What if Brazilians reduce their beef consumption?

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Abstract: In favor of sustainability and human health, a dietary change is urgent. Beef, among all foods, has the greatest environmental impact and is associated with several chronic diseases. Brazil is one of the largest consumers of meat in the world, on par with developed countries, and most of its greenhouse gas emissions are related to deforestation and agricultural activities. Therefore, this article projects economic and environmental impacts of a beef consumption reduction by households preference changes in the country. A dynamic interregional Computable General Equilibrium model, for regions of the Brazilian Amazon, Matopiba and the rest of Brazil, is used, and it has a land use change module and allows substitution between different foods in its consumption and production structure. The results show that a 40% reduction in beef consumption could contribute to avoid a 63,297 km² area of deforestation and would have a virtually zero impact on the national GDP by 2050, although regional effects are heterogeneous.

Keywords: *beef, computable general equilibrium, deforestation.*

JEL Classification: C68, Q15, R11

1. INTRODUCTION

In 2019, the United Nations (UN) recommended diet changes in favor of environmental sustainability and human health (IPCC-2019). It implies a reduction in meat consumption, especially beef, due to its high environmental impact.

Brazil is among the largest beef producers and consumers, besides holding the biggest Amazon portion in its territory. Historically, much of the deforestation in Brazilian Amazon was due to agricultural frontier expansion, driven mainly by livestock in the region (Rivero *et al.*, 2009; Fearnside, 2017).

A growth in global consumption of meat proteins is projected over the next decades (Gerber *et al.*, 2013), mainly due to the growth of the world population and *per capita* income in developing countries. And Brazilian commodities are exported especially to countries responsible for this trend, such as China. Thus, foreign demand may not fall over the next decades. However, as the Brazilian *per capita* consumption of beef exceeds WHO recommendations, it is important to reduce domestic demand for meat. This reduction, in addition to health benefits, can contribute to decreasing the environmental impact of livestock activity (FAO, 2017; WHO, 2015).

World average *per capita* meat consumption (including beef, pork, chicken and fish) is about 43 kilograms (FAO, 2017), while WHO recommends a maximum of 25 kilograms per person annually (WHO, 2015). Asian developing countries are still below average, but Brazil is not. As developed countries, meat consumption in Brazil exceeds the average by 2 to 4 times. Excessive meat consumption is often associated with cardiovascular disease, colorectal cancer, type 2 diabetes and obesity, and beef carries the greatest risks. In order to keep the consumption of beef within the maximum limit, a 40% reduction in the *per capita* consumption is necessary.

Recently, some consumers have become concerned about their own health, the environment and also about animal cruelty, which is why they have already started changing their diet. Some changes in preference and eating habits are being noticed around the world, but it is not enough to

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mitigate environmental pressures. In the last decade, United Kingdom has decreased its meat consumption by 17%, but it should be around 50% (McMichael *et al.*, 2007; Stewart *et al.*, 2021). Reducing meat consumption has already reached the public debate in developed countries as England, Spain, Switzerland, Denmark, Norway, Germany and New Zeland (Godfray *et al.,* 2018; Willet *et al.*, 2019; TAPPC, 2021; Hundsheid *et al.*, 2022). Should not Brazil participate of this debate?

Emissions mitigation on agriculture can be more effective through demand than supply (Hedenus *et al.*, 2014). From the supply point of view, investments and technology advances are required, which take a long time to be effective. Furthermore, surveillance in this sector is hard. On the other hand, demand does not require technological advances and forces farmers to migrate their production to crops and livestock products that are less harmful to the environment.

In this context, this article aims to contribute to the debate on reducing beef consumption through changes in preferences. To do so, an interregional dynamic computable general equilibrium model was used, which considers 32 mesoregions of the Amazon, Matopiba and the rest of Brazil, called REGIA+. This model also has a land use module, and changes in the theoretical structure in the production and consumption modules that allow substitution between different types of food.

Changes in preferences can lead to a lower demand for beef and, consequently, reduce the intermediate demand for livestock inputs, leading to a slowdown in deforestation in the Amazon, in addition to negatively impacting the carbon emissions associated to this activity. On the other hand, as livestock is an important activity in the region, negative regional economic impacts can be an undesirable consequence if other industries do not develop to support local economy. Understand regional impacts is essential considering the great heterogeneity between these regions in Brazil.

This study is divided into three more sections in addition to this introduction. Next presents a review of the literature on the subject. The third section describes methodology, database and simulation strategy. Then, the results are presented and discussed, and finallly, we have the final considerations.

2. LITERATURE REVIEW

According to IPCC report, of all foods, the production of animal-based foods is the largest source of greenhouse gas (GHG) emissions from agricultural activity, anthropogenic use of land and water, in addition to causing more eutrophication and soil acidification (Poore and Nemecek, 2018). Livestock alone is said to be directly responsible for 14.5% of global emissions each year, which represents 56% of agricultural emissions (Tilman and Clark, 2014). Despite providing only 18% of food, livestock covers 83% of global agricultural land (Poore and Nemecek, 2018).

Ruminant meat has more than 100 times greater impacts than plant-based food per kilocalorie of food produced (Clark and Tilman, 2017). Ruminant animals emit carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4) through enteric fermentation and manure management, which represent 41% of livestock emissions. The cultivation of cereals and the fertilization of pastures to feed the herd, also emit another 21% of emissions (Gerber *et al.*, 2013).

Another problem pointed out in the literature is the nutritional and energy inefficiency of meat production, which can aggravate food insecurity in the world. Livestock expend 2.5 to 10 times more energy to produce the same number of calories and protein than grains (Molden *et al.*, 2007). About a third of the world's agriculture output is used to feed the animals that are consumed by humans, and in the process, two thirds of the calories are lost. In addition, producing one kilogram of meat requires about 15,000 liters of fresh water, while vegetarian diets require 2,000 liters (Molden *et al.*, 2007).

Hence, UN`s recommendation to adopt diets with less greenhouse's emissions implies a reduction of beef consumption. As Brazil is among the largest producers and consumers of beef, changing the diet towards plant-based food is a relevant issue to discuss. In 2020, the country had the largest herd in the world, with 217 million heads, which represents 14,3% of global herd (FAOSTATS, 2021). Furthermore, Brazilians are one of the largest consumers of beef in the world, matching the consumption of developed countries (FAO, 2017). Consumption greater than the limit recommended by the WHO for health, which is a maximum of 25kg *per capita* for all types of meat and 15kg *per capita* for beef. The total *per capita* consumption of meat by Brazilians is 99kg, while the USA and Australia exceed 100kg and European countries maintain between 80kg and 90kg. The consumption of red meat, specifically, is around 24,4kg *per capita*[3], which means that needs to be reduced by 40%. In addition, Brazil plays a central role in the global concern with the mitigation of emissions in the agricultural sector, mainly through the control of deforestation in the Amazon rainforest, a vital biome for Earth's climate regulation, which has an enormous carbon stock. Livestock has been identified as the main driver of deforestation and loss of biodiversity due the expansion of pastures (IPCC, 2019, Gerber *et al.*, 2013). Livestock accounts for 71% of deforestation in Latin America (De Sy *et al.*, 2015).

