Grazing to feedlots: an integrated multi-scale analysis of ABC+ in Brazil by 2030*

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1. Introduction

The ABC+ plan (Sectoral Plan for Climate Change Adaptation and Low Carbon Emission in Agriculture), released in 2021, seeks to make Brazilian agriculture more sustainable and resilient. In this second phase, the plan will continue to act as an instrument that promotes sustainable agriculture contributing to greenhouse gas (GHG) mitigation. This requires reinforcement of the strategies adopted from the original ABC Plan (2012-2020), which were focused on stimulating the adoption of Sustainable Production Systems, Practices, Products and Processes and based on technical and scientific innovation.

The technological innovation is key to sustainable food production and Brazil has the means, at the end of the ABC+ period (2030), to increase productive area that utilizes sustainable technologies. In the long-term, the ABC+ sets the path for Brazilian agricultural area to be under sustainable production. Since the Plan promotes actions towards adaptation and mitigation of climate change in rural sectors with several spillovers to other supply chains, the ABC+ is one of the most important national public policies in the fight against climate change.

Among other goals in ABC+, one of them is to expand the number of cattle fattened through the intensive grazing termination method (the provision of feed to animals in the drought period and the improvement of manure in pastures) to 5 million heads. Under this method, fattening is quicker, and the GHG emission by the cattle is reduced.

This paper aims at enhancing ABC+'s impact on agricultural land expansion and crop production in Brazil, by answers research questions below: Considering the increased demand for feedstock impact on crop production, how would ABC+ goals influence land allocation in Brazil? What is the possible range of those impacts given uncertainties in future socioeconomic scenarios and policy? Will the ABC+ plan drive Brazil to be more intensive or extensive in land use, and what is its implication on environment and sustainability? To answer these questions, it is necessary to connect several drivers and crop production under a multi-scale framework, which can both take drivers from national and global level, and also

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reveal local feedback with spatial heterogeneity. Results from spatial level would enrich the understanding of ABC+ plan impacts on local hot spots and distribution and provide guidance for targeted policy-making, adaptation and mitigation.

2. SIMPLE-G-Brazil-Pasture model

The SIMPLE-G-Brazil-P is based on SIMPLE-G-Brazil (De Lima, *et al*, 2022; Wang, *et al,* 2022), a *Simplified International Model of Agricultural Prices, Land use, and the Environment for Brazil*. The first difference between the versions of the model is the geographic coverage since in SIMPLE-G-Brazil-P we have 87,665 grid cells. This is an expected result as the pastureland area is higher than cropland and more widespread throughout the country. This means that in a certain grid cell we can have only cropland or pasture, or a combination of both. As a second difference, unprecedentedly, the SIMPLE-G-Brazil-P is capable of representing the land use competition among cropland and pasture. Thus, the livestock technology has changed under the SIMPLE-G-Brazil-P and this is the third major difference. As in the previous versions, the SIMPLE-G-Brazil-Pasture has greater detail of production technology at grid cell level (e.g., inputs, such as fertilizer demand and water use, capital, and labor), and each of the other regions in the global model is treated as one-single grid cell according to specific regional data.

Under this new model the livestock production has now an additional effect on cropland extensification/intensification. The first effect the livestock production demands crop-derived feedstock as an intermediate input which could increase/decrease the pressure on cropland. The second effect is the direct competition of pastureland with crop production. As livestock production expands the extensive and intensive margins act to demand more (or less) land as pasture. One could assume the net effect is an increase in pasture, so a new land allocation would be determined with less use as cropland and more use as pasture. This is just one of the possible results. Several forces act to mitigate or exacerbate the demand for land in agricultural production.

a. Pastureland data

Historically, pasture area in Brazil was mainly estimated through data reported at the Agricultural Census, the last one being carried out in (2017)[4]. However, reports on land-use cover and change, pastureland data inclusive, have evolved a lot in Brazil in the last decade. There has been an ample effort to compile and make compatible several databases, from 1985 on, to estimate native vegetation, cropland and pasture area changes in Brazil. Comprehensive projects were developed and gained national and international attention in the systematic construction of data, data maintenance, as well as on methodological validation, such as MAPBIOMAS[5], Atlas de Pastagem[6], SEEG[7].

The classification of pasture area ranging from high quality pasture to pasture with some trace of degradation, up to degraded pasture has generated intense debates creating a *mother ducks* problem in Brazil (*once you've identified yours*...). Furthermore, different methodological approaches and assumptions (e.g. grassland and pastures) have led to publications reporting different pasture areas

[4] See https://censos.ibge.gov.br/agro/2017/ for more information.
[5] MapBiomas data is public and free of charge. MapBiomas Project - is a multi-institutional initiative to generate annual land use land cover maps based on automatic classification processes applied to satellite images. See https://mapbiomas.org/ for more information.
[6] See https://atlasdaspastagens.ufg.br/map for more information.
[7] See https://seeg.eco.br/ for more information.

