2011). Climate volatility and poverty vulnerability in Tanzania. *Global environmental change*, *21*(1), 46-55.

Araújo, P. H. C., Silva, F. F, Gomes, M. F. M., Féres, J. G., & Braga, M. J. (2014). Uma análise do impacto das mudanças climáticas na produtividade agrícola da região nordeste do Brasil. *Revista Econômica do Nordeste*, *45*(3), 46-57.

Formatado: Português (Brasil)

Assunção, J., & Chein, F. (2016). Climate change and agricultural productivity in Brazil: future perspectives. *Environment and Development Economics*, *21*(5), 581-602.

Brasil. Ministério da Ciência, Tecnologia e Inovação – MCTI. Secretaria de Políticas e Programas de Pesquisa e Desenvolvimento. Coordenação-Geral de Mudanças Globais de Clima (2016). *Modelagem climática e vulnerabilidades setoriais*: a mudança do clima no Brasil. Brasília: MCTI.

Formatado: Português (Brasil)

Brasil. Presidência da República. Secretaria de Assuntos Estratégicos – SAE. (2015). *Brasil 2040, Resumo Executivo.* Brasília. Retrieved in 2018, December 5, from http://www.mma.gov.br/images/arquivo/ 80182/BRASIL-2040-Resumo-Executivo.pdf

Centro de Estudos Avançados em Economia Aplicada – CEPEA. (2019). Boletim Cepea do mercado de trabalho. Piracicaba, v. 1, n. 4. Retrieved in 2021, May 12, from https://www.cepea.esalq.usp.br/upload/kceditor/files/2018_Relatorio%20MERCADODETRABALHO_CEPEA(2).pdf

Cera, J. C., Streck, N. A., Fensterseifer, C. A. J., Ferraz, S. E. T., Bexaira, K. P., Silveira, W. B., & Cardoso, A. P. (2017). Soybean yield in future climate scenarios for the state of Rio Grande do Sul, Brazil. *Pesquisa Agropecuária Brasileira*, *52*(6), 380-392.

Chalise, S., Naranpanawa, A., Bandara, J. S., & Sarker, T. (2017). A general equilibrium assessment of climate change–induced loss of agricultural productivity in Nepal. *Economic Modelling*, *62*, 43-50.

Chalise, S., & Naranpanawa, A. (2016). Climate change adaptation in agriculture: A computable general equilibrium analysis of land-use change in Nepal. *Land use policy*, *59*, 241-250.

Cline, W. R. (2007). *Global warming and agriculture*: *impact estimates by country.* Washington, DC: Center for Global Development/Peterson Institute for International Economics.

Cruz, J. L., Alves, A. A. C;, LeCain, D. R., Ellis, D. D., & Morgan, J. A. (2016). Elevated CO2 concentrations alleviate the inhibitory effect of drought on physiology and growth of cassava plants. *Scientia Horticulturae*, *210*, 122-129.

Darwin, R., Tsigas, M., Lewandrowski, J., & Raneses, A. (1995). World agriculture and climate change: economic adaptations. *Agriculture Economic Report*, (AER-703), USDA, Washington, DC.

Deconto, J. G. (Coord.) (2008). *Aquecimento global ea nova geografia da produção agrícola no Brasil.* Campinas: Embrapa/Unicamp.

Diniz, T. B. (2019). *Impactos econômicos e regionais dos investimentos em geração de energia elétrica no Brasil* (Tese de doutorado). Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba.

Diniz, T., & Ferreira Filho, J. B. S. (2015). Impactos Econômicos do Código Florestal Brasileiro: uma discussão à luz de um modelo computável de equilíbrio geral. *Revista de Economia e Sociologia Rural*, *53*(2), 229-250.

Domingues, E. P., Haddad, E. A., Perobelli, F. S., Azzoni, C. R., Guilhoto, J. J. M., Kankzuc, F., & Almeida, E. S. (2010). Impactos econômicos das mudanças climáticas no Brasil. In *Anais do XXXVIII Encontro Nacional de Economia*, Salvador: ANPEC.

Domingues, E. P., Magalhães, A. S., & Ruiz, R. M. (2008). *Cenários de mudanças climáticas e agricultura no Brasil: impactos econômicos na região Nordeste.* (Texto para Discussão, 340). Belo Horizonte: Cedeplar.

Eboli, F., Parrado, R., & Roson, R. (2010). Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model. *Environment and Development Economics*, *15*(5), 515-533.

