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# Assessing the impacts of the EU bioeconomy on third countries

*Potential environmental impacts in Brazil of EU biofuel demand to 2030*

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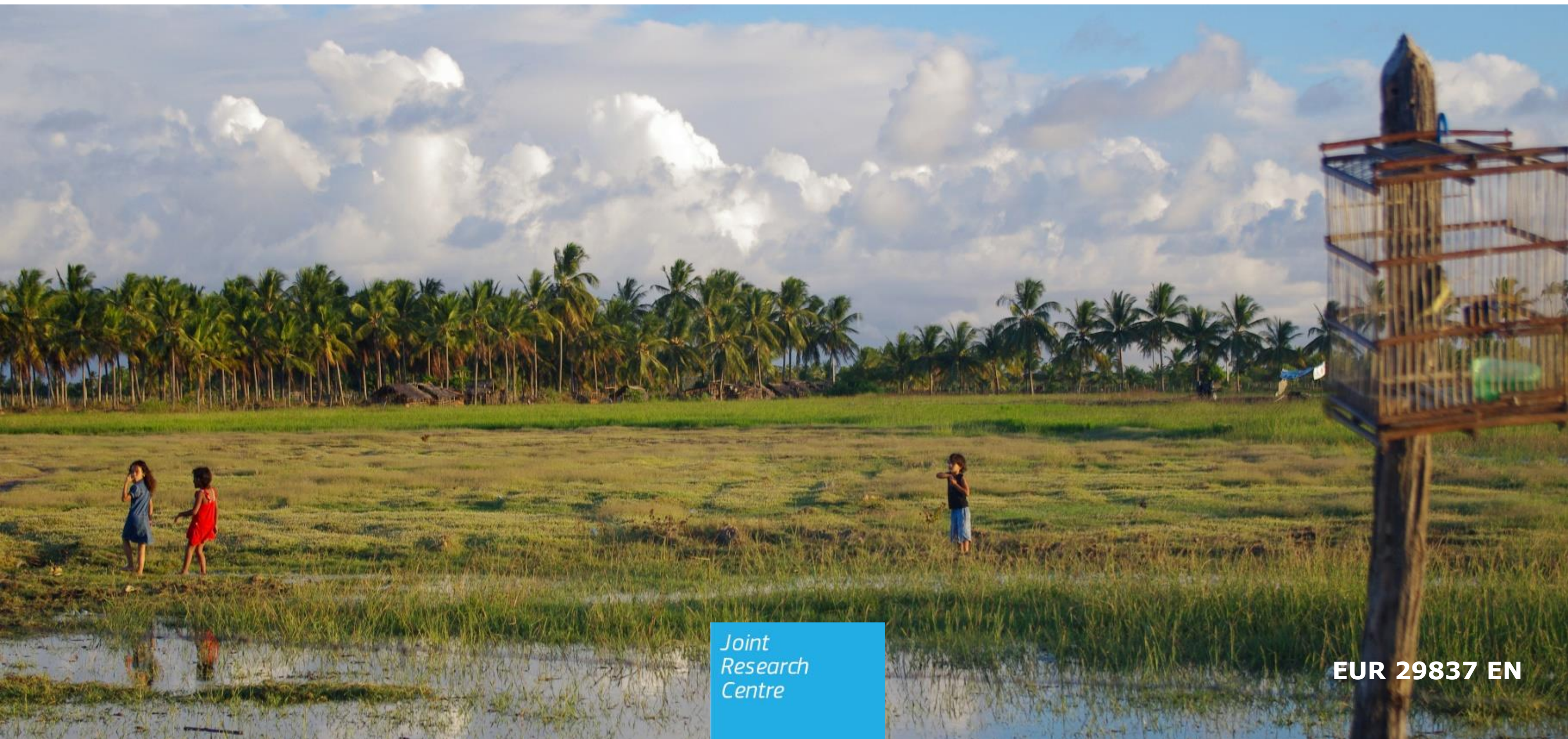
**2019**



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[1] https://ec.europa.eu/knowledge4policy/projects-activities/jrc-biomass-assessment-study_en

## Executive summary

The updated EU Bioeconomy Strategy of 2018[2] reinforced the importance of enhancing the knowledge on the ecological boundaries of the bioeconomy at EU and global level. It is recognized that the global context is highly relevant to align the EU bioeconomy targets with world-wide sustainable development goals. To achieve its decarbonisation targets and boost the bioeconomy, the EU will inevitably consume more biomass. The EU's own biomass resources will meet part of the demand although these ambitious targets will also require reliable and sustained access to third country suppliers.

Brazil is a key player in the global climate agenda since it is home to the largest tropical forest and the seventh largest emitter of greenhouse gases (GHGs), mainly due to deforestation and agriculture expansion. From the perspective of the EU, Brazil is also the biggest exporter of agricultural commodities and its second trading partner overall. The environmental impacts arising from European consumption of bio-commodities are already evident in Brazil, and may become more pronounced under a weakened environmental governance scenario. To integrate its goal of curbing climate change with the promotion of world-wide sustainable development, the EU needs to guarantee the sustainability of its supply chains also by ensuring that trade between Europe and Mercosur respects strict environmental standards. Until now, the lack of clear environmental and social criteria associated with the production of traded biocommodities has hindered the definition of an internationally agreed approach to monitor the compliance of third country supply with EU standards. The recast Renewable Energy Directive (REDII) made a step in this direction by setting environmental criteria for conventional biofuel feedstock production, even though the final definition of these criteria and the technical rules to assess compliance with them remain under discussion.

The tariff-rate quota (TRQ) for Brazilian ethanol has long been a sticking point in the EU-Mercosur trade-talks: the European offer of 600 thousand tonnes (ca. 760 million litres) has been deemed too low by the Brazilian delegation, whose request was for one million tonnes (ca. 1.3 billion litres). This ex-ante study assesses the potential impacts on land use changes, and associated GHG emissions, in Brazil resulting from increased EU demand for ethanol, and draws evidence-based conclusions to verify the compliance of sugarcane feedstock production with the REDII environmental criteria, by combining the computable general equilibrium model MAGNET with the land use model of Brazil OTIMIZAGRO. In the baseline scenario (business as usual, BAU), the main market drivers of EU demand are economic growth and population projections to 2030 and the progressive implementation of the 1st and 2nd generation biofuel mandates. The "high-import scenario" (phase-out biodiesel scenario, POB) deviates from the BAU by eliminating EU imports of palm oil from Asia by 2020, and progressively substituting biodiesel with bioethanol, leading to greater EU dependence on imports from Brazilian bioethanol. Projections for other crops' expansion (including soybeans), plantations and deforestation scenarios have also been included to provide a more comprehensive picture of plausible outcomes for Brazilian land use changes from 2017 to 2030.

The results reveal that, under the BAU scenario, the Brazilian supply of ethanol reaches ca. 51.5 billion litres by 2030 (from an estimated 33 billion litres in 2018), of which only 0.18 billion litres are exported to the EU (i.e. 7% of Brazil's ethanol exports). With the ethanol supply in Brazil rising to 52.2 billion litres under the POB scenario, Brazil's export volume to the EU also rises rapidly to ca. 1.1 billion litres – close to the Brazilian TRQ request – representing ca. 30% of Brazil's total exports. To meet these demands the sugarcane area would increase to between 14.6 (BAU) and 14.8 (POB) million hectares by 2030, with a marginal difference in terms of land use changes and GHG emissions between the scenarios. Sugarcane expansion into Amazonian and Cerrado (savannah-like) native vegetation is marginal (less than 2%) resulting in limited forest biomass loss and associated GHG emissions. The conversion of other croplands (including food crops) to sugarcane is also negligible and does not displace their production elsewhere or affect other

[2] https://ec.europa.eu/knowledge4policy/publication/updated-bioeconomy-strategy-2018_en

crop markets. Most of the sugarcane expansion occurs at the expense of pasturelands (ca. 97%) in the Southeast and Midwest regions. Conversion of pasture to sugarcane and achieving the expected yield require the application of fertilizer and lime, which represent the highest source of GHG emission from sugarcane cropping. Nonetheless, restoring pasturelands could avoid further forest clearance and associated high GHG emissions from changes in biomass carbon stock, thereby representing an effective way to satisfy growing domestic and international ethanol demand while helping to achieve Brazil's mitigation targets.

This study points out that sugarcane feedstock production could comply with REDII environmental criteria under both scenarios, given its marginal expansion into high carbon stock lands and limited displacement of other crops. Moreover, even though most of the sugarcane expansion is into pasturelands, it is possible – but far from certain - that new forest clearance in the northern regions is linked to the displacement of pasture from the Southeast and Midwest (uncertain risk of indirect land use change).

By comparison, in the same period, production of soybean – the largest crop in Brazil, mainly used for animal feed – is projected to expand considerably into the native vegetation of the Amazon (ca 7%, i.e. 0.9 million hectares) and the Cerrado (ca 6%, i.e. 0.7 million hectares) resulting in high GHG emissions from biomass loss, not to mention that most of the soybean expansion occurs in pasturelands in the Midwest and Northeast regions, leading to potential pasture displacement and new forest clearance in the nearby Amazonian and Cerrado biomes, as well as significant loss of soil carbon stock from conversion of the pasture itself.

Accounting for all land use changes (i.e. the main 14 crops, plantations, forest regrowth and deforestation), the country's cumulative net GHG emission balance rises steeply between 2017 and 2030, putting the Brazilian contribution to the Paris Agreements at risk, whilst the difference between the country's Nationally Determined Contribution (NDC) targets by 2030 (ca. 22 million $CO_2$ tonnes) and our results is approximately an additional 900 million $CO_2$ tonnes. The higher emissions due to increasing deforestation rates – linked to lax enforcement of the Forest Code (the principal law regulating forest conservation in private properties) – will have to be compensated by large mitigation efforts in other economic sectors so that Brazil can meet its NDC targets.

Understanding the ecological boundaries of the bioeconomy is one of the key-actions of the updated EU Bioeconomy Strategy of 2018. This includes quantifying the spillovers of EU trade with the main biomass suppliers, like Brazil, to assess the potential impacts of the EU bioeconomy on global sustainable development goals. The results reveal that sugarcane feedstock production could have limited impacts on GHG emissions through land use changes and farming practices, even under conditions of high EU demand for ethanol – a sticking point during the last EU-Mercosur trade talks. The conversion of pasturelands to sugarcane could represent an opportunity for the Brazilian sugar industry to meet the rising demand for ethanol and sugar while achieving sectoral mitigation targets as well as compliance with the EU's environmental criteria. Pasture displacement towards northern regions due to sugarcane expansion is possible but highly uncertain, and could be avoided through investments in cattle ranching intensification. In contrast, large-scale soybean expansion could lead to further loss of Amazonian forest and Cerrado native vegetation, through direct and indirect land use changes, i.e. pasture displacement.

From 2005 to 2012, Brazil was able to curb deforestation and substantially reduce its GHG emissions with strong improvements in environmental governance. Our modelling results from 2017 to 2030 show that the contribution of all land use changes to country's cumulative GHG emission balance could be an additional 900 million $CO_2$ tonnes above the NDC target. This implies that a dismantling of Brazil's environmental protection could threaten uncontrolled rates of deforestation in the near future, thereby risking to jeopardise compliance with the Paris Agreement. A firm commitment ensuring that a trade deal with Brazil is conditional on strict environmental criteria for agricultural commodities would be an effective way to promote responsible sustainable development and avoid further deforestation directly or indirectly linked to the expansion of farming and ranching activities, in line with the commitments of the EU "trade for all" strategy.

***Main findings***

For the sake of simplicity, we provide an overall analysis of the land use changes from 2017 to 2030 and associated GHG emissions, due to the marginal differences between the scenarios' outcomes.

| IMPACT | SUGARCANE: MAIN OUTCOMES, 2017-2030 | COMPLIANCE WITH EU ENVIRONMENTAL CRITERIA |
|---|---|---|
| | Marginal expansion (<2%) into forest (high carbon stock lands) and savannah native vegetation | ✓ |
| | Marginal expansion (<1%) into other croplands (including food crops). Negligible displacement of farming activities and associated ILUC | ✓ |
| | 97% of expansion into pasturelands in the Southeast and Midwest. Uncertain link between sugarcane expansion in the south and pasture displacement into northern regions (and associated forest clearance) | ✓ ⚠ |
| | Converting pastureland to sugarcane demands the application of lime and fertilizers. It represents the largest source of GHG emission (>35%) from sugarcane production – but far lower than emissions associated with the conversion of native vegetation to croplands | ✓ |
| | • 24.5 Mtons CO2/year<br>• 2 tons CO2/ha year and 2 gCO2/MJ<br>• Cumulative emissions 2018-2030: ca. 312-323 Mton CO2<br>• GHG emission profile: 1) Agricultural practices 56% (38% from fertilizer and lime application; 18% from straw burning); 2) LULUCF 44% (26% from carbon stock change in soil; 18% from carbon stock change in biomass). Straw burning should be gradually dismissed | ✓ |

| IMPACT | SOYBEAN: MAIN OUTCOMES, 2017-2030 | COMPLIANCE WITH EU ENVIRONMENTAL CRITERIA |
|---|---|---|
| | Significant expansion into forest (high carbon stock lands, ca. 7% = 0.88 Mha) and savannah native vegetation (ca. 6% = 0.73 Mha). | ⚠ |
| | Marginal expansion (<1%) into other croplands (including food crops). Negligible displacement of farming activities and associated ILUC | ✓ |
| | 87% of expansion into pasturelands mainly in the Midwest and northern regions. Soybean large-scale occupation of northern pasturelands could displace pasture into Amazon and Cerrado biomes (with associated new forest clearance) | ⚠ |
| | Only LULUCF emissions:<br>• 73 Mton CO2/year<br>• 1.8 ton CO2/ha year and 56 gCO2/MJ<br>• Cumulative emissions 2017-2030: ca. 950 Mton CO2<br>(By comparison, sugarcane LULUCF: ca. 11 Mton CO2/year and 0.85 CO2/ha year; cumulative emissions: ca. 140 Mton CO2)<br>• Soybean LULUCF emissions (ton CO2/ha year) are two times larger than the sugarcane ones (higher conversion of forest and native vegetation to croplands) | ⚠ |

| IMPACT | COUNTRY CUMULATIVE LAND USE CHANGES: MAIN OUTCOMES, 2017-2030 | CONTRIBUTION TO PARIS AGREEMENT |
| --- | --- | --- |
| | The difference between the country’s Nationally Determined Contribution (NDC) targets by 2030 (ca. 22 million CO2 tons) and our results is approximately an additional 900 million CO2 tons. Deforestation is the main source of the additional LULUCF emissions – we assumed that the deforestation rates observed since 2013 continue to 2030 (weakened environmental governance scenario) | |

It must be noted that the impacts reported here are only first order impacts. A comparison with bioethanol production in the EU or emissions associated with alternative forms of energy, are beyond the scope of this study.

***Quick guide***

Chapter 1 briefly introduces the key questions to be addressed to develop a sustainable EU bioeconomy in the mid to long term.

Chapter 2 describes the policy context and the main legislative tools considered in this study. Both European and Brazilian laws, directives and criteria have been used to support the simulations and to interpret the results.

Chapter 3 summarises the state of play in monitoring and modelling the impacts of the EU bioeconomy and the sustainability of traded commodities at the global level.

Chapter 4 briefly describes the region of focus and the impact modelling framework to assess the sustainability of sugarcane feedstock production to satisfy varying EU demand for ethanol.

Chapter 5 shows the model results for two projected scenarios of EU demand (baseline and high-import scenario) to 2030.

Finally, chapter 6 summarises the main results of the study.

# 1 Introduction

Demographic, economic and environmental questions of the 21st century present major sustainability challenges for the biophysical boundaries of our planet. These concerns are fundamentally incompatible with the continued usage of a linear 'make-take-dispose' model of economic growth, and heavy reliance on limited carbon-based resources and their associated environmentally prejudicial fossil-based production technologies. As a result, socially responsible strategies are required to alleviate the pressures on the biosphere, whilst harmonising environmentally friendly progress with a sustainable model of economic growth, employment and social inclusion. A key tenet underlying this thesis is the design, development and implementation of a symbiotic economy-environment 'circular economy' model of regenerative resource usage. An important component part of this paradigm is the conversion of biologically renewable resources and biological waste, i.e. biomass, into value-added streams (i.e. food, feed, industrial and energy applications).

Against this background, it is important that policymakers have a solid grasp of current and future biomass availability when prescribing multi-objective policies (i.e. higher value added growth and employment, lower emissions, energy self-sufficiency, biodiversity etc.). This in turn requires knowledge of the scope of those biomass-using activities that comprise the broad and diverse collective known as the bioeconomy, which in the EU is estimated to employ over 18 million people with a turnover of €2.3 trillion (Ronzon and M'barek, 2018). Indeed, in understanding how best to monitor and assess the performance of the bioeconomy with a view to providing high quality information to policymakers, there remains considerable scope for improving our knowledge of the sector.

This is precisely the aim of the European Commission's Knowledge Centre for Bioeconomy, which is housed at the Joint Research Centre. Moreover, ongoing consultations between the policy and academic communities reveals a clear need to plough additional resources into removing knowledge gaps through further data collection and construction (Gurria et al., 2017) to reduce existing levels of uncertainty surrounding biomass availability and usage within the European Union. Indeed, access to detailed (i.e. time and space) data sources not only provides a basis for formulating relevant indicators to conduct *ex-post* monitoring and performance evaluation of the bioeconomy, but is also an essential input for *ex-ante* modelling impact assessments. To draw insights from these data trends for modelling exercises and policy formulation, one also requires an appreciation of the economic, societal and biophysical driving forces behind them (i.e. technological change, biomass availability, consumer preferences, policy coherence or conflict, etc.) and how they may be expected to continue shaping the progress of this collective of activities in the coming years.

On this latter point, the focus of the EU's evolving internal energy requirements has been an important driver of biomass markets over the past 15 years. The role of biomass, as a part-solution for decarbonising EU energy markets whilst ensuring self-sufficiency in the coming decades, plays a dominant role on the policy agenda. According to the Knowledge Centre for Bioeconomy, biomass for bioenergy, largely from forestry, constitutes approximately 60% of the EU's renewable energy. Of this total, 75%, 13% and 12% is dedicated to heating and cooling, bioelectricity and liquid biofuels, respectively, whilst 96% of the EU's biomass requirement for energy is internally sourced (KCB, 2018).

