GHG Emissions in Brazil by 2030[1]

Marcos Spínola Nazareth[2];
Rayan Wolf[3];
Cícero Zanetti de Lima[4];
Angelo Costa Gurgel[5];
Geraldo Bueno Martha Junior[6]

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ABSTRACT

Given the extent and importance of the agricultural sector in Brazil, strategies have been adopted to promote sustainability in agriculture, such as investments in technological development aimed at improving agribusiness activities in a more efficient and sustainable way. However, identifying the economic effects of these initiatives in a regionalized way and their spillovers to other regions in the country and in the world has been an empirical challenge. Thus, the main objective of the paper is to evaluate how projections of agricultural productivity changes in the world economy by 2030 can impact the general level of GHG emissions. More specifically, we aim to assess the changes in sectoral efficiency measured in terms of emissions per sectoral product. We developed and applied the PAEG-Cerrado Computable General Equilibrium (CGE) model, which is fully coupled to the most recent version of GTAP, incorporating Land Use and Emissions modules. PAEG-Cerrado is disaggregated into 8 Brazilian states, the most important agricultural producers, and 13 other regions of the world. Furthermore, 37 sectors are considered, along with three aggregates of production factors: capital, land, and labor. We apply shocks on the productivity of primary factors to assess how increases in productivity in agricultural sectors would impact the emissions of greenhouse gases and air pollutants. The main findings were (*i*) the two of the greatest agribusiness states in Brazil achieved a net positive balance in greenhouse gas emissions efficiency, signaling few environmental growth restrictions for the coming years; (*ii*) there was a robust and consistent increase in efficiency across all regions in sectors related to Brazilian livestock production related to adoption of new technologies; and (*iii*) however, there was a deterioration in emissions efficiency in other sectors of states traditionally relevant to the Brazilian economy.

Keywords: *Climate Impacts; Agricultural policies; Technological change.*

INTRODUCTION

There was a considerable increase in agricultural and livestock activities in Brazil, with growth rates of 172% and 46% respectively from 1985 to 2017. On the one hand, the productivity gains observed in recent decades in Brazilian agriculture have provided a land-saving effect that has allowed millions of hectares to be spared from cultivation (Martha Jr., Alves, 2018). Due to these technological gains and more comprehensive sectoral public policies, about 66% of Brazil's native vegetation cover was preserved in 2021 (Mapbiomas, 2023).

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[2] Professor at Centro Universitário de Viçosa – Univiçosa, marcos.snazareth@univicosa.com.br.
[3] Professor at Universidade Estadual de Mato Grosso do Sul (UEMS), rayanwolf@gmail.com.
[4] Researcher at Observatório de Bioeconomia da FGV-EESP, cicero.lima@fgv.br.
[5] Researcher at *Massachusetts Institute of Technology* (MIT), angelo.gurgel@fgv.br
[6] Researcher at Embrapa Agricultura Digital, geraldo.martha@embrapa.br.

The increase in agricultural production at higher rates than demand has led to a reduction in food prices over the period, which has particularly benefited the poorer population (Pereira et al., 2012). On the other hand, the expansion of the agricultural area represented a loss of vegetation cover of 102 million hectares (Mha) in the country, of which 71 Mha correspond to native vegetation (Souza et al., 2020). The Amazon and Cerrado biomes were the most affected, facing significant pressure on their natural vegetation cover (Souza *et al*., 2020).

In addition, it is important to note that deforestation in Brazil, as well as other sources of GHG emissions in industrialized and developing countries, contribute to global climate change (World Bank Group, 2021). Brazil ranks fifth among the largest GHG emitters, accounting for approximately 3.2% of total global emissions, behind only China, the United States, Russia, and India. In 2020, changes in land use and agricultural activities in the country were responsible for 73% of national GHG emissions (SEEG, 2021).

Given the extent and importance of the agricultural sector in Brazil, strategies have been adopted to promote sustainability in agriculture, such as investments in technological development aimed at improving agribusiness activities in a more efficient and sustainable way (Mores *et al*., 2022; Rocha *et al*., 2019). However, identifying the economic effects of these initiatives in a regionalized way and their spillovers to other regions in the country and in the world has been an empirical challenge (Souza *et al*., 2023).