Elshennawy, A., Robinson, S., & Willenbockel, D. (2016). Climate change and economic growth: An intertemporal general equilibrium analysis for Egypt. *Economic Modelling*, *52*, 681-689.

Fachinello, A. L., & Ferreira Filho, J. B. S. (2010). Gripe aviária no Brasil: uma análise econômica de equilíbrio geral. *Revista de Economia e Sociologia Rural*, *48*(3), 539-566.

Féres, J., REIS, E., & SPERANZA, J. (2009). Mudanças climáticas globais e seus impactos sobre os padrões de uso do solo no Brasil. In *Anais do XXXVII Encontro Nacional de Economia*, Foz do Iguaçu: ANPEC.

Ferreira Filho, J. B. S., & Horridge, M. (2014). Ethanol expansion and indirect land use change in Brazil. *Land Use Policy*, *36*, 595-604.

Ferreira Filho, J. B. S., & Moraes, G. I. (2015). Climate change, agriculture and economic effects on different regions of Brazil. *Environment and Development Economics*, *20*(1), 37-56.

Código de campo alterado

Formatado: Português (Brasil)

Ferreira Filho, J. B. S., Pinto, L. F. G., Faria, V. G., & Sparovek, G. (2018). Environmental and welfare impacts of deforestation reduction in Brazil. In *Annals of 21th Annual Conference on Global Economic Analysis*. Purdue: GTAP.

Ferreira Filho, J. B. S., Ribera, L., & Horridge, M. (2015). Deforestation control and agricultural supply in Brazil. *American Journal of Agricultural Economics*, *97*(2), 589-601.

Fischer, G., Shah, M., & Velthuizen, H. V. (2002). *Climate change and agricultural vulnerability*. Special Report, International Institute for Applied Systems Analysis to World Summit on Sustainable Development, Johannesburg.

Fundação Centro de Estudos do Comércio Exterior – FUNCEX. (2018). *Indicadores.* Rio de Janeiro: FUNCEX. Retrieved in 2018, October 25, from http://www.funcexdata.com.br

Haddad, E. A., Porsse, A. A., & Pereda, P. C. (2013). Regional economic impacts of climate anomalies in Brazil. *Revista Brasileira de Estudos Regionais e Urbanos*, *7*(2), 19-33.

Horridge, M., Madden, J., & Wittwer, G. (2005). The impact of the 2002–2003 drought on Australia. *Journal of Policy Modeling*, *27*(3), 285-308.

Horridge, M. (2012). The TERM model and its database. In: G. Wittwer (Ed.), *Economic modeling of water*: *the Australian CGE experience*. (pp. 13-35). Dordrecht: Springer.

Instituto Brasileiro de Geografia e Estatística – IBGE. (2018a). *Projeções da População do Brasil e Unidades da Federação por sexo e idade: 2010-2060*. Rio de janeiro: IBGE. Retrieved in 2018, November 9, from https://www.ibge.gov.br/estatisticas-novoportal/sociais/populacao/ 9109-projecao-da-populacao.html?=&t=resultados

Instituto Brasileiro de Geografia e Estatística – IBGE. (2018b). *Séries históricas e estatísticas*. Rio de janeiro: IBGE. Retrieved in 2018, October 25, from http://seriesestatisticas.ibge.gov.br

Instituto Brasileiro de Geografia e Estatística – IBGE. (2018c). *Sistema IBGE de recuperação automática - SIDRA*. Rio de Janeiro: IBGE. Retrieved in 2018, October 25, from http://www.sidra.ibge.gov.br/

Intergovernmental Panel on Change Climate – IPCC. (2007). *Climate change 2007*: *synthesis report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (Eds.)]. Geneva, Switzerland.

Intergovernmental Panel on Change Climate – IPCC. (2014). *Summary for policymakers.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York: Cambridge University Press.

Ipeadata. (2019). *Base de dados do IPEA*: *dados macroeconômicos*. Retrieved in 2019, January 21, from http://www.ipeadata.gov.br/

Marin, F. R., Jones, J. W., Singels, A., Royce, F., Assad, E. D., Pellegrino, G. Q., & Justino, F. (2013). Climate change impacts on sugarcane attainable yield in southern Brazil. *Climatic change*, *117*(1), 227-239.

Mendelsohn, R., & Dinar, A. (1999). Climate change, agriculture, and developing countries: does adaptation matter?. *The World Bank Research Observer*, *14*(2), 277-293.