Turning the focus toward first-generation biofuel markets, the EU has an internal market requirement of approximately 16 billion litres of first-generation biodiesel, of which approximately 14% was sourced from extra-EU imports, principally from Argentina and Malaysia (USDA, 2018). Ethanol for fuel usage in the EU is approximately one-third the size of the biodiesel market, whilst ethanol imports for fuel totalled approximately 150 million litres, or 3% of the EU's internal market.

Whilst these statistics reveal a steady picture in terms of EU biomass for energy availability, of particular pertinence to the production of first-generation biofuels is the ongoing debate which encompasses sustainability criteria regarding indirect land use change (ILUC), reliable access to trade sources, and feed and food security. This, in turn, gave rise to an EU roadmap, known as the Fuel Quality Directive (FQD) (EC, 2009) for the adoption of sustainable biofuel usage. In terms of securing stable trade access to third country imports of biomass for energy, the EU's reliance on Latin American sources would be consolidated further with a successful conclusion to the longstanding Mercosur-EU trade negotiations. Perhaps of more immediate concern is the ILUC issue, which has cast the spotlight very much on biodiesel feedstocks, particularly EU palm oil imports from Asia, which have been deemed as a higher deforestation risk, leading to potential policy conflicts with global environmental and food security objectives. This has resulted in the expected phasing out of palm oil imports for biodiesel feedstock by 2030.

In seeking a more sustainable solution to meet the EU's internal commitments regarding biomass usage in liquid biofuels, the adoption of advanced generation biofuels avoids conflicts with competing food crops whilst offering a potential solution for minimising ILUC effects. Notwithstanding, in the short- to medium-term, there is a high degree of uncertainty regarding the economic viability at mass scale of currently available technologies. As a result, with conventional EU biofuels facing stricter sustainability requirements, the use of first-generation ethanol is touted as a possible medium-term solution. As noted above, biodiesel currently represents a considerably larger biofuel market within the EU, where the switch to bioethanol would require reliable supplementary access to third country imports. With its dominance in global bioethanol markets, Brazil would be a key player in supporting such a policy initiative.

Accordingly, the aim of this study is to quantitatively assess the impacts of a hypothetical switch in EU conventional biofuels in favour of bioethanol to meet the EU's internal market requirements. A key focus of the work is to assess the ramifications of this policy on the pattern of land use in Brazil.

We use a global economic trade model called MAGNET to assess the EU's ethanol import requirements. As noted in EC 2018c (SWD(2018)431), with its state-of-the-art coverage of bio-based activities, MAGNET includes various features for assessing policy coherence in the context of the bioeconomy and Sustainable Development Goals (SDGs), and can be connected to sector-specific models that capture in detail the impacts of increased biomass usage. In the context of this research, MAGNET is linked with a spatially explicit land use model of the Brazilian regions, called OTIMIZAGRO, which measures the resulting impacts on the pattern of demand for crops, the direct and indirect land use changes (LUC and ILUC) and the implications for $CO_2$ emissions as a result of land use, land use change and forestry (LULUCF).

# 2 Policy context

## 2.1 Overview

Europe and many other world regions are boosting their bioeconomy – the part of the economy that uses biologically renewable resources from land and sea – as an engine of sustainable industrialisation, discovering innovative markets and creating wealth across all economic sectors. Its crosscutting nature offers a great opportunity to address global environmental and societal challenges, such as (inter alia) ensuring food security, managing land uses for competing biomass feedstocks production, mitigating climate change, while achieving long-term sustainable economic growth. The bioeconomy sectors are central to at least half of the Sustainable Development Goals (SDGs ), but conflicting national priorities and a fragmented definition of bioeconomy boundaries hinder progress toward the statement of a common agreed alignment on how bioeconomy could contribute to the SGDs on a global scale (El-Chichakli et al., 2016). In Europe, the Long-Term Strategy 2050 confirmed the increasingly important role of bio-based sectors in achieving energy and climate targets. Nonetheless, the recent review of the 2012 Bioeconomy Strategy pointed to the existing gaps concerning the monitoring and evaluation framework (M&E), calling for the development of a comprehensive M&E system of bioeconomy performances and impacts at national, European and global level .

The recast Renewable Energy Directive (REDII) recognizes the overall direct and indirect land use change impacts associated with the production of biofuels and bioliquids. In particular, it introduces a new approach to address emissions from indirect land use changes (ILUC) by limiting the amount of high ILUC-risk fuels that can be counted towards the 2030 energy targets. Therefore, it is important to create a strong knowledge base to support the identification of low ILUC-risk[3] fuels exempted from these limits when calculating the overall national share of renewables and the share of renewables in the transport sector. To an extent, this new approach could lead to long-standing trade negotiations between Europe and its trading partners about the certification rules for low ILUC-risk commodities. In order to address this issue, the Commission is expected to adopt a Delegated Act (COM,2019) setting out the criteria for certifying low ILUC-risk biofuels, bioliquids and biomass fuels.

The EU underlines its firm commitment to promote sustainable development globally through its trade policy by setting high binding environmental and social standards (EP, 2016). Therefore, assessing the sustainability of traded bio-commodities is a milestone for the definition of any agreement between the EU and its trading partners - together with its potential business opportunities. The implementation of the agreements should be monitored periodically to ensure compliance with the EU standards.

## 2.2 EU Bioeconomy strategy

The European bioeconomy encompasses a wide range of productive sectors – i.e., agriculture, forestry, fisheries, food, bio-energy and bio-based industry – with an annual turnover of ca. €2 trillion, over 18 million people employed and €621 billion in value added. These numbers account for ca. 4.2% and 8% of the EU's GDP and workforce, respectively (Ronzon et al, 2018). Traditional agriculture and its manufactured products represent by far the most important contribution to EU bioeconomy, whilst new services and products (e.g., bio-based chemicals or bioenergy) are still in their early stages (Figure 1).

[3] See the chapter 2.4 for the explication of "low ILUC-risk fuels"

| | EMPLOYMENT (MILLION JOBS) | TURNOVER (BILLION EUR) | VALUE ADDED (BILLION EUR) |
|---|---|---|---|
| AGRICULTURE | 9.2 | 380 | 174 |
| FORESTRY | 0.5 | 50 | 24 |
| FISHING AND AQUACULTURE | 0.2 | 12 | 7 |
| FOOD, BEVERAGES AND OTHER AGRO-MANUFACTURING | 4.5 | 1 153 | 233 |
| BIO-BASED TEXTILES | 1.0 | 103 | 28 |
| WOOD PRODUCTS AND FURNITURE | 1.4 | 174 | 47 |
| PAPER | 0.6 | 187 | 46 |
| BIO-BASED CHEMICALS AND PHARMA - CEUTICALS, PLASTICS AND RUBBER | 0.4 | 177 | 56 |
| LIQUID BIOFUELS | 0.03 | 12 | 3 |
| BIOELECTRICITY | 0.01 | 11 | 3 |

*Figure 1: Quantified Socioeconomic Indicators of the EU Bioeconomy in 2015. Source: based on Ronzon and M'barek (2018).*

The 2018 update[4] of the 2012 Bioeconomy Strategy reinforced the scope of its action towards the 2030 Agenda and SDGs[5], as well as the Paris Agreement targets[6], by setting new action plans to: i) Strengthen and scale up bio-based sectors, unlock investments and increase market uptake; ii) Deploy local bioeconomies rapidly across Europe; iii)Understand the ecological boundaries of the bioeconomy (EC, 2018d).

The third action aims at increasing the knowledge base on bioeconomy sustainability dimensions through improved observation, measurement, monitoring and modelling capacities (Figure 2).

[4] https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf#view=fit&pagemode=none
[5] https://www.un.org/sustainabledevelopment/development-agenda/
[6] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

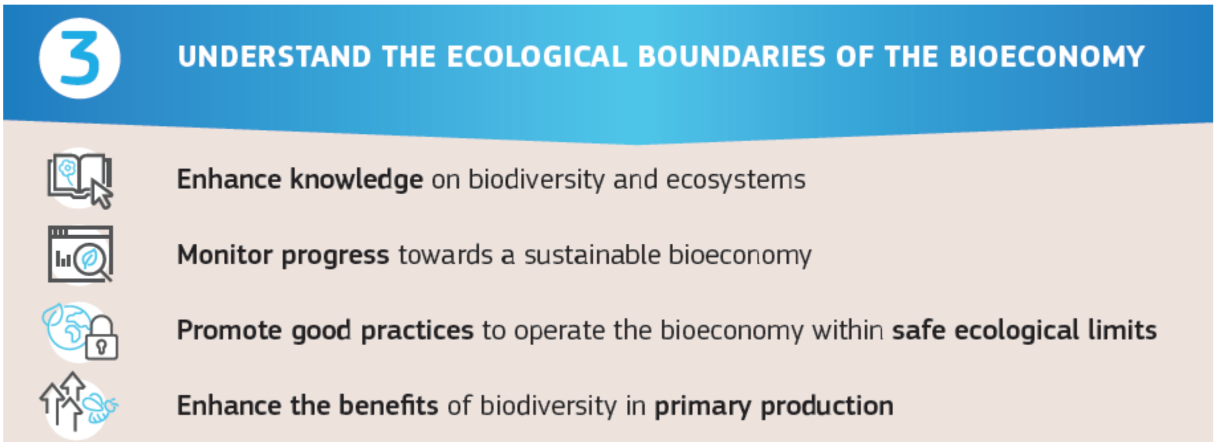


*Figure 2: Third action of the Bioeconomy strategy*

Forward-looking modelling tools are essential for ex-ante assessment of environmental, social and economic trends and trade-offs under different policy scenarios and socioeconomic pathways, to help drive sectoral policy coherence towards EU bioeconomy sustainability targets. This action recognizes the importance of modelling and quantifying direct and indirect land use changes resulting from increasing demand for different biomass feedstock and bio-based products at EU28 and global level, to guarantee the optimal use of available natural resources and limit biodiversity, carbon stock and ecosystem services degradation.

Bioenergy is by far the largest EU renewable energy source, supplying 12% of the EU28's final energy demand, whilst the Bioeconomy strategy foresees a major role for bioenergy in achieving the 2020, 2030 and 2050 EU energy and climate targets. Nonetheless, the environmental impacts of bioenergy production could negate some or all the benefits of its usage. To mitigate this risk, after 2020 the EU sustainability criteria will be applied not only to biofuels and bioliquids but also to solid biomass and biogas for heating and power generation (according to the EU bioenergy sustainability framework reinforced under the recast REDII). Monitoring and evaluating the environmental compliance of these energy sources ensures a credible global transition to a bioeconomy by confirming sustainably responsible producer behaviour, whilst creating a deterrence mechanism for the offenders.

## 2.3 EU Long term strategy 2050

In November 2018, the Commission presented its strategic vision for a long-term competitive and climate-neutral economy by 2050 (EC, 2018a). The strategy covers nearly all EU policies and is in line with the Paris Agreement targets. It recognizes the important role played by the bioeconomy sectors towards the decarbonization of the European economy. It estimates that by 2050, the current EU consumption of biomass could be doubled, intensifying the pressure on EU natural resources and leading to steeply increasing biomass imports. The access to third country trade would also raise concerns related to emissions from indirect land use change. To achieve a gradual reduction of import dependency on third country markets, most of the biomass used in 2050 to fulfil the EU demand for bioenergy could be produced domestically by improving farmland productivity and agroforestry techniques, by switching from first-generation biofuel croplands to lignocellulosic grass, and by re-introducing abandoned land into cultivation, among others (Figure 3). This assumption raises some concerns, since Europe is already one of the most intensively used continents on the globe and an increasing pressure on land resources could lead to a decline in the delivery of ecosystem services, including those related to climate change (e.g., carbon sink).

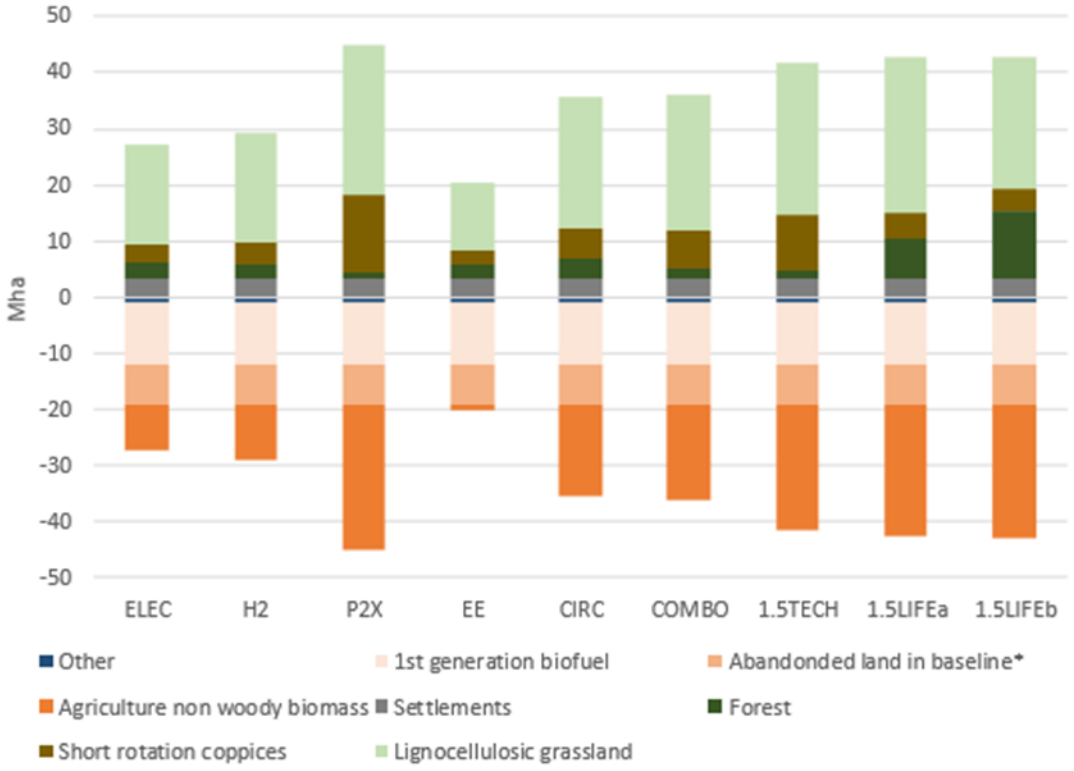


*Figure 3: Projected land use changes 2020-2050 (Mha) for different scenarios. Source: EC, (2018b)*

## 2.4 EU Renewable Energy Directive (REDII)

The recast Renewable Energy Directive[7] (REDII) entered into force on 24th December 2018 by setting an EU-wide renewable energy target of at least 32% by 2030 (with a review for increasing this figure in 2023). It limits the amount of conventional biofuels consumed in the transport sector that can be considered when calculating the national overall share of renewable energy, to the levels existing in each member State in 2020[8]. Under REDII biofuels are required to reduce GHG emissions by at least 50% compared to the use of fossil fuels[9]. Thus, the REDII paves the road for the decarbonization of the EU energy system through a number of low-carbon measures in transport, heating and cooling and electricity sectors to reduce their GHG emissions, improve energy security and provide energy at affordable prices, strengthen EU industrial and technological leadership, create new opportunities for employment and regional development, and provide certainty for investors (EU, 2018).

The REDII also reinforces the EU sustainability framework for bioenergy to guarantee GHG emission savings and minimize unintended environmental impacts. In particular, it recognizes that the magnitude of GHG emission-linked indirect land use changes (ILUC[10]) due to biofuel feedstock production is capable of negating some (or all) emission savings of biofuel consumption. To address this issue, the REDII sets national limits for high ILUC-risk biofuels - produced from food and feed crops for which a significant expansion of the production areas into lands with high carbon stock is observed - at 2019 levels starting from 2020, and then gradually reduces their contribution to zero by 2030 at the latest. Low

[7] https://ec.europa.eu/info/news/new-renewables-energy-efficiency-and-governance-legislation-comes-force-24-december-2018-2018-dec-21_en

[8] Some flexibility is allowed: the national limits can be increased by 1%, with an overall limit of 7% of the 2020 final consumption of road and rail transport sector

[9] Based on a LCA that covers only direct emissions. The threshold for new installations rises to 60% in 2020 and 65% in 2021

[10] Indirect land use changes (ILUC) occur when biofuel expansion into pasture or cropland previously destined for food and feed market causes the displacement of this production elsewhere, resulting in further conversion of native vegetation into new agricultural land or pasture, and associated GHG emissions.

ILUC-risk fuels are exempted from these limits when calculating the overall national share of renewables and the share of renewables in transport sector.

COM (2019a) and COM (2019b) define the rules to assess the sustainability of biofuel feedstock production, by determining what constitutes a "significant" expansion of feedstock into high carbon stock lands[11] and by criteria for low-ILUC risk biofuels[12].

## 2.5 Brazilian Bioeconomy

The national Strategy of Science, Technology and Innovation 2016-2022 (MCTIC, 2017[13]) presented the guidelines for the development of the Brazilian bioeconomy. In 2016, the Brazilian bioeconomy sectors totaled ca. US$ 40 billion and ca. US$ 286 billion on the global and domestic markets, respectively (BNDES, 2018), accounting for ca. 14% of country GDP in the same period. Agribusiness represented more than 50% of domestic sales, with food and beverage and tobacco sectors ranked second (20%), whilst the sugarcane sector totaled ca. BR$ 164 billion. The MCTIC (2018)[14] report detailed the country action plan for bioeconomy by defining measures and targets for different sectors to stimulate economic activities that add value to biological processes and natural resources through technological solutions to produce food, feed, materials, chemicals, fuels and energy. The plan is structured into three thematic areas, namely i) biomass, ii) processing and biorefinaries, iii) bioproducts (Figure 4).

