Synergies of low-carbon technologies and land-sparing in Brazilian regions

Cicero Zanetti de Lima*[1], Angelo Costa Gurgel[1], and Erly Cardoso Teixeira[2]

[1] *São Paulo School of Economics, Fundação Getulio Vargas, São Paulo, SP, Brazil.*
[1] *Sao Paulo School of Economics, Fundação Getulio Vargas, Sao Paulo, SP, Brazil.*
[2] *Department of Agricultural Economics, Universidade Federal de Viçosa, Vicosa, MG, Brazil.*

Resumo: O Plano de Agricultura de Baixo Carbono (Plano ABC) no Brasil tenta conciliar crescimento sustentável da produção agrícola e minimização dos impactos ambientais promovidos pelas mudanças no uso da terra. O setor agropecuário e a mudança no uso da terra são as principais fontes de GEE do Brasil atingindo em 2015 67% (1.310 Mt CO2eq) do total das emissões. As tecnologias de recuperação de pastagens e sistemas integrados de produção surgem como estratégias promissoras para uma intensificação sustentável da agricultura brasileira, à medida que aumentam a matéria orgânica do solo, o sequestro de carbono e a produção agrícola por hectare. Esse artigo analisa a relação dessas tecnologias com o chamado efeito poupa terra. Considerando somente aspectos econômicos do Plano ABC, os resultados indicam que a associação das duas tecnologias promove o efeito poupa terra de modo agregado. Há um aumento das áreas naturais e áreas de florestas, especialmente aquelas localizadas dentro dos estabelecimentos agropecuários, bem como uma redução das áreas de culturas. Por outro lado, os resultados regionais indicam que regiões de fronteira agrícola intensificam o uso de pastagens em detrimento as áreas de vegetação nativa e florestas.

Palavras-chave: uso da terra, tecnologias de baixo carbono, equilíbrio geral computável.

Abstract: The Low-carbon Agriculture Plan in Brazil (ABC Plan) tries to conciliate sustainable growth of agricultural production and minimize the environmental impacts promoted by land-use changes. The agriculture, florest and other land uses (AFOLU) sector is the main source of GHG emissions in Brazil reaching in 2015 67% (1,310 Mt CO2eq) of total emissions. The implementation of pasture recovery and integrated systems technologies are therefore seen as a promising strategy for sustainable agricultural intensification in Brazil, since they can increase the organic matter in the soil, sequester carbon, as well as increase the production per hectare. This article analysis the relationship between these technologies and the land-sparing concept. Considering only the economic aspects of ABC Plan, the outcomes suggest that the interaction of both technologies promotes the land-spare effect in a aggregated way. There is a increase of natural and forest areas, specially those inside the rural establishments. However, the regional results show a different dynamic in the agricultural frontier. These regions intensify the pasture use to the detriment of native vegetation and forests areas.
Keywords: land-use change, land-sparing, CGE modeling.

Código JEL: C68, Q16, Q18, Q24.

*Corresponding author: FGV-EESP, 474, Itapeva st, 6th floor. Zip code: 01332-000, São Paulo - SP Tel.: +55 11 3799-3645 Mobile: +55 11 99665 7771. E-mail: czlima@gmail.com

1 Introduction

Brazil is considered one of the major players in World agriculture. The Brazilian Agribusiness sector has grown in real terms around 2.1% per year between 1994-2015 and is responsible for 21.5% of Brazil's GDP (CEPEA, 2016). The Agribusiness GDP was US$ 374 billion in 2015. The agro-processing industry accounts for 27% of it, the input and supply industry contributes with 12% inputs, service sectors 31%, and primary agriculture and livestock production with 30%. For the same year, the Agribusiness exports were US$ 88.2 billion and its trade balance was four times greater than Brazilian trade balance.

The crop and vegetables production grew from 76.6 Mt to 209 Mt between 1998-2016. In the same period the planted area grew from 35 Mha to 58.4 Mha. The production growth rate has been 2.6 greater than the area expansion, representing a strong productivity gain. The increase in yields was responsible for 94% of the growth in the period 1975-2011 (GASQUES *et al.*, 2013). In the period from 1990 to 2014 the livestock production grew 460% in the poultry sector, 225% in the case of pork, and 101% for beef. It was related to a productivity gain of 3.62% per year between 1975-1996, and 6.64% between 1996-2006 (MARTHA *et al.*, 2012).

In 2010 the Brazilian Government released the Low Carbon Agriculture Plan (ABC Plan) (MAPA, 2012) as part of the voluntary climate policy commitments set in the COP-15 in Copenhagen, to be implemented until 2020. The ABC Plan aims to mitigate GHG emissions in agriculture, improve efficiency in the use natural resources and increase the resilience of productive systems and rural communities, as well as enable the sector to adapt to climate change.

The actions present in the ABC plan seek to train technicians and rural producers, technology transfer, environmental and land regularization, technical assistance and rural extension, research, development and innovation, availability of inputs, seeds and forest seedings production, and subsidized rural credit (ABC Program).

The ABC Plan targets strategic investments in sustainable technologies to recover 15 Mha of degraded pasture, increase the use of production systems combining crop, livestock and/or forestry production in the same area in 4 Mha, expand no-tillage use and foster other low carbon technologies. Such technologies for emissions mitigation are derived from their own capacity to directly reduce GHG emissions, i.e., as a consequence of the productive process itself, and not as intensifying technologies which reduce the pressure on agricultural area expansion.

Recovered pastures reduce CO2 emissions by at least 60% in a production system and increase the biomass production. The nutrient replacement in the pasture improves the quality of the animal diet, reducing the time of slaughter and the emission of methane gas (CH4) by the enteric fermentation (KURIHARA *et al.*, 1999). Also reducing the pressure to convert new natural areas into pasture. When compared to a degraded pasture recovered areas provide a higher carbon stock to the system since with the accumulation of organic matter in the soil provides lower CO2 losses to the atmosphere.

Integrated crop-livestock systems (ICLs) are planned systems involving temporal and spatial interactions on different scales with animal and crop exploitation within the same area, simultaneously or disjointedly and in rotation or succession. The adoption of integrated systems is beneficial by reducing pasture degradation. The benefits of ICLs include improved nutrient cycling, increased fertilizer efficiency, increased soil fertility due to the accumulation of organic matter, and better soil aggregation (De Moraes *et al.*, 2014). Also, ICLs promote improvement in production processes, such as the machinery and labor, economic stability of factors, as well as risk reduction.

The ABC Plan actions mentioned above are strictly correlated to the concepts of land-sparing and agricultural intensification driven by technological changes. Land-sparing is based on the theory that aggregate increases in agricultural yields over time can reduce the overall area of agriculture lands from what would have been needed without the increase in yields. These increases could occur through either the use of degraded, marginal, and abandoned lands or through increases in yields on lands currently in cultivation (COHN *et al.*, 2014).

Intensification is define by an increase in the productivity of land measured by the real value of agricultural output per hectare (HAYAMI *et al.*, 1971). In this sense, one of the major pathways to intensification is technological process. Technology-driven intensification occurs when technical change in a crop allows more output per unit of land for the same level of inputs. This is a result of R&D, such as new seeds, better crop, and resource management practices (BYERLEE *et al.*, 2014).

The objective of this paper is assess the impacts of the ABC Plan's actions on land-use and land-use changes. What will be the new pattern of land use and competition and regional production given the large volume of degraded areas that will be recovered? We evaluate an agro-environmental policy that has not yet been quantitatively assessed in Brazil. Specifically, it also innovates by proposing the construction of a new Computable General Equilibrium (CGE) model. It represents the agricultural markets and segments of the main Brazilian agro-industrial chains, taking into account regional differences, competition for land use by different crops and activities, environmental aspects related to greenhouse gas emissions, and the evolution dynamics of the Brazilian economy, inserted in the global context.

The rest of the article is organized as follows. Section 2 presents the BREA model with land use representation, as well as the backstop technologies such as pasture recovery and ICLs. Section 3 concerns the main outcomes of the policy simulation, and some final remarks are given in section 4.