The main objective of the paper is to evaluate how projections of agricultural productivity changes in the world economy by 2030 can impact the general level of GHG emissions. More specifically, we aim to assess the changes in sectoral efficiency measured in terms of emissions per sectoral product.

LITERATURE REVIEW

Over the past few decades, significant transformations have occurred in the global economy, driving, in many cases, the growth of productivity and income, as well as providing a reduction in the use of non-renewable natural resources and greenhouse gas (GHG) emissions associated with the production and consumption of goods and services (Gianetti; Ferreira Filho, 2023; Stark et al., 2022). However, these changes have not been uniformed among countries, sectors, and regions (Amann et al., 2018). In the Brazilian context, for example, regional studies have revealed notable heterogeneity in the country's agricultural development (Arias et al., 2017; Martinelli et al., 2017; Silva et al., 2017; Trigueiro et al., 2020).

The extensive territorial area of Brazil covers regions with distinct climatic characteristics, soil types, relief, and socioeconomic levels. Added to this, disparities in infrastructure and access to resources, technologies, and services related to agriculture also influence this diversity (Buainain et al., 2019; Gomes et al., 2022; Silva et al., 2019).

In this context, the Brazilian agribusiness, which includes inputs, agricultural production, agroindustry, and services, represents a significant portion of the country's Gross Domestic Product (GDP) (CEPEA, 2023). From 2020 to 2022, Brazilian agribusiness represented, on average, 26.1% of the national GDP (CEPEA, 2023), with positive prospects due to the expansion of production and exports (MAPA, 2023; and OECD-FAO, 2021).

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In this scenario, the Cerrado region has established itself as one of the main agricultural production poles in Brazil, with worldwide recognition (Arias et al., 2017). Until the 1970s, agriculture in this region was limited by low productivity and the lack of technologies suitable for local conditions (Arias et al., 2017). The production of soybeans in the Cerrado, for example, represented less than 7% of national production in the 1970s (Pereira et al., 2012), but in 2021, it already exceeded 51% of Brazilian production (Rudorff et al., 2022). Currently, the Cerrado stands out with expressive percentages of national production, being responsible for 35% of the cattle herd, 52% of sugarcane production, 54% of corn, and 96% of cotton in 2018 (Luis et al., 2022). Also noteworthy is the significant increase in the production of milk, beans, sorghum, cassava, and wheat (Luis et al., 2022; Pereira et al., 2012).

In this sense, Souza et al. (2023) and Gianetti and Ferreira Filho (2023) used different regionalized CGE models for research purposes related to agricultural production and environmental issues. Souza et al. (2023) simulated the effects of deforestation reduction policies in the main Brazilian biomes, incorporating investments in the agricultural sector to simulate economic growth with forest preservation. The results showed that public policies, when well implemented, are efficient in reducing deforestation and GHG emissions, but have a negative effect on Brazil's economic growth.

Ferreira Filho and Horridge (2016), in turn, analyzed the effects of different climate change scenarios on agricultural activity and migration. The results revealed that climate pressures would have adverse effects on agricultural production in the states of Maranhão, Piauí, and Mato Grosso do Sul. This would stimulate migratory flows from this region to others with more stable production, such as the south, southeast, and north regions. This situation raises growing concerns regarding the increase in immigration to the Amazon, as this can exert additional pressure on the use of natural resources in this region.

Studies like that of Souza and Haddad (2022) also use a CGE model to estimate the effects of climate change on Brazilian regions. The results point to a broad spatial heterogeneity of economic effects throughout the country, with average annual losses ranging from 0.4% to 1.8% of GDP by the end of the century.

In the same environmental line, Gianetti and Ferreira Filho (2023) estimated the effects of pasture recovery policies on the mitigation of GHG emissions in the agricultural sector. Their results showed that each real invested in such policies generates a social return of R$ 8.31. In addition, livestock would expand its production using less area, resulting in a land saving of 972.6 thousand hectares by 2035. Furthermore, the mitigation of emissions would be 38.9% in 2030 and 42.9% in 2035.

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METHODS

We developed and applied the PAEG-Cerrado Computable General Equilibrium (CGE) model, which is fully coupled to the most recent version of GTAP, incorporating Land Use and Emissions modules. The PAEG (Project for General Equilibrium Analysis of the Brazilian Economy), like GTAP, is a global, multiregional and multisectoral economic model. However, it enhances the GTAP data by disaggregating the Brazilian economy in several sub-regions.