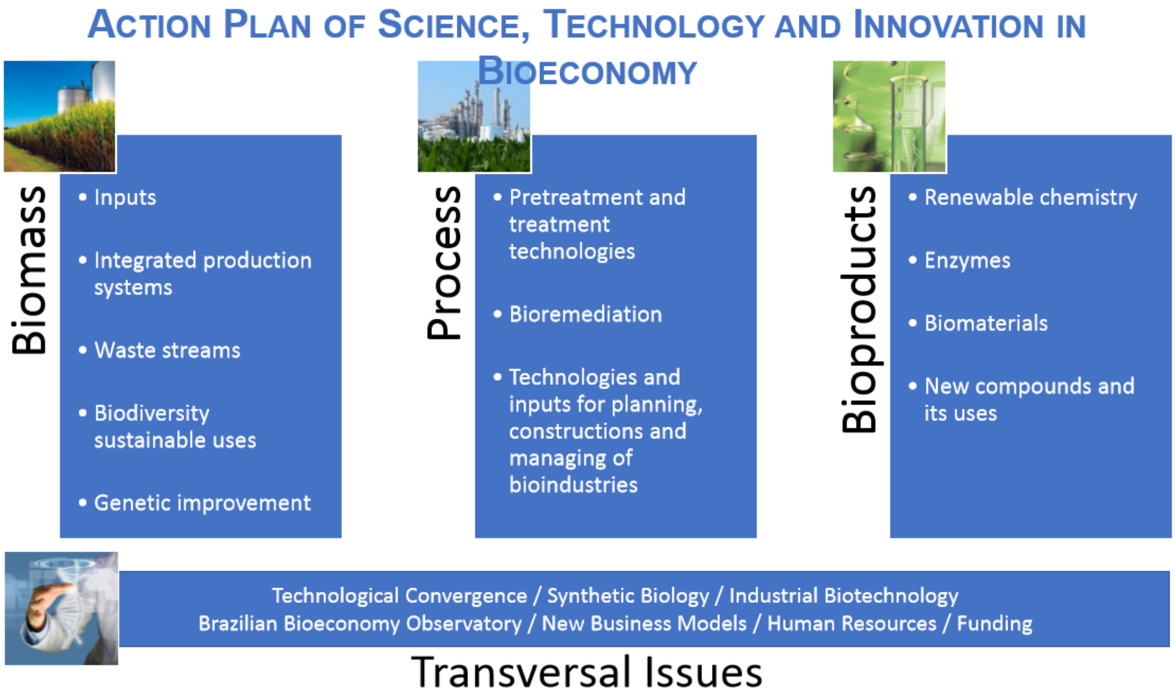


*Figure 4: thematic areas of the Brazilian action plan in bioeconomy. Source: Nunes, B. (2018).*

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[11] Absolute magnitude of crop expansion and its share compared to total production area of the feedstock: Indicative values of 100000 ha/year is considered a sizeable expansion, and 1% of total production area have been suggested. 2. Share of the expansion into high carbon stock land: A conservative threshold of 10% of total expansion is suggested. 3. Type of crops and type of land with high carbon stock must be considered.

[12] Preventing land displacement through increased productivity or by cultivation feedstock on previously unused lands (abandoned or severely degraded). But there is an exemption for production by smallholders with <2ha

[13] http://www.finep.gov.br/images/afinep/Politica/16_03_2018_Estrategia_Nacional_de_Ciencia_Tecnologia_e_Inovacao_2016_2022.pdf

[14] http://www.mctic.gov.br/mctic/export/sites/institucional/ciencia/SEPED/Arquivos/PlanosDeAcao/PACTI_BIOECONOMIA_web.pdf

Given the importance for the Brazilian economy and its decarbonization targets, the strategy for biofuels has been presented in a separate action plan[15] (MCTIC, 2018b). In 2017, sugarcane biomass had a significant contribution toward the renewable energy targets of Brazilian NDC, accounting for ca. 18% of domestic energy supply. Recently, two new biorefinaries for the production of second generation ethanol have been built in Sao Miguel dos Campos (AL) – GranBio company, with a potential capacity of 82 million litres/year) – and in Piracicaba (SP) – Raizen company, with a potential capacity of 40 million litres/year – but they still represent a very small percentage of Brazil's ethanol production. Moreover, remaining challenges continue to limit the scaling up of these bio refineries, mainly due to the uncertainty about policies and mandates for advanced low carbon fuels, the lack of recognition and proper pricing of advanced biofuel environmental services and positive externalities and the lack of cost-effective feedstock management strategy[16].

## 2.6 Brazilian National Policy on Biofuels (Renovabio)

On the 26th December 2017, the Brazilian Ministry of Mines and Energy published the new National Policy on Biofuels – called Renovabio[17] – that aims at boosting the production and distribution of biofuels in Brazil to decarbonize the energy matrix and meet the country's climate commitments. The expected starting date is 2020. Key elements of this program are: i) the certification of emissions associated to the production/import of biofuels, where authorized producers/importers are rated according to the GHG emission saving of each biofuel compared to the conventional fossil fuel alternative; ii) the issuance of decarbonization credits (CBIO) and their distribution to biofuel producers and importers according to the volume of biofuels produced or imported. The annual mandatory GHG emission reduction target for fuel sales is split into individual targets and applied to all fuel distributors by the National Agency of Petroleum, Gas, and Biofuels, in proportion to their market share in fossil fuel sales in the previous year. Distributors can achieve their targets through the direct purchase of certified biofuels, or by trading CBIO in the stock market. Trading CBIO will represent an additional revenue for biofuel producers and a stimulus for new investments in this sector. As regards ethanol, the Brazilian Ministry of Mines and Energy aims to double the current production up to 50 billion litres by 2030, in line with the projections of our study. The environmental criteria set by the Renovabio initiative avoid the production of biofuel feedstock on lands converted from forest areas after December 2017, and limit the lands for sugarcane expansion within the demarked Agroecological Zoning.

## 2.7 EU-Mercosur Trade talks

With a combined GDP of US$ 2.7 trillion in 2017, Mercosur[18] is the largest trading bloc of Latin America and Caribbean regions. In 2017, the EU lost its long-standing position to China, as the largest trading partner of Mercosur. China accounts for 21.8% of Mercosur trade (EPRS, 2018), whilst the EU makes up for 20.3%, ahead of the USA (14.9%). Indeed, trade between the EU and Mercosur reached €111.6 billion in 2011 shortly before the end of the commodities boom, but declined to €84.9 billion in 2017 (Figure 5).

[15] https://www.mctic.gov.br/mctic/export/sites/institucional/tecnologia/tecnologiasSetoriais/Plano-de-Ciencia-Tecnologia-e-Inovacao-Para-Energias-Renovaveis-e-Biocombustiveis.pdf

[16] http://biofutureplatform.org/about/

[17] http://www.mme.gov.br/web/guest/secretarias/petroleo-gas-natural-e-combustiveis-renovaveis/programas/renovabio/principal

[18] Mercosur: the common market of the south was founded in 1991 by Argentina, Brazil, Paraguay and Uruguay. In 2012 Venezuela joined the trading bloc but the country was temporarily suspended in 2016.

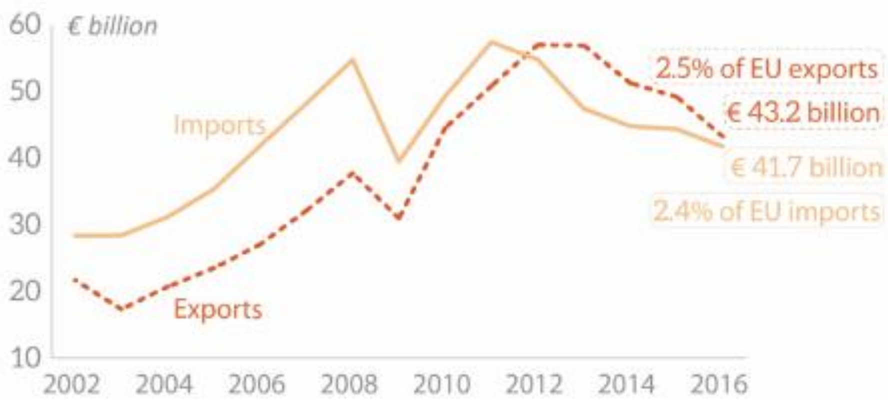



*Figure 5: EU trade in goods with Mercosur. Source: EPRS, 2018*

Since 1999, the European Union and Mercosur have been negotiating a bilateral agreement governing trade relations[19]. In May 2004, the EU made a formal market access proposal for the concession of additional quotas for agricultural products[20] (Kume et al., 2010). Unfortunately, the parties were not able to reach an agreement since the outcome of a follow-up trade negotiators' meeting at ministerial level determined that the EU's offers were not ambitious enough, especially in agriculture and service sectors (SIA, 2008). The negotiations have regained momentum since 2016, where rounds in March and July 2017 made considerable progress on a wide range of chapters, although division between the parties still remains on a number of particularly sensitive issues. Opening the EU market to agricultural imports has long been a sticking point, since many EU products - including sugar, ethanol and beef - would come under pressure. During the negotiation round in October 2017 the EU completed its quota offers on beef and ethanol, which the Mercosur countries deemed as too low[21]. On June 28th, the EU and Mercosur reached a provisional free trade agreement – the final text and the market access schedules have not determined yet. According to the released details, the EU will establish a duty-free tariff rate quota (TRQ) of 562 million litres of ethanol for industrial use per year, and an additional 250 million litres at reduced tariff rates (USDA, 2019). The EU will also increase the TRQ for cane sugar to 180000 tons.

Even though Brazil is one of the world's top producers and exporters of sugar and ethanol, it supplies a small share of the European market. In 2016, Brazilian ethanol accounted for only ca. 5% of EU purchases (Figure 6) due to the high tariff of 0.19 euro/l, which renders Brazilian exports to the EU as uncompetitive. The Brazilian sugarcane industry complained that other countries benefited from favorable duty-free sugar and ethanol agreements and insisted on keeping these commodities on the table within the ongoing Mercosur-EU trade negotiations (UNICA, 2016).

[19] http://trade.ec.europa.eu/doclib/press/index.cfm?id=1769

[20] The EU proposal included a TRQ for ethanol of 1.000.000 tons.

[21] The last EU offer included a 600,000 tonne-quota for ethanol, of which 400,000 tonnes for industrial use. The Brazilian counterpart wants to achieve a volume of ca. 1,000,000 tons, as in the EU 2004 proposal (Reuters, 2017).

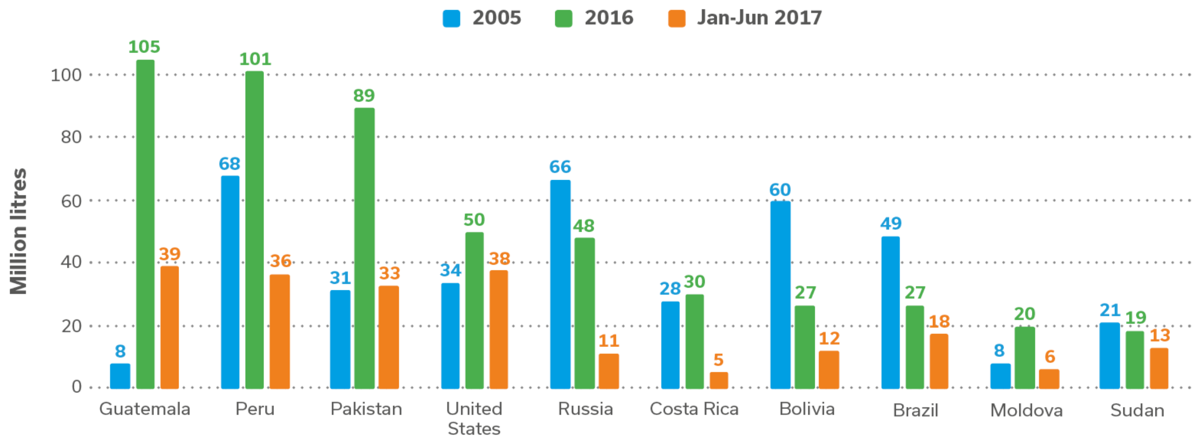



*Figure 6: main countries of origin of ethanol imports to EU. Source: Eurostat and ePURE, 2017.*

The new planned Sustainability Impact Assessment in support of the association agreement negotiations between the European Union and Mercosur (SIA, 2018) will provide a knowledge base on the potential consequences for the economic, social, human and environmental dimensions in the EU and Mercosur of the awaited trade agreement. Its scope, sectoral coverage and resolution significantly differ from the objective of our study.

## 2.8 List of legislative tools

The questions addressed by this study can be categorized into different European and international policy areas related to energy, environment, and climate change (Table 1, 2 and 3).

*Table 1: list of EU documents and legislative tools considered in this study*

| Policy sector | Legislative tool | Main issues relevant to this study |
|---|---|---|
| Energy/Environment | Directive 2009/28/EC[22] of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (RED) | ✓ Sets sustainability criteria (including impacts on biodiverse lands and lands with high carbon stocks) and GHG saving criteria to comply with Union's commitments under the Kyoto Protocol and with Union 2030 energy and climate agenda;<br>✓ Does not cover the issue of ILUC<br>✓ Sets a 20% binding target for the overall share of energy from renewable sources and 10% minimum target for the share of biofuels in transport by 2020<br>✓ Points out the role of biofuel imports to achieve the correct balance between domestic production and production in 3rd |

[22] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0028

| | | |
|---|---|---|
| | | countries, taking into account trade negotiations, environmental, social and economic considerations (16) |
| Energy/Environment | Directive (EU) 2015/1513[23] of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources | ✓ Recognizes that the magnitude of GHG emissions from ILUC can negate some of GHG emission savings of individual biofuels<br>✓ Define an overall limit of a 7% maximum contribution of fuels produced from cereals, sugar and oil crops, starch-rich crops on agricultural lands, towards the final consumption of energy in rail and road transport in each Member State |
| Energy/Environment | Directive (EU) 2018/2001[24] of the EU parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (REDII) | ✓ Sets sustainability criteria (including impacts on lands with high carbon stocks) and GHG saving criteria to comply with the EU's commitments under the Paris Agreement and its 2030 energy and climate agenda;<br>✓ Limits the contribution of conventional biofuels and bioliquids towards 2030 energy target in rail and road transport to the 2020 national share, with the possibility of increasing them by +1% up to a maximum of 7%<br>✓ Recognizes the magnitude of GHG emissions due to ILUC<br>✓ Limits high ILUC-risk biofuel and bioliquid contribution towards 2030 energy target to the 2019 country consumption level; from 2023 their contribution will be gradually reduced to zero by 2030 at latest<br>✓ Points out the need of a clear definition of high and low ILUC-risk feedstock |

[23] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1550150723129&uri=CELEX:32015L1513
[24] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

| | | |
|---|---|---|
| Energy/Environment | Commission Delegated act (EU) 2019 (COM 2019)- The proposal is made pursuant to Article 26(2) of the REDII | ✓ Set criteria for determining the high ILUC-risk feedstock (including sugarcane and soybean) for which a significant expansion of the production area into land with high carbon stock is observed;<br>✓ Set criteria for certifying low ILUC-risk biofuels and bioliquids |
| Bioeconomy/Bioenergy | COM(2018) 673 final[25], 11.10.2018. Communication from the Commission to the European Parliament, the European economic and social committee and the committee of the region. A sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment. | ✓ Reinforces sustainability criteria in line with the Union's commitments under the Paris Agreement and SDGs (e.g, land degradation neutrality)<br>✓ States the need for improving the knowledge base and understanding the bioeconomy ecological boundaries, through data collection, forward looking, cross sectoral assessments, modelling and scenarios<br>✓ Points out existing gaps in monitoring bioeconomy performances and impacts and calls for an overarching monitoring and evaluation framework on different bioeconomy sectors at national, European and global level. |
| Energy/climate | COM(2018) 773 final[26], 28.11.2018. Communication from the commission to the European Parliament, the European Council, the Council, the European economic and social committee, the committee of the regions and the European Investment Bank. A Clean Planet for all, a European strategic long-term vision for a prosperous, modern, competitive and | ✓ Estimates that meeting EU decarbonization targets will double the EU consumption of biomass. Part of this demand will be satisfied by increasing access to 3rd country markets<br>✓ Points out the EU's global role as major import market: the EU's high environmental standards can have effects on 3rd country's productive systems – EU trade policy should be used to promote sustainability |

[25] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0673
[26] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1550150941903&uri=CELEX:52018DC0773

| | | |
|---|---|---|
| | climate neutral economy (LTS 2050) | |

*Table 2: list of Brazilian legislative tools considered in this study*

| Policy sector | Legislative tool | Main issues relevant to this study |
|---|---|---|
| Energy/Environment | Renovabio program – National law on biofuels, nº13.576, on 26th December 2007 | ✓ Set environmental criteria for the production of sugarcane: i) avoid the production of biofuel feedstock on lands converted from forest areas after December 2017; ii) limit the lands for sugarcane expansion within the demarked Agro-ecological Zoning.<br>✓ Certify the sustainability of feedstock productive systems |
| Environment | Revised Forest Code, 2012 (Law Nº 4.771/65) | ✓ Set legal requirements for landowners (i.e., forest conservation in private properties) |
| Agriculture | Agro-Ecological Zoning (AEZ), 2009 | ✓ Set limits of the available areas for the expansion of sugarcane in Brazil |

*Table 3: EU-Mercosur trade negotiation considered in this study*

| Policy sector | Legislative tool | Main issues relevant to this study |
|---|---|---|
| Trade | Trade talks EU-Mercosur 2018/19 | ✓ Will define the duty-free volume of Brazilian ethanol sold in the EU market<br>✓ Sets binding environmental criteria and working standards for EU suppliers of agricultural commodities<br>✓ Commits the signatories to emission-reduction targets and to deforestation combat |

# 3 Impacts of EU biomass demand in third countries: state of play

## 3.1 Introduction

In a recent report by EEA (2018), it was acknowledged that increasing demand for food, feedstock, biomaterials, and bioenergy will exacerbate the pressure on natural resources and potential demand/supply conflicts, which in turn requires coordinated action and careful consideration of the trade-offs. Nevertheless, there is a relative dearth of literature examining the global impacts of EU bioeconomy activity on indirect land use changes (LUC and ILUC), and their GHG emissions.

Studies on the impacts induced by the demand for biomass feedstocks differ depending on how the bioeconomy is defined in the respective strategies and which sectors are considered being part of it, since a commonly agreed definition currently does not exist.

Differences in the sectors and subsectors included into bioeconomy strategies mainly reflect the priorities and competitive advantages of each country or economic block. Examples are given in Table 4 .