(see, for example, (Lima 2017), (Silva, Ruviaro, and Ferreira Filho 2017), (Cohn et al. 2011)). For example, in reports based on geoprocessing techniques, pasture area ranges from 112,52 M ha (year 2018; (IBGE 2020)) to 154,49 M ha (year 2020; (Souza et al. 2020)), and to 160,89 M ha (year 2020; (LAPIG 2022)). The difference between IBGE and the two other approaches rely mainly on assumptions and image processing techniques about the so called agricultural mosaic areas that reached 108,79 M ha in 2018. In addition, those approaches differ on the native pasture area (e.g. grassland), which could increase Mapbiomas' estimates to 201,13 M ha. Just for comparison, the latest Agricultural Census reported the cultivated plus native pasture area in Brazil in 2017 amounted 159.50 M ha, whereas FAOStat database reports 173.30 Mha for the same year.

The starting point to feed SIMPLE with pasture area is, thus, the determination of the data source. For the other regions (non-gridded) in the model, we choose the FAOStat database. We use the permanent meadows and pasture category data. Table 1 below shows the pasture data for 2000 and 2017 that will be used for calibration (2017) and model validation (2000).

The global pasture area (excluding Brazil) decreased about 5.6% in the period, which represents about 178 Mha. In 2017, the total pasture area was 3,033 Mha. This area is concentrated in some regions such as Australia and New Zealand (350 Mha), China (392 Mha), East Europe (303 Mha), Sub-Saharan Africa (619 Mha), and United States (245 Mha).

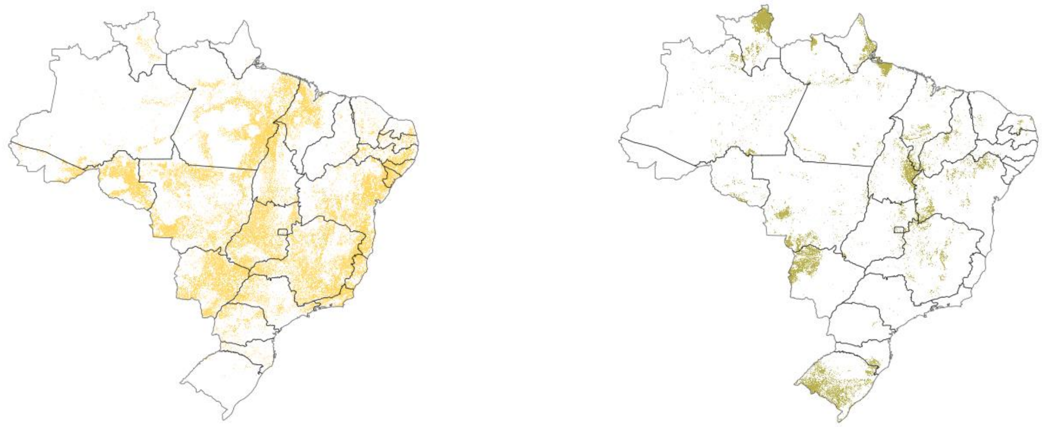
Table 1. Pastureland for non-gridded regions in SIMPLE-G-Brazil (1,000 ha)

SIMPLE-G-Brazil	2000	2017	% change
Australia and New Zealand	445,563	350,849	-21.3
Central Asia	228,272	208,144	-8.8
Canada	20,149	19,342	-4.0
Central America	95,945	88,848	-7.4
China	392,834	392,834	0.0
East Europe	302,243	303,452	0.4
European Union	68,500	61,874	-9.7
Japan and Korea	533	106	-80.1
Middle East	268,184	251,703	-6.1
North Africa	70,690	71,902	1.7
South Africa	150,567	150,567	0.0
South America	255,993	232,811	-9.1
South Asia	19,076	18,509	-3.0
Southeast Asia	17,007	17,266	1.5
Sub-Saharan Africa	639,538	619,433	-3.1
United States	236,331	245,374	3.8
Total	**3,211,425**	**3,033,015**	**-5.6**

Source: FAO database, 2022.

On the Brazilian side, we have noted the same trend of decreasing pasture area. While the Agricultural Census reported a peak in pasture area in 1995/1996 (e.g. 177,7 M ha), Mapbiomas and Atlas da Pastagem have reported a peak of 162,42 M ha and 173,35 M ha of pasture in 2006 and in 2007, respectively. In addition, a more detailed information about the pasture area is needed since Brazil is represented at gridded cell level in SIMPLE-G-Brazil.