Mendelsohn, R. (2000). Measuring the effect of climate change on developing country agriculture. In FAO (Food and Agriculture Organization of the United Nations). *Two essays on climate change and agriculture*: *a developing country perspective*. Rome: FAO. (FAO Economic and Development Paper, 145). Retrieved in 2018, May 24, from http://www.fao.org/3/ x8044e/x8044e00.htm/

Nazareth, M. S., Cunha, D. A., & GURGEL, A. C. (2018). Economic effects of projected changes productivity in the agricultural crops. In *Anais do XVI Encontro Nacional da Associação Brasileira de Estudos Regionais e Urbanos*, Caruaru: ABER.

Nobre, C. A., & Assad, E. D. (2005). *Aquecimento Global e o Impacto na Amazônia e na Agricultura Brasileira*. INPE Eprint: Available in: http://www. sid. inpe. br/ePrint, 80, 09-12.

Formatado: Português (Brasil)

Código de campo alterado

Pavão, A. R., & Ferreira Filho, J. B. S. (2011). Impactos econômicos da introdução do milho Bt11 no Brasil: uma abordagem de equilíbrio geral inter-regional. *Revista de Economia e Sociologia Rural*, *49*(1), 81-108.

Pires, G. F., Abrahão, G. M., Brumatti, L. M., Oliveira, L. J. C., Costa, M. H., Liddicoat, S.; Kato, E., & Ladle, R. J. (2016). Increased climate risk in Brazilian double cropping agriculture systems: Implications for land use in Northern Brazil. *Agricultural and Forest Meteorology*, v. 228-229, p. 286–298.

Quiroga, S., & Iglesias, A. (2007). Projections of economic impacts of climate change in agriculture in Europe. *Economía Agraria y Recursos Naturales-Agricultural and Resource Economics*, *7*(14), 65-82.

Sanghi, A., Alves, D., Evenson, R., & Mendelsohn, R. (1997). Global warming impacts on Brazilian agriculture: estimates of the Ricardian model. *Economía aplicada*, *1*(1), 7-33.

Santos, C. V., & Ferreira Filho, J. B. S. (2007). Efeitos potenciais da política tributária sobre o consumo de alimentos e insumos agropecuários: uma análise de equilíbrio geral inter-regional. *Revista de Economia e Sociologia Rural*, *45*(4), 921-962.

Santos, C. V. (2006). *Política tributária, nível de atividade econômica e bem-estar: lições de um modelo de equilíbrio geral inter-regional* (Tese de doutorado). Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba.

Santos,, J. A., & Ferreira Filho, J. B. S. (2017). Substituição de combustíveis fósseis por etanol e biodiesel no Brasil e seus impactos econômicos: uma avaliação do Plano Nacional de Energia de 2030. *Pesquisa e Planejamento Econômico*, *47*(3), 185-216.

Santos, R. S., Costa, L. C., Sediyama, G. C., Leal, B. G., Oliveira, R. A., & Justino, F. B. (2011). Avaliação da relação seca/produtividade agrícola em cenário de mudanças climáticas. *Revista Brasileira de Meteorologia*, *26*(2), 313-321.

Silva, D. I., & Ferreira Filho, J. B. S. (2018). Impactos dos programas de transferência de renda Benefício de Prestação Continuada e Bolsa Família sobre a economia brasileira: uma análise de equilíbrio geral. *Pesquisa e Planejamento Econômico*, *48*(1), 161-183.

Silva, J. G., Ruviaro, C. F., & Ferreira Filho, J. B. S. (2017). Livestock intensification as a climate policy: Lessons from the Brazilian case. *Land Use Policy*, *62*, 232-245.

Souza, B. S. (2018). *Mudanças climáticas no Brasil: efeitos sistêmicos sobre a economia brasileira provenientes de alterações na produtividade agrícola* (Dissertação de mestrado). Faculdade de Economia, Administração e Contabilidade, Universidade de São Paulo, São Paulo.

Tanure, T. M. P., Miyajima, D. N., Magalhães, A. S., Domingues, E. P., & Carvalho, T. S. (2020). The Impacts of Climate Change on Agricultural Production, Land Use and Economy of the Legal Amazon Region between 2030 and 2049. *EconomiA*, *21*(1), 73-90.

Tavares, P. S., Giarolla, A., Chou, S. C., de Paula Silva, A. J., & de Arruda Lyra, A. (2018). Climate change impact on the potential yield of Arabica coffee in southeast Brazil. *Regional environmental change*, *18*(3), 873-883.