2 The BREA model

The Brazilian Economic Analysis (BREA) is a static computable general equilibrium model. BREA is a multi-regional and multi-sector model which represents the Brazilian economy by six regions: South, Southeast, Center-West, Northeast, Northeast Cerrado (Savanna), and North Amazon. Figure 1 shows the model representation. Each region's final demand structure is composed of

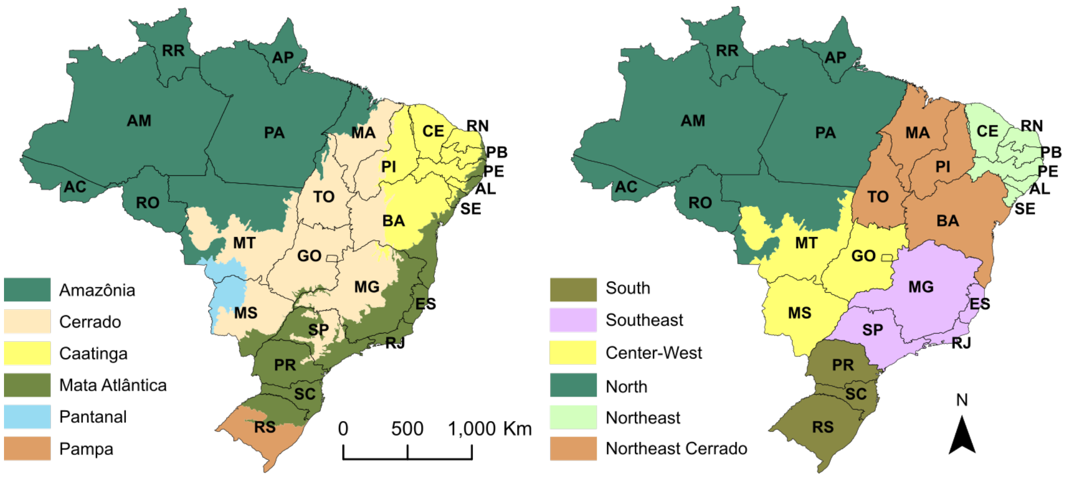

Figure 1: Brazilian biomes and regional aggregation in the model.
Source: IBGE (2016) adapted by author and research data.

public and private – consumption and investment – expenditure across goods. The model is based on optimizing behavior and the agents produce, consume and sell services and products. Consumers with their budget constraints and preferences demand goods maximizing their utility function. Preferences are hypothetically continuous and convex, and their resulting continuous demand functions are zero degree homogeneous with regard to prices, i.e., only relative prices can be determined.

On the production side, technology is described by a production function with constant returns to scale combining intermediate inputs, and primary factors (capital, labor, and land). In equilibrium the profit of firms is zero. Firms are assumed to have a specific production technology and demand factors to minimize their costs. The model enables analysis of direct and indirect effects arising from changes in public policies such as tariff shocks, tax rates, and endowments.

The model is based on GTAPinGAMS nomenclature and is written in MSPGE language, designed and solved as a nonlinear mixed complementarity problem in GAMS programming language (RUTHERFORD; PALTSEV, 2000; RUTHERFORD, 2005). Figure 2 shows the economic structure underlying the BREA model. The symbols in this flow chart correspond to variables in the economic model. Y_{ir} portrays the production of good i in region r, C_r, I_r, and G_r portray private consumption, investment, and public demand, respectively. XR_{ir} and MR_{ir} represent the regional trade of good i in region r, and M_{ir} the import of good i into region r. RA_r and $GOVT_r$ are the representative household and government consumers, and FT_r the activity through which the 'sluggish' factor of production is allocated to individual sectors. Commodity and market flows appear in solid lines and the doted lines represent the tax flows. To complete the economic structure, $difm_r$ is the sum of

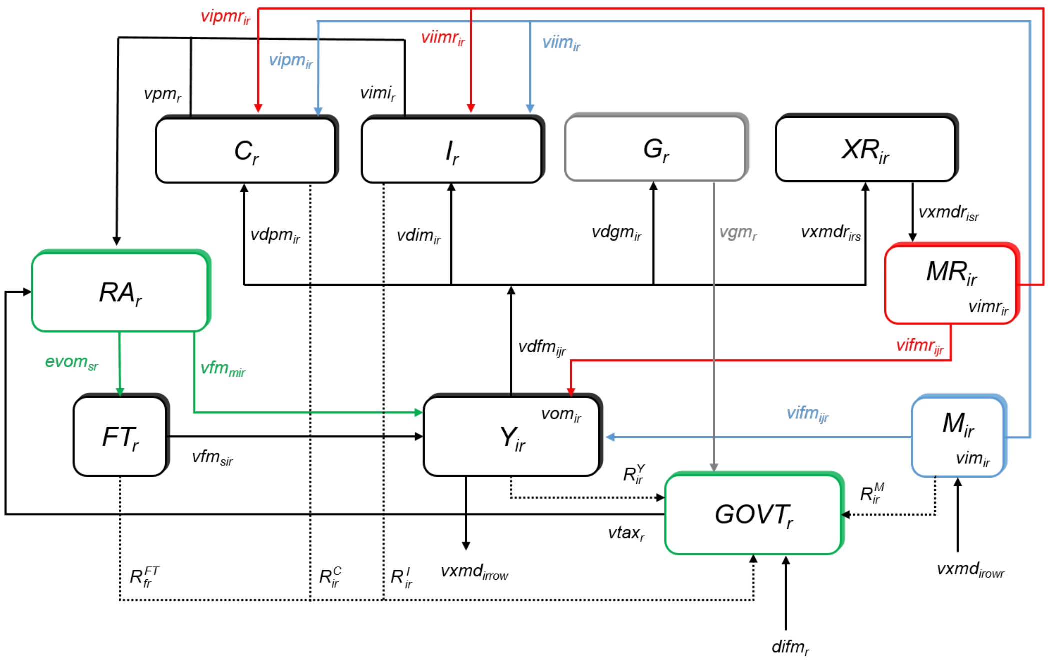

Figure 2: Regional economic structure.

Source: author.

regional and international trade balance, and $vtax_r$ is the government transfer to the households.

2.1 Database

The model runs with several database and these are divided in two different modules: economic and land use. The economic module uses the 2009 input-output table for Brazil made available by IBGE, and disaggregated among all Brazilian municipalities by NEREUS-USP [1]. The final data is aggregated into 36 sectors and three factors of production: capital, labor, and land as shown in Table 1. Several different data sets were revised and combined to build BREA, as those produced by IBGE, INPE (Brazilian National Institute for Space Research), MMA (Federal Ministry for the Environment), MAPA (Federal Ministry for the Agriculture), CONAB (Brazilian Supply Company), and SOS Mata Atlântica.

[1] <http://www.usp.br/nereus/>

Table 1: Regions, sectors, primary factors, and land use categories

Region		**Sectors**		**Primary factor inputs**	
South	STH	Mineral Iron	MIN	Capital	CAP
Southeast	SST	Coal	COAL	Labor	LAB
Midwest	MST	Mineral Extraction	NMM	Land	LND
North Amazon	NTH	Meats	MEAT	*Cropland*	*CROP*
Northeast Coast	NST	Soy oil	OSD	*Pasture*	*PAST*
Northeast Cerrado	NSTC	Foods	FOOD	*Degraded pasture*	*DPAS*
		Textile and wood	TEX	*Natural Forest*	*NFOR*
Sectors		Refined oil	ROIL	*Planted Forest*	*PFOR*
Rice	RICE	Ethanol	ETH	*Managed Forest*	*MFOR*
Corn	CORN	Chemistry	CHM	*Protected areas*	*PA*
Cane	CANE	Fertilizer	FERT	*Unused land*	*UNU*
Soy	SOY	Defensives	DFN		
Fruit	FRIT	Steel metal non-metallic	MMI		
Other Cultures	OCUL	Machines	MAC		
Forestry	FRST	Other Industries	OIND		
Cattle	CTTL	Electricity	ETRY		
Other live animals	OLA	Pipe gas	PGAS		
Swine	SWIN	Water	WTR		
Poultry	PTRY	Public Services	PSRV		
Milk	MILK	Construction	CONS		
Oil	OIL	Services	SERV		
Gas	GAS	Transportation	TRNS		

Source: research data.