*Table 4: Sectors included into bioeconomy strategies of countries examined. "X": included into bioeconomy strategy; "XX": included into bioeconomy strategy and monitored. Source: FAO 2018 and Bracco et al., 2018.*

| Sector | Argentina | Australia | Malaysia | South Africa | USA | EU | Germany |
|---|---|---|---|---|---|---|---|
| Agriculture | xx | x | Xx | x | xx | xx | xx |
| Chemistry (incl. bioplastic) | xx | x | Xx | x | xx | xx | xx |
| Biofuels/bioenergy | xx | x | Xx | x | | xx | xx |
| Biorefining | | x | xx | x | xx | | xx |
| Feed | xx | x | xx | x | | xx | xx |
| Consumer goods (cosmetics…) | xx | | | x | | | xx |
| Fisheries | xx | x | xx | x | | xx | xx |
| Food and beverage | xx | x | xx | x | | xx | xx |
| Forestry | xx | x | xx | x | xx | xx | xx |
| Construction/building industry | | | | | | | xx |

Therefore, this uncertainty in the bioeconomy boundaries and its sectoral targets hinders the definition of a globally agreed framework to identify potential impacts of the transition to a bioeconomy (Table 5). Most countries measure the contribution of bio-based activities to sectoral macroeconomic indicators – e.g., GDP, turnover, value added and employment (Ronzon and M'Barek, 2018; FAO, 2018) – whilst regulatory, social and environmental dimensions are not systematically covered (Bracco *et al*., 2018; Rodriguez et al., 2017; Maes et al., 2016). This knowledge gap calls for international guidelines to assist countries to monitor bioeconomy sustainability aspects in a systematic and harmonized way (FAO, 2016; O'Brien et al., 2017). LUC and ILUC) are not an exception and their global assessment for the main sectors of the bioeconomy still remains relatively neglected, coarsely aggregated at regional level and highly uncertain (Giljum et al., 2016; Hertel et al., 2012; O'Brien et al., 2015; Philippidis et al., 2016).

*Table 5: Main studies reviewed on global monitoring and impact assessment of bioeconomy sectors*

| **Study** | **Description** | **Geographical scope** | **Sectors and products** | **Output** |
|---|---|---|---|---|
| Bracco et al., 2018 | Assessment of the bioeconomy contribution to total economy | 6 pilot countries in Africa, Latin America, USA, Europe, Asia | Sectors in the bioeconomy strategies | Sectoral macroeconomic indicators, mainly GDP, turnover and employment |
| FAO, 2018 | Assessment of the bioeconomy contribution select national economies | 7 pilot countries in Africa, Latin America, USA, Europe, Asia, Australia | Sectors in the bioeconomy strategies | Sectoral macroeconomic indicators, mainly GDP, turnover and employment |
| Giljum et al, 2016 | Assessment of global land demand for non-food products of the EU bioeconomy | Global | Bioplastic, biofuels | Cropland footprint. Qualitative assessment of social and environmental impacts |
| Hertel et al., 2012 | Global land use implications of biofuels expansion (2006-2035) | Global | Biofuels | Cropland footprint. GHG emissions from land conversion |
| O'Brien et al., 2017 | General evaluation about monitoring and modelling tools of the EU bioeconomy (gaps, needs, criteria) | EU and global | EU bioeconomy sectors | General consideration on a dashboard of indicators to assess the impacts on environment, society and economy. Focus on land footprint |
| O'Brien et al., 2015 | Assessment of the land footprint of the EU bioeconomy | Global | Agriculture | Cropland footprint, global land use (including imported and exported commodities) |
| Parisi and Ronzon, 2016 | Technical report on the workshop "a global view of | Global | Bio-Based Industry | General considerations on the needs for methods, |

| | | | | |
|---|---|---|---|---|
| | bio-based industry” | | | data and indicators to monitor socioeconomic impacts of the bioeconomy |
| Philippidis et al., 2016 | *Ex-ante* CGE impact assessment of potential EU bioeconomy drivers in a baseline scenario to 2030 | Global with a focus on EU28 | EU bioeconomy sectors | Macroeconomic indicators; GHG emissions by sectors; land use change by regions |
| Rodriguez et al., 2017 | Overview about the main policy frameworks that drive the bioeconomy in Latin America and the Caribbean. | Global with a focus on Latin America and Caribbean | Bioeconomy sectors of Latin American and Caribbean countries | Policy frameworks and institutions linked to bioeconomy development; export profile for the main sectors included into bioeconomy strategy |

## 3.2 Macroeconomic indicators

### 3.2.1 Monitoring

Most countries assess the contribution of the bioeconomy to their economy through changes in typical macroeconomic indicators, such as Gross Domestic Product (GDP), employment rates, turnover and value added. This approach provides a coarse picture of the progress of the bioeconomy toward the targets set by the country strategy, whilst it is unable to capture faithfully the complexity and heterogeneous nature of country-specific bioeconomy sectors and products. Moreover, socioeconomic data are often only available at different degrees of granularity, which limits the direct comparison between countries or sectors.

Bracco et al., (2018) and FAO, (2018) compare how seven pilot countries: i) define their bioeconomy; ii) set their bioeconomy strategy objectives; and iii) monitor and report the contribution of the bioeconomy to their economy and objectives. Most countries rely on traditional statistical accounts on production and consumption (e.g., Germany and Netherlands) but lack a systematic approach and metrics fully implemented to measure the impacts of the bioeconomy. In contrast, Malaysia, for example, developed a Bioeconomy Contribution Index to assess the contribution of bioeconomy on overall economy, based on 5 indicators: value added, bio-based exports, investment in bio-based activities, employment and productivity performance.

Table 6 lists some of the most common indicators adopted to measure the impact of the transition to a bioeconomy, even though an international agreed indicator framework cannot be stated due to the current fragmentation of the research on bioeconomy boundaries (FAO,2018; Ronzon et M’Barek, 2018; SAT-BBE, 2014).

*Table 6: Most common indicators used to assess the contribution of bioeconomy sectors to total country economy*

| Indicator | Description |
|---|---|
| Number of persons employed | Total number of persons working in the bioeconomy sectors |
| Turnover | Total invoiced by the bioeconomy sectors (revenues from sales) |
| Value added | Gross income from operating activities after adjusting for operating subsidies and indirect taxes |
| Sectoral GDP | Contribution of the bioeconomy and its sectors to the macroeconomy |
| Primary production | Country production in agriculture, forestry, residues, fisheries, waste sectors |
| Trade flows | Import/export of biomass and bio-based products |
| Production/Consumption | Production and use of bioeconomy products (in volume and value) |

### 3.2.2 Modelling future socioeconomic pathways

In the economic analysis of bioeconomy pathways, the modelling literature is broadly split between 'bottom-up' and 'top-down' approaches (Angenendt et al., 2018). The appropriate choice of approach is contingent upon the nature and scale of the research question. For example, the need to analyse very specific technological processes and the behaviour of detailed agents within the supply chain (i.e., farms, refineries etc) favours the use of a bottoms-up approach. On the other hand, given their spatial limits, they cannot deal with broader questions relating to biomass resource competition across different biobased activities, the interactions and resource competition effects that ensue with the non biobased part of the economy and the resulting structural economic change over time to which these dynamic effects give rise. These type of 'big-picture' questions are therefore more suited to top-down economy-wide approaches.

For example, input-output (I/O) analysis and social accounting matrices (SAM) are top-down tools often used to explore in a short term (*inter alia*) the wealth and employment generation impacts arising from assumed different demand shocks. The use of multiplier analysis generates useful insights on the structure and strength of the interlinkages between sectors in an economy and their contribution to employment, value added, and energy use, among others (SAT-BBE, 2013).

Global computable general equilibrium (CGE) models take an additional step by allowing for technological and structural economic changes within an economy. The timeframe is therefore rather medium to long term, whilst such ex-ante assessments can be used to model biomass demand and supply under different policy, socioeconomic or technological scenarios, and evaluate their potential impacts on sector macroeconomic indicators, such as output, prices, trade and employment (Figure 7).

| | 2015 | 2020 | 2030 |
|---|---|---|---|
| **Agriculture, fishing, forestry:** | | | |
| wheat | 330 | 333.2 | 328.6 |
| other grain | 443.4 | 443.9 | 418.3 |
| CEREALS | 784.8 | 789.2 | 761.1 |
| oilseed | 688.7 | 700 | 626.3 |
| beet/cane sugar | 206.9 | 205.8 | 189.3 |
| CROPS | 5974.7 | 5965.3 | 5550.9 |
| LIVESTOCK | 3586.2 | 3587.2 | 3425 |
| AGRIC | 9560.9 | 9552.5 | 8975.9 |
| fishing | 172.6 | 177.8 | 179.9 |
| forestry | 507.4 | 495.9 | 454.5 |
| **Food:** | | | |
| MEAT | 1211.6 | 1210.6 | 1133.8 |
| DAIRY | 1340.3 | 1331.2 | 1250.4 |
| FOOD | 4688.6 | 4694.3 | 4430.7 |
| **Bioenergy:** | | | |
| bioethanol 1G | 11.2 | 15 | 11.6 |
| biodiesel 1G | 17.6 | 22.4 | 17.3 |
| BF1G | 28.8 | 37.4 | 29 |
| BF2G | 0.2 | 4.6 | 16.9 |
| bioelectric | 100 | 98.4 | 125.7 |
| **Bio-industry:** | | | |
| BIOCHEM2G | 0.4 | 0.3 | 0.4 |
| **BIOECONOMY** | **18084.6** | **17938.1** | **16641.4** |

*Figure 7: Employment (1000 head) in EU28 bio-based sectors. Source: Philippidis et al., 2018*

Thus, these models, by their very nature, are ideally suited to questions regarding policy trade-offs and synergies in biomass usage, not only within countries, but also across international boundaries. For example, CGE models which are calibrated to the well-known GTAP (Global Trade Analysis Project[27]) database, have coverage of 57 tradable activities across 140 world regions, whilst more advanced biobased variants such as MAGNET extend the activity coverage even further.

## 3.3 Global land use change

A few studies on measuring the global land use impacts of the EU bioeconomy exist although all of them present a coarse assessment of land use changes through a sectorial lens.

Philippidis et al., (2016) present changes in land use ($Km^2$) of EU28 bio-based sectors for different countries/regions and based on policy driven narratives defined by the degree of EU engagement with bioeconomy and sustainability objectives. Interestingly, the authors note, for example, that greater EU efforts to decarbonise its economy and turn to biomass as a source of sustainable economic growth, would imply a significant land expansion in Mercosur and North American economic blocs, compared to the reference scenario (Figure 8).

[27] https://www.gtap.agecon.purdue.edu/

| | GERMANY | FRANCE | ITALY | SPAIN | EU28 | AMERICA | MERCOSUR |
|---|---|---|---|---|---|---|---|
| **2013 RS** | | | | | | | |
| AGRICULTURE | 180,414 | 297,009 | 139,631 | 247,239 | 1,890,320 | 4,682,025 | 4,988,271 |
| BIOSUPPLY | 178 | 35 | 36 | 18 | 658 | 965 | 130 |
| TOTAL | 180,591 | 297,045 | 139,667 | 247,258 | 1,890,978 | 4,682,989 | 4,988,400 |
| **2020 RS** | | | | | | | |
| AGRICULTURE | 174,864 | 293,337 | 136,850 | 245,486 | 1,858,526 | 4,582,882 | 5,004,567 |
| BIOSUPPLY | 293 | 58 | 58 | 31 | 1,068 | 1,091 | 279 |
| TOTAL | 175,157 | 293,394 | 136,907 | 245,517 | 1,859,594 | 4,583,973 | 5,004,846 |
| **2030 RS** | | | | | | | |
| AGRICULTURE | 172,318 | 293,509 | 135,663 | 244,892 | 1,847,800 | 4,498,385 | 5,189,821 |
| BIOSUPPLY | 300 | 58 | 60 | 32 | 1,100 | 1,085 | 522 |
| TOTAL | 172,618 | 293,566 | 135,722 | 244,924 | 1,848,900 | 4,499,470 | 5,190,343 |
| **IL VS RS 2030** | | | | | | | |
| AGRICULTURE | -14,989 | -13,497 | -7,521 | -5,878 | -99,791 | -386,861 | -269,871 |
| BIOSUPPLY | -150 | -29 | -46 | -17 | -707 | -720 | -379 |
| TOTAL | -15,139 | -13,526 | -7,567 | -5,895 | -100,498 | -386,954 | -269,898 |
| **OL VS RS 2030** | | | | | | | |
| AGRICULTURE | -4,115 | -6,375 | -3,406 | -1,722 | -42,487 | 319,473 | 334,606 |
| BIOSUPPLY | 247 | 45 | 43 | 24 | 841 | 1,109 | 4,373 |
| TOTAL | -3,868 | -6,330 | -3,363 | -1,698 | -41,646 | 320,581 | 338,979 |

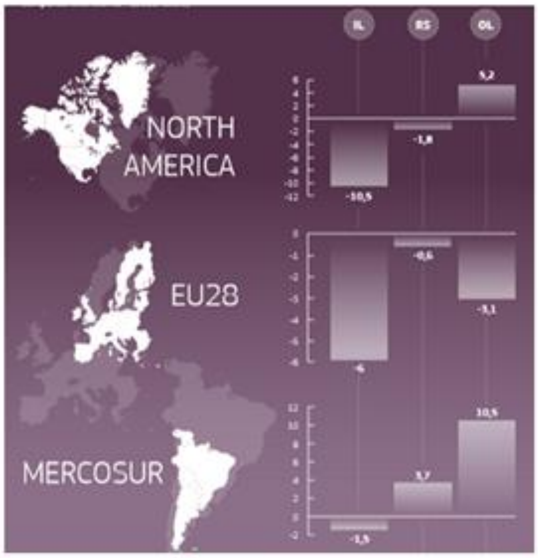



*Figure 8: Changes (Km² and %) from 2020 to 2030 in global land use by regions due to different policy narratives (IL and OL) compared with the reference scenario (RS). Source: Philippidis et al., 2016.*

Giljum et al, (2016) assess the global cropland demand related to EU non-food sectors (e.g., oil crops, fibers, rubber, cereals for biofuels and bioplastic) [28], focusing on two key products, i.e. biofuels and bioplastic. The former has the highest current land demand between the non-food products, whilst the latter is expected to exhibit a high potential degree of sectoral growth. The study reveals that 65% of the land area (18.3 Mha) employed to meet EU demand for non-food products, are located in other world regions, notably in Asia (e.g., soybean, palm oil), stressing the high EU dependency rate on imported biomass and bio-based products. According to the same study, a significant part of land conversion to biofuel crops will occur in Asia and Latin America. In general, the ambitious targets of bioeconomy strategies around the world could lead to an intensification of land competition at global level, calling for a systemic monitoring of LUC/ILUC both domestically and abroad (O'Brien et al., 2017). The EU was a net importer of virtual agricultural land between 2000 and 2013 (O'Brien et al., 2015), even though the trend of the ratio of imported to exported lands is declining, suggesting an increased independence of Europe from imported biomass (Figure 9). For example, the EU-27 demanded ca. 45 Mha of agricultural land from global suppliers in 2011, of which 42 Mha were cropland. In the same year, exported EU land totaled 19 Mha, of which ca. 17 Mha were cropland. The global cropland footprint of the EU-27 was on average ca. 0.3 (ha/cap) with a declining trends over the period.

[28] Wood and wood-products were not considered in the assessment

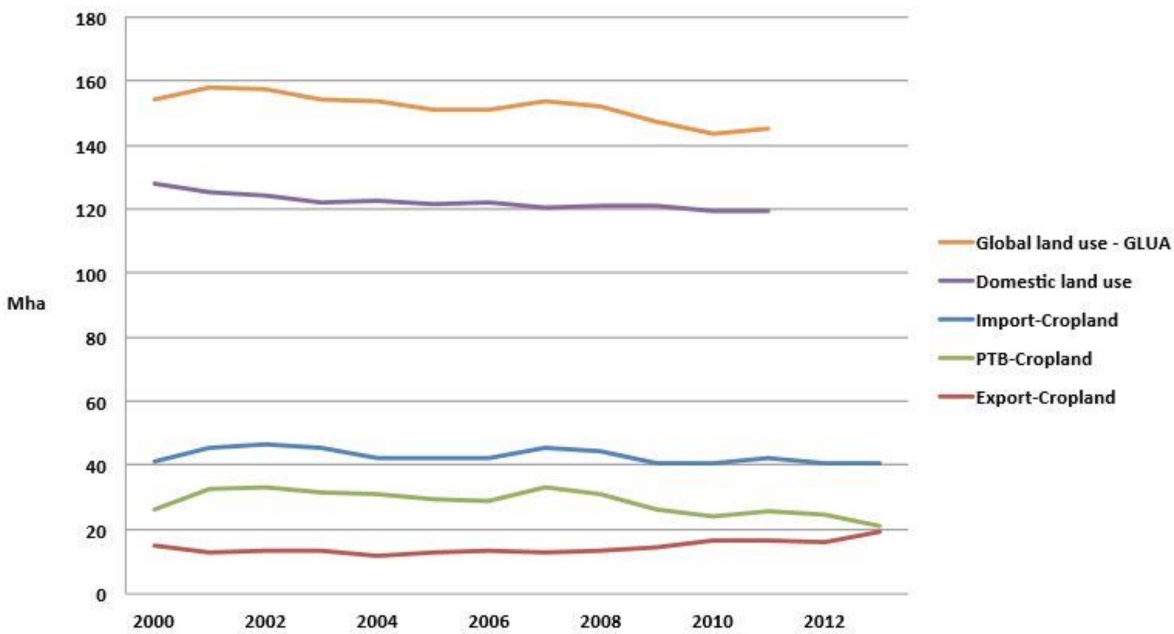



*Figure 9: Global cropland use of EU-27 between 2000 and 2013. Source: O'Brien et al., 2015*

Table 7 presents the common indicators adopted to measure changes in land use due to bioeconomy sectors/subsectors; most of the countries account for croplands.

*Table 7: some common indicators used to assess the impacts of bioeconomy sectors on land use*

| Indicator | Description |
|---|---|
| Cropland footprint[29] | Productive areas ($Km^2$) required to meet a specific demand for biomass or bio-based products. Gross production land: land for production of specific crop (e.g., sugarcane). Net production land: allocation of land to different products produced on the same land (e.g., sugar and ethanol). Net consumption land=domestic croplands + net traded land requirement (imports-exports); it defines the global land use for domestic consumption |
| Intensity of land use | Land productivity (ton/ha or head/ha) |
| Land conversion share | Productive lands obtained from conversion of other land uses (e.g., forest, pasture, abandoned lands) |
| Virtual land (import/export) | Land required in third countries for biomass production to satisfy domestic consumption (virtual land import). Land used to produce biomass for export to other countries (virtual land export). |

## 3.4 Sustainability of traded bio-commodities: existing assessment tools

Several data sharing and data visualization tools to assess and monitor the sustainability of bio-commodities' trade at the global level exist. These tools allow for a broad exploratory analysis of the consequences of the demand for agricultural goods and services in the place of origin, through a limited number of environmental indicators. With only a few exceptions, their outputs are mainly aggregated at country level, which hinders a subnational impact assessment.