Approximately 60% of all deforested lands in the Brazilian Amazon is covered by pastures (Carvalho *et al.*, 2020). Between 1985 and 2019, the northern region of Brazil (where Amazon is located) had the largest change in the number of ruminant animals and from 2012 onwards, it showed an absolute increase in head of cattle, even greater than Central-West region, although the latter still has the largest herd (IBGE, 2020). Rivero *et al.* (2009) found a correlation coefficient between livestock and deforestation of 0,7345, and showed that livestock explains about 54% of deforestation. In 2020, livestock was the main land use in Brazil with 75% of public forest deforested and not destined (Salomão *et al.*, 2021).

The expansion of deforestation follows the growth in demand for beef, both domestically and abroad, and is encouraged by low land prices and improvements in regional transportation infrastructure (Rivero *et al.*, 2009). Livestock is practiced by small and large farms, but deforestation has been caused mainly by medium and large cattle producers (Carvalho, 2014). Cattle ranching also drives deforestation through land grabbing, which is an illegal private appropriation of public lands. The transfers of cattle to this lands present an aspect of a productive enterprise, but low risk capital (MMA, 2006), since it requires low amount of capital and low investment in soil (Rivero *et al.*, 2009). The high availability of land in the Amazon discourages investments in other production factors (capital and labor), making livestock an activity with low-productivity and competitiveness (Carvalho *et al.*, 2016).

Deforestation and emissions from livestock make Brazil the seventh largest emitter of greenhouses gas in the world. In 2016, a total of 2.278 MtCO2e (millions of tons of CO2 equivalent) were emitted in Brazil, of which about 51% (1.167 MtCO2e) was due to land use change (WRI, 2017). Therefore, it is necessary to engage the Brazilian agricultural in the GHG mitigation efforts. This is also the Brazilian sector that would most benefit from climate change mitigation, given its dependence on the climate. In addition, in Brazil, crops depend on rainfall regime, as only 10% of the agricultural areas are irrigated (IBGE, 2020).

The mitigation of supply-side emissions in the agricultural sector is necessary, but it requires technological advances, investments, and long term to show results (Pais *et al.*, 2020). The main strategies suggested in literature to reduce GHG emissions per animal are carbon sequestration by reversing deforestation and restoring degraded soils; improvements in diet and digestibility of ruminant animals to reduce methane emissions from enteric fermentation; increasing the proportion of monogastric animals in livestock production, as they have a smaller environmental footprint; improvements in manure management, mitigating methane emissions and producing biogas, and efficient use of fertilizers as a way to reduce nitrous oxide emissions (McMichael *et al.*, 2007). Increasing livestock productivity with technological improvements in feed and nutrition, genetics, reprodution and animal health can also contribute (Gerber e Steinfeld, 2013).

However, mitigating emissions from the demand side, as suggested by the UN (IPCC, 2019),

[3] There is variation in consumption among different income classes, and according to the 2017/2018 Consumer Expenditure Survey (POF), the lowest class (with income up to R$1,908) consumes 25% less than the average consumption in Brazil, and higher class (income over R$14,000) consumes 46% more than the average.

can be more efficient, with faster and cheaper results, and would help to pressure supply to migrate its production to foods with less environmental impact (Pais *et al.*, 2020). Strategies to reduce meat consumption are already being considered in the public debate in several countries. It reached its peak in the 2019, the pre-pandemic year of COVID-19, but gained strength from 2015 after WHO publication on the carcinogenic potential of red meat. Red meat is also associated with other chronic diseases such as cardiovascular disease, obesity, and type 2 diabetes (Bradbury *et al*., 2020).

Even with the current lack of formal interventions, developed countries have already noticed a change in the eating behavior of part of their populations. Environmental and health-related issues encouraged individuals to reduce their meat consumption (Cordts *et al.*, 2014). The share of vegetarians and vegans (by choice, not by necessity) in the world is still small, but it already draws the attention of the market. However, there is a new group, which has been growing a lot in the recent years: flexitarians. Flexitarians are those individuals who have chosen to reduce their meat consumption, without radically restricting their diet (Dagevos, 2021).

Movements such as the Meatless Mondays campaign, adopted by more than 40 countries in 2016, and the Fridays for Future movement promoted by Swedish teenager Greta Thunberg in 2019, have had great impact as an educational campaign on reducing meat consumption (Wallis *et al*., 2021), especially in Europe. In the European Union, 40% of omnivorous individuals have reduced their consumption of red meat. In the UK, there was a 17% drop in average daily meat consumption between 2008 and 2018, and 39% of the population reported reducing their meat intake. Furthermore, the proportion of vegetarians and vegans in the region increased from 2% in 2008 to 4% in 2018 (Stewart *et al*., 2021). Australia, New Zealand, Canada and the United States also already have a considerable number of flexitarians (Whitton *et al*., 2021; Dagevos, 2021).

And it is essential that developed countries have taken the lead in this debate, since their meat consumption is between 90 and 120 kg *per capita* per year, while the world average is 43 kg. The drop in consumption of almost 20% is still very little compared to the need for a reduction of 50% to 67%, to maintain the level of consumption within the WHO recommendations, which would be 25 kg *per capita* per year (Pais *et al.*, 2020). The reduction can also contribute to alleviate the impact on the environment, mainly because developing countries are increasing their consumption. In Asia, in countries such as China and India, demand for meat has increased due to population growth and rising in *per capita* income, after decades of high levels of hunger and poverty.

Both the recent adherence to dietary change in developed countries and the growing consumption in Asia can be explained by the relationship between meat consumption with income and education. Individuals with higher incomes can spend more on meat, and, in fact consume more meat than individuals with lower income, but in a non-linear way. Vranken *et al.* (2014) found, using FAO dataset from 1970 to 2007 for 120 countries, that *per capita* income and meat consumption have an inverted U-shaped relationship. They explain that the income elasticity of demand for environmental quality may be the reason.

The relationship between education and decreased meat consumption is positive (Vandermoere *et al*., 2019; Kirbis *et al*., 2021). More educated individuals (starting with a high school education) are more open to science and more likely to seek new information, in addition to being more aware and concerned about their own health and environmental sustainability (Kirbis *et al*., 2021). Individuals who only received basic education, on the other hand, believe that a plant-based diet would not provide enough protein and would be harmful to health, although scientific studies show positive evidence of adherence to this diet (Lea *et al*., 2006). Brazilian studies have also identified a positive relationship between education and healthier eating habits, with reduced consumption of red meat (Marinho *et al*., 2007; Schneider *et al*., 2014).