We choose the MapBiomas database since it is free, public available, and has a high-level standards of data maintenance and validation (Silva Junior et al. 2020). Figure 1 shows the category of pasture area (Panel (a)) and Natural grassland (Panel B) for Brazil at high resolution. The pasture area in 2017 was 156.8 Mha, whereas natural grassland was 46.7 Mha.



(a) (b)

Figure 1. Pasture area (a) and natural grassland (b) from Mapbiomas Collection 6.0 in 2017. The total pasture area is 156.8 Mha and 46.7 Mha of natural grassland.

The first representation of the data in two categories is important since we need to track some specificities of Brazilian regions, such as the Pampa biome in Rio Grande do Sul State, and the Pantanal biome in the Western part of Mato Grosso do Sul State, where grassland areas are more expressive, as shown in Figure 1.

Table summarizes the pasture data by State in 2017. There is a concentration of pasture in the States of Mato Grosso (13.3%), Minas Gerais (13%), and Pará (13.2%) followed by Bahia (10.2%). Also, other hotspots of pasture area are Góias State (8.6%), Rondônia (5.3%) and Mato Grosso do Sul (9.1%).

b. Modelling approach

Figure 2, below, summarizes the model's structure update in SIMPLE-G-Brazil-P. In the previous v1.0 model structure, the total endowment of land (QLAND), as cropland, is allocated by a constant elasticity transformation function (CET) in cropland under irrigation and rainfed technology. These two inputs are used for the crop production under irrigation and rainfed conditions, respectively.

In the SIMPLE-G-Brazil-Pasture (right hand side of Figure 2), the total endowment of land is now referred to "QCPLAND" which is the sum of cropland (QLAND) and pasture (QPLAND). In practice, we add a new level in the CET function, allowing for land use competition between cropland and pasture. The new elasticity of transformation, $\sigma_{etrancp}$, controls the land resource allocation between cropland and pasture.

Additionally, we slightly changed the livestock technology, so the production function now considers pasture as a primary factor. In this procedure, we split the cost share named QNCRPFEED – non-crop feed –, which already considers the cost of land, into pasture area (QPLAND) and the remaining share of non-land-crop inputs (QNCRPFEED). A new lower nest combines pastureland (QPLAND) and feedstock (QCRPFEED) resulting an aggregate intermediate input named QCPFEED which in turn is combined with non-land-crop inputs (QNCRPFEED) in the top nest.

Under this new approach the livestock production has now an additional effect on cropland extensification/intensification in the model. The first effect, as in SIMPLE-BR and SIMPLE-G-Brazil v1.0, the livestock production demands crop-derived feedstock as an intermediate input which could increase/decrease the pressure on cropland. The second effect is the direct competition of pastureland with crop production. As livestock production expands the extensive and intensive margins act to demand more (or less) land as pasture. One could assume the net effect is an increase in pasture, so a new land allocation would be determined by the model with less use as cropland and more use as pasture. This is just one of the possible results. Careful readers will see in the structure below that several forces act to mitigate or exacerbate the demand for land in agricultural production.