2.2 Technology representation

The production technologies are represented by nested CES functions. The nested structure allows greater flexibility for inputs substitution, which is convenient when there is a higher level of sector disaggregation, but it requires the availability of elasticities of substitution related to each nest. The common nest structure for the agricultural sectors (rice, corn, cane, soy, frit, ocul), livestock sectors (cttl, ola), and forestry (frst) is presented in Figure 3. The structure shows how various inputs are aggregated in a nested fashion to represent the technology production. Components in dashed line denote separate functions. The fossil-based energy consumption is combined through a Leontief function, this fossil energy bundle is combined with the electricity consumption using a CES function, which generates an *Aggregate energy* nest. The other intermediate inputs are combined by a Leontief function (elasticity σ_{ne} equals to zero), and this nest is combined with the aggregate energy one resulting the *Energy-materials* nest. The primary factors of production, capital and labor, are combined in the top nest under elasticity σ_{va}, and combining with the *Resource-intense* nest resulting the sector output level. Note that the output is divided through a Constant Elasticity Transformation (CET) function in domestic demand and export demand under elasticity of transformation σ_t.

The elasticity σ_{fx} governs the substitution between *Energy-materials* and land and σ_s governs the substitution between the *Energy-materials-land* input bundle and the *Capital-Labor* bundle. These elasticities are set as 0.3 and 0.7, respectively (CHEN *et al.*, 2017). It means that higher prices for land can be overcome by substituting in the lower nest toward energy, fertilizer, and other materials, and in the upper nest toward capital. The actual simulated output of agricultural product per hectare of land in a scenario in each agricultural sector in BREA is a combination of endogenous intensification possibilities that depend on relative prices of inputs.

Technological change may enter in BREA model through three different ways. First, exogenous productivity growth in production factors following future trends expected in the scientific literature; second, different techniques or technology to mix inputs through substitution in the production function in each sector and induced by changes in relative prices; and third, new technology representation whose the inputs requirements and production function are specified in the model database. All three forms of technological change are pertinent in the land use modeling as described below.

In the first option, land is subject to an exogenous productivity improvement for each land type and agricultural sector. However, for a static version of the model is not trivial to justify productivity

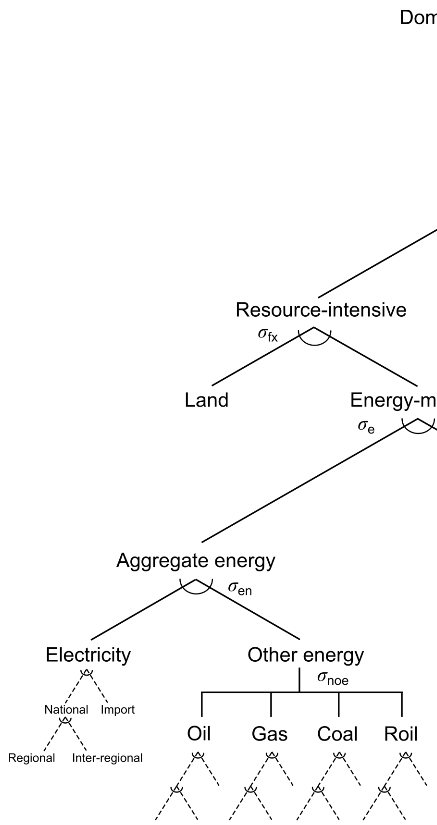

Figure 3: Structure of Production Sectors: agricultural, livestock, and forestry
Source: own elaboration.

gains in primary factors, the costs, and the benefits associated to it. Besides, it is possible to intensify conventional agricultural production in BREA as land can be partially substituted by inputs and other primary factors as relative prices changes.

The production intensification is controlled primarily by two substitution elasticities in the land-use sectors as aforementioned. The representation of new technologies is also a key feature of CGE models dealing with natural resources and environmental goods and services. In the case of land-use modeling and new agricultural technologies, such as presented in the ABC plan, the BREA model is the first one to explicitly represent these technologies, as well as its adoption.

Private consumption consistent with utility maximization is portrayed by minimization of the expenditure to reach a given level of aggregate consumption. Final demand in the core model is characterized by a Cobb-Douglas tradeoff across composite goods which include both domestic and imported inputs. Figure 4 displays the nested function for consumption. The lower level of the nested structure has three different bundle of goods. The first bundle is the energy bundle, a combination of all types of energy such as electricity, oil, gas, coal, and refined oil; the second is a combination of food and agricultural goods, and finally the third bundle is a combination of all other goods. The top level shows the household consumption of transportation. The transportation nest captures the total value spent in transportation services not including fuels.

2.3 Land Supply

Land use is one of the key elements for equilibrium conditions in CGE models, due to land being a factor in the production of agricultural sectors. There is an increasing debate about the land supply and its capacity to feed the global population, produce bioenergy crops and mitigate GHG emissions. Several models have been developed to address these issues (GTAP-BIO, EPPA, MIRAGE-bioF, IMAGE, LEITAP, and TERM-BR) (GOLUB *et al.*, 2012; GOLUB; HERTEL, 2012;

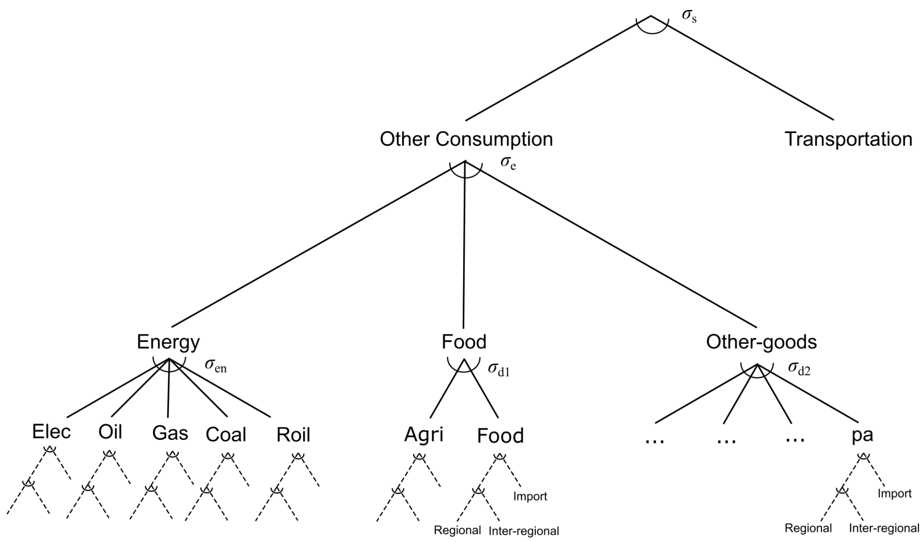

Figure 4: Structure of private consumption

Source: own elaboration.

GURGEL *et al.*, 2007; LABORDE; VALIN, 2012; STEHFEST *et al.*, 2013; Ferreira Filho; MORAES, 2015; SILVA *et al.*, 2017).

Figure 5 shows the nested CET structure for land supply. In this function the rent-maximizing land owner first decides on the allocation of land among natural uses. The land owner decides the allocation of land in natural areas and natural forest (public). Here, the CET structure captures the pressure for deforestation over native vegetation. The land owner then decides on the allocation of land between natural forest (private) and managed forest. Finally, the land owner decides on the allocation of land among pasture, planted forest, and cropland.

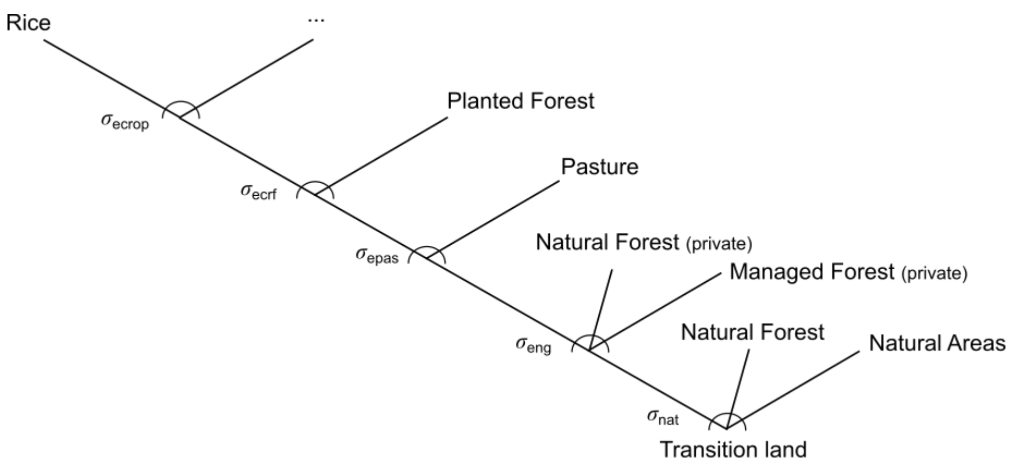

Figure 5: Land supply.