Indeed, changing eating habits is not easy, especially when it comes to meat consumption, which is linked to cultural, and even affective characteristics (Kwasny *et al*., 2022). "Most people eat meat, because most people eat meat" (Leenaert, 2017). Because it has such a strong social factor, changing preferences in relation to meat must occur through social mechanisms, including State incentives with fiscal, informational and behavioral instruments. Although informally dietary changes are already happening, adaptations of formal institutions are still pending (Vranken *et al*., 2014).

The drop in voluntary consumption is still timid in relation to the environmental need and the timeframe available to meet sustainability goals. Government coordination in promoting changes in eating habits is indispensable, especially on issues related to price (through taxes and subsidies), policy dissemination, and nutrition education (de Boer *et al*., 2014). In Europe, the adoption of a meat tax is already being discussed, but it has been quite controversial. Taxes in competitive markets generate deadweight losses, and its application should be well studied to reduce them as much as possible. In a carbon tax simulation in France, the results showed that taxing only red meat instead of all meat provides a two-thirds reduction in emissions at a lower cost to the consumer (Bonnet *et al*., 2018). However, policies that provoke changes in consumer preferences seem to be more cost-effective and can make use of informational and behavioral tools.

Informational strategies include the description of the ingredients and nutritional composition of foods on their labels and certification labels indicating specific characteristics, such as cruelty-free or the level on a scale of GHG emissions. Campaigns pointing out the benefits and harms of food for consumers are also important (Bonnet *et al*., 2020). And educational campaigns in schools can influence future consumers, whether children or adolescents, in forming their eating habits and can also influence their families (Pais *et al*., 2020). Stoll-Kleemann and Schmidt (2017) recommend the use of emotional messages and images, because knowledge alone is not enough for a change in diet.

Behavioral strategies include psychological phenomena such as cognitive dissonance, culture, emotions, and morality. The Meatless Mondays campaign is an example, as are social movements (Bonnet *et al*., 2020). The application of well-designed nudges can also be effective, inducing consumers to make choices that best favor them (Thaler and Sunstein, 2008). For example, in restaurants, hospitals and school canteens, offering healthier options on the menu, or highlighting vegetarian options (Pais *et al*., 2020).

Even if consumption habits are difficult to change, a well-designed campaign with a set of informational and behavioral components can help accelerate the decline in *per capita* meat consumption in a country, as it allows reducing the social barrier to changing behavior. The initial focus can be on beef and then be extended to other types of meat. Some researchers have already carried out simulations of changes in preferences for eating habits in Europe, the United States, Canada, and worldwide.

Westhoek *et al*. (2014) examined the effects of a 50% switch from an animal-based diet (meat, eggs, and dairy products) to a plant-based diet, using a partial biophysical model for European Union countries. This level of reduction accommodates a balanced diet, within nutritional recommendations. The results showed a 40% reduction in nitrogen emissions and a 25% to 40% reduction in GHG emissions, 23% less land use for grain production for animal feed, a drop in cardiovascular diseases in the population, and improvements in water and air quality. Another consequence for the region studied is the increase in grains exports, which will no longer be inputs.

Springmann *et al*. (2015) performed a comparative analysis between global dietary changes, health, and environment, using a global model of 9 macro-regions. The four simulated diet scenarios represent levels of transition to plant-based diets. The results showed a 6% and 10% decrease in global mortality and a 29% to 70% reduction in GHG emissions relative to the baseline in 2050. About 65% of economics gains come from directly reducing health costs and avoid loss of life, 32% are indirect health gains, and 3% are productivity gains in the labor market. Developed countries have the greatest impact *per capita*, but in total terms developing countries are the biggest beneficiaries.

An OECD/PAHO publication in 2015 modeled some public health policies and among them a study with CGE (GTAP) simulated the adoption of a healthier diet in Canada, which include a 20% reduction in meat consumption and 41% and 50% increase in dairy, fruit and vegetable consumption respectively. The analysis considered the effect on agriculture and food sectors by changing consumer preferences and demonstrated a positive impact on the Canadian economy and to a lesser extent, its trading partners such as the US, Mexico, Brazil, and Chile, due to increased exports.

Dixon and Rimmer (2020) performed several simulations to verify the effects of a reduction in beef consumption in the United States, induced by taxes and by changes in consumer preferences, to varying degrees, from beef to other foods or to alternative products such as plant-based meat. Among the simulations involving taxes, the additional tax revenue was used to increase public spending or as a return to the consumer in the form of subsidies for other commodities or exclusively food. The researchers used the USAGE-Food, a national CGE model calibrated for the United States, which modifications in the structure of production and consumption allow for substitutions between different types of food. The results showed a low impact on GDP, but important sectoral effects, with capital and labor mobility. There was also a drop in agricultural production, mainly in the scenarios of tax increases, and a more pronounced drop in the processed meat sector, in addition to an increase in imports of other foods. The tax-induced drop in beef consumption leads to a contraction in exports, and the one induced by a change in preferences affects the trade balance depending on the intensity of imports of substitute foods. The study shows that a policy of raising taxes on beef generates efficiency losses, with a reduction in real wages, which does not occur in policies of changing consumer preferences.

Simulations regarding this theme for Brazil are still absent in the literature, as far as we know. As Brazil is a major producer, exporter and consumer of beef, it becomes relevant to explore the effects of a possible drop in domestic demand for beef. Acting to reduce the consumption of beef, currently consumed in excess according to health recommendations, is also an opportunity to combat climate change, with potential benefits to health and welfare of the Brazilian population.

3. METHODOLOGY

REGIA+ (Interregional General Equilibrium Model for the Brazilian Amazon and Matopiba) is a recursive dynamic Computable General Equilibrium (CGE) model, which has a land use module and is disaggregated for 32 mesoregions of the Legal Amazon, Matopiba and the rest of Brazil. It is an extended version of the REGIA model (Carvalho, 2014), the first model built for the economy of the Brazilian Amazon, originally with 30 mesoregions (Carvalho, 2014). REGIA is a bottom-up multiregional model, derived from the Australian TERM model (Horridge *et al*., 2005). It was calibrated with data from 2015 National Accounting Matrix and regionalized according to the procedure proposed by Horridge (2006), which has been used in several regional models for Brazil (Santos, 2006; Fachinello, 2008; Cechin *et al*., 2021). It has a sectoral disaggregation of 44 economic activities, 14 of which are foods.

3.1. Theoretical structure of REGIA+[4]

In each region, the relationships between supply and demand capture the optimizing behavior of agents, that is, firms minimize costs and consumers seek to maximize their utility. The model operates with a market equilibrium of all domestic and imported goods, and primary factors (labor, capital, and land) in each region. Markets are competitive, in which firms' prices are endogenously equal to their marginal cost. Production costs are subject to constant returns to scale, and the composite of inputs (divided between food and other inputs) and primary factors follows a Leontief

[4] Further details about theoretical structure of this model in Carvalho (2014).

function, with fixed coefficients (see Figure 1).