Verhage, F. Y. F., Anten, N. P. R., & Sentelhas, P. C. (2017). Carbon dioxide fertilization offsets negative impacts of climate change on Arabica coffee yield in Brazil. *Climatic Change*, *144*(4), 671-685.

Walter, L. C., Streck, N. A., Rosa, H. T., Ferraz, S. E. T., & Cera, J. C. (2014). Mudanças climáticas e seus efeitos no rendimento de arroz irrigado no Rio Grande do Sul. *Pesquisa Agropecuária Brasileira*, *49*(12), 915-924.

Wittwer, G., & Verikios, G. (2012). Introducing dynamics to TERM. In G. Wittwer (Ed.), *Economic modeling of water*: *the Australian CGE experience*. (pp. 37-55). Dordrecht: Springer.

World Trade Organization – WTO. (2021). Retrieved in 2021, May 12, from https://data.wto.org

Zhai, F., Lin, T., & Byambadorj, E. (2009). A General Equilibrium Analysis of the Impact of Climate Change on Agriculture in the People's Republic of China. *Asian Development Review*, Vol. *26*(1), 206-225.

Formatado: Português (Brasil)

Annex 1

Figure 1A – 15 Regions of the model

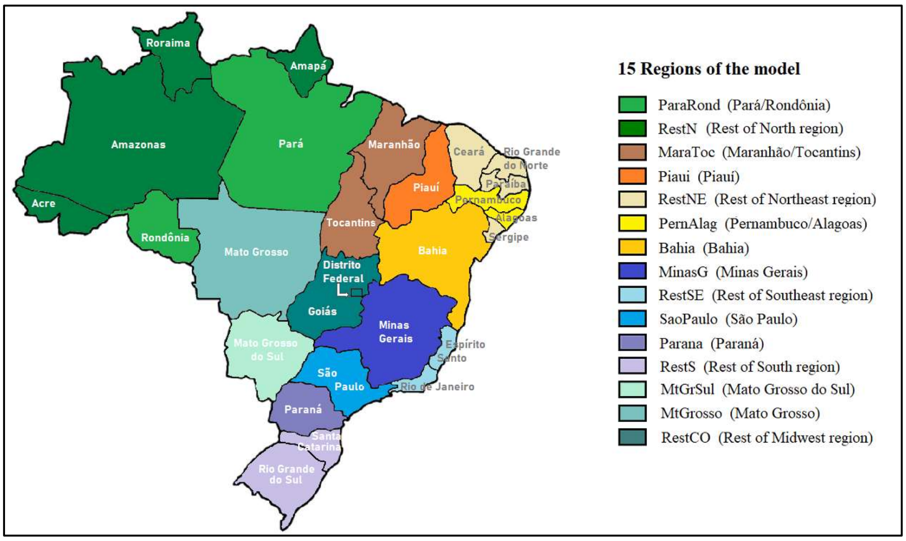

Table 1B - Sectors (industries) of the aggregate model

	Sector			Sector	
	In full	**Abreviated**		**In full**	**Abreviated**
1	Rice and other cereals	RiceOut	**18**	Vegetable and animal oils and fats	VegAnOils
2	Corn	Corn	**19**	Processed coffee	ProcessCoff
3	Cotton	Cotton	**20**	Processed rice and rice products	ProcessRice
4	Sugar cane	Sugarcane	**21**	Processing of oils and other vegetables	BenefOPOVeg
5	Soybeans	Soybeans	**22**	Textile and leather	Textil
6	Other annual crops	OutAnC	**23**	Wood, furniture, pulp, paper, printing	WoodPaper
7	Coffee	Coffee	**24**	Fuels, other refining products	FuelOthers
8	Other permanent crops	OutPermC	**25**	Chemicals	Chemicals
9	Livestock	Livestock	**26**	Other manufatured products	OutManuf
10	Milk prodution	MilkProd	**27**	Metallurgy	Metallurgy
11	Hogs and poultry	HogsPout	**28**	Electro-electronics	ElectElectron
12	Forestry	Forestry	**29**	Automobiles	Automobiles
13	Mining	Mining	**30**	Electricity, gas, water, sewage	EletricOth
14	Oil, natural gas and support services	OilNGas	**31**	Construction industry	Construction
15	Meats	Meats	**32**	Trade	Trade
16	Sugar	Sugar	**33**	Transportation	Transport
17	Dairy products, beverages and others	DairyPrOut	**34**	Services	Services

Annex 2

Figure 2A – Regional share (%) in the total produced for each crop in 2012