PAEG-Cerrado is disaggregated into 8 Brazilian states (the most important agricultural producers): Goiás (BDG), Mato Grosso do Sul (BMS), Mato Grosso (BMT), Minas Gerais (BMG), São Paulo (BSP), Paraná (BPR), Rio Grande do Sul (BRS) and Santa Catarina (BSC), in addition to Rio de Janeiro and Espírito Santo together (BER), while the other units of the Brazilian federation are grouped into the regions called North Region (BNO) and Northeast Region (BNE). In addition, another 13 regions of the world are explicitly represented[7]. As for sectoral disaggregation, 37 sectors are considered, along with three aggregates of production factors: capital, land and labor. We also represent ten households by different income classes in each Brazilian region.

The model also represents sources of Emissions of five pollutants, measured in tons: methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), carbon monoxide (CO) and nitrogen oxide (NO_x). These emissions were expressed in terms of equivalent carbon dioxide (CO_2eq) and were obtained from the data of the System of Estimates of Emissions and Removals of Greenhouse Gases (SEEG)[8]. Those emissions are linked to the economic transaction or process where they are generated, which can be the production process itself, the use of capital (specific to the livestock), fossil fuel burning, and the use of agricultural inputs.

The Land Use Module represents the 6 (six) biomes found in Brazil, namely: Amazon, Caatinga, Cerrado, Atlantic Forest, Pampa and Pantanal. Land use information was taken, organized, and estimated from the extensive documentation of the MapBiomas Brazil Project[9], which carries out the mapping of land cover and use throughout the national territory.

We apply shocks on the productivity of primary factors to assess how increases in productivity in agricultural sectors would impact the emissions of greenhouse gases and air pollutants. We measure the changes in sectoral efficiency in terms of the amount emitted per sectoral product. We project productivity gains in the world economy until 2030. Such projections were taken from various national and international sources, such as the Brazilian Institute of Geography and Statistics (IBGE)[10], Central Bank of Brazil (BCB)[11], National Supply Company (CONAB)[12], Ministry of Agriculture and Livestock (MAPA)[13], *EconMap*[14] (Fontagné *et al*, 2022), and Fuglie (2018).

RESULTS

Table 1 presents the variation in sectoral efficiency of GHG emissions in terms of the amount emitted per sectoral product for the Brazilian regions due to productivity shocks in capital, labor and land for the world economy until 2030.

The changes in the overall GHG emissions efficiency (first line marked in blue) are positive, that is, less is emitted per total product produced, which does not imply in lower absolute emissions[15]. Highlight for two of the states in the Cerrado region that have grown the most in Brazilian agribusiness in recent years, including in exports of crucial commodities for the food security of the rest of the world: BMS (Mato Grosso do Sul) and BMT (Mato Grosso). This fact may be promising

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[7] USA; CHN; IND; RUS; UKR; EUR; REU; RMS; ROA; AFR; MES; RAS; ANZ.
[8] https://energiaeambiente.org.br/produto/seeg.
[9] https://brasil.mapbiomas.org/.
[10] https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9054-contas-regionais-do-brasil.
[11] https://www.bcb.gov.br/publicacoes/focus.
[12] https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras/itemlist/category/907-graos-por-unidades-da-federacao.
[13] https://www.gov.br/agricultura/pt-br/assuntos/politica-agricola/todas-publicacoes-de-politica-agricola/projecoes-do-agronegocio/tabelas-gerais-projecoes-do-agronegocio-2020-2021-a-2030-2031-1.xlsx/view.
[14] http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=11.
[15] The finished paper intends to present the other results of GHG emissions obtained, better tracking the effects and deepen the discussions.

from the point of view of the continuity of the supply of these goods without additional costly interventions due to climate issues.