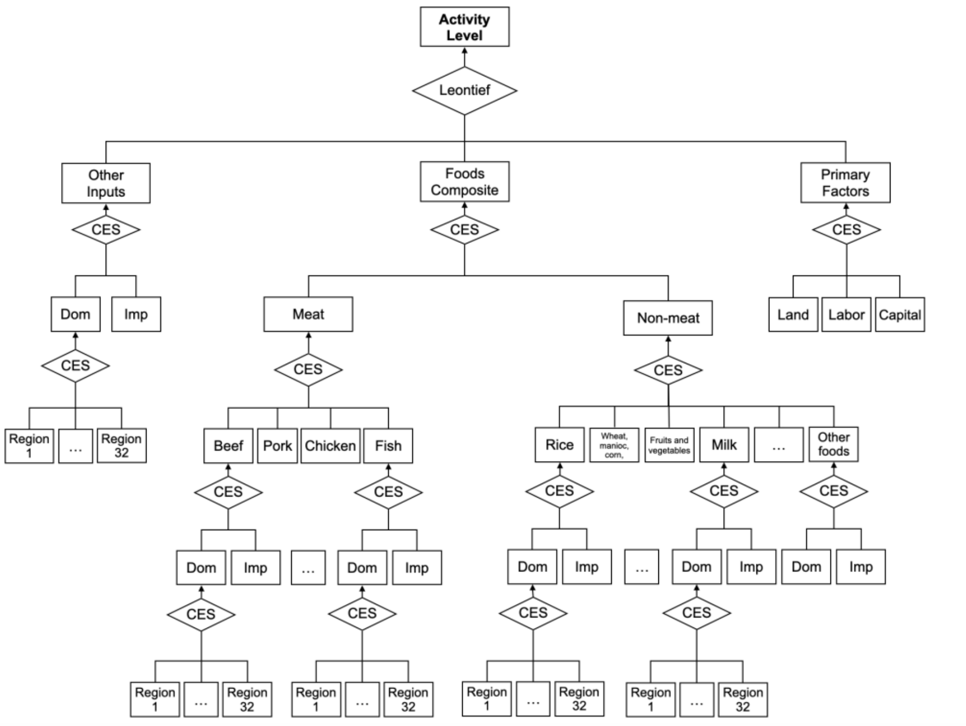

Figure 1 — Production structure
Source: Elaborated by the authors. Adapted from Santos (2006), Magalhães (2013) and Carvalho (2014).

The allocation of primary factors between sectors follows a constant elasticity of substitution (CES) function, although the land factor can be allocated only to the agricultural sectors. CES also conducts the mix of inputs used by sectors, adopting the Armington's (1969) elasticity, which treats domestic goods (from the region itself or from other regions of the country) and imported goods as imperfect substitutes.

The structure of production technology has been changed to allow for imperfect substitution between food composite goods. This composite contains two groups: meat and other foods[5]. This modification allows each industry to choose between commodities of the two groups according to a CES function, as well as the substitution between commodities of each group. The adapted production structure can be seen in Figure 1.

When commodities are delivered from one region to another, two margins, trade and transport, are added to their basic value to form the delivery price. The share of each margin in the price depends on the combination of region of origin, region of destination, type of commodity and its source (domestic or imported). Margins can be produced in different regions or in those that transacted the commodities, e.g, transport can be produced in an intermediate region between two distant ones. Substitution between margins suppliers also follows a CES function. The demand for margins is proportional to the flow of commodities.

Final demand is composed by four users, namely investors, households, exports, and government. There is a single representative household per region, whose demand is based on a preference system that adopts the CES and Klein-Rubin functions. The CES function specifies, by the Armington's hypothesis, the choice between domestic and imported goods, while the Klein-Rubin function establishes a minimum level of subsistence consumption, at which minimum quantities of goods are purchased whatever the price of the product. The consumer remaining available budget is

[5] There are 14 commodities, 4 in the meat group (beef, pork, chicken, and fish) and 10 in the other food groups (milk, dairy (others), sugar, fruits and vegetables, veg. oils and fats, coffee, rice, products of wheat, manioc and corn, other foods and beverages)

called luxury spending, and this alone affects the consumer's utility. Under the Linear Spending System (LES), in which spending on each good is a linear function of average prices (domestic and imported goods) and expenditures, additional (luxury) spending is a constant proportion of total subsistence spending. Furthermore, as well as the structure of production, the structure of household consumption has also been modified to allow substitution between goods within food composite, which consists of two groups (meat and other foods), according to a CES function, as shown in Figure 2.

Government consumption is exogenous. Direct and indirect sales taxes are *ad valorem* taxes on basic flows. The sum of the basic values, margins, and taxes results in purchase prices for each user, intermediate (producers) or final demand (households, government, exports, and investors) in each region. And, since Rest of the World is exogenous in the model, foreign demand curves are negatively sloped in relation to international market price, so shifts in price and demand for exports allow for shocks in demand curves. Foreign demand is reflected by the export of commodities from regions where goods leave the country, that is, those with a port, but the specification by origin of good allows the model to capture transportation costs and report distinctly the region of production and the export region of the exported commodity.

Since this is a dynamic model, it has a capital accumulation mechanism that links investment flows to capital stocks. There is also an intersectoral shift of investments according to their rates of return and depreciation. The growth of a given industry incurs a higher rate of return than the normal rate of return, which attracts investors, until this rate deviates and is insufficient to compensate for the cost of the investment. Each year, if the capital is applied to an industrial sector in a percentage greater than its depreciation rate, there will be an increase in capital stock. This makes investors responsible for gross fixed capital formation. In production of capital goods, subject to cost minimization, primary factors are not used directly, but there is demand for domestic and imported inputs, under the CES function, while the pool of inputs follows fixed proportions (Leontief).