Source: research data.

The CET parameter governs the ease of land mobility across uses within each region. The parameter in cropland, planted forest, and pasture determines the ease with which land is transformed across three economic uses, e.g., from planted forest to cropland. In the same way, the CET parameter in the cropland nest determines the ease of transformation of land from one cropping activity to another, e.g., from soybean to corn.

To keep consistency in land-use changes measured in physical hectares, the BREA model incorporates an adjustment in the land supply. This is done by incorporating an additional constraint into the model that requires physical hectares employed in cropping, pasture, and forestry to add up to total physical area. The model applies an adjustment to the CET aggregator such that it could maintain the equivalence of input and output flows in terms of both value and physical units, respectively (CHEN *et al.*, 2013).

Once we have priced natural forest and natural areas, these are incorporated in the model as part of the initial endowments of households in each region. The areas may be converted to other uses or conserved in their natural state. The reservation value of natural lands enter each regional representative agent welfare function with an elasticity of substitution with other consumption goods and services (CHEN *et al.*, 2017; GURGEL *et al.*, 2017).

2.4 Backstop technologies

The central idea of the backstop technology is an approach for representing adoption in a CGE framework (MORRIS *et al.*, 2014). We seek a simple formulation that can be parameterized based on observations, while capturing elements of rent and real cost increases if demand suddenly increases due to a policy shock. The process is consistent with a general equilibrium framework and applied to the Brazilian Economic Analysis model.

To produce the same outputs as those from current technologies (e.g. pasture land) backstop technologies are usually more expensive to operate in the base year. Because of this, most backstop technologies have not run at commercial scales, have been adopted only marginally by some producers, or have not operated at all so far, but they may become economic in the future pending changes such as economic incentives or policy interventions.

Some backstop technologies have been run at nontrivial scales since 2012 (mostly due to incentives or support provided by the government), including consortium production and crop-livestock systems. BREA model represents the technology for pasture recovery considering different regional costs regardless the degradation level of pasture. Moreover, the model explicitly represents two types of integrated production: crop-livestock and crop-livestock-forestry. To the former the output is a combination of grain (maize or soybean) and cattle, while the latter is a combination of grain (maize or soybean), cattle, and forestry.

The calibration process is based on technical and engineering observed data about the costs and the output levels of these technologies (ANUALPEC, 2010; SENAR, 2013). The backstop technology for pasture recovery combines the capital-labor bundle, intermediate inputs - mainly chemicals and fertilizers - and degraded pasture land to produce pasture as output (Figure 6). This representation permits to aggregate value in land since the farmer could apply new agricultural techniques trough combination of chemicals and fertilizers as well as machinery to improve the pasture productivity. Consequently, the farmer has a better pasture land with higher productivity and value added.

Table 2 and Figure 6 show how the backstop technologies are connected to the technology representation in the model. The value of land portrays the ratio between the rents of degraded pastures and good pastures. In this fashion way the conversion occurs by one hectare of land each time keeping the equivalence of input and output flows in terms of both value and physical units, respectively.

Furthermore, the markups shown in Table 2 portray the regional difference between the calibrated costs for pasture recovery and the observed loans data that the farmers took in the ABC program. For example, for South region as a whole the total farmers' loans reach 32.3 times greater than the total cost to recovery the observed area. The model considers only the cost with chemicals and machinery to recover the pasture, however according to the ABC program the farmers could use the loan to build, for example, a fence on the property or on the recovered area, as well as other types of investments. As a result the markup values should be higher to capture these regional differences.

The integrated systems use only pasture as land primary factor. The combination with intermediate inputs, capital, and labor produces different levels of output such as grain, beef, and forestry.

Equally important, the ICLs do not have markups to reflect the costs of its economic penetra-

Table 2: Markups for pasture recovery backstop technologies.

Regions	**South**	**Southeast**	**Center-West**	**North**	**Northeast**	**Northeast Cerrado**
Fertilizers	0.093	0.081	0.076	0.144	0.141	0.097
Defensives	0.056	0.049	0.046	0.087	0.085	0.058
Chemicals	0.054	0.047	0.044	0.083	0.082	0.056
Capital	0.141	0.123	0.115	0.219	0.215	0.147
Labor	0.022	0.019	0.018	0.033	0.033	0.022
Land	0.634	0.682	0.703	0.433	0.444	0.620
Total	1.000	1.000	1.000	1.000	1.000	1.000
Markup	**32.3**	**49.1**	**78.6**	**61.4**	**63.4**	**120.4**

Source: based on (ANUALPEC, 2010) and own elaboration.

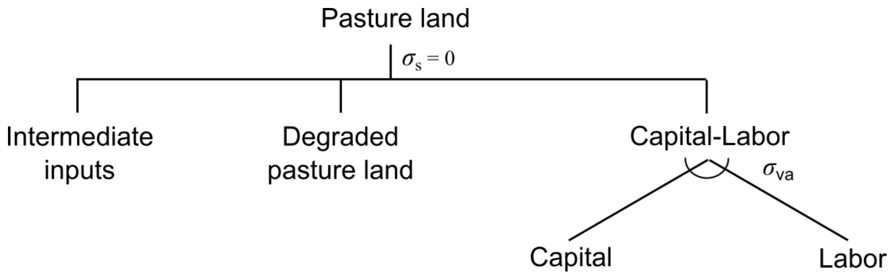

Figure 6: Backstop technology for pasture recovery.

Source: research data.

tion. Assuring the ICLs can only use pasture land all the costs of pasture recovery are captured in the function shown in Figure 6. With this approach the functions representing the ICLs give the total direct investment to implement these systems.

2.5 Strategic scenarios

We assess the economic impacts ABC Plan's actions, such as pasture recovery (15 Mha) and increase the integrated systems (4 Mha). The range of scenarios is chosen to represent quite different approaches to policy implementation. The assessment of the likely results from the *Priority* scenario are evaluated against the *Non-Priority* scenario. The *Combined* scenario assess the costs when the assumption over priority areas for pasture recovery is relaxed.

Non-priority: We simulate the Brazilian voluntary commitment recovering 15 Mha of degraded pasture and increasing the integrated systems in 4 Mha by 2020. The model applies freely such technologies in different Brazilian regions.

Priority: In the second policy simulation, we add a constraint in the new technology adoption. Such technologies are strictly used in priority regions defined by the degraded level of pasture present in the model benchmark and shown in Table 3. The technology for integrated systems is calibrated based on the observed data rather than freely as in the previous scenario. Simulating this combination offers insights into comparing the policy design in terms of costs and effectiveness.

Combined: In the third scenario, we relax the constraint over priority areas. Their combination offers insights about how much could be spend in pasture recovery when the constraint is relaxed. It also offers the possibility to explore synergies between two different policy instruments.

In practice the shock enters into the model via subsidy of the regional governments for the backstop technologies. It is possible to capture the penetration costs of each action as they become available to farmers. These technologies are calibrated based on observed data, technical reports, and agricultural engineering data to represent all the ABC costs as well as the penetration of the new agricultural practices in the economic system.

3 Results

We start defining the main land-uses in BREA model. A better representation of land in a CGE framework allows investigation of its use as an input to economic activities, as well as environmental consequences of using land since the natural areas - forest and non-forest - are represented in the database. The land-use and land-use changes are driven not only by increasing the demand for food, fuel and fiber, and the maintenance of natural environmental, but also by the agricultural aptitude of these areas, as well as the willingness to convert them (GURGEL *et al.*, 2017).