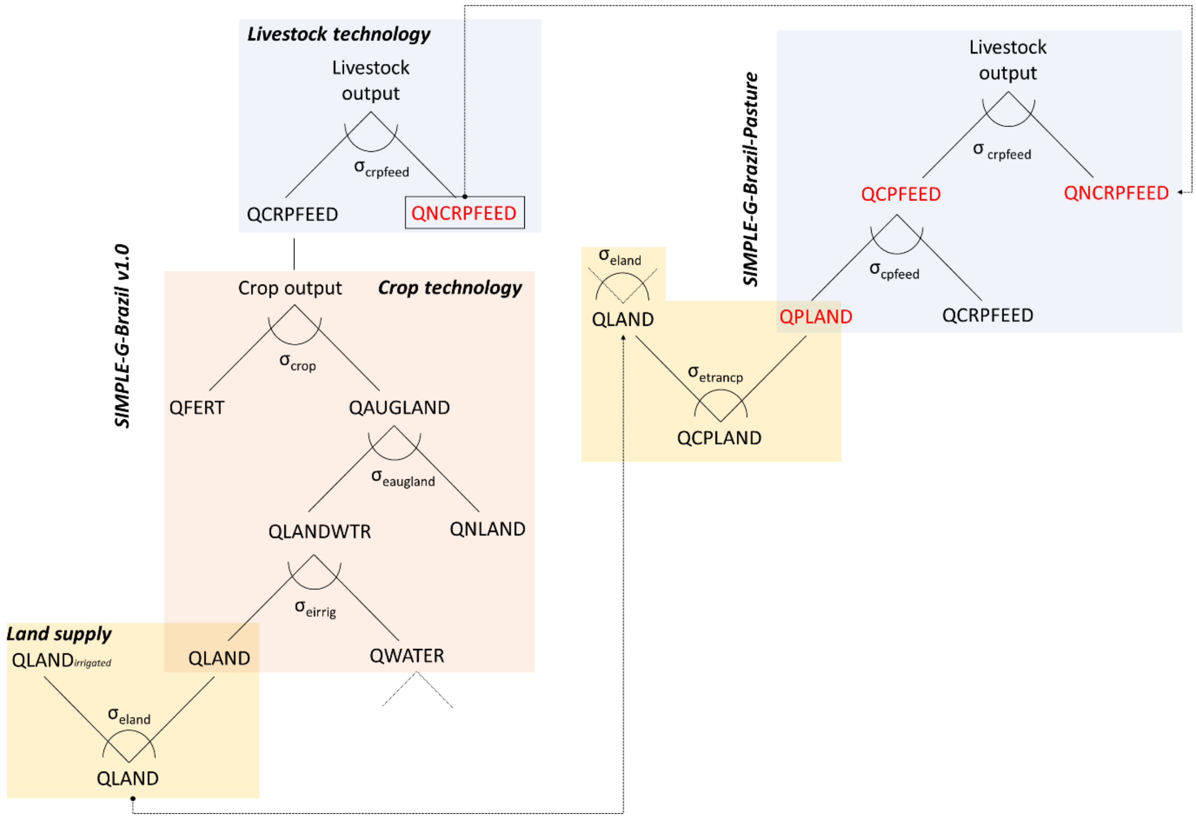


Figure 2. Model updates underlying SIMPLE-G-Brazil-P. Under the new model the livestock production technology changes to represent the land use competition (cropland and pastureland) and the substitution of pasture and feedstock. The diagram on the left-hand side portrays the actual technology for land supply, crop, and livestock output. The introduction of pasture data slightly changes the land supply function adding a new lower level in the CET function (right-hand side). The total area (cropland and pasture) shows as QCPLAND is split between QPLAND and QLAND. This implies livestock production competes directly for land with crop production. Additionally, the livestock technology changes adding a new nest which combines pastureland (QPLAND) and feedstock (QCRPFEED) resulting an aggregate intermediate input named QCPFEED which in turn is combined with non-land-crop inputs (QNCRPFEED) in the top nest. The other aggregate intermediate inputs in the crop output technology such as QLANDWTR (combination of QLAND and QWATER) and QAUGLAND (aggregation of non-fertilizer inputs) remain the same. The indexes r (region) or (g) grid were omitted for better visualization.

Under this version of the model the livestock technology is defined at national level as shown in Figure 2, differently from the crop technology which is defined at gridded level. This limitation is due by data quality and uncertainty in determining the demand of feedstock (QCRPFEED – M ton) at gridded level, as well as the level of non-land-crop inputs (QNCRPFEED – M $USD). However, the pasture allocation is defined at gridded level. In an effort to simplify the model structure, while preserving its economic content, we propose a single, national livestock production function, with multiple grid (pastureland) inputs. So, the QPLAND shown in Figure 2 is a result of thousands grid cells pasture allocation.

What are the implications of this specification? To answer this question, we must think about the desirable model and through the economic implications of a model under development. The most natural approach following SIMPLE-G family models is to have a different production activity for each grid cell, with the resulting aggregated output (e.g., livestock products) competing in the product markets. As a result, we have a proliferation of livestock production functions that in a static partial equilibrium model is not so complicate solving the model. However, high resolution representation requires more data and processing time making different data sources compatible, therefore creating a reliable dataset of prices and quantities. The approach with a single national livestock production implies a uniform pastureland price across thousands grid cells, i.e., change in pastureland price at gridded level follows the same change in price at national level. This is a drawback for a country like Brazil which has several allocations of cost and land in the livestock production. Furthermore, the perfect transformation between cropland and pastureland is not reflecting any rigidity in the land use allocation.

3. Simulation

We use SIMPLE-G-Brazil-Pasture to identify the impacts from various dimensions of ABC+ and socio-economic growth. We run the model in several steps to produce a set of simulations by 2030. In practice, the socio-economic shocks are the same across scenarios, and simulations were elaborated in order to estimate the contribution of each driver, as follow:

i. **Demand**: only population, per capita income, and biofuel shocks are considered which represents the demand-side.

ii**. Farm productivity**: **demand** + total factor productivity growth rates for crop, livestock and processed food are considered.

iii. **Feed demand**: **demand** + **farm productivity** + increased feedstock demand due to +5 million animals under intensive feedlot termination.