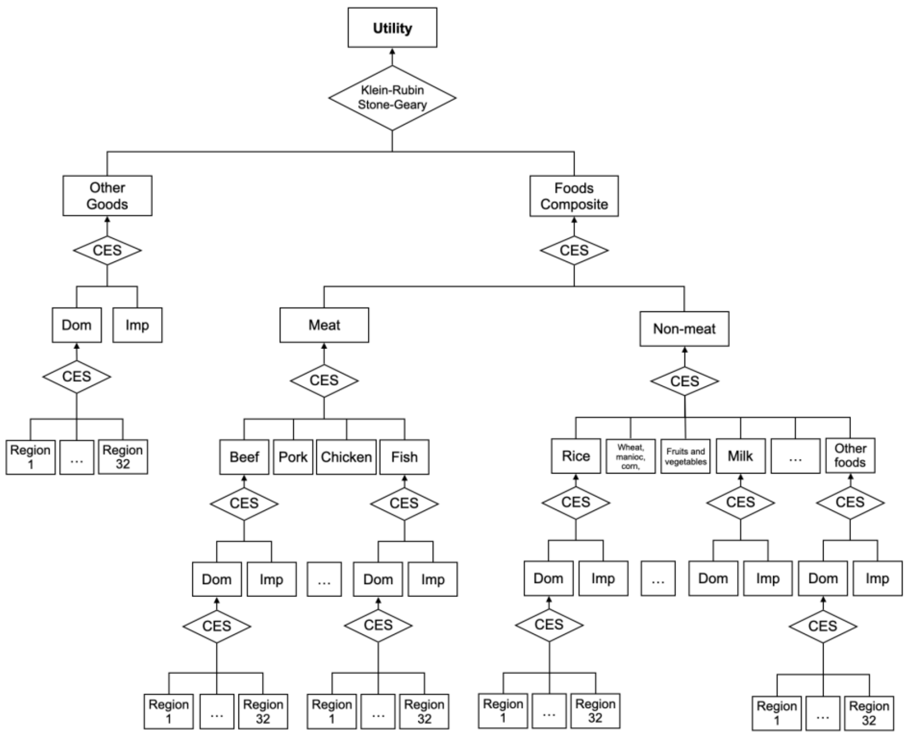

Figure 2 — Demand structure

Source: Elaborated by the authors Adapted from Santos (2006), Magalhães (2013) and Carvalho (2014).

REGIA+ also has a dynamic labor market adjustment involving employment variables such as real wage, current employment, and trend employment. When the level of employment exceeds trend growth, the real wage increases. However, in the long run, the level of employment adjusts until it converges again to trend employment (Carvalho *et al*., 2020).

The model has a land use module that allows conversion between different types of land within each region. Land is a primary factor that can be used for cropland, pasture, planted forest, or natural forest. The land factor can be allocated among different agricultural sectors according to remuneration differentials within each use. Thus, the demand for land in the model responds to changes in sectoral returns. On the supply side, there is the conversion among different uses, where the conversion process is controlled by a transition matrix that represents the possibilities of land conversion between periods. The matrix represents the land changes between uses, indicating transformation possibilities from different land uses (Carvalho and Domingues, 2016)[6].

The model also calculates macroeconomic aggregates and indicators, such as: a) GDP on the expenditure side and on the income side; b) Trade Balance; c) Price indexes of household consumption, investment, exports, imports and GDP (implicit deflator); d) Primary factor aggregates (capital, labor and land); e) Sales decompositions (intermediate and final use); and f) GDP decompositions (income and expenditure sides).

3.2. Database

REGIA+ was calibrated within NEDUR[7] with 2015 National Accounting data and regionally disaggregated according to the procedure proposed by Horridge (2016) and adapted for Brazil as developed in Carvalho (2014). The land use transition matrix was updated with satellite data from INPE's[8] Terra Class (2012 and 2014) and IBGE's Agricultural Censuses (2006 and 2017). It was also updated with deforestation data[9] until year 2021. The model contains 44 industries and 44 commodities, with disaggregation into 14 agricultural sectors, 14 food sectors, 6 industrial sectors, and 10 service sectors.

As compared to the original REGIA model (Carvalho *et al*., 2016; Carvalho *et al*., 2017), REGIA+ additionally presents, in its regional disaggregation, the region of Matopiba, previously belonging to the rest of Brazil region. For this study, 32 regions will be considered as presented in

[6] More details about the land use module can be found in Carvalho and Domingues (2016) and Carvalho *et al*. (2017).
[7] Center for Urban and Regional Development Studies at the Federal University of Paraná
[8] National Institute for Spatial Research
[9] Data from PRODES/INPE by municipality by year.

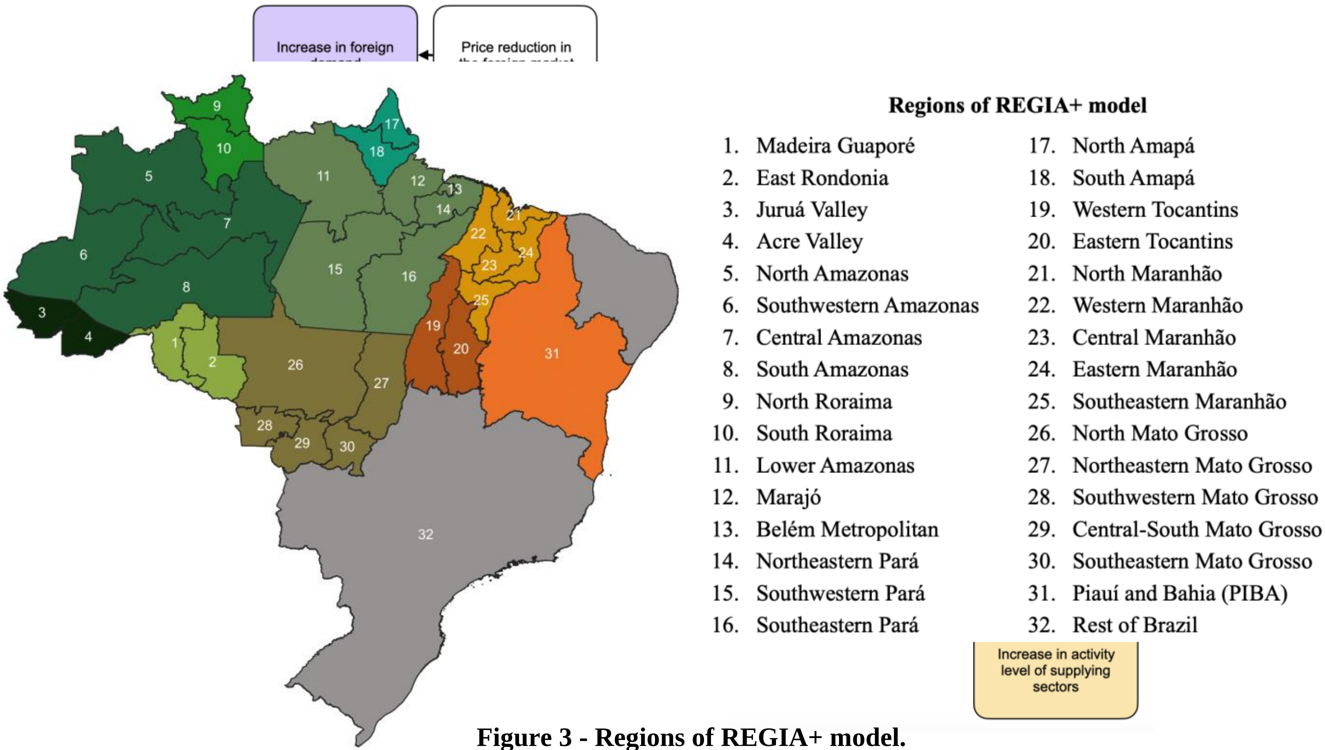

Figure 3 - Regions of REGIA+ model.