The GRAS Project[30] aims at supporting the establishment and monitoring of sustainable and deforestation-free supply chains of agricultural products. It provides information about land use changes, biodiversity, carbon stock and social indices with varying resolutions for 16 countries and regions. Some indices are coarsely aggregated at country level (e.g., social indices) and can be useful only for inter-country or inter-regional comparison, without allowing for a subnational assessment. Georeferenced raster data on biophysical attributes are provided with a better resolution (e.g., biomass carbon, pixel 1x1 $Km^2$) according to the quality of publicly available datasets

The TRASE[31] platform seeks to describe the links between agricultural commodities supply chains and environmental and social risks in tropical forest regions. TRASE uses publicly available data to map trade flows (via trading companies) from the place of production to the consumer and provide a picture of potential impacts, offering a knowledge base to move towards a more sustainable production, trade and consumption for the major forest-risk agricultural commodities. TRASE covers only Latin America soy, beef in Argentina, Brazil and Paraguay, palm oil in Indonesia and Colombia and coffee in Colombia. The scale of analysis is defined by the availability of country's production data; trade volumes of commodities and financial flows are quantified at national level, whilst only information about Brazil and Paraguay soy production are disaggregated at municipality level. Flows of traded commodities and their environmental impacts - from production to final destination - are described in sankey diagrams.

The ATLAS[32] of Economic Complexity is a visualization tool that allows one to explore global trade flows over time for 250 countries and territories, classified into 20 categories of goods and 5 categories of services (covering ca. 6000 products). Raw trade data on goods are derived from COMTRADE[33] (UN Statistical division), whilst raw data on services are from the international Monetary Fund[34]. It should be noted, however, that ATLAS does not assess any kind of environmental and socioeconomic impact due to trade flows.

The EORA[35] global supply chain database consists of a multi-region Input-Output table (MRIO) model working with a common 26-sector classification across 190 countries. It provides high-resolution IO tables and environmental satellite accounts, covering a 1990-2015 time window. EORA produces spatially explicit environmental and carbon footprints associated with the consumption in a given country (domestic resource use, resources embodied in imports and exports) and allows for linking consumers to the upstream hotspots of their purchases.

[30] https://www.gras-system.org/about-gras/the-gras-project/
[31] https://trase.earth/?
[32] http://atlas.cid.harvard.edu/
[33] https://comtrade.un.org/
[34] http://data.imf.org/?sk=9D6028D4-F14A-464C-A2F2-59B2CD424B85
[35] https://www.worldmrio.com/

## 3.5 The need for a subnational impact assessment

" […] limit for biofuels, bioliquids and biomass fuels produced from food and feed crops for which a significant expansion of the production area into land with high carbon stock is observed". (Directive (EU) 2015/1513, EU Council 2018, Pag. 33).

The main limitation of the above-mentioned studies is their coarse spatial resolution, which cannot fully address key-questions set by European Directives (e.g., REDII environmental criteria) and international commitments (e.g., Paris Agreement). Indeed, aggregated results at country/regional level hide the causal links between productive systems and their impacts within a site-specific context (Brinkman et al., 2018).

For example, understanding if a cultivation of crops for biofuels is expanding into lands with a high carbon stock or results in high ILUC risk elsewhere requires the use of spatial indicators with a proper spatial resolution, able to capture the geographic heterogeneity of the socioeconomic, environmental, climate and ecosystem dimensions (Maes et al., 2016). In large countries such as Brazil - hosting different biomes with very different biophysical attributes– the average estimation of carbon emissions and removals and biodiversity losses at national level, does not make sense. Agriculture practices and deforestation in the Amazon biome have more severe consequences in terms of $CO_2$ emissions per hectare than in the Cerrado, for example, due to the considerable differences in carbon stocks (Figure 10).

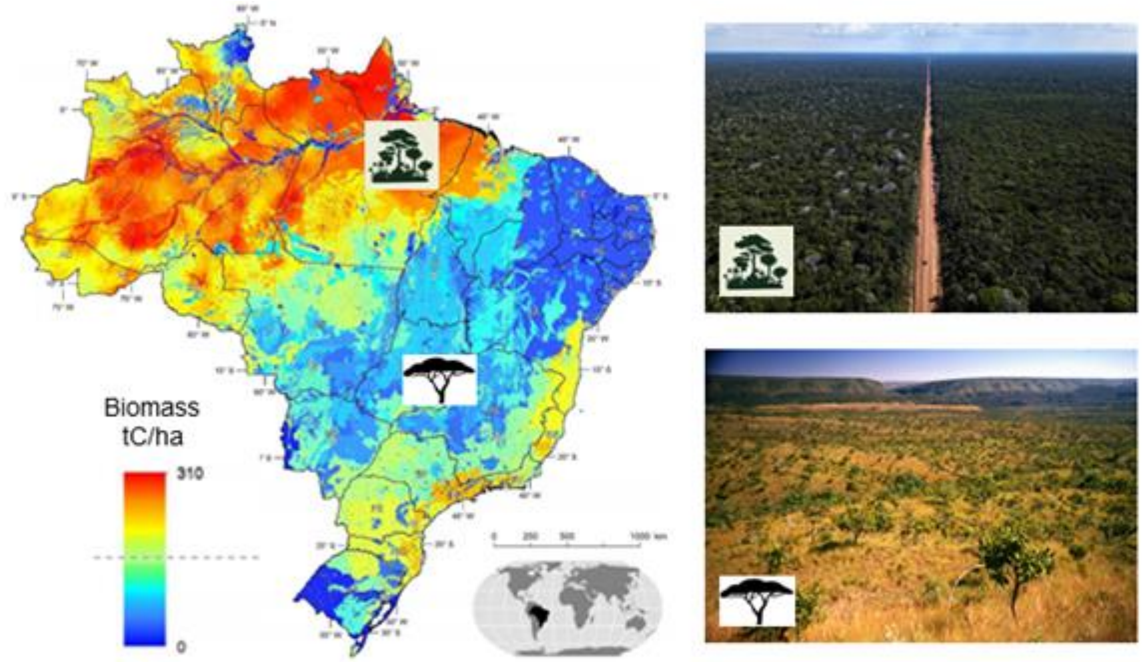



*Figure 10: Biomass content (tons C per hectare) across Brazilian biomes (Aguiar et al., 2015). The Amazon and Cerrado biomes recorded the highest deforestation rates due to agriculture and livestock expansion and land grabbing.*

Therefore, a spatially-explicit tool that provides estimates of the subnational allocation of projected land use changes across the country biomes due to varying demand for bio-commodities is needed to (i) reduce the uncertainty about the estimation of LULUCF emissions and biodiversity losses and (ii) to offer a strong scientific knowledge base to assess the compliance with the international environmental criteria and country climate commitments (Figure 11).

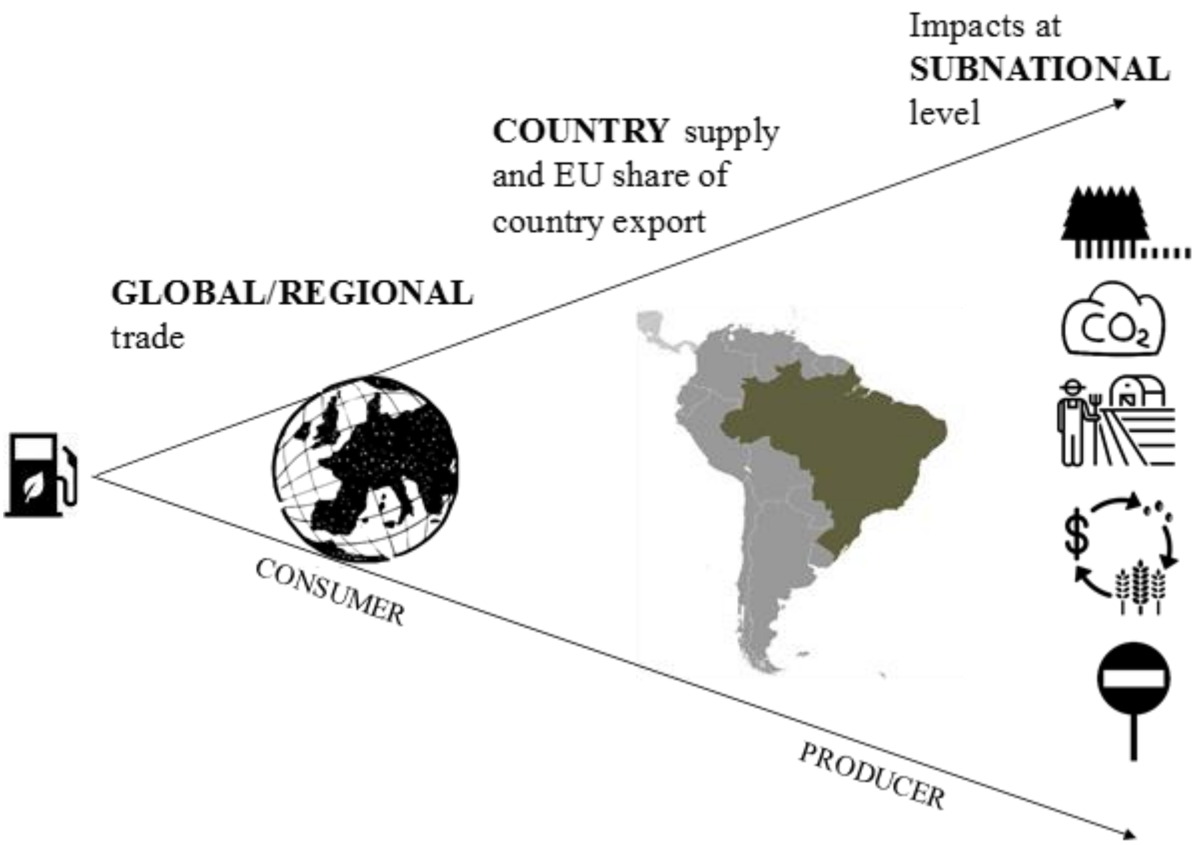



*Figure 11: a multilevel assessment translates the EU bioeconomy demand into potential environmental consequences at local scale. Example of Brazilian bioethanol*

# 4 Region of focus: Brazil

## 4.1 Sustainability of Europe-Brazil trade

Brazil is the biggest economy of Latin America and the largest exporter of agricultural products to Europe. The EU is the Brazil's second-biggest trading partner, accounting for ca. 18% of its total trade, importing from Brazil mainly primary products (70%) and exporting to Brazil manufacturing goods (84%) (Figure 12). That said, understanding the impacts of EU demand in Brazil means, above all, assessing the sustainability of Brazilian agribusiness sectors.

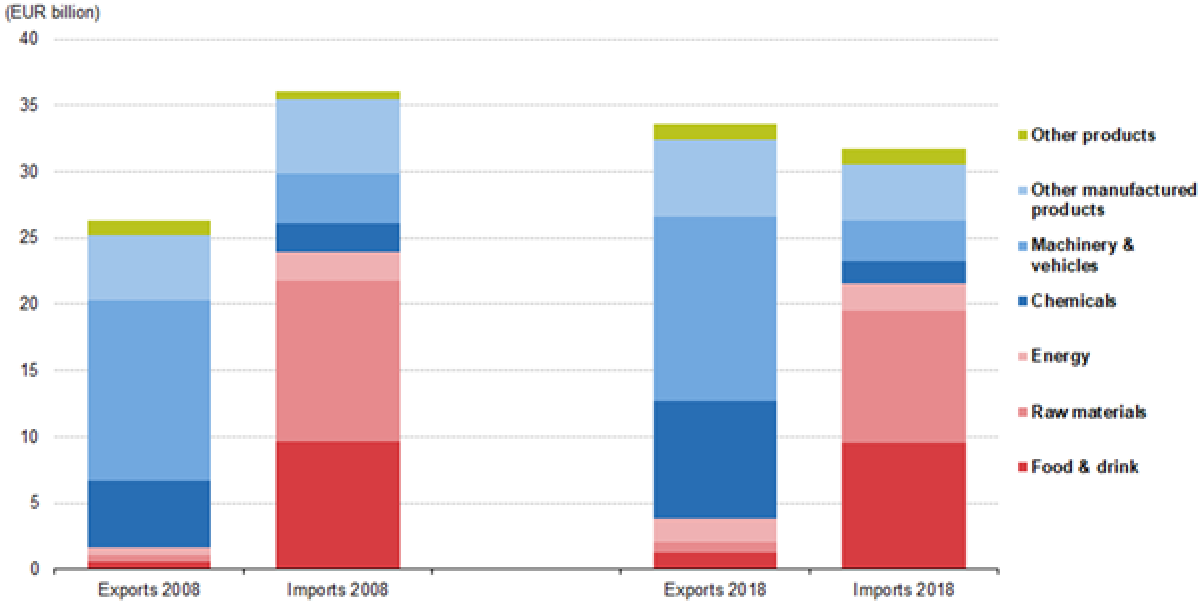



*Figure 12: EU28 exports to and imports from Brazil in 2008 and 2018 by product group (EUR billion). Source: Eurostat Comext, 2018[36].*

Concerns have been raising about the potential environmental damages of predatory agriculture practices in Brazil under scenarios of lax enforcement of environmental laws (Fuchs at al., 2019; Rochedo et al., 2018; Tollefson, 2018; Gibbs et al., 2015). A recent letter to the journal Science signed by more than 600 European scientists urged the EU to make the trade negotiations with Brazil conditional to strict social and environmental criteria, in order to halt deforestation, contribute to curb climate change and guarantee the respect of human rights of indigenous communities (Kehoe et al., 2019).

The need for guaranteeing a sustainable supply-chain governance by linking producers and consumers through an awareness on the potential consequences of traded products in the place of origin has been discussed on 27 June 2018 during the first EU-Brazil Fair and Ethical Trade Consultation Forum[37].

## 4.2 Land use changes in Brazil until 2017

Between 1985 and 2017 Brazil lost ca. 71 million hectares of its native vegetation due to the rapid expansion of croplands and pasturelands (Mapbiomas, 2019), mainly in the Cerrado and Amazon biomes (Figure 13).

[36] https://webgate.ec.europa.eu/isdb_results/factsheets/country/details_brazil_en.pdf

[37] https://eeas.europa.eu/delegations/brazil/47546/first-eu-brazil-fair-and-ethical-trade-consultation-forum-held-rio-de-janeiro-21st-june-2018_en

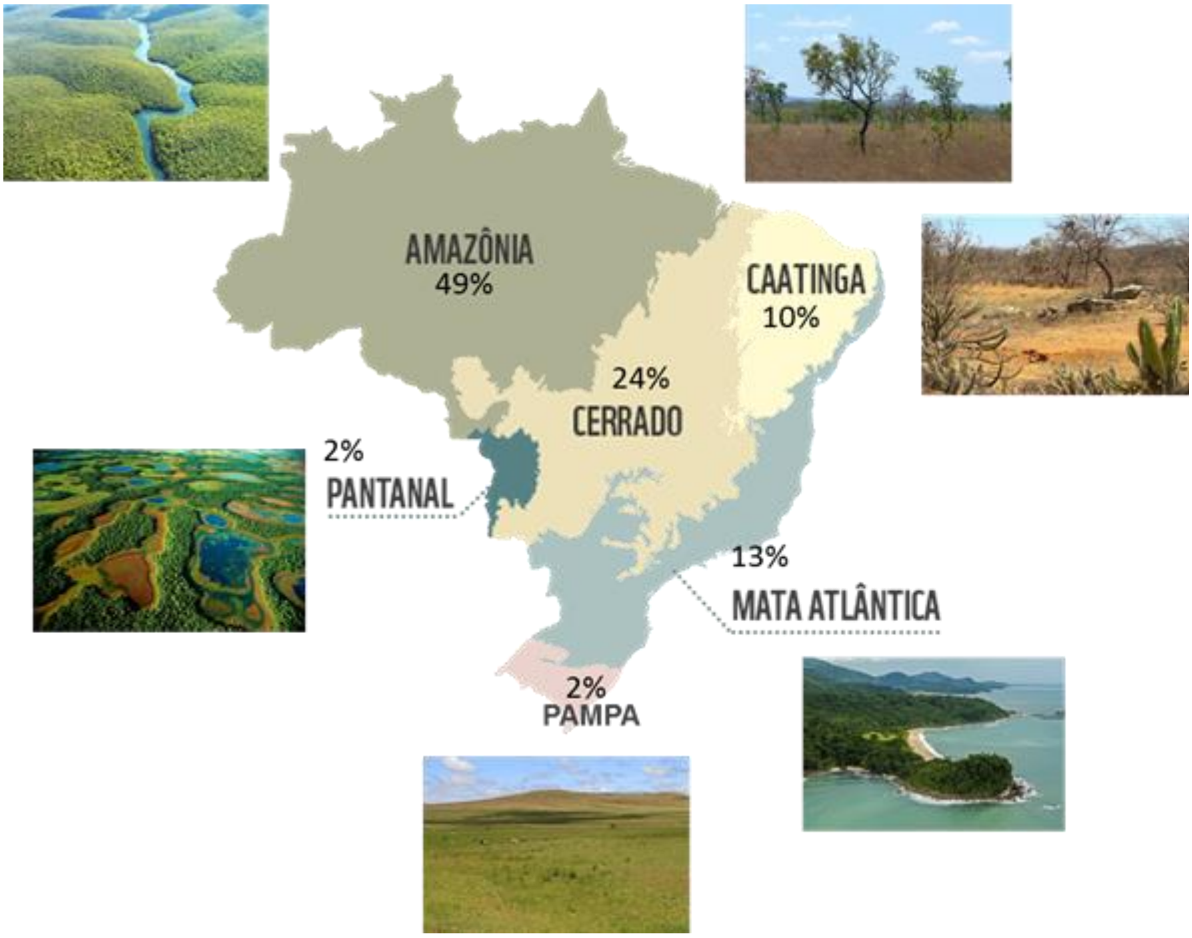



*Figure 13: contribution of Brazilian biomes to country area (%).*

Land use changes in Brazil are strongly influenced by federal government's policies. As suggested by Rochedo et al., (2018), the environmental governance in Brazil can be divided into 3 periods: pre 2005, with a very poor governance and the highest deforestation rates; 2005-2011, with an improved governance that reduced deforestation by 78% and the associated GHG emissions by 54%; and a post 2012 period, when deforestation rates have levelled up again, especially in the Cerrado biome (Figure 13), due to lax enforcement of the Forest Code. In the period 1985-2017 the Amazon lost ca. 36 million hectares (10%) of native vegetation, while the Cerrado lost 24 million hectares (18%) due to predatory farming practices and land grabbing (Figure 14 and Figure 15).