Under this strategy is possible to disentangle the total impact on agricultural land expansion (cropland and pastureland), crop output, and feedstock demand, by driver contribution, because of ABC+ strategies. For example, the simplest simulation considers only the demand-side drivers, whereas the most complex simulation considers the effects of demand, technology, and increased feedstock demand.

The growth rates for population, per capita income, livestock and processed foods are the same across scenarios. For the projections for population growth and per capita income increase we use the information available in the **S**hared **S**ocioeconomic **P**athways (SSP v2.0) (Riahi et al. 2017), scenario “middle of the road” (SSP2) (Fricko et al. 2017). Population growth rates for different regions are from IIASA (Lutz and KC 2011) and aggregated according to the regional representation in SIMPLE-G-Brazil. The same process is done for per capita income growth rates estimated by the OECD (Dellink et al. 2017). Finally, for the biofuels’ crop demand, we use the OECD-FAO Agricultural Outlook 2019-2028 (OECD; FOOD; NATIONS, 2020) variable “biofuel use” by crop and region. Livestock productivity growth rates are from (Ludena 2010), and for processed food from (Griffith, Redding, and Van Reenen 2004). These rates are prepared for the model as well as in (Hertel, Baldos, and Fuglie 2020).

4. Results

a. Country level: Brazil

Figure 3 below shows the impact on crop output, cropland, and pastureland by 2030 for Brazil. A higher demand due population, income, and biofuels growth increases cropland by 10.5 p.p. and pastureland by 4.4 p.p.. These results indicate a scale effect from increased demand as a driver pushing agricultural land expansion up in Brazil. On the other hand, farm productivity enhances the land saving effect both on cropland and pastureland due technological progress and reduces the cropland expansion by 9.6 p.p. and pastureland by 21.3 p.p.. The increased demand for feedstock has a marginal effect on pastureland expansion (+0.3 p.p.), whereas increases the cropland expansion by 3.1 p.p.. The overall effect is a cropland expansion by 4% and pastureland reduction by 16.7%. As a net result the agricultural land reduces by 26.1 Mha reaching 208 Mha which is the same level from 80's but at a high yield level. The land rents are quite sensible to this dynamic and the cropland rent decreases by 5% on average.

As expected, the crop output expands to accommodate a higher demand due population, income, and biofuels demand. The demand-side portrays 16.5 p.p. of overall change by 2030, whereas the farm productivity represents 57.3 p.p.. The additional feedstock demand due more animals under intensive termination expands the crop output by 8.1 p.p. (Figure 3). The volume of production increases by 584.7 M ton corn-eq by 2030 driven majority by farm productivity, whereas the increased feedstock demand represents only 10% of this change – around 58 M ton corn-eq. A higher level of crop output implies a high yield gain in the period since we have a small expansion in cropland. The crop yield increases by 75% in the period.

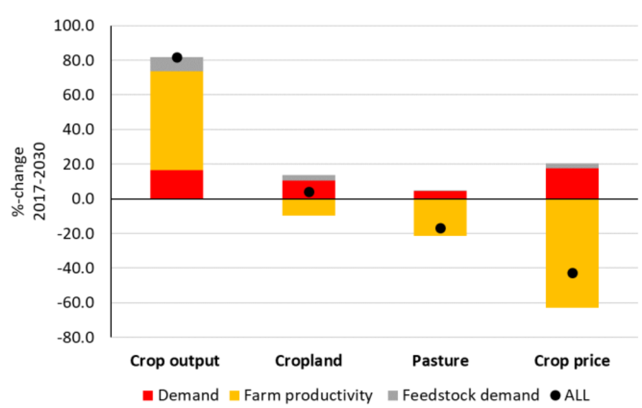
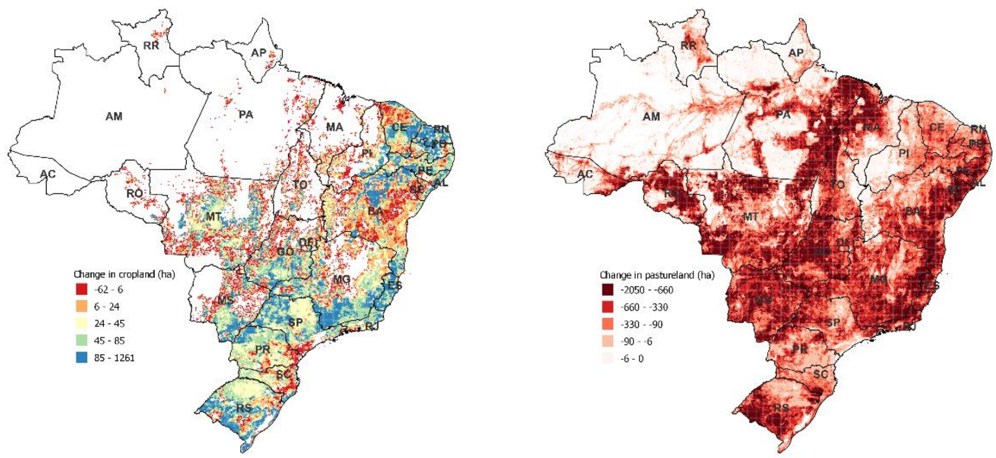


Figure 3. Crop output, crop price, cropland, and pastureland change (%) by driver by 2030 given ABC+ targets in Brazil.