Source: Elaborated by the authors

Source: Elaborated by the authors. Adapted from Carvalho (2014).

Figure 3.

Matopiba is also a relevant region for land use change studies because it is an important agricultural frontier for Brazil. It supplies almost 10% of the country's grain production, and its main crops are soybeans, corn, and cotton. Although pasture areas have gradually reduced since 1980, in 2015 about 17% of production in this region was cattle (INPUT, 2017). In addition, this region is made up of areas of the Cerrado biome in the states of Maranhão, Tocantins, Piauí, and Bahia, which have ideal geographical conditions for grain cultivation. Its name is an acronym of these states. The delimitation of Matopiba was made official by presidential decree in 2015 (EMBRAPA, 2019).

The cerrado is the second largest biome in Brazil, and agriculture and livestock already occupies 44.2% of its territory. The Matopiba region concentrates around 60% of the deforestation suffered by the biome. The biome still has 54.5% of its territory covered by native vegetation, 44% of which are found precisely in the Matopiba region, which accentuates the conflicts between agricultural production and environmental protection (IPAM, 2022).

In order to analyze the interactions between beef consumption and changes in land use, modifications to the theoretical structure of the REGIA+ model made to allow for imperfect substitution between foods require data on the price elasticities of demand. For that, we use price elasticities calculated by Two Stages Almost Ideal Demand System (AIDS) method with data from POF[10] 2008/2009 by Dassow *et al*. (2015).

3.3. Simulation Strategies

The first step is to build a baseline scenario (business as usual), in which the economy follows a growth trajectory, which is divided into two parts. In the first, national macroeconomic data are updated from 2016 to 2021 according to IBGE[11] observed data, as well as deforestation data by region according to INPE[12] data. From 2022 to 2050, the national economy follows a 2% GDP growth per

[10] Consumer Expenditure Survey
[11] Brazilian Statistics Institute
[12] National Institute of Spatial Researches

year and *per capita* beef consumption is kept constant[13] at 2021 level.

From this baseline, it is simulated a scenario of 40% reduction in beef consumption (to meet WHO's recommendation) due to preferences change. This change in preferences may occur naturally in Brazil, from a possible adoption of alternative diets, or even be encouraged by national campaigns, with the dissemination of information and behavioral strategies. As dietary preferences are strongly linked to culture and would not change quickly, the reduction of beef consumption would happens over time[14], starting in 2022, reaching 40% in the 2050 accumulated. Although the consumption of other meats should also be significantly reduced, this exercise can provide interesting results that could support future discussions regarding both economic and environmental impacts of a shift in meat consumption toward what is considered healthier by WHO.

If a change in eating habits successfully reduces beef consumption in Brazil, the drop in demand would have repercussions on the economy. In addition, the model shows the impacts of this reduction on land use and consequently, on deforestation of the Amazon and Matopiba. The results of this scenario are given as a deviation (in cumulative percentage change) in relation to the baseline scenario (in which the economy follows a growth path with no change in preferences).

Figure 4 presents the transmission mechanisms of the model in the face of this scenario. The change in preferences causes a reduction in beef consumption, which leads to a decrease in the demand for livestock inputs, negatively affecting the level of activity in this sector, and consequently, reducing its need for land, which allows a slowdown in the deforestation, since pasture is the first conversion of natural forest. At the same time, consumer preferences are shifting towards other foods, substituting demand, interfering with the level of activity of others agricultural sectors, which depending on remuneration of the factors, may capture inputs and primary factors from livestock. Regions with greater participation of cattle ranching and beef sectors in their productive structure may suffer negative economic effects. Meanwhile, the reduction in domestic demand may reduce the price of beef and favor an increase in foreign demand for this commodity.

4. RESULTS

Simulation results are presented as deviations (in cumulative % change) from the baseline scenario, in which the economy follows its natural trend. By applying a shock to change consumer preferences, leading to a 40% reduction in household demand for beef, there is a direct negative effect on this industry, while other sectors of the economy suffer indirect impacts via supply chains.

4.1. Sectorial Results

The drop in demand for beef by households has a direct impact on the beef industry, contributing to the reduction of its activity level (by 21.79%) in the accumulated of 2050 in relation to its growth trend in the baseline scenario, as shown in Table 1. Initially, other animal-based food sectors (other meats and dairy products) show growth in the level of activity, a result associated with higher consumption of other foods due to the substitution effect as households preferences change.

It is noted that dairy, chicken and fish productions are prominent in 2025 but have a negative cumulative effect in 2050. This is because, initially, the substitution of demand for these other foods puts pressure on their prices, increasing return on investments in these industries, generating an expansion of their activities. Over time, the higher demand for primary factors generates a drop in rates of return, leading to a decline in investments and, consequently, in the level of activity in these sectors. The opposite happens with sugar, fruits and vegetables, vegetal oils and fat, and rice.

The reduction in the level of activity in the beef sector has a negative impact on the livestock

[13] Total beef consumption follows population growth. It is a conservative approach, since FAO (2021) projects a small decrease in beef consumption in Brazil for the next decades.
[14] Five years periods, except the first one (2022 to 2025, which has four years).

sector, as this sector is its largest supplier of inputs. The greatest impact occurs in the year 2050, since the decrease in demand reduces attractiveness and investments, contributing to a decline in the level of activity over time. The agriculture sectors, on the other hand, have a positive impact, although less than 1%. Other sectors of the economy are benefit as the share of household budget previously allocated to beef consumption is transferred to other goods.

Table 1 - Results of sectorial production in Brazil in cumulative % var. for 2025 and 2050

	Industries	2025	2050		Industries	2025	2050
Agribusiness – Farming sectors	Rice, wheat and other cereals	0.05	0.31	Food Industries – Non-Meat	Fruits and vegetables	-0.11	0.74
	Grain maize	0.06	0.15		Veg. oils and fats	-0.13	-0.41
	Cotton and other fibers	0.07	0.52		Coffee	-0.16	0.83
	Sugarcane	0.06	0.54		Rice	-0.13	0.85
	Soybeans	0.07	0.39		Wheat, manioc and corn	-0.23	-0.03
	Other crops	0.08	0.99		Other foods	-0.25	-0.15
	Orange	0.00	0.16		Beverages	-0.10	0.35
	Coffee bean	0.07	0.45		Textiles, clothing and footwear	0.19	0.70
Agribusiness – Livestock sectors	Cattle	-0.51	-6.76		Wood, paper and cellulose	0.03	0.01
	Cow's milk and other animals	-0.22	-4.72		Fuels	0.08	0.33
	Pigs	-0.68	-9.07		Chemicals and others	0.06	0.09
	Poultry and eggs	-0.13	-3.96		Other industries	0.08	0.19
	Forestry and Logging	0.09	0.59		Energy and Water	0.05	0.34
	Fishing	0.01	0.16		Construction	0.00	-0.07
	Extractive Industry	0.05	0.15		Trade	-0.05	-0.42
Food Industries – Meat	Beef	-3.36	-21.79		Transportation	0.03	0.01
	Pork	0.42	-2.55		Housing	0.12	0.24
	Chicken	0.84	-0.59		Food	0.18	0.76
	Fish	0.77	-0.64		Public Administration	0.00	-0.02
Food Industries – Non-Meat	Milk	0.37	-3.13		Public Health	0.00	-0.03
	Dairy (others)	1.26	-0.92		Private Health Care	0.13	0.61
	Sugar	-0.02	0.51		Other Services	0.07	0.36