Table 1. % changes in CGH emission efficiency in terms of sectoral product

	BDG	BMS	BMT	BMG	BSP	BPR	BRS	BSC	BER	BNO	BNE
total	6.04	17.14	28.09	3.01	2.88	3.37	1.79	10.41	4.49	6.14	0.61
agr	0.00	0.00	0.00	-0.39	-0.82	-0.08	-0.03	0.00	0.89	0.05	0.01
gro	0.00	0.00	0.00	-0.34	-0.79	-0.01	0.00	0.00	3.31	0.23	0.02
osd	0.00	0.00	0.00	-1.21	-0.84	-0.03	0.00	0.00	0.00	0.31	0.04
c_b	0.00	0.00	0.01	-0.57	-0.85	-0.05	-0.09	-0.01	1.01	0.85	0.03
pdr	0.00	0.01	0.06	-0.96	-0.80	-0.01	0.00	0.00	1.16	0.01	0.01
wht	0.00	0.09	0.00	-1.59	-0.83	-0.01	0.00	0.00	0.00	0.00	0.00
ctl	16.71	28.34	32.79	21.59	14.23	18.72	15.14	23.44	21.16	28.01	17.58
rmk	16.89	27.55	34.79	21.90	14.59	19.64	15.12	24.26	22.26	28.57	17.54
swn	16.18	23.47	31.63	20.12	8.65	19.15	15.08	24.03	19.64	26.71	17.03
pty	13.89	11.87	21.78	14.59	9.11	18.85	14.74	23.93	19.12	18.24	13.03
fsh	0.01	0.25	0.79	-1.96	2.00	-1.07	-0.24	-0.02	4.92	1.72	0.18
ffw	0.00	0.01	0.00	-0.02	0.44	-1.04	0.00	0.00	0.30	0.00	0.01
oxt	0.00	0.20	1.24	-0.84	-0.35	-0.68	-0.12	-0.14	2.52	0.46	0.00
coa	0.01	3.39	2.47	-2.09	-39.78	0.01	0.00	0.00	4.47	1.38	0.37
oil	0.80	20.33	26.02	-0.94	-0.88	-0.41	-0.23	0.29	-6.22	0.62	0.64
gas	3.53	17.70	25.37	-1.35	-0.78	-0.07	-0.04	0.12	-2.96	0.63	0.39
i_s	0.01	0.05	0.00	-0.08	-0.83	-2.20	-0.97	-0.82	0.23	1.06	0.02
cmt	0.00	0.00	0.00	-0.70	-0.14	-0.14	-0.04	-0.09	3.74	0.08	0.02
omt	0.00	0.01	0.00	-0.51	-0.10	-0.03	-0.01	-0.01	3.74	0.43	0.03
mil	0.02	0.31	0.42	-1.17	-0.36	-0.24	-0.08	-0.09	3.92	0.66	0.03
sgr	0.00	0.06	8.65	-1.85	-1.19	-1.16	-0.41	-0.07	4.02	0.75	0.01
foo	0.00	0.02	0.04	-2.79	-3.21	-0.62	-0.20	-0.12	1.72	0.91	0.43
tex	0.08	0.55	3.20	-2.86	-2.78	-0.65	-0.16	-0.31	0.88	0.69	0.14
wpp	0.00	0.01	0.00	-2.33	-1.96	-0.13	-0.29	0.09	4.94	1.11	0.02
p_c	0.19	17.55	25.62	-1.26	-0.70	-0.02	-0.10	0.62	7.87	0.95	-0.17
bio	0.00	0.01	0.03	-1.30	-0.91	-0.36	-0.12	-0.19	3.79	1.13	0.09
afe	0.01	0.08	0.24	-2.39	-1.40	-0.50	-0.21	-0.26	1.93	0.67	0.23
def	0.00	0.07	0.13	-2.50	-1.75	-0.44	-0.19	-0.31	2.61	0.61	0.24
mab	0.21	0.07	0.01	-1.16	-1.62	-0.18	-0.21	0.13	1.79	0.76	0.19
ely	0.01	0.01	0.04	-2.17	-2.99	-0.54	-0.22	1.71	-5.44	0.36	0.83
wtr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.70	0.00	0.00
cns	0.00	0.23	0.56	-2.60	-1.66	-1.44	-0.52	-0.30	3.41	1.11	0.18
trd	0.00	0.03	0.05	-2.54	-1.60	-1.03	-0.37	-0.77	4.22	1.09	0.18
otp	0.00	0.00	0.00	-2.27	1.37	-1.23	-0.29	-0.02	4.47	1.46	0.28
wtp	0.00	0.02	0.02	0.52	3.24	-1.36	-0.11	-0.03	3.87	1.58	0.13
atp	0.00	0.08	0.07	-0.70	-0.60	-0.53	-1.19	-0.01	3.87	0.47	0.21
ser	0.01	0.16	0.28	-2.69	-2.18	-1.26	-0.59	-1.09	3.29	1.00	0.24

Source: prepared by the authors.