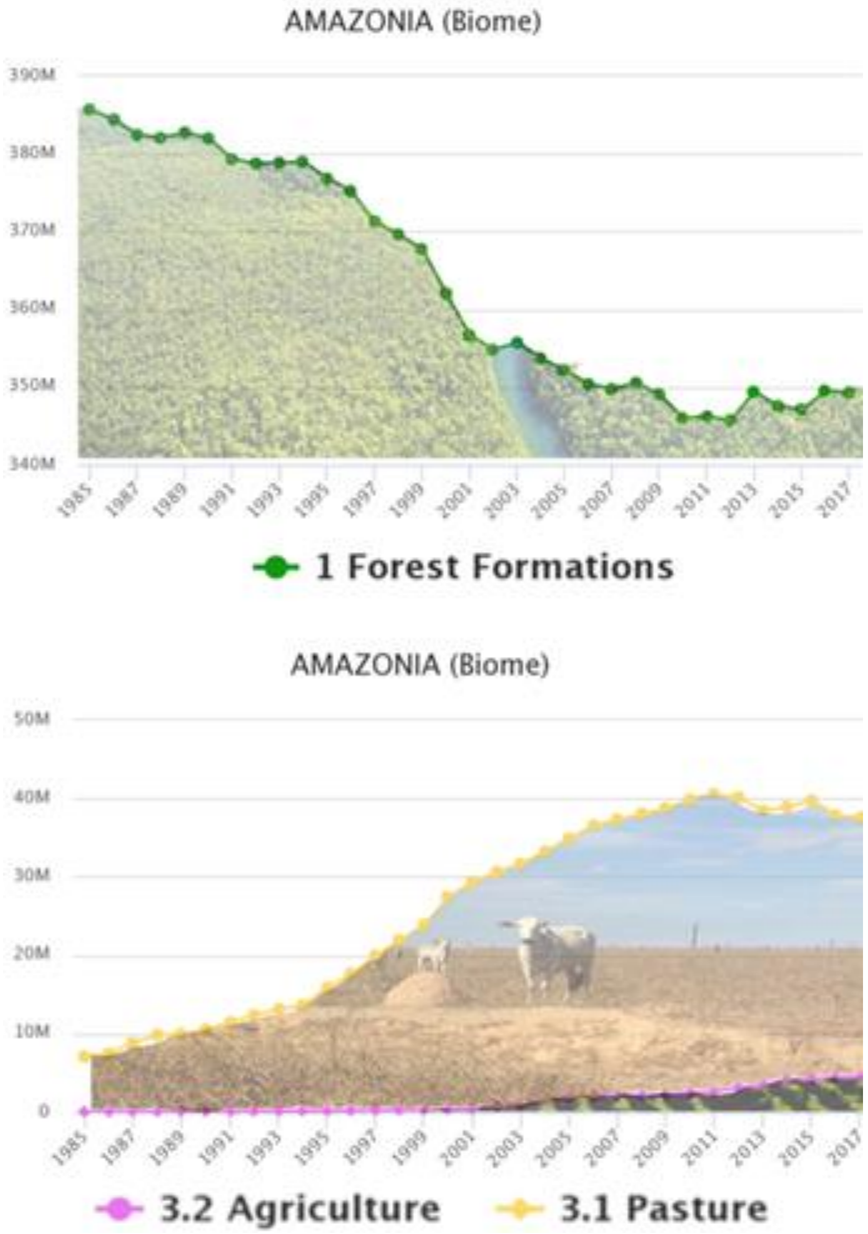
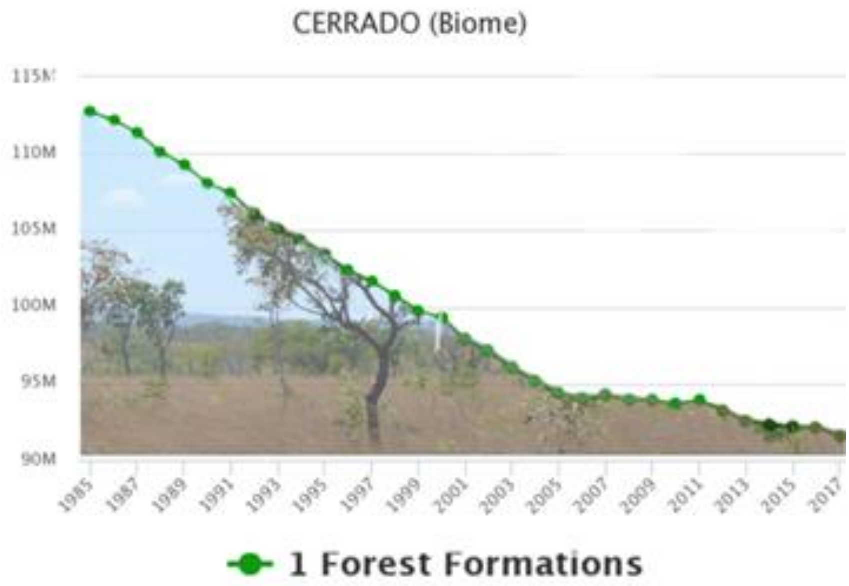



*Figure 14: Trends of forests, croplands and pasturelands in the Amazon biome from 1985 to 2017 (million hectares). Source: MapBiomas, 2019.*



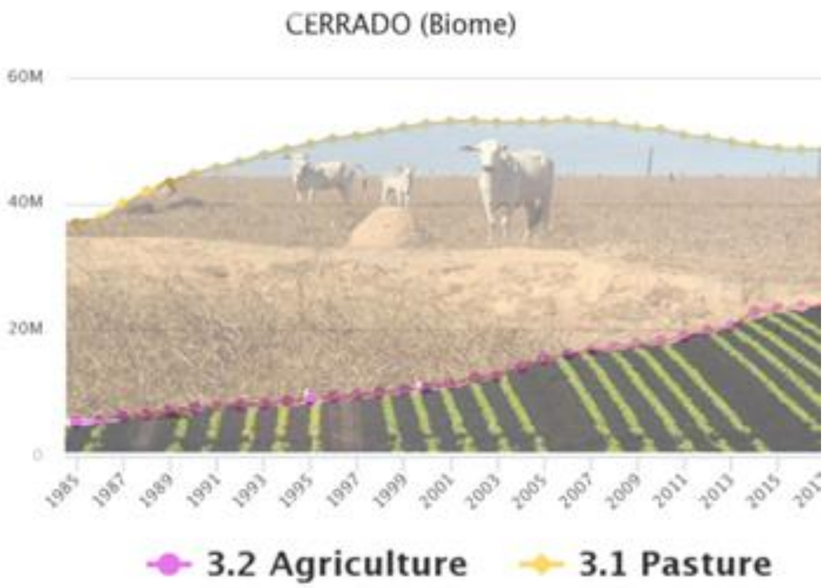




*Figure 15: Trends of forests, croplands and pasturelands in the Cerrado biome from 1985 to 2017 (million hectares). Source: MapBiomas, 2019.*

The most important crops in Brazil are soybean, sugarcane and corn, representing around 85% of total production (Fuchs et al., 2019). Sugarcane is considered as a semiperennial crop; its expansion in the 1985-2017 period occurred mainly into the Cerrado and Mata Atlantica[38] pasturelands (Figure 16). The contribution to sugarcane production of the other biomes is very limited.

[38] The Mata Atlantica biome has been widely deforested in the past. Nowadays, it conserves less about 20% of its native vegetation. Most of expansion of sugarcane and other crops occurs into pasturelands.

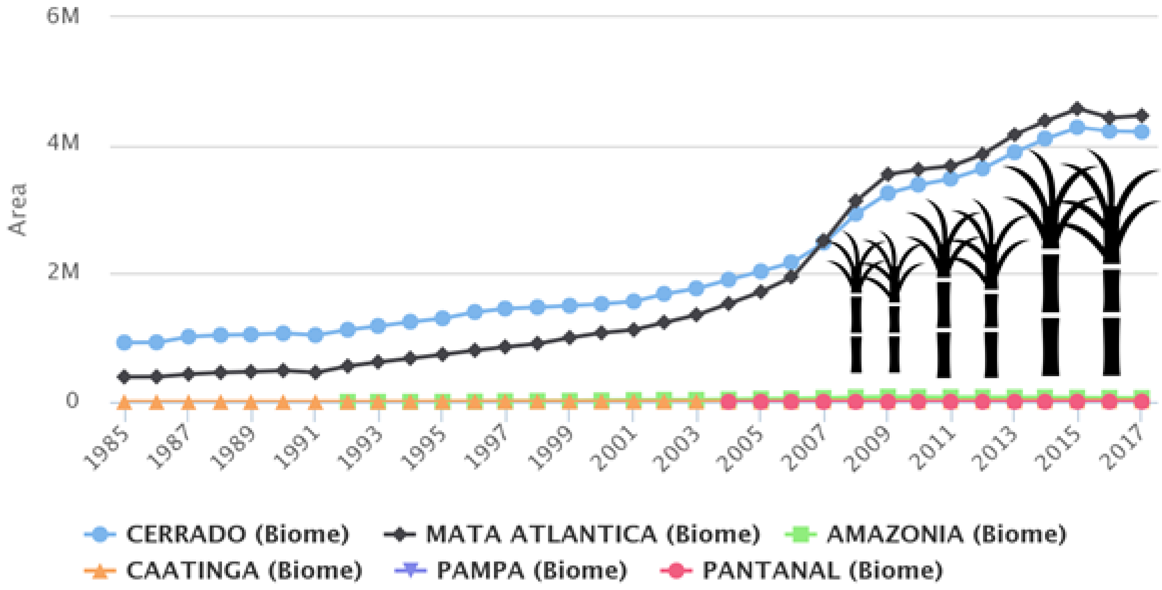



*Figure 16: Expansion of semiperennial crops, notably sugarcane, into the Brazilian biomes. Source: Mapbiomas, 2019*

Soybean and corn are the largest annual crops in Brazil; they expanded mainly into the Cerrado and Mata Atlantica biomes (Figure 17). Since 2001, the areas with annual crops have shown a steeply increasing trend in the Amazon biome (about a tenfold increase), which raises concerns about soybean expansion into the Amazon rainforest, even though most of the increase occurred on lands cleared before 2008 (starting year of Brazil's Soy Moratorium).

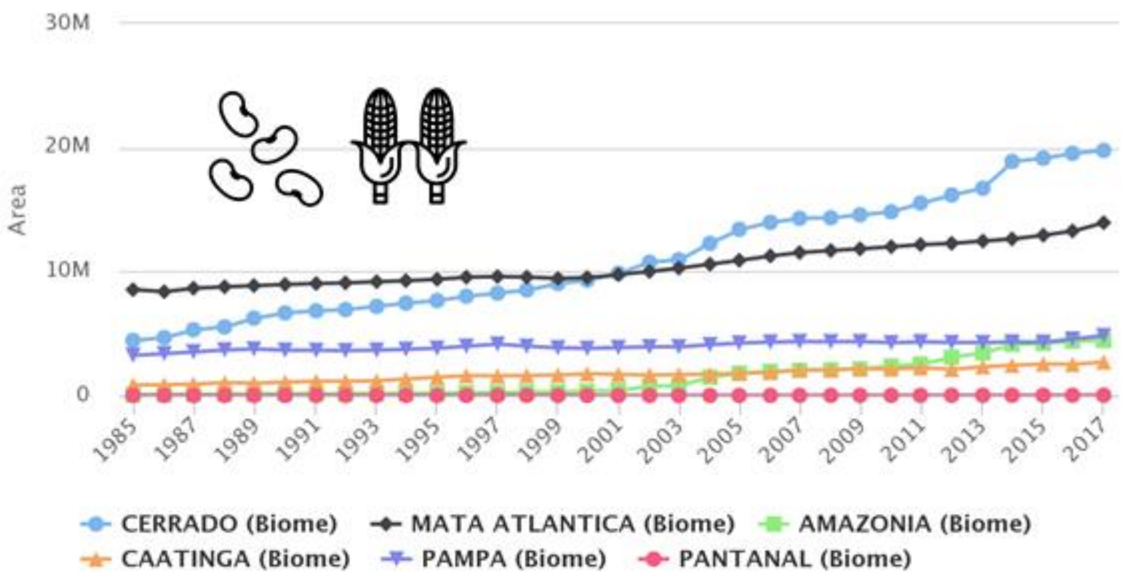



*Figure 17: Expansion of annual and perennial crops, notably soybean and 2nd corn, into the Brazilian biomes. Source: MapBiomas, 2019.*

## 4.3 GHG emission profile

Brazil is the 7th largest emitter of GHG, accounting for ca. 3.4% of the world's $CO_2$ emissions. From 1990 to 2017, almost 64% of Brazil's GHG emissions came from land use change and forestry (LULUCF), whilst in 2017 this value dropped off to ca. 46% (Figure

18). Between 2005 and 2012, Brazil's GHG emissions were reduced by 54%, mostly by reducing deforestation by 78% (Rochedo et al., 2018). Most Brazilian GHG emissions are linked to agribusiness activities; in 2017 about 70% of GHG emissions came from agriculture and livestock (SEEG Brazil, 2019[39]).

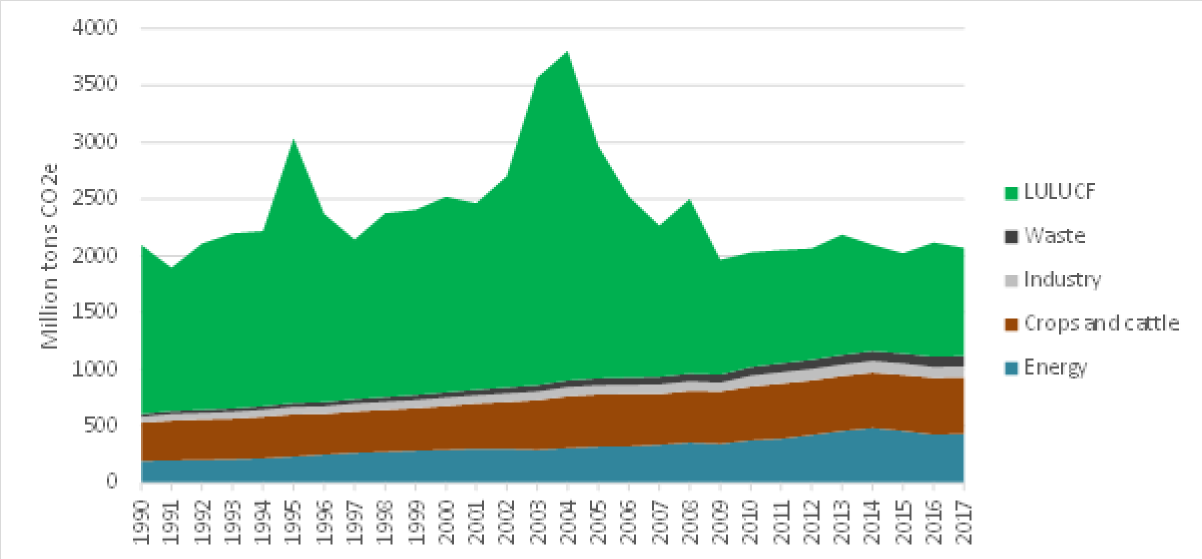



*Figure 18: Gross GHG emission profile of Brazil from 1990 to 2017. Source: SEEG Brazil, 2019.*

Figure 19 shows the distribution of GHG emissions and removals, sorted by regional areas. In the Northern region, most of the emissions came from land use changes (mainly deforestation). The high removals are linked to the large Amazon conservation units and indigenous lands. In the Centerwest – one of the most important regions for commodity production – the emissions are associated to farming activities, whilst in the Southeast – the most industrialized and urbanized area – the energy sector is the largest source of GHG.

[39] http://seeg.eco.br/en/ (April 2019).

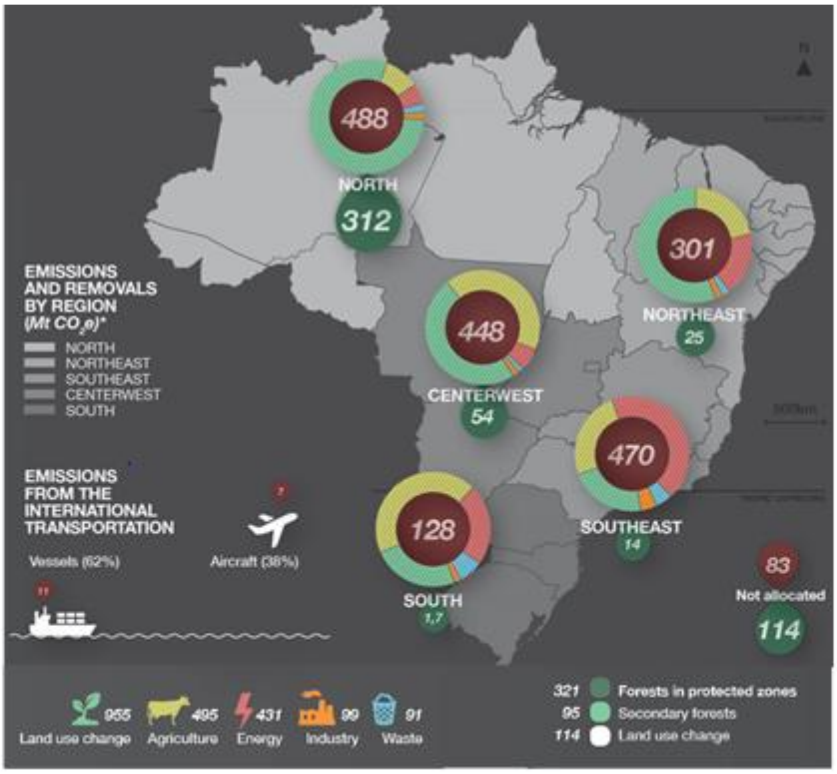



*Figure 19: GHG emissions (dark red) and removals (dark green) sorted by IBGE macroregions. Source: SEEG Brazil, 2019.*

## 4.4 The Brazilian Nationally Determined Contribution (NDC)

Brazil's NDC[40] committed to reduce its GHG emissions by 37% below 2005 levels in 2025, and by 43% below 2005 levels in 2030. The national climate plan includes actions, targets and legislative tools relevant to this study, in particular (FRB, 2015):

- Biofuels: increasing the share of sustainable biofuels in the Brazilian energy mix to approximately 18% by 2030, by expanding biofuel consumption, increasing ethanol supply by increasing the share of advanced biofuels (second generation), and increasing the share of biodiesel in the diesel mix;
- Land use change and forests: i) strengthening and enforcing the implementation of the Forest Code, at federal, state and municipal levels; ii) strengthening policies and measures aimed to achieve, in the Brazilian Amazonia, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030; iii) restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes;
- Agriculture: i) strengthen the Low Carbon Emission Agriculture Program (ABC) as the main strategy for sustainable agriculture development; ii) restoring an additional 15 million hectares of degraded pasturelands by 2030 and enhancing 5 million hectares of integrated cropland-livestock-forestry systems (ICLFS) by 2030.