Cropland - areas planted with one of the six crops[2] categories in the model: rice, maize, sugar cane, soybean, fruits, and other cultures. Total area for cropland is around 65 Mha. Southern, Southeastern, and Center-Western regions concentrate around 74% of total area, while the Northern and Northeastern Cerrado region – the new agricultural frontier – represents around 21%.

Pasture - areas with natural grass or planted pasture used for livestock ranching and other live animals. The regions North and Northeast Cerrado represent 43% of pasture in the model and as aforementioned are the new agricultural frontier in Brazil. The total pasture estimated is 168 Mha and 48 Mha of that is considered degraded pasture.

Degraded Pasture - areas with natural grass or planted pasture used for livestock ranching and other live animals with low productive capacity. The occupation rate (or) is the ratio of total heads and total pasture. The occupation rate determines the degradation level of pasture as well as the division among different degradation levels. Pasture areas supporting levels of 0.75 animal units or less per hectare are considered degraded areas. Table 3 shows the data of degraded pasture in the model representation.

Table 3: Total pasture, degraded pasture, occupation rate (or), and levels of degradation.

Regions	Pasture (1,000 ha)			Levels of degradation	
	Total	Degraded	Occupation rate	Very High $0 \leq or \leq 0.4$	High $0.4 < or \leq 0.75$
South	17,740	5,663	0.59	403	5,260
Southeast	28,480	8,398	0.56	1,231	7,168
Center-West	37,743	1,232	0.65	10	1,222
North	34,325	1,834	0.54	461	1,373
Northeast	14,259	11,317	0.38	6,586	4,731
Northeast Cerrado	36,248	19,775	0.32	13,627	6,148
Total	168,794	48,220	0.51*	22,317	25,903

Source: research data, own elaboration.
* Average of all regions.

Table 4: Area of BREA classes per region in Brazil.

Regions	Cropland	Pasture	Degraded pasture	Natural areas	Natural forest	Managed forest	Planted forest	Others categories	Total
sth	19,146	12,077	5,663	7,566	2,624	512	2,153	7,936	**57,677**
sst	13,778	20,082	8,398	23,676	6,762	1,164	3,463	15,138	**92,462**
cst	14,988	36,510	1,232	21,143	11,371	675	675	26,436	**113,031**
nth	5,168	32,491	1,834	2,522	50,275	1,039	413	311,465	**405,206**
nst	3,519	2,942	11,317	14,070	4,567	1,605	8	2,574	**40,601**
nstc	8,568	16,472	19,775	42,059	28,504	3,479	906	22,837	**142,600**
Total	**65,166**	**120,575**	**48,220**	**111,035**	**104,103**	**8,472**	**7,619**	**386,387**	**851,577**

Source: research data.

Considering pasture recovery the regional technology costs are driven by the land rentals. The ratio between the rentals of degraded pastures and good pastures represents how much economic effort

[2] The areas of second and third harvest of crops in the same calendar year, such as corn, potato, peanut, and bean are not considered. We avoid the overestimation of planted area using only the data for the first crop in these cultures.

must be applied to recovery these areas. For instance, ratios of 0.70 and 0.44 for Center-West and North regions, respectively, show lower investment to recovery the same quantity of area in Center-West when compare to North (as shown in Table 2). Integrated systems such as crop-livestock and crop-livestock-forestry only demand good pasture land as sector-specific primary factor, i.e., these systems compete for land with cattle (cttl) and other live animals (ola) sectors. In this case, the farmers are willing to apply these technologies only in high productivity or recovered areas, given the investment volume and the profitability time, specially the case of integrated system with forest component. Consequently, the ICLs are not considered a recovery strategy in this research, even though these systems have shown recovery and mitigation potentials (De Moraes *et al.*, 2014).

The aggregated value of land-use change is presented in Figure 7 under different scenarios. Duo to the policy implementation the outcomes of degraded pasture recovered under all scenarios are the same (15 Mha). First, the outcomes show an increase in pasture land around 10 Mha under *Non-priority* and *Priority* scenarios, and a slightly smaller area (9.6 Mha) under *Combined* scenario. Despite the type of land recovered these values are a result of the competition for land by different uses, i.e., not necessarily all 15 Mha would be converted in pasture land. As the supply of land increases and also its productivity less land is used for traditional activities and more land is available for other uses.

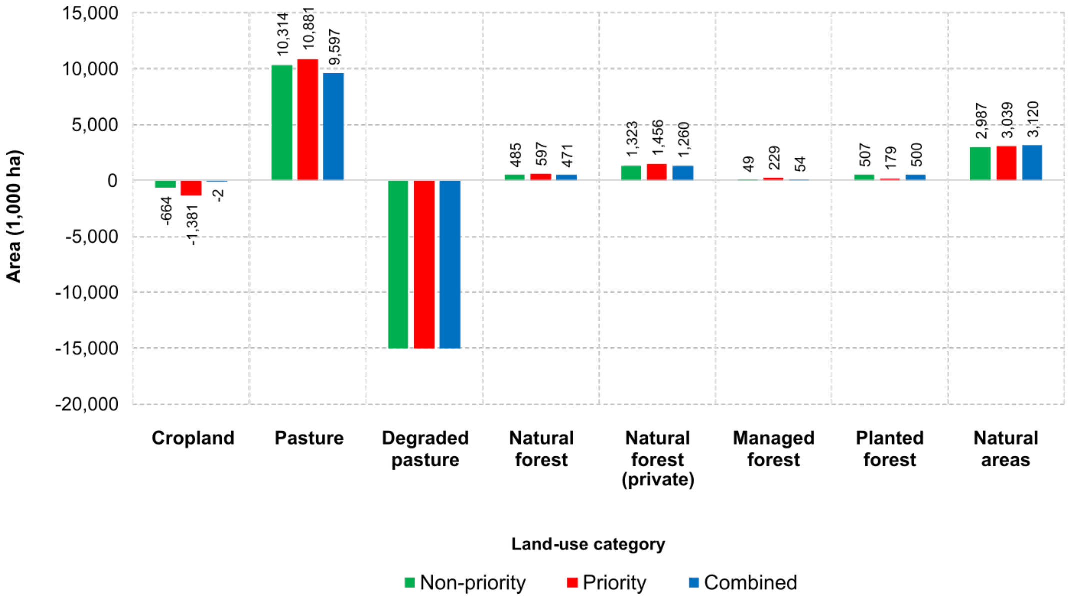

Figure 7: Aggregated land-use change under different scenarios.
Source: research outcomes.

Second, the technologies associated to the ABC Plan reduce the pressure over natural areas and natural forests. Outcomes for all scenarios show an increase around 4.8 Mha in natural and forest areas (public and private), which approximately 38% occurs in forest areas, specially those areas inside the private establishments. For managed and planted forest areas the outcomes show a small increase by 0.556 Mha and 0.554 Mha under *Non-priority* and *Combined* scenarios, respectively, and 0.408 Mha under *Priority* scenario. At a national level there is a synergy between the recovery pasture and forest actions such as control of deforestation, and planted forest, even though the model does not explicitly represent the forest sector's actions. As the recovered areas of pasture increase there is more suitable land for planted and managed forest activities, as well as less pressure to clear new natural land.

Third, there is a decrease in cropland use indicating a intensification process across commodities production despite the regional outcomes. Under *Priority* scenario the value of cropland use decreases 1.4 Mha. This result suggest a synergy between the two ABC Plan's actions analyzed in this research. As the productivity of the recovered areas increases, such areas are destined to the production of more profitable crops, such as soybean and maize. Indeed, there are two factors that governs the intensification of production. On the one hand, the livestock sectors demand less land per output and, by other side, soybean and maize are produced in an integrated system with livestock and/or forest. Also there are indirect environmental externalities, such as control of deforestation, biodiversity conservation, ecosystem services, since the natural and forest areas are preserved. It is a strategy *win-win-win* for land-sparing. The agricultural intensification and environmental preservation to achieve a sustainable production of beef and grains are dependent of ICLs' implementation and diffusion.

Figure 8 shows the areas of integrated systems under different scenarios. The areas of integrated systems with maize or soybean and livestock represent more than 90% of total observed data. The outcomes for these integrated systems differ across scenarios. The addition of a restriction to recover pasture (*Priority* scenario) increases the allocated area with soybean integration. The same occurs under *Combined* scenario. Even if the technology representation for integration with maize and soybean are similar these results are consequence of the regional aptitude and share of soybean production.