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In this sense, another outstanding result (marked horizontally in blue) is the robust and consistent increase in efficiency, in all regions, of livestock sectors. Certainly, the magnitude of the variations was influenced by the connection of emissions in the capital used by these sectors and the consequent productivity shock in this factor. Even so, it signals the direction of the potential for emission reductions with possible productivity gains in the implementation of technologies that save emitting resources.

On the other hand, marked vertically in red in the table, we can notice a deterioration in the efficiency of emissions in the other sectors of states traditionally relevant in the Brazilian economy, such as BMG (Minas Gerais), BSP (São Paulo), BPR (Paraná) and BRS (Rio Grande do Sul). It is likely that the economic sectors of these states, after the shock, tend to attract more resources, which makes them more emitters per unit of production. This phenomenon may have implications for mitigation policies in the coming years that consider these differences in the regional economic structure.

CONCLUSION

Agriculture in Brazil, and in the Cerrado in particular, is widely recognized worldwide, as Brazil is one of the main global suppliers of agri-food goods and agricultural inputs. Given this, the main objective of the paper is to evaluate how projections of agricultural productivity changes in the world economy by 2030 can impact the general level of GHG emissions. More specifically, we aim to assess the changes in sectoral efficiency measured in terms of emissions per sectoral product

The main findings were (*i*) the two of the greatest agribusiness states in Brazil achieved a net positive balance in greenhouse gas emissions efficiency, signaling few environmental growth restrictions for the coming years; (*ii*) there was a robust and consistent increase in efficiency across all regions in sectors related to Brazilian livestock production related to adoption of new technologies; and (*iii*) however, there was a deterioration in emissions efficiency in other sectors of states traditionally relevant to the Brazilian economy.

In general, the results reinforce the crucial role of R&D investments to, for example, expand the availability of new knowledge and technologies to increase productivity that have demonstrated potential to maintain efficiency gains in emissions.

Therefore, the model built and the results found allow for a more precise and comprehensive analysis of the changes in Brazilian GHG emissions until 2030 for different sectors and regions, contributing to more informed decision-making on the topic in the coming years in Brazil.

REFERENCES

AMANN, E.; AZZONI, C.; BAER, W. **The Oxford Handbook of the Brazilian Economy**. New York: Oxford University Press, 2018.

ARIAS, D.; VIEIRA, P. A.; CONTINI, E.; FARINELLI, B.; MORRIS, M. **Agriculture Productivity Growth in Brazil: Recent Trends and Future Prospects**. Washington, DC, 2017.

BUAINAIN, A. M.; LANNA, R.; NAVARRO, Z. **Agricultural Development in Brazil**. 1º ed. London: Routledge, 2019.

CEPEA. PIB-AGRO/CEPEA: APÓS RECORDES EM 2020 E 2021, PIB DO AGRO CAI 4,22% EM 2022. <https://www.cepea.esalq.usp.br/upload/kceditor/files/PIB-DO-AGRONEGOCIO-2022.17MAR2023.pdf>.

FERREIRA FILHO, J. B. DE S.; HORRIDGE, M. **Climate change impacts on agricultrue and internal migrations in Brazil**. Melbourne, 2016.

FONTAGNÉ, L.; PEREGO, E.; SANTONI, G. MaGE 3.1: Long-term macroeconomic projections of the World economy. **International Economics**, v. 172, p. 168–189, 2022.

FUGLIE, K. R&D Capital, R&D Spillovers, and Productivity Growth in World Agriculture. **Applied Economic Perspectives and Policy**, v. 40, n. 3, p. 421–444, 2018.

DRAFT: NOT FOR PUBLICATION

GIANETTI, G. W.; FERREIRA FILHO, J. B. DE S. Socioeconomic and environmental impacts of degraded pasture recovery in Brazil: contribution to the NDC. p.21, 2023. Bordeaux, France: **26th Annual Conference on Global Economic Analysis**.

GOMES, L. A. DE V.; SAES, M. S. M.; NUNES, R.; VILPOUX, O. F. Heuristics and farm heterogeneity: Evidence from small-scale farmers in Brazil. **Journal of Rural Studies**, v. 92, p. 328–341, 2022.