[40] http://mma.gov.br/clima/ndc-do-brasil

In 2017, renewables accounted for ca. 43% of Brazil's energy matrix, thanks also to an important contribution of sugarcane biomass (ca. 17%), according to the last National Energy Balance report (BEN, 2018)[41].

[41] http://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2018

## 5 Integrated impact assessment for Brazil case study

### 5.1 Modelling framework

To calculate the environmental impacts of varying EU demands for ethanol in Brazil we established a comprehensive methodological procedure by combining two well-respected models: the global economic market simulation model, MAGNET, and the spatially explicit land-use model OTIMIZAGRO (Figure 20). This multilevel assessment framework allows moving from a regional/country outlook on socioeconomic trends to a subnational analysis of land use impacts, with the proper spatial resolution to assess the compliance with EU environmental criteria for biofuels production.

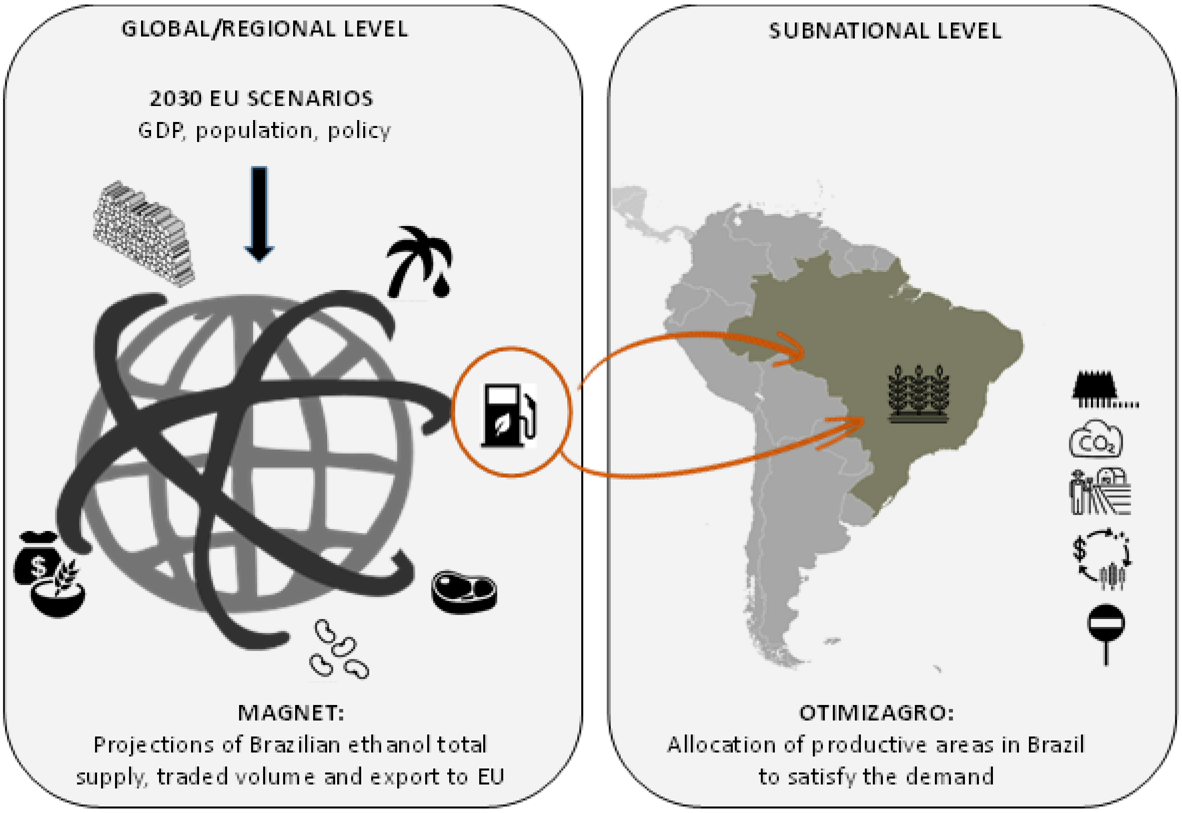



*Figure 20: Theoretical modelling framework. MAGNET projects the total and EU demand for Brazilian ethanol from different EU scenarios (Consumer side). OTIMIZAGRO calculates and allocates the croplands to satisfy the demand at subnational level with a proper resolution to correctly quantify environmental impacts (Producer side).*

To estimate the trade impact of changes in EU biofuel policies on Brazilian production of bioethanol requires an appropriate system-wide market modelling tool which can capture the interrelationship between economic policy changes in region 'A' and their resulting repercussions on prices, trade and ultimately, production decisions in region 'B'. MAGNET projected the EU demand for ethanol until 2030 from a baseline and a "conventional biodiesel phase out" scenario. Future crop production across 13 commodities (including soy) is derived from MAPA (2017)[42], whilst deforestation and regrowth rates come from Rochedo et al., (2018). The projected demand for wood (plantations) and meat (livestock) are taken from MCTIC and ONU (2017). All these exogenous estimations are inputted into OTIMIZAGRO, which translates a demand for a commodity into production areas, and allocates them to agro climatic and soil aptitude maps for each crop. Concurrent allocation of crops at a cell level of 25 ha is a function of biophysical attributes, land use constraints, crop profitability (calculated using regional selling prices, production and transportation costs) and agro-climatic suitability. The probability of deforestation is a function of spatial determinants, such as the distance from paved roads and previously deforested areas. Net LULUCF emissions account for carbon stock changes in biomass and soils due to land use changes, such as crop and pasture expansion, deforestation, forest plantation and regrowth. To fully assess the impact of sugarcane crop expansion into degraded and marginal lands, we also estimated GHG emissions associated with agricultural practices, fertilizer and lime application and burning sugarcane straw.

A more detailed description of the integrated modelling framework is included in the Supplementary Information (Annexes 1, 2 and 3).

## 5.2 EU Socioeconomic and policy scenarios

The construction of the Baseline, or business as usual (BAU), scenario for the MAGNET model is conducted over three time periods from 2011 to 2030 (2011–2015; 2015–2020; 2020–2030). Employing secondary data and assumptions, the main market drivers over this period are macroeconomic (real GDP, population), biophysical (land productivities) and energy related (fossil fuel prices, energy consumption and production trends). To further refine the developments on biobased markets and the resulting impacts on third country trade trends, additional exogenous impacts are introduced relating to environmental- (worldwide GHG reductions), EU agricultural support, bioenergy and trade policies. A detailed discussion of all these assumptions and the modelling approach is available online in Philippidis et al. (2018). In the context of the current research, the key baseline assumptions regarding the biofuel market trends are discussed briefly here (Table 8).

*Table 8: Baseline assumptions over the three time periods disaggregation of commodities and regions.*

| |
|---|
| Periods: (2011-2015; 2015-2020; 2020-2030)<br>• Real GDP and population growth projections from European Commission (EC, 2016).<br>• Land productivity growth: projections from von Lampe et al., (2014).<br>• Global fossil fuel price projections for coal, crude oil and gas (World Bank, 2017) for each period.<br>• Greenhouse gas emissions reductions from European Commission (EC, 2016) for each period. |
| (2011-2015 period)<br>Trade Policy (Trade)<br>• EU28 Enlargement elimination of tariffs between the EU and Croatia<br>• Extension to Croatia of an EU common external tariff (CET) on third country trade and reciprocal third country CETs extended to Croatia as an EU28 member.<br>Agricultural Policy<br>• Continued phasing in of decoupled payments for 2004 and 2007 accession members<br>• Targeted removal of specific pillar 1 coupled support payments: Seeds, beef and veal payments (except the suckler cow premium) decoupled by 2012, Protein crops, rice and nuts decoupled by 1 January 2012 |

| |
|---|
| • Re-coupling of support under the article 68 provision<br>• Greening of 30% of first pillar payments<br>• Pillar 2 payments to the EU Member States under the financial framework<br>• Abolition of raw milk (2015) quota<br>EU Biofuels Policy (BF)<br>• 1st generation EU average bio-fuel mandate of 5.75% |
| (2015-2020 period)<br>Trade Policy (Trade)<br>• EU-Canada trade shocks with HS6 product exceptions tariffs<br>• EU-Vietnam trade shocks with HS6 product exceptions tariffs<br>Agricultural Policy (CAP)<br>• First and second pillar payments follow financial framework budget envelopes.<br>• Abolition of raw sugar (2017) quotas<br>EU Biofuels Policy (BF)<br>• 1st generation bio-fuel mandate of 7 %<br>• Elimination of all palm oil imports flows from Asia to the EU. |
| (2020-2030 period)<br>Agricultural Policy (CAP)<br>• 2% p.a. reductions in CAP budget payments. Pillar 1 (coupled/decoupled) and pillar 2 (by rural development measure) payment structures assumed unchanged from 2020.<br>Bio-energy Policy (BF)<br>• EU28-wide 1st generation bio-fuel mandate of 7 % EU28-wide 2nd generation bio-fuel mandate of 3.5% |

Following Banse et al., (2008), fiscal-neutral first- and second-generation biofuel mandates consistent with the recent EU energy package finalized in June 2018, are assumed. Thus, in the baseline scenario, the EU-wide average first generation biofuel mandate reaches 7% by 2020 and is maintained to 2030. Taking a time-linear approach, advanced biofuel blending mandates of close to zero in the benchmark year (2011) to 3.5% in 2030, are implemented.

Given the specific focus on EU-Brazil trade relations, additional shocks to the baseline description in Philippidis et al., (2018) have been introduced. In seeking to reinforce the sustainability criterion underlying the EU's first-generation biofuels policy in the EU Energy Package agreed in June 2018, all EU imports of palm oil from Asia are eliminated by 2020. Employing data from the Brazilian Ministry of Mines and Energy (EPE, 2018), additional Brazilian bioethanol export trade share shocks (principally to the EU, USA, South Korea and Japan) have been introduced to mimic the export quantity trends from official Brazilian government sources and projections. To reflect their key status as determinants of marginal changes in land usage in Brazil, further baseline shocks have been imposed on historical and projected production trends for Brazilian bioethanol (billions of litres) based on data from (EPE, 2018). Further examination of the baseline scenario revealed that the outcomes for Brazilian oilseeds (i.e., soybean) and sugar tracked reasonably well the production and export trends reported by official Brazilian sources (MAPA, 2017).

# 6 Results

## 6.1 Projections of demand and supply to 2030

### 6.1.1 Ethanol and sugar

MAGNET projected the total supply and the EU demand for Brazilian ethanol under two policy scenarios (Figure 21)

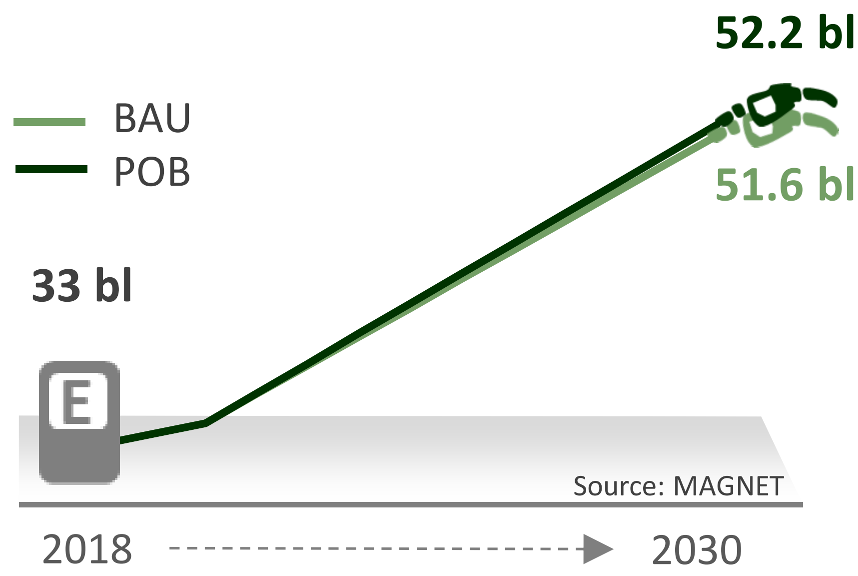



*Figure 21: Total supply of Brazilian ethanol to 2030. Source: MAGNET, 2018*

In the BAU scenario, the total country supply of ethanol (51.6 billion litres) tracked reasonably well the official projections of the Brazilian Ministry of Mines and Energy (i.e., 49.4 billion litres) from a scenario of intermediate growth of sugar-energy sector due to the implementation of Renovabio (EPE, 2018). The EU share of total Brazilian export slowly increases from ca. 5% (0.11 billion litres) in 2018 to 6.8% (0.18 billion litres), far below the EU proposal of duty-free import quota (tariff rate quotas, TRQ) for ethanol of 600 thousand tons[43] (Figure 22).

In the POB scenario, EU imports of ethanol rise rapidly after 2020, due to the progressive substitution of conventional biodiesel with bioethanol. By 2030 the EU share of Brazilian bioethanol exports is expected to be ca. 30% (ca. 1.13 billion litres). From a trade policy perspective, EU bioethanol imports cross the TRQ line (2017 proposal) in 2026, but remain below the EU offer made in May 2004.

[43] About 0,76 billion litres. EU-Mercosur trade talks , October 2017.

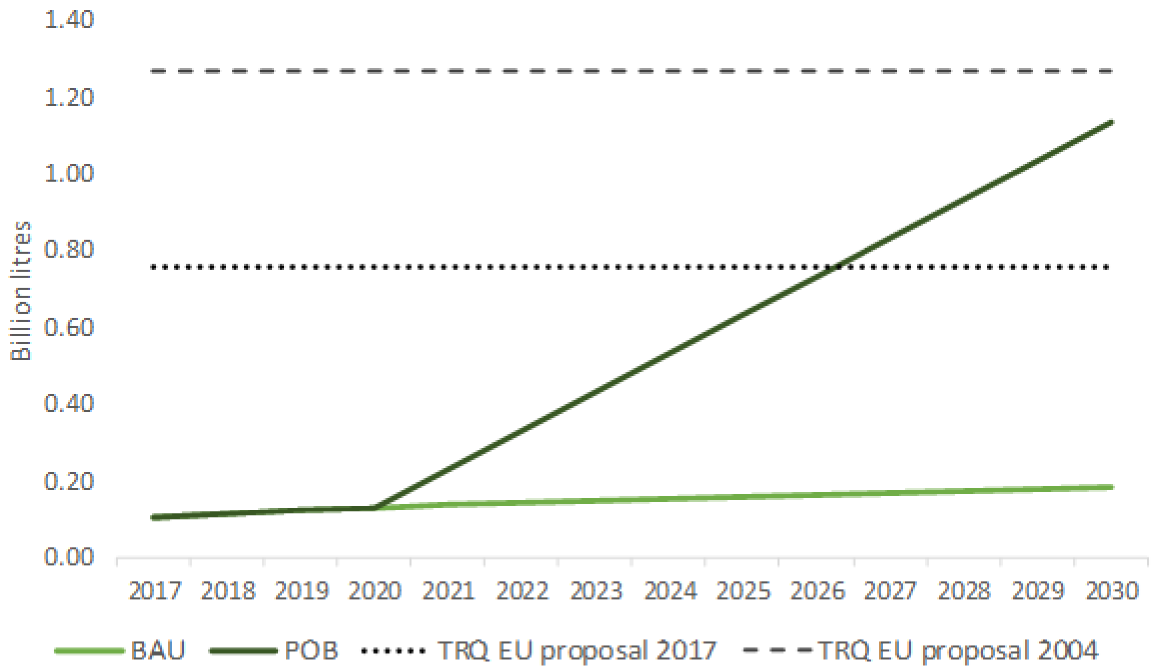



*Figure 22: Projections of EU import of Brazilian ethanol from a baseline (BAU) and phase out biodiesel (POB) scenario. The dotted lines identify two different Tariff Rate Quotas (TRQ) for ethanol, under discussion in the ongoing trade talks between EU and Mercosur. Source: MAGNET, 2018.*

The Brazilian production of sugar has been derived from official projections of the Brazilian Ministry of Agriculture (Figure 23).

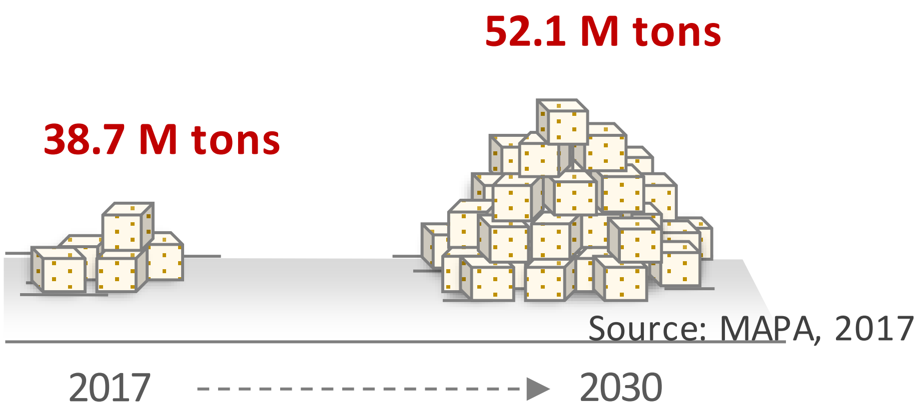



*Figure 23: Total sugar supply to 2030 (million tons). Source: MAPA, 2017.*

The total area of sugarcane to meet the demand for ethanol and sugar has been calculated by considering an average Total Recoverable Sugar (ATR) of 129 kg sugar per ton of sugarcane, an 82% effectiveness of milling and productive processes and an increasing land productivity trend (EPE, 2018). From 2017 to 2030 the sugarcane cropland increases by 45% (4.6 million hectares) in the POB scenario and by 43% (4.4 million hectares) in the BAU (Figure 24).