Source: Elaborated by the authors based on the simulation results

Furthermore, it is clear that the food sectors, which use more inputs from the beef industry, benefit from the drop in production costs caused by the lower price of beef. The biggest positive impact can be seen in the food sector (0.76% accumulated in 2050), as the lower demand from households reduced the price of beef, lowering the production cost of this activity. However, trade sector is negatively affected (-0.42%) since beef represents 3.8% of the total trade margin.

4.2. Regional macroeconomic results

The regions with a significant share of beef and livestock in its total production are the most negatively impacted. Although the impact is relatively small, it is quite heterogeneous. Figure 5 presents the regional GDP variation in 2050. The most negatively affected regions were Southern Roraima (-2.91%), Northern Amapá (-1.96%), Southwestern Pará (-1.89%), Northern and Northeastern Mato Grosso (-1.76% and -1.68%), Juruá Valley (-1.64%) and Central Maranhão (-1.57%). Although some of them are small regions, they have a high relative importance in livestock in total production. The North of Mato Grosso, on the other hand, is a region that has greater relevance in national production of beef and in cattle sectors.

Some regions present small increases in GDP, although the result is almost null. But it is noticeable that these are regions that have greater productive diversity, such as the most aggregated regions (PIBA and Rest of Brazil), and the regions where the capitals Belém and Manaus are located (Metropolitan Belém and Central Amazonas). The regions that show positive results are the most industrialized, in which the share of agricultural and food products in their economies are small, and are also favored by the increase in activity in other sectors.

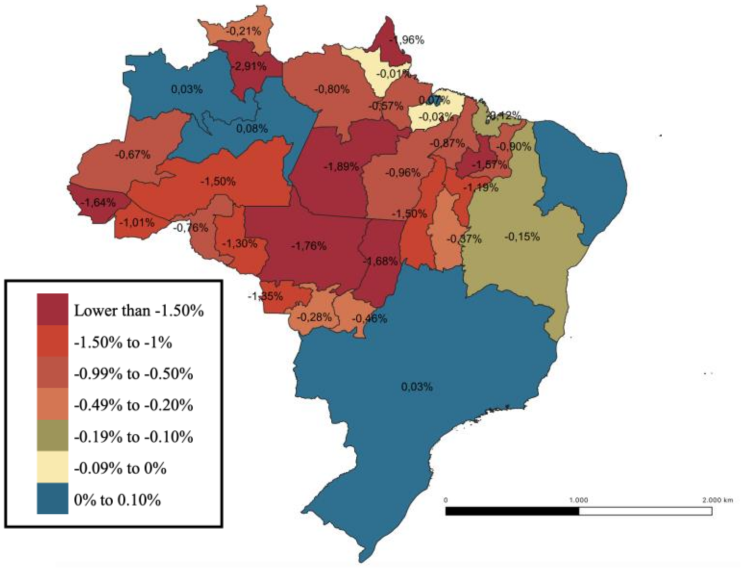

Figure 5 - Real GDP deviations of Amazon, Matopiba and remaining Brazilian regions

4.3. National macroeconomic results

Analyzing national macroeconomic indicators, presented in Table 2, we find that the economic impact of a consumers changes in preferences to reduce beef consumption is practically null. The greatest impacts are on investments and exports. This result is due to the substitution effect that benefits other sectors of the economy, driven mainly by the drop in the beef sector. And the positive effect on exports is due to the drop in prices caused by the demand reduction in this sector, leading to relatively cheaper domestic products.

Table 2 - National Macroeconomic Results in Cumulative 2050 (in % var.) as deviation from baseline scenario

Indicators	2050
National GDP	-0.03%
Households Consumption	0.00%
Government Consumption	-0.03%
Investiment	-0.08%
Exports	0.19%
Imports	0.05%

Source: Elaborated by the authors based on the simulation results

4.4. Household consumption

Although household consumption does not vary in terms of macroeconomic results, the composition of the basic food basket changes, since the reduction in beef consumption increases the demand for other foods. Figure 6 presents the variation in household demand for food (6.a) and the share of each food item in the household budget for the base year and for 2050 (6.b and 6.c).

In the initial periods of the simulation, the foods that replaces beef in household meals are other meats, milk and other dairy products, while the quantity demanded for other foods slightly reduces because the relative price of those animal-based foods decreases more. Prices fall because beef industry, which buys other foods to processed meats and other frozen foods, reduces its intermediate demand. In 2050, the demand for other foods increases while the demand for meats in general decreases. On the other hand, purchases of food meals in restaurants and others (food sector) increased slightly over the years (6.a), although its share in household budgets changed barely (6.b). The purchase of food, in the base year, occupies 19.93% of households budget, and in 2050, this share is smaller, 18.41%, due to the drop in food prices, including beef, which is still being consumed. The composition of food consumption basket is modified and beef starts to account for only 12.44% (of the 18.41%), against 22.21% in the base year. All other food items increase its share, especially fish, fruits and vegetables, veg. oils and fats, beverages, rice, and other food items. Households also increase their demand for other goods and services, in a distributed form, in 2050 accumulated, averaging 0.92%, and ranging from 0.70% to 1%.