LUIS, É.; EYJI, B. E.; SILVIA, S.; CAMPOS, K.; TÉCNICOS, E. **Dinâmica agrícola no Cerrado: análises e projeções**. 1º ed. Brasília - DF: Embrapa, 2022.

MAPA. Projeções do Agronegócio 2020-2021 a 2030-2031.

MAPBIOMAS. Infográficos. Disponível em: <https://mapbiomas.org/infograficos-1?cama_set_language=pt-BR>.

MARTHA, G.B., ALVES, E. The Role and Impact of Public Research and Technology Transfer in Brazilian Agriculture. In: Kalaitzandonakes, N., Carayannis, E., Grigoroudis, E., Rozakis, S. (eds) **From Agriscience to Agribusiness. Innovation, Technology, and Knowledge Management**. Springer, Cham, 2018.

MARTINELLI, L.; BATISTELLA, M.; SILVA, R.; MORAN, E. Soy Expansion and Socioeconomic Development in Municipalities of Brazil. **Land**, v. 6, n. 3, p. 62, 2017.

MORES, G. DE V.; DEWES, H.; TALAMINI, E.; et al. A Longitudinal Study of Brazilian Food Production Dynamics. **Agriculture**, v. 12, n. 11, p. 1811, 2022.

OECD-FAO. **OECD-FAO Agricultural Outlook 2021-2030**. Paris: OECD, 2021.

PEREIRA, P. A. A.; MARTHA, G. B.; SANTANA, C. A.; ALVES, E. The development of Brazilian agriculture: future technological challenges and opportunities. **Agriculture & Food Security**, v. 1, n. 1, p. 4, 2012.

ROCHA, A.; GONÇALVES, E.; ALMEIDA, E. Agricultural technology adoption and land use: evidence for Brazilian municipalities. **Journal of Land Use Science**, v. 14, n. 4–6, p. 320–346, 2019.

RUDORFF, B.; RISSO, J.; AGUIAR, D. **Análise geoespacial da expansão da soja no bioma Cerrado: 2000/01 a 2021/22**. Florianópolis-SC, 2022.

SEEG. **Análise das emissões brasileiras de gases de efeito estufa e suas implicações para as metas climáticas do Brasil 1970-2021.** São Paulo, 2023.

SILVA, F. P.; ARAUJO, J. A.; COSTA, E. M.; VIEIRA FILHO, J. E. R. Eficiência técnica e heterogeneidade tecnológica na agropecuária das regiões semiárida e não semiárida do Nordeste brasileiro. **Revista de Economia e Sociologia Rural**, v. 57, n. 3, p. 379–395, 2019.

SILVA, J. G. DA; RUVIARO, C. F.; FERREIRA FILHO, J. B. DE S. Livestock intensification as a climate policy: Lessons from the Brazilian case. **Land Use Policy**, v. 62, p. 232–245, 2017.

SOUZA, G.; DOMINGUES, E. P.; MAGALHÃES, A. Impacts of economic growth with forest

DRAFT: NOT FOR PUBLICATION

preservation in the Amazon and Cerrado biomes in Brazil. 26th Annual Conference on Global Economic Analysis. **Anais...** . p.33, 2023. Bordeaux, France: 2023 Conference Paper. GTAP Resource #7015.

SOUZA, B.; HADDAD, E. Climate change in Brazil: dealing with uncertainty in agricultural productivity models and the implications for economy-wide impacts. **Spatial Economic Analysis**, v. 17, n. 1, p. 83–100, 2022.

SOUZA, C. M.; Z. SHIMBO, J.; ROSA, M. R.; et al. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. **Remote Sensing**, v. 12, n. 17, p. 2735, 2020.

STARK, S.; BIBER-FREUDENBERGER, L.; DIETZ, T.; et al. Sustainability implications of transformation pathways for the bioeconomy. **Sustainable Production and Consumption**, v. 29, p. 215–227, 2022.

TRIGUEIRO, W. R.; NABOUT, J. C.; TESSAROLO, G. Uncovering the spatial variability of recent deforestation drivers in the Brazilian Cerrado. **Journal of Environmental Management**, v. 275, p. 111243, 2020.

WORLD BANK GROUP. **World Bank Group Climate Change Action Plan 2021–2025: Supporting Green, Resilient, and Inclusive Development**. Washington, DC, 2021.

DRAFT: NOT FOR PUBLICATION