The model outcomes at regional level show the additional feedstock demand due intensive termination would not put high pressure on land use in Brazil. The livestock intensification due to better management system and low-carbon technologies offset the cropland expansion releasing any additional area needed for crop-derived feedstock. Next section shows the local responses since at local level the same drivers can lead a new set of trade-offs in crop production.

b. Spatial pattern of agricultural land

As shown in Figure 3, the aggregated impact on cropland expansion is positive for Brazil however the local responses are ambiguous and dependent on the land use pattern in each grid cell. Figure 4 shows the change in agricultural land in hectares.



(a) (b)

Figure 4. Change in agricultural land in Brazil by 2030. (a) Cropland (b) Pastureland. The legends show the quantile distribution for each dataset.

Even though the reduction in cropland areas is marginal and limited to 62 ha there is a pattern of intensification and direction of crop production since the majority of grid cells area expanding area. Traditional areas such as West part of Paraná (PR) and São Paulo (SP) states increases the cropland area as well as the center of Mato Grosso (MT) and South of Minas Gerais (MG). On the other hand, the intensification of livestock production has a strong impact on pastureland. The pasture area decreases, such as pampa biome (South of Rio Grande do Sul (RS) state), and in the center of Goiás (GO) state up to the north reaching important areas of Pará (PA), Tocantins (TO), and Maranhão (MA) states a region well know as arc of deforestation. Other important hotspots are the north of Mato Grosso (MT) and the Rondônia (RO) states the "south" part of the arc of deforestation.

While the cropland is expanding in different parts of the country, we are interested in the contribution of increased feedstock demand to this expansion. Figure 5 shows this contribution to the cropland expansion. Around 60% of grid cells increase the cropland more than 21 ha up to 313 ha. The new feedstock demand is widespread throughout the country however the center of Mato Grosso (MT) and the south production (RS, SC, PR and SP states) are the sensible regions to accommodate a higher demand in crop production.

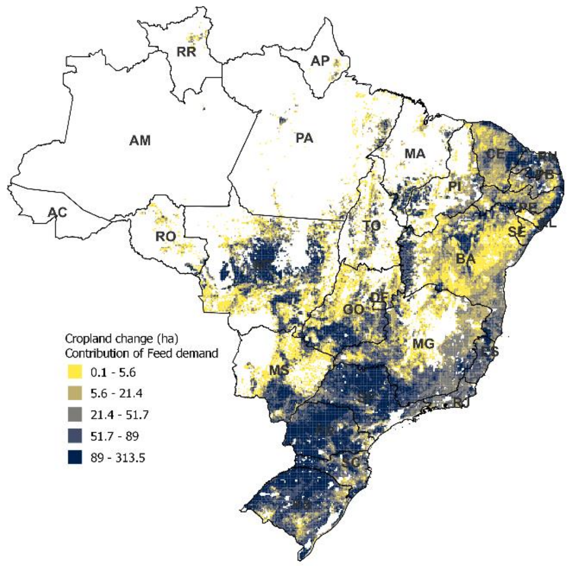


Figure 5. Contribution of feed demand in cropland expansion (ha) by 2030 given the ABC+ target in Brazil. The legend shows the quantile distribution.

c. Local responses: the case of MATOPIBA

One beauty of SIMPLE-G-Brazil-Pasture based on GEMPACK language is the possibility to decompose several model outcomes by contribution or subtotals[8]. The combination of decomposition with the spatial analysis is invaluable in SIMPLE-G-Brazil applications and sustainability research. This section dives in the spatial resolution to better understand the local responses driven by agri-environmental policy.

Figure 6 shows how the drivers (shocks) impact agricultural land by 2030, following special local aggregation: MATOPIBA. MATOPIBA is the acronym for the States of Maranhão (MA), Tocantins (TO), Piauí (PI), and Bahia (BA). MATOPIBA is the new agricultural frontier in Brazil and covered majority by Cerrado biome. About 10% of national production of soybean and corn comes from the region, whereas the West part of Bahia (BA) state is the second largest cotton producer. Additionally, the water supply is equally important since the region benefits from important hydrographic basis, such as *Bacia do Rio Tocantins* (43% of MATOPIBA region), *Bacia do Atlântico – Trecho Norte/Nordeste* (40%), and *Bacia do Rio São Francisco* (17%).