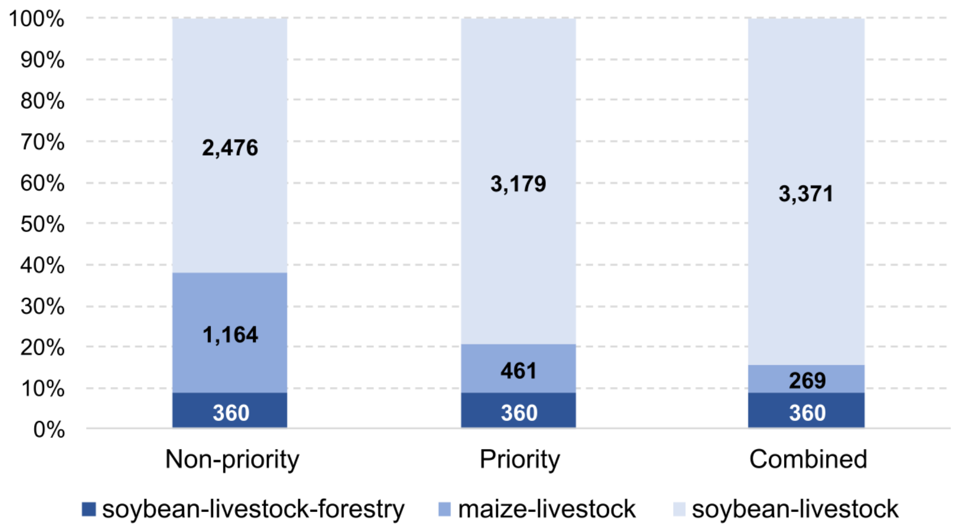

Figure 8: Area of each integrated systems under different scenarios (1,000 ha).
Source: research outcomes.

3.1 Regional land-use changes

Regional outcomes of land-use changes are summarized in Figure 9. They are differently across regions since each regional economic structure is unique, however the outcomes among alternative scenarios preserve direction and intensity.

Under *Non-priority* scenario South and Southeast regions show the largest shares of recovered areas followed by Northeast Cerrado. These regions have lower recovery costs and large areas with degraded pasture which means more suitability to actions present in the ABC Plan. Also these three regions have an increase in natural areas and natural forest under all scenarios. It means the process of recover degraded pasture slow the pressure over natural areas and settle area for other agricultural activities, such as crops and planted forest. The same dynamic occurs under *Priority* and *Combined* scenarios.

However, in the Center-West region there is a decrease in the natural areas and forests under all scenarios. In the North region there is a decrease in the managed and planted forests, and a small increase in the natural forest (private). Additionally, the pasture land in these regions increases more than the recovered pasture under all scenarios. The same occurs in the Northeast Cerrado. This result is unique when compare to the other regions. The Center-West region was the agricultural frontier in Brazil during 80's. Nowadays, the region presents a large area of pasture land and the livestock ranching is an important regional economic activity. The higher return of land allocated to livestock compared to other land uses creates an incentive to keep pasture as the main land use, even though with the ABC actions. The period between 1990-2014 was marked by the diffusion of different technologies such as no-till system, seed quality, legalization of planting of genetically modified cultivars that simplified agricultural management and practices, as well as monetary and market stability (Vieira Filho, 2014). These factors reshaped the agricultural frontier into Northeast Cerrado region. Our results suggest at regional landscape, specially in the agricultural frontier the technologies for pasture recovery and ICLs are not capable to promote land-sparing, as a result the farmers keep pasture as the main land use. The ABC Plan should concern the complexity and cost of establishing the necessary facilities to implement ICLs, which require technical and economic expertise and other types of unattained knowledge (De Moraes *et al.*, 2014); the absence of small-scale business models that could be used on small-scale farms (GIL *et al.*, 2015); and credit access, technical extension and labour scarcity (LATAWIEC *et al.*, 2017);

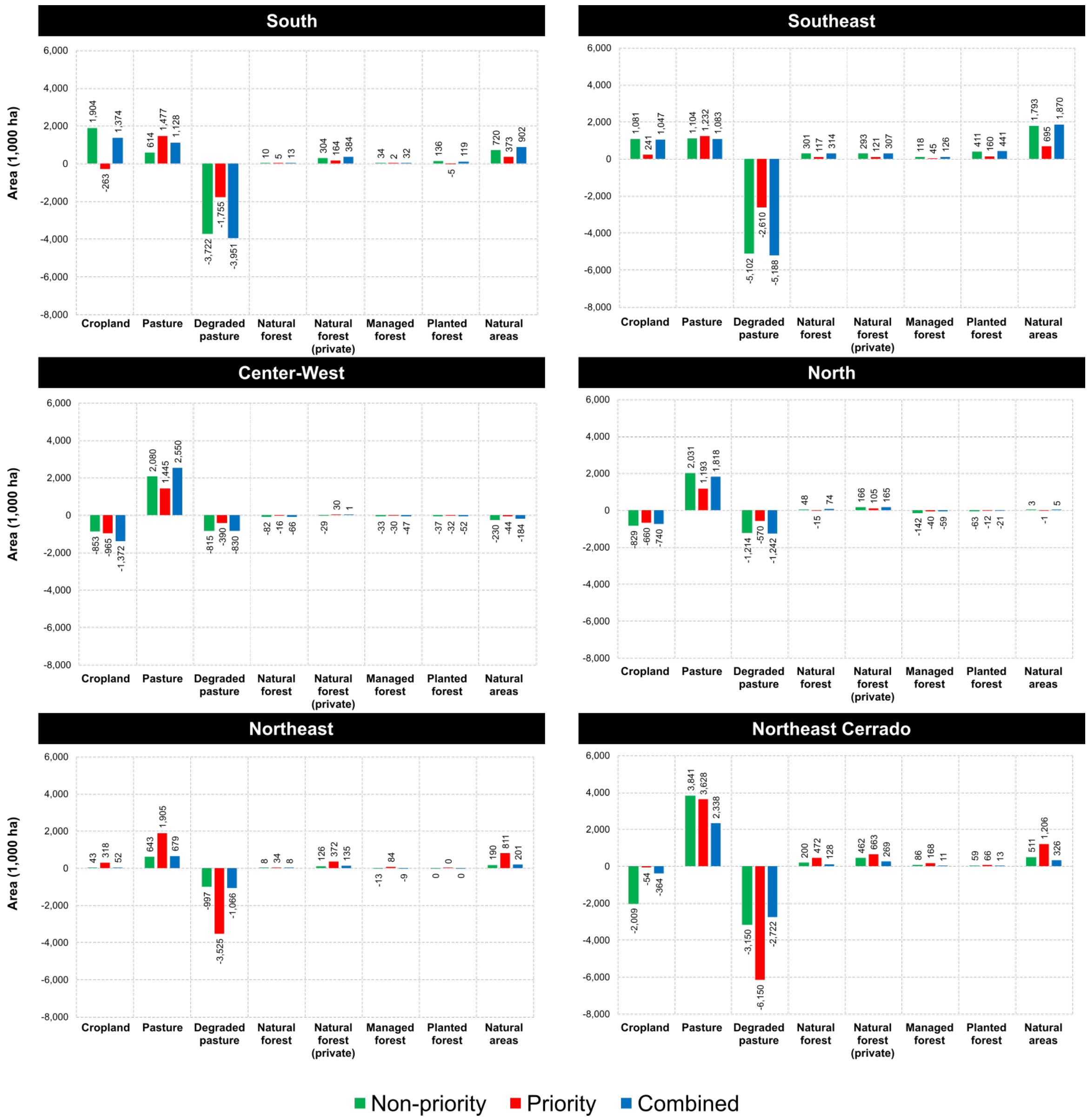

Figure 9: Land-use changes by region under different scenarios.
Source: research outcomes.