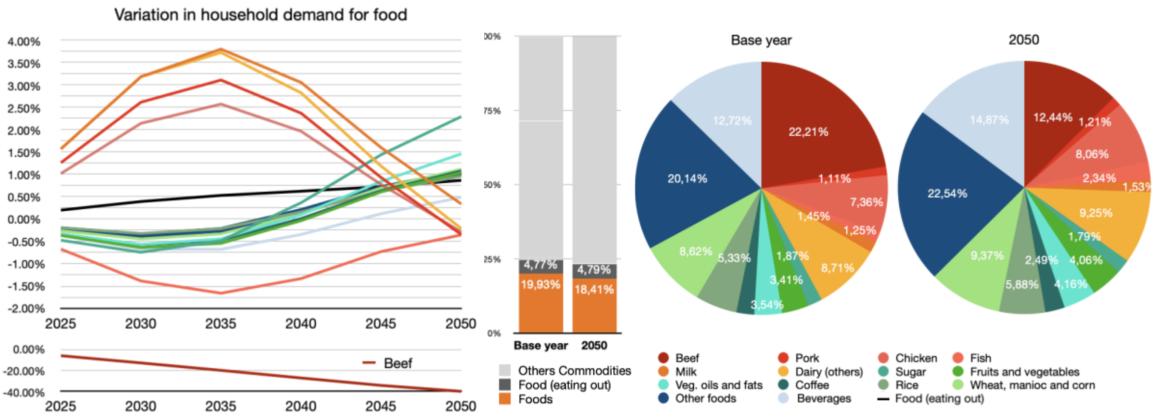

Figure 6 - Budget Share and Variation in household demand for food
Source: Elaborated by the authors based on the simulation results

4.3. Land Use Results

The reduction in livestock activity as a result of the drop in demand for beef causes a decrease in pasture area relative to the baseline scenario. With the reduction of this activity, a smaller area is required for its production, which decreases by 67,142 km², considering the area of all Amazon and Matopiba regions, as shown in Table 3. Despite this reduction in pasture area, there is an increase of 3,844 km² in crop area in 2050, compared to baseline scenario. This is because crop goods become more attractive in this simulation, and the growth of these activities led to an increase in the area used for these crops.

Even so, this change in preferences would lead to a reduction in deforestation by 63,297 km², which is equivalent to an area twice the size of Belgium. Figure 7 shows avoided deforestation by region. The region with the largest reduction in deforestation is Northern Mato Grosso, totaling 7,706 km², followed by the Northeast Mato Grosso, Southwest and Southeast Pará regions, which demarcate the so-called Arc of Deforestation. In Matopiba, PIBA region stands out for having the greater aggregated area of land, but when we add the preserved area of the mesoregions of each of the 4 states that comprise it, we note that each state contributes with 1/4 of the preserved area, about 5,200 km² each. In the rest of Brazil there is also a reduction of pasture, but with a more significant conversion to cropland.

Regions	FU	Cropland	Pasture	Regions	FU	Cropland	Pasture
Madeira Guaporé	RO	29.4	-2,801.2	North Amapá	AP	0.89	-312.29
East Rondonia	RO	73.45	-1,900.92	South Amapá	AP	1.88	-364.26
Juruá Valley	AC	6.15	-582.32	Western Tocantins	TO	193.37	-2,339.33
Acre Valley	AC	16.42	-1,386.54	Eastern Tocantins	TO	73.89	-2,338.54
North Amazonas	AM	0.56	-4.86	North Maranhão	MA	48.51	-712.75
Southwestern Amazonas	AM	0.89	-150.95	Western Maranhão	MA	66.20	-1,371.47
Central Amazonas	AM	4.16	-688.58	Central Maranhão	MA	56.13	-1,302.43
South Amazonas	AM	5.12	-2,619.23	Eastern Maranhão	MA	41.28	-1,239.79
North Roraima	RR	6.26	-975.29	Southeastern Maranhão	MA	104.64	-1,498.73
South Roraima	RR	3.05	-759.94	Piauí and Bahia	PI/BA	1,451.55	-12,303.89
Lower Amazonas	PA	15.3	-1,772.15	North Mato Grosso	MT	819.63	-8,526.14
Marajó	PA	22.74	-1,078.79	Northeastern Mato Grosso	MT	242.08	-3,828.67
Belém Metropolitan	PA	1.85	-13.74	Southwestern Mato Grosso	MT	61.99	-1,071.71
Northeastern Pará	PA	78.08	-649.11	Central-South Mato Grosso	MT	40.51	-2,516.74
Southwestern Pará	PA	46.94	-6,329.94	Southeastern Mato Grosso	MT	207.84	-1,191.74
Southeastern Pará	PA	123.74	-4,510.2	Rest of Brazil	-	4,994.28	-24,602.81
Amazon + Matopiba						**3,844.50**	**-67,142.24**
Avoided Deforestation (km²)							**-63,297.74**

Table 3 - Areas of pasture and cropland in km² - in 2050 accumulated
Source: Elaborated by the authors based on the simulation results

FINAL CONSIDERATIONS

This article aimed to identify the effects of a possible reduction in beef consumption on the Brazilian economy and on deforestation in the Amazon and Matopiba. As the results show, a reduction in beef consumption through changing consumer preferences would discourage livestock activity. Then the level of activity in this sector falls and discourages forest-pasture conversion, slowing deforestation. For a 40% reduction in demand for beef distributed over time up to 2050, the national economic impact is virtually zero. However, some regions that are more dependent on cattle sector may have a negative result on GDP and therefore regional effects are more heterogeneous. Even so, it is clear that environmental results are positive as the avoided deforestation area is 63,297 km², which represents 65% of the deforestation in the Amazon from 2016 to 2021.

Future studies could investigate the effects of a fiscal policy that acts to reduce the demand for beef in Brazil, and evaluate its economic and environmental effects in comparison with this

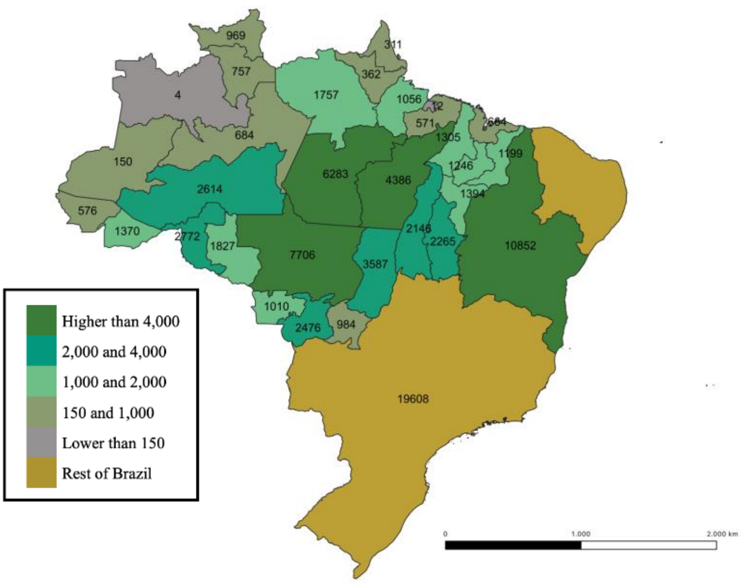

Figure 7 - Avoided deforestation (area in km²)
Source: Elaborated by the authors based on the simulation results

preferences change scenario. Although beef is a food of high nutritional value, its excess should be avoided since its production and consumption generates negative externalities, either on health or on environment via deforestation and GHG emissions. A fiscal stimulus scenario, through prices, can also address issues of social inequality, since individuals who consume beef below WHO's recommendations levels are the same ones who would suffer the greatest effect from higher prices.

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