Panel (b) in Figure 6 shows the pastureland change in MATOPIBA. The pastureland decreases in the center-northwest portion of Tocantins (TO) state where the remain native vegetation is a mix of Cerrado and Amazon biomes. This result indicates that intensification technologies for livestock production may indeed be useful to relieve pressure in areas with forest remnants as in some regions of MATOPIBA. In fact, the model outcomes are heterogenous for the region showing how important a spatial analysis is

[8] A technique to decompose changes in model variables due to several shocks into components due to each individual shock (Harrison, Horridge, and Pearson 2000).

for Brazil. Panel (a) shows the cropland expansion in the West part of Bahia (BA) and not in the whole region. The area has great agricultural potential as it is close to the main highways for transporting production, as well as benefiting from the water supply from the São Francisco River basin.

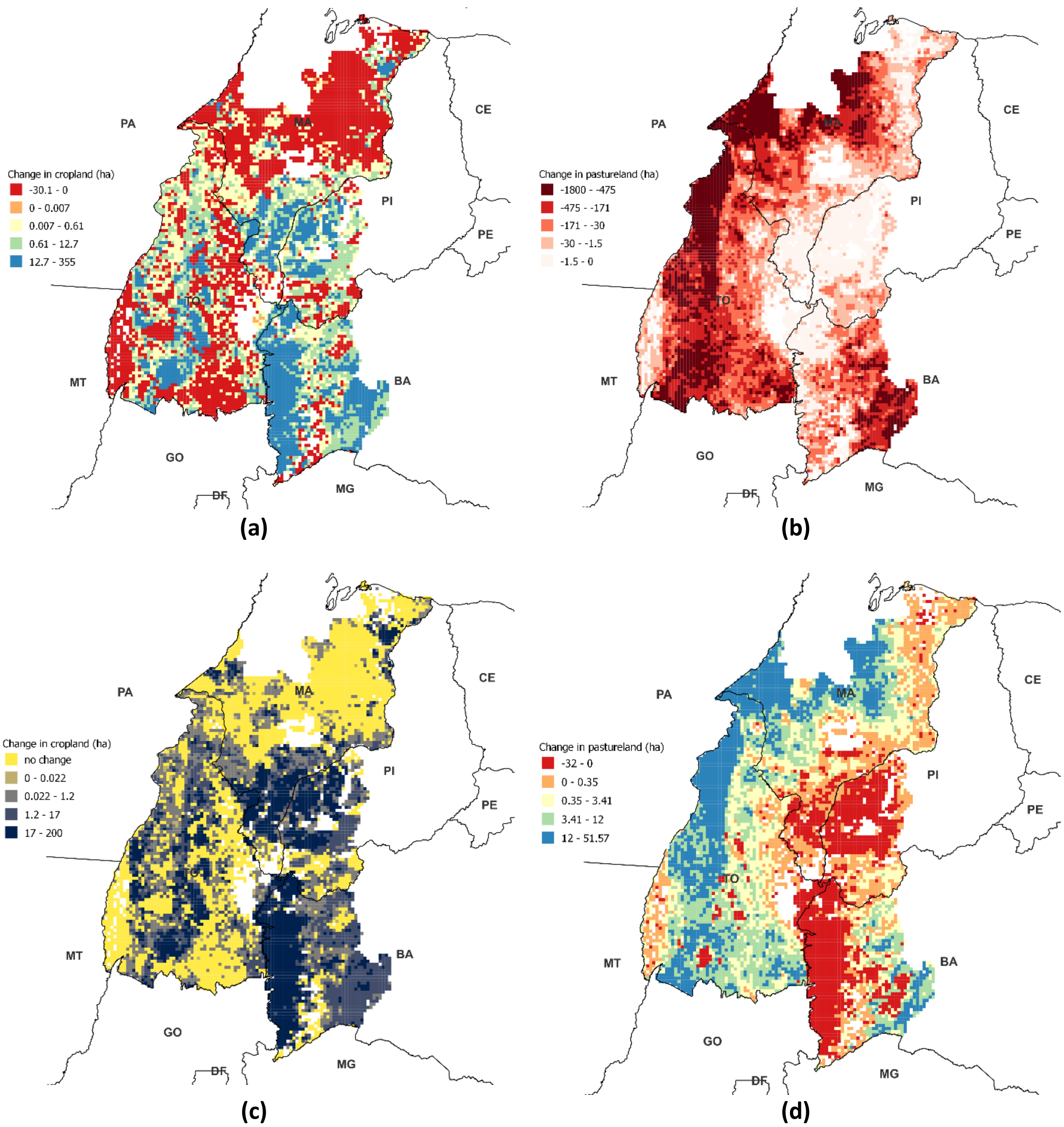


Figure 6. Total cropland (a) and pastureland (b) change (ha) by 2030 in MATOPIBA region. Panels (c) and (d) show the contribution of increased feedstock demand to cropland (c) and pastureland (d) expansion/reduction. The legends show the quantile distribution for each dataset.