Third, the land-use changes are less sensible in the Northeast region when compare to other regions in the model. Only under *Priority* scenario the land-use change in this region has a strong response to the policy implementation. It shows the regional dependency of specific policies for this region, which historically is the poorest region in Brazil. Also, the Caatinga biome represents a challenge to the agricultural development in Brazil, because the region is a seasonally dry tropical forest and consists of dry forest species rather than savanna species. On the other hand, the Northeast Cerrado region shows an increase in the pasture land and as mentioned above, and an increase in the natural and forest areas. This region represents a good opportunity for agricultural intensification since is present in a large part of the Cerrado biome and presents soil with agricultural aptitude.

Figure 10 shows the outcomes of land-use by integrated systems and regions. These type of technologies are not active in the benchmark equilibrium, consequently the results show absolute value of area. Looking carefully the regional outcomes are extremely dependent on how the policy scenario is designed and the parameters associated to them. Under *Non-priority* scenario, which

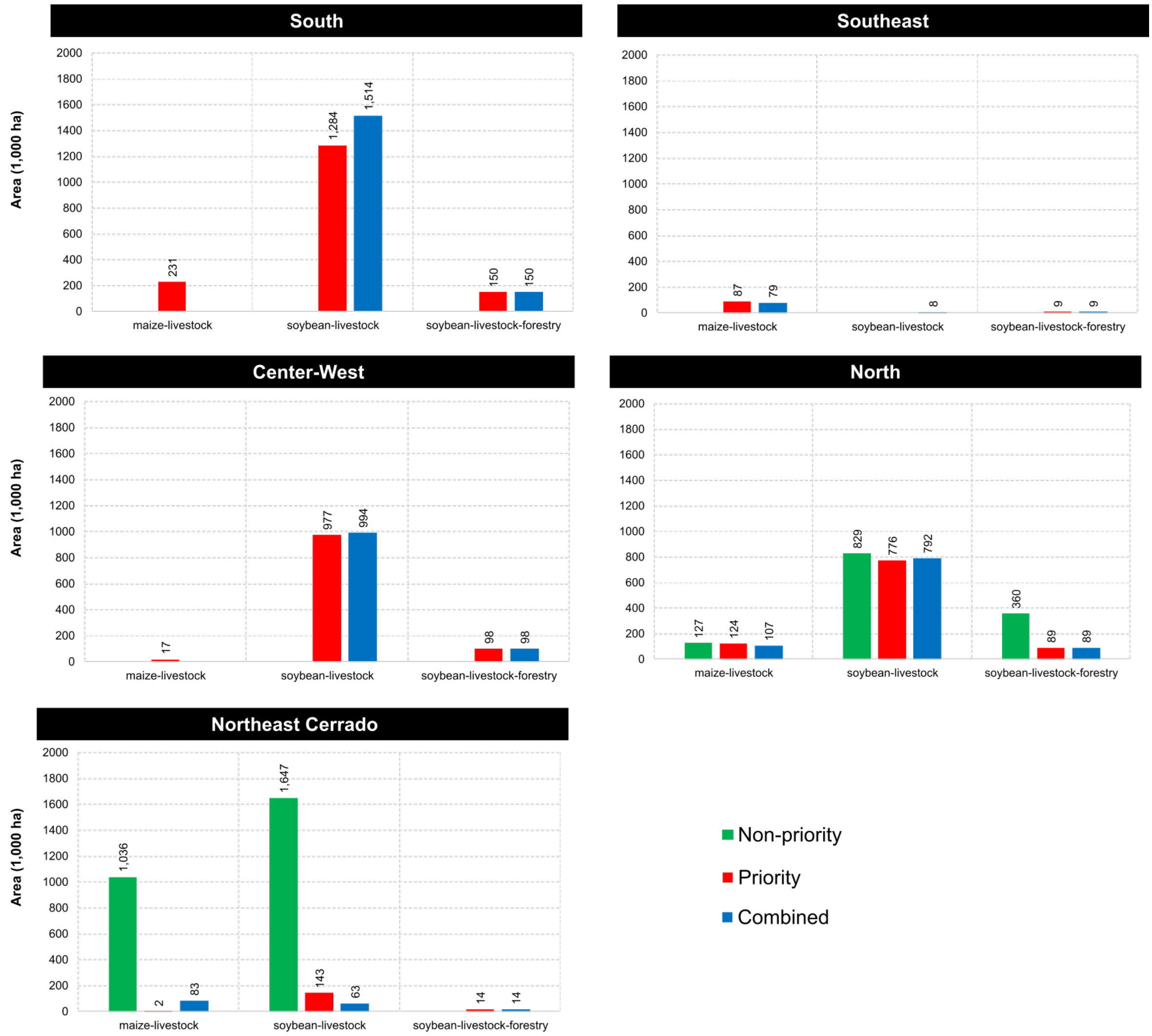

Figure 10: Area of each integrated systems by region under different scenarios.
Source: research outcomes.

allows the free policy implementation, the Northeast Cerrado region has the largest areas of ICLs (74%), followed by North region (26%). The large areas of pasture and degraded pasture associated to low prices of intermediate inputs and primary factors attract the available resources for implementing the ICLs. The restriction added under Priority and *Combined* scenarios interrupt the flow of resources towards the Northeast Cerrado region. As a result, the area of ICLs drops drastically from 2.7 Mha to 0.145 Mha. Also, the ICLs in the North region decrease from 0.956 Mha to 0.899 Mha representing around 24.7% of total ICLs area.

The participation of other regions, such as South, Center-West reaches 41.6% and 27.3% of total ICLs areas, respectively. The Southeast has only 2.4% of total. These results are strictly correlated to the observed data of integrated systems in Brazilian regions. However, the scenarios simulation shows that the implementation constraint increases the volume of resources allocated to carry out the crop-livestock and crop-livestock-forestry technologies.

The first insight here concerns about the flow of resources to Northeast Cerrado and North regions under *Non-priority* scenario. Indeed, this scenario has the lowest cost for ICLs implementation around R$ 5.9 billion. However, the model does not capture the implicit costs to carry out theses technologies, such as land tenure, propriety rights, and infrastructure, specially for transportation, which is extremely important for agricultural production.

Nevertheless, the other two scenarios show that technologies migrate to South, Center-West, and North regions, as a result the policy cost is higher than the first scenario. These regions show higher prices for intermediate inputs and primary factors, specially land, which reflect in the policy costs. Also, in regions such as Center-West and Southeast, these new technologies are in competition with traditional agricultural activities, which are technology-intensive with high specialization. It might create barriers to the entry of low-carbon technologies.

4 Final remarks

The modeling results provide important quantitative insights and help identify stakeholders that stand to benefit or lose, along with the extent of impact on them. The ABC policy simulated through priority areas of degraded pasture results in the highest decline in consumer welfare.

Under different simulated scenarios we have endeavored to analyze the land-use changes by regions. Both policies with enforcement or not have shown that the pasture recovery associated to the ICLs technologies are land-sparing technologies. As the productivity of recovered areas increase settle area for new production systems, such as ICLs. ICL technologies have presented a great opportunity for livestock intensification as well as reduce the pressure to clear new natural areas and forest areas in Brazil. In fact, the model projects an increase of natural forest inside the rural establishments indicating a growth in the agricultural income. Despite the regional costs of implementing each ICL system the integration with soybean has shown economic advantages across regions, specially without enforce policy.

The comparison of diferent production values per ha across sectos and ICLs has shown an increase in the productivity, which could achieve around 20% in the Northeast Cerrado region. The ICLs could improve the efficacy of investments, intensify land use, and provide a stable productive system. Also, with the livestock integration the landholders have more options for diversification and consequentially additional income.

At regional land-use level the outcomes have suggested a maintenance of some traditional agricultural activities in their regions. It is the case of single livestock production in the Center-West and North regions, rice in the South, and sugarcane in the Southeast and Northeast regions. Concerning regional land-use changes only Center-West, North, and Northeast Cerrado have shown an increase in pasture land more than the recovered area. It suggests that both traditional activities as livestock ranching and the ICL systems increase this land-use category.

References

ANUALPEC. **Anuário estatístico da pecuária de corte**. São Paulo, 2010.

BYERLEE, D.; STEVENSON, J.; VILLORIA, N. Does intensification slow crop land expansion or encourage deforestation? **Global Food Security**, Elsevier, v. 3, n. 2, p. 92–98, 2014.