Additional outcomes from the contribution of increased feedstock demand can be explored. Panel (c) shows the isolated contribution from feedstock on cropland expansion. As we shown before the West part of Bahia absorbs this expansion and the final effect is exacerbated by other drivers, such as population and income. The spatial analysis here shows that the intensification process in crop production takes place in the Cerrado biome and not in the Amazon biome. On the other hand, Panel (d) shows that the high demand for feedstock has a marginal leakage effect on pastureland in the center-northwest part of Tocantins (TO) state.

5. Conclusions

The SIMPLE-G-Brazil-Pasture, a muti-scale framework used in this research has allowed us to identify location-specific crop production intensification potential as well as the spillover effects of policy. The latter arises when a new agri-environmental policy intervention boost crop demand, thereby inducing increased crop price and agricultural land expansion in some grid cells. We have shown a location-specific leakage in MATOPIBA where the feedlot intensification may induce a marginal pastureland expansion. We find that these spillovers effects can be relevant, particularly in the agriculture frontier since close to forest remnants and hydrographic basins. Of course, we find the technological progress can offset these spillovers resulting in smaller agricultural land with high yield. This result comes with high level of investments in agricultural research and development, technology transfer for small and medium farmers that should be observed for many years and, for now, is not addressed in the scope of this research. The ABC+ plan has other targets, such as recover degraded pasture, irrigation system, no-tillage system, planted forest, and bioinputs. All these technologies will affect agricultural production in Brazil, reshaping the spatial distribution of crop production in the country.

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7. Supplemental material

Table S1. Pasture and natural grassland area by state in 2017 (1,000 ha).

STATE	PASTURE AREA	NATURAL GRASSLAND	TOTAL	%pasture area	% natural grass land	% total
ACRE (AC)	2,025	49	2,073	1.29	0.10	1.02

ALAGOAS (AL)	1,448	1	1,449	0.92	0.00	0.71
AMAPÁ (AP)	229	1,786	2,015	0.15	3.82	0.99
AMAZONAS (AM)	2,298	2,761	5,059	1.47	5.90	2.48
BAHIA (BA)	16,086	4,043	20,129	10.25	8.64	9.88
CEARÁ (CE)	1,630	133	1,763	1.04	0.28	0.87
DISTRITO FEDERAL (DF)	95	88	183	0.06	0.19	0.09
ESPIRITO SANTO (ES)	2,180	-	2,180	1.39	0.00	1.07
GOIÁS (GO)	13,620	1,385	15,005	8.68	2.96	7.37
MARANHÃO (MA)	7,311	2,316	9,627	4.66	4.95	4.73
MATO GROSSO (MT)	20,923	3,532	24,455	13.34	7.55	12.01
MATO GROSSO DO SUL (MS)	14,357	3,994	18,351	9.15	8.54	9.01
MINAS GERAIS (MG)	20,429	2,917	23,346	13.02	6.24	11.46
PARÁ (PA)	20,804	3,836	24,640	13.26	8.20	12.10
PARAÍBA (PB)	1,347	213	1,560	0.86	0.45	0.77
PARANÁ (PR)	2,712	71	2,783	1.73	0.15	1.37
PERNAMBUCO (PE)	2,799	226	3,024	1.78	0.48	1.49
PIAUÍ (PI)	1,079	1,987	3,066	0.69	4.25	1.51
RIO DE JANEIRO (RJ)	1,932	-	1,932	1.23	0.00	0.95
RIO GRANDE DO NORTE (RN)	750	430	1,180	0.48	0.92	0.58
RIO GRANDE DO SUL (RS)	378	7,681	8,059	0.24	16.42	3.96
RONDÔNIA (RO)	8,403	808	9,211	5.36	1.73	4.52
RORAIMA (RR)	922	4,622	5,544	0.59	9.88	2.72
SANTA CATARINA (SC)	800	411	1,210	0.51	0.88	0.59
SÃO PAULO (SP)	4,576	75	4,651	2.92	0.16	2.28
SERGIPE (SE)	1,396	20	1,415	0.89	0.04	0.69
TOCANTINS (TO)	6,350	3,396	9,747	4.05	7.26	4.79
TOTAL	**156,876**	**46,781**	**203,657**	**100.00**	**100.00**	**100.00**