CEPEA. **Centro de Estudos Avançados em Economia Aplicada**. 2016. Disponível em: <http://www.cepea.esalq.usp.br/>.

CHEN, Y.-H.; PALTSEV, S.; REILLY, J.; MORRIS, J.; KARPLUS, V.; GURGEL, A.; N. Winchester, P. K.; BLANC, É.; BABIKER, M. **The MIT Economic Projection and Policy Analysis (EPPA) Model: Version 5**. Cambridge, MA, 2017.

CHEN, Y. H. H.; TIMILSINA, G. R.; LANDIS, F. Economic implications of reducing carbon emissions from energy use and industrial processes in Brazil. **Journal of Environmental Management**, Elsevier Ltd, v. 130, p. 436–446, 2013. ISSN 03014797. Disponível em: <http://dx.doi.org/10.1016/j.jenvman.2013.08.049>.

COHN, A. S.; MOSNIER, A.; HAVLÍK, P.; VALIN, H.; HERRERO, M.; SCHMID, E.; O'HARE, M.; OBERSTEINER, M. Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation. **Proceedings of the National Academy of Sciences of the United States of America**, v. 111, n. 20, p. 7236–7241, 2014. ISSN 1091-6490.

De Moraes, A.; CARVALHO, P. C. d. F.; ANGHINONI, I.; LUSTOSA, S. B. C.; COSTA, S. E. V. G. d. A.; KUNRATH, T. R. Integrated crop-livestock systems in the Brazilian subtropics. **European Journal of Agronomy**, Elsevier B.V., v. 57, p. 4–9, 2014. ISSN 11610301. Disponível em: <http://dx.doi.org/10.1016/j.eja.2013.10.004>.

Ferreira Filho, J. B. d. S.; MORAES, G. I. de. Climate change, agriculture and economic effects on different regions of Brazil. **Environment and Development Economics**, v. 20, n. 01, p. 37–56, 2015.

GASQUES, J. G.; BASTOS, E. T.; VALDES, C.; BACCHI, M. **Produtividade e crescimento: algumas comparações**. [S.l.], 2013. 9 p. Disponível em: <http://www.agricultura.gov.br/arq{_}editor/file/0tabelas/ProdutividadeeCrescimento-Artigo310113{_}>.

GIL, J.; SIEBOLD, M.; BERGER, T. Adoption and development of integrated crop-livestock-forestry systems in Mato Grosso, Brazil. **Agriculture, Ecosystems and Environment**, Elsevier B.V., v. 199, p. 394–406, 2015. ISSN 01678809. Disponível em: <http://dx.doi.org/10.1016/j.agee.2014.10.008>.

GOLUB, A. A.; HENDERSON, B. B.; HERTEL, T. W.; GERBER, P. J.; ROSE, S. K.; SOHNGEN, B. Global climate policy impacts on livestock, land use, livelihoods, and food security. **Proceedings of the National Academy of Sciences of the United States of America**, v. 110, n. 52, p. 1108772109–, 2012. ISSN 1091-6490. Disponível em: <http://www.pnas.org/cgi/content/long/1108772109v1>.

GOLUB, A. A.; HERTEL, T. W. Modeling land-use change impacts of biofuels in the gtap-bio framework. **Climate Change Economics**, v. 03, n. 03, p. 1250015, 2012. Disponível em: <http://www.worldscientific.com/doi/abs/10.1142/S2010007812500157>.

GURGEL, A.; CHENB, Y.-H. H.; PALTSEVB, S.; REILLYB, J. Cge models: Linking natural resources to the cge framework. In: **WORLD SCIENTIFIC REFERENCE ON NATURAL RESOURCES AND ENVIRONMENTAL POLICY IN THE ERA OF GLOBAL CHANGE: Volume 3: Computable General Equilibrium Models**. [S.l.: s.n.], 2017. p. 57–98.

GURGEL, A.; REILLY, J. M.; PALTSEV, S. Potential Land Use Implications of a Global Biofuels Industry. **Journal of Agricultural Food Industrial Organization**, v. 5, n. 2, p. 1–34, 2007. ISSN 1542-0485. Disponível em: <http://www.degruyter.com/view/j/jafio.2007.5.2/jafio.2007.5.2.1202/jafio.2007.5.2.1202.xml{\%}5Cnhttp://www.bepress.com/jafio/vol5/iss2/a>.

HAYAMI, Y.; RUTTAN, V. W. *et al.* **Agricultural development: an international perspective.** [S.l.]: Baltimore, Md/London: The Johns Hopkins Press, 1971.

KURIHARA, M.; MAGNER, T.; HUNTER, R. A.; MCCRABB, G. J. Methane production and energy partition of cattle in the tropics. **British Journal of Nutrition**, v. 81, n. 1, p. 227–234, 1999. Disponível em: <https://www.cambridge.org/core/services/aop-cambridge-core/content/view/S0007114599000422>.

LABORDE, D.; VALIN, H. Modeling Land-use changes in a Global CGE: assessing the EU Biofuel mandates with the Mirage-BioF model. **Climate Change Economics**, v. 03, n. 03, p. 1250017, 2012. Disponível em: <http://www.worldscientific.com/doi/abs/10.1142/S2010007812500170>.

LATAWIEC, A. E.; STRASSBURG, B. B. N.; SILVA, D.; ALVES-PINTO, H. N.; FELTRAN-BARBIERI, R.; CASTRO, A.; IRIBARREM, A.; RANGEL, M. C.; KALIF, K. A. B.; GARDNER, T.; BEDUSCHI, F. Improving land management in Brazil: A perspective from producers. **Agriculture, Ecosystems and Environment**, v. 240, p. 276–286, 2017. Disponível em: <http://ac-els-cdn-com.ez67.periodicos.capes.gov.br/S0167880917300634/1-s2.0-S0167880917300634-main.pdf?{_}tid=d5f98514-3997-11e7-8c40-00000aab0f27{&}acdnat=1494871175{_}1da7806ed3b55635539b416>.

MAPA. **Plano Setorial de Mitigação e de Adaptação às Mudanças Climáticas para a Consolidação de uma Economia de Baixa Emissão de Carbono na Agricultura**. Brasília, DF, 2012.

MARTHA, G. B.; ALVES, E.; CONTINI, E. Land-saving approaches and beef production growth in Brazil. **Agricultural Systems**, Elsevier Ltd, v. 110, p. 173–177, 2012. ISSN 0308521X. Disponível em: <http://dx.doi.org/10.1016/j.agsy.2012.03.001>.

MORRIS, J.; REILLY, J.; CHEN, Y.-H. **Advanced Technologies in Energy-Economy Models for Climate Change Assessment**. Cambridge, MA, 2014. 24 p. Disponível em: <http://globalchange.mit.edu/publication/15600>.

RUTHERFORD, T. F. **GTAP6inGAMS: The dataset and static model.** http://www.mpsge.org/gtap6/gtap6gams.pdf, 2005.

RUTHERFORD, T. F.; PALTSEV, S. V. **GTAPinGAMS and GTAP-EG: global datasets for economic research and illustrative models.** [S.l.], 2000.

SENAR. **PROJETO FIP-ABC Produção sustentável em áreas já convertidas para o uso agropecuário (com base no Plano ABC)**. Brasília, DF, 2013. 53 p.

SILVA, J. G. da; RUVIARO, C. F.; Ferreira Filho, J. B. d. S. Livestock intensification as a climate policy: Lessons from the Brazilian case. **Land Use Policy**, v. 62, p. 232–245, 2017. ISSN 02648377. Disponível em: <http://linkinghub.elsevier.com/retrieve/pii/S0264837716308171>.

STEHFEST, E.; BERG, M. van den; WOLTJER, G.; MSANGI, S.; WESTHOEK, H. Options to reduce the environmental effects of livestock production – Comparison of two economic models. **Agricultural Systems**, v. 114, p. 38–53, jan 2013. ISSN 0308521X. Disponível em: <http://linkinghub.elsevier.com/retrieve/pii/S0308521X1200100X>.

Vieira Filho, J. E. R. Transformação histórica e padrões tecnológicos da agricultura brasileira. **O mundo rural do Brasil no século 21: a formação de um novo padrão agrário e agrícola**, 2014.