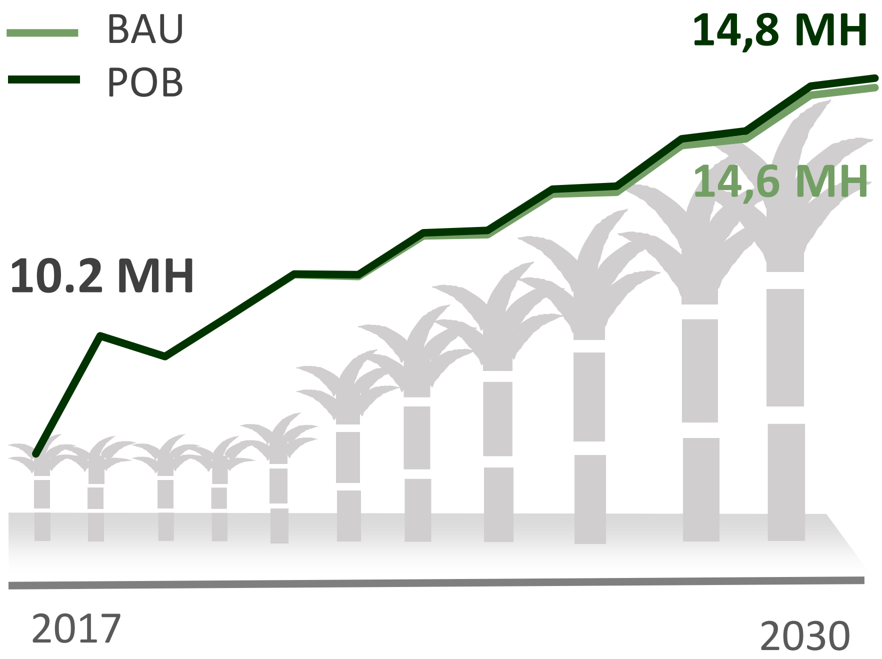



*Figure 24: Projections of sugarcane area (million hectares) to satisfy the supply of sugar and ethanol from a baseline (BAU) and a phase out biodiesel (POB) scenario. Source: own elaboration.*

### 6.1.2 Main crops

Land use changes with respect to sugarcane production are driven also by the competition with other commodities for viable agricultural lands. Therefore, it is necessary to simultaneously allocate the expansion (or reduction) of the other croplands to fully represent the direct and indirect land use changes due to agricultural activities, including the displacement of marginal farming and ranching systems in favour of more lucrative energy crops. The projections to 2030 for the main crops (Table 9) have been derived from the official estimations of MAPA, (2017).

Soybean areas rise rapidly to satisfy internal and external demands. According to MAPA, (2017) exports will represent more than 60% of total production (without considering the potential additional demand from China due to the tariff trade war with US[44]), moving from ca. 73 million tons in 2017 to 100 million tons in 2030. The increase of soybean production to satisfy China's appetite and substitute the entire US shortfall is raising many concerns about its potential environmental consequences, especially in terms of tropical forest loss (Fuchs et al., 2019).

Double cropping systems that combine first-crop soybeans and then second crop corn are the main reason for the expansion of the 2$^{nd}$-crop corn (61%) and the progressive reduction of first-crop corn. Other crops show limited changes, flat or decreasing trends (e.g., beans, rice, and coffee).

Soybean, sugarcane and second crop corn (2$^{nd}$ corn) areas, which represented more than 70% of total cropland in Brazil in 2018, record the highest increments by 2030 – i.e, 29% (ca. 10 million hectares), 44% (ca. 4 million hectares, BAU scenario) and 61% (ca. 8 million hectares) respectively.

[44] The export to China of soybean increased in the first semester 2018 (+6% compared to previous year); many farmers decided to move part of their sugarcane productive area to soybean (Reuters, 2018). There are not official projections about this new scenario yet.

*Table 9: projection of productive areas for the main crops from 2018 to 2030. Source: MAPA, 2017*

| Crop | Area 2018 (Mha) | Area 2030 (Mha) |
|---|---|---|
| Soybean | 35.2 | 47.1 |
| Corn (2st crop) | 12.9 | 20.9 |
| Corn (1st crop) | 5.64 | 3.28 |
| Bean | 3.65 | 3.19 |
| Wheat | 2.02 | 2.27 |
| Rice | 2.39 | 2.10 |
| Coffee | 1.92 | 1.80 |
| Manioc | 1.38 | 1.19 |
| Feather cotton | 1.08 | 1.16 |
| Cocoa | 0.63 | 0.66 |
| Banana | 0.53 | 0.53 |
| Orange | 0.61 | 0.49 |
| Tobacco | 0.39 | 0.42 |

### 6.1.3 Wood and plantations

The projected demand to 2030 for wood from plantations (to produce charcoal, firewood, panels, lumber, and pulp) has been derived from MCTIC and ONU (2017). The consumption of wood from plantations increases from 192.2 million cubic meters in 2012 to 350.8 million cubic meters in 2050 with an average annual increment of 1.55%. To satisfy this growing demand for wood, plantations' area – mainly eucalyptus and pine – will increase by 1,7% per year, on average. The estimated plantation expansion is ca. 138 thousand hectares per year in the period 2015-2025, and 159 thousand hectares to 2050 (Figure 25). In 2030, plantations will cover ca 9 million hectares.

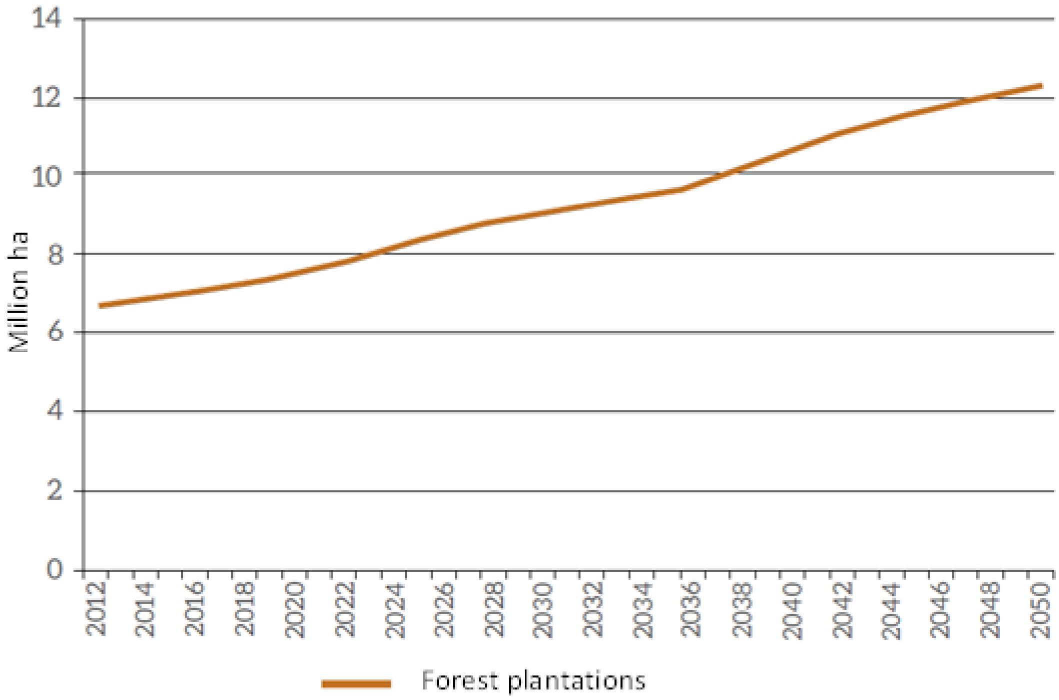



*Figure 25: Projected area (ha) of forest plantations to 2050. Source: MCTIC and ONU, 2017.*

### 6.1.4 Forest recovery and deforestation rates

Starting from the targets of the National Plan for Native Vegetation Recovery (Planaveg, 2014)[45] - which set an ambitious objective of 12.5 million hectares of forest restoration by 2035 - we projected the area of recovered forest to 2030 by including in the modelling some land use restrictions (i.e, available pasture areas for recovery purpose). That said, the results showed a gradual increase of the areas for native forest recovery from ca. 1.9 million hectares in 2017 to ca. 7 million hectares in 2030.

The projection to 2030 of deforestation rates for the Amazon and Cerrado biomes is derived from Rochedo et al., (2018). We selected the intermediate environmental governance scenario, which assumes the maintenance of current deforestation policies and considers a growing political support for predatory agriculture practices, land-grabbing and a progressive undermining of protected areas legislation and the Forest Code. The annual deforestation rates for the other biomes, i.e. Caatinga, Pantanal, and Pampas, come from Aguiar et al., (2015), and for Atlantic Forest from SOS Mata Atlantica (Figure 26).

45 http://www.mma.gov.br/florestas/pol%C3%ADtica-nacional-de-recupera%C3%A7%C3%A3o-da-vegeta%C3%A7%C3%A3o-nativa.html

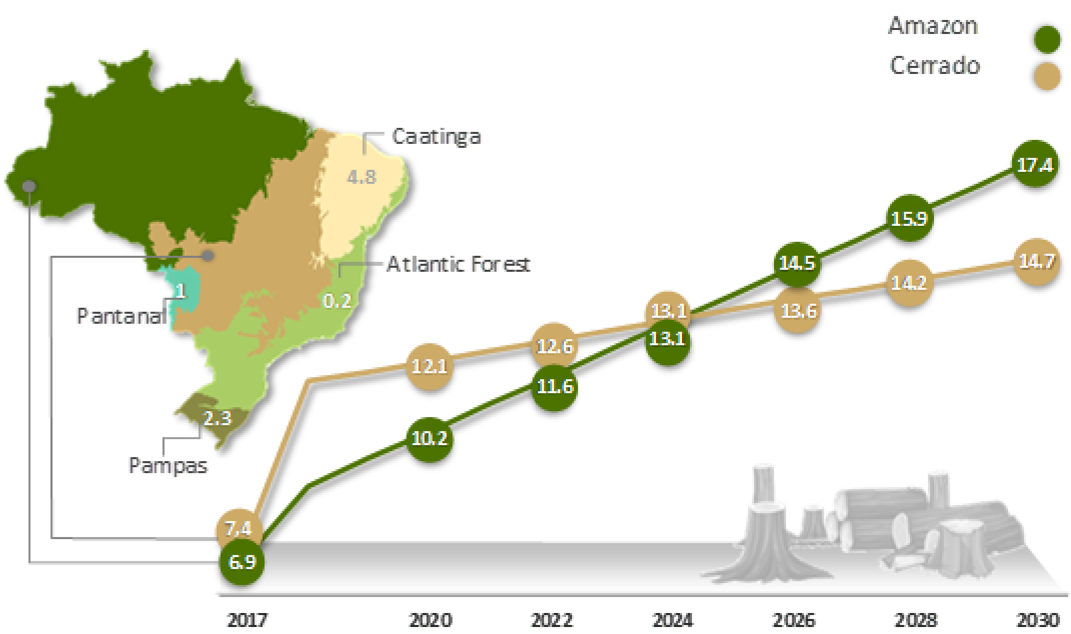



*Figure 26: Deforestation trends in the Brazilian biomes to 2030. Sources: Rochedo et al., (2018) for Cerrado and Amazon biomes [1000 Km$^2$]; Aguiar et al., (2015) and SOS Mata Atlantica, for the other biomes [average 1000 Km$^2$/year]*

## 6.2 Projected Land use changes in Brazil to 2030

Finally, Otimizagro uses as input the exogenous projections for the main crops, forest plantations, forest recovery, and deforestation rates to 2030. The model allocates these quantities according to biophysical, climate, governance, and economic explicative factors to simulate land use and land use changes under the baseline (BAU) and phase out biodiesel (POB) scenarios. Otimizagro outputs yearly land use raster maps with a cell resolution of 25 ha (Figure 27).

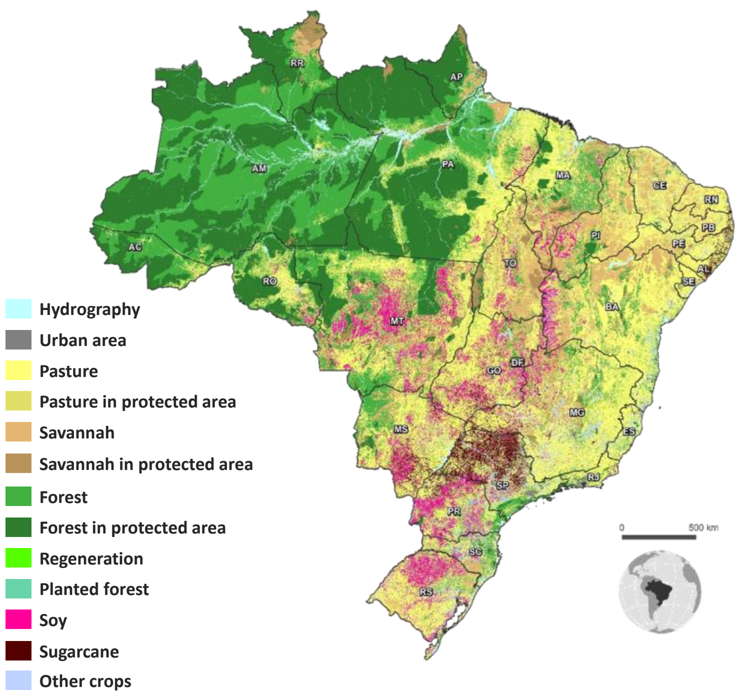



*Figure 27: Projected land use change map in 2030 (BAU).*

The scenarios' transition matrices and the final 2030 maps slightly differ, due to the limited increase of sugarcane croplands between BAU and POB scenario (by 1%). For the sake of simplicity, we provide an overall analysis of the land use changes from 2017 to 2030 in the BAU scenario only (Figure 28). The land-use transition matrix of the POB scenario can be found in the Supplementary Information section (Annex 4).

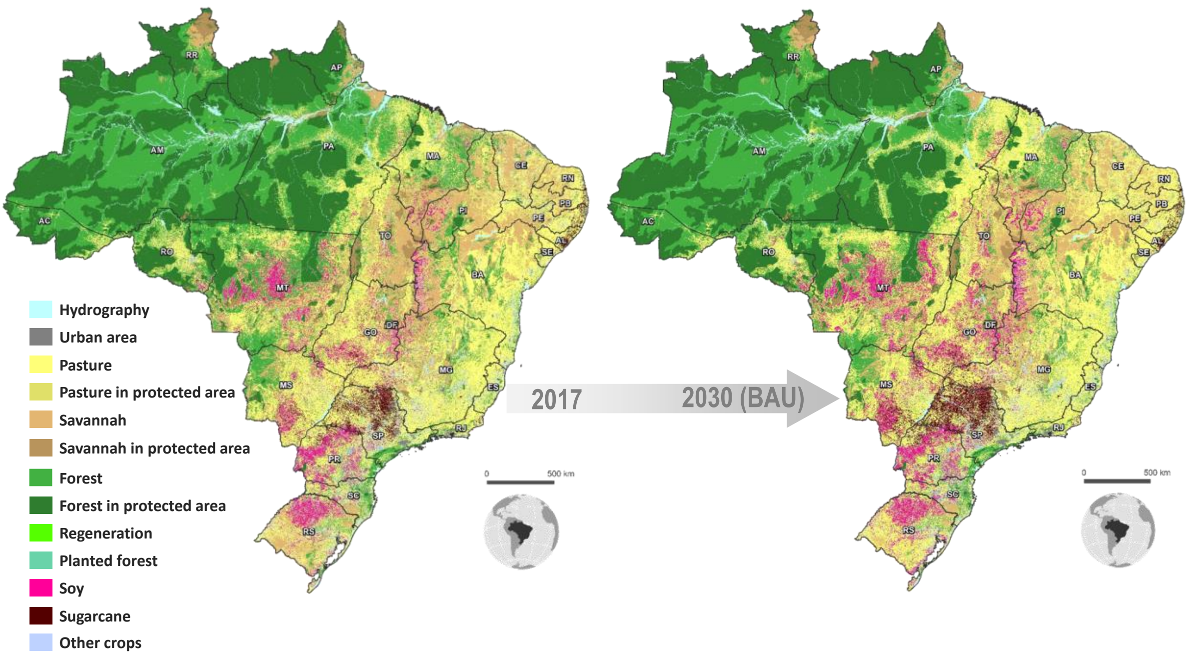



*Figure 28: Land use changes from 2017 to 2030 under the baseline (BAU) scenario.*

According to the land use transition matrix (Figure 29), most of agricultural lands in 2017 continue to be agricultural in 2030 (ca. 75%). Agriculture expansion always puts pressure on native vegetation conversion as it raises land prices locally and elsewhere, the latter due to land speculation (Miranda et al., 2019). The new croplands (ca. 18 million hectares) expand mainly into pasture (ca. 93% of expansion), whilst only ca. 4% coming from conversion of forests and 3% from savannah. In 2017 pasturelands are more than 230 million hectares, whilst the restoration of degraded land represents a huge opportunity for Brazilian agriculture to meet domestic and international demand without the need of clearing new forest areas.

Pasture expansion: almost 50% into forest, and 48% into savannah

BAU Transition Matrix – Cumulative Land use - 2017/2030 (ha)

| 2030 \ 2017 — Categories of land use | Pasture | Savannah | Forest | Regeneration | Agricultural area | Planted forest | Landuse 2030 |
|---|---|---|---|---|---|---|---|
| Pasture | 209,885,925 | 20,324,525 | 22,095,875 | - | 2,418,400 | - | 254,724,725 |
| Savannah | 0 | 96,707,275 | 0 | - | 0 | - | 96,707,275 |
| Forest | 0 | 0 | 378,368,600 | - | 0 | - | 378,368,600 |
| Regeneration | 4,191,200 | 224,925 | 527,800 | 1,915,025 | 16,350 | - | 6,875,300 |
| Agricultural area | 16,453,675 | 812,750 | 938,950 | - | 56,759,500 | - | 74,964,875 |
| Planted forest | 1,164,525 | 12,800 | 14,950 | - | 35,625 | 7,839,950 | 9,067,850 |
| Landuse 2017 | 231,695,325 | 118,082,275 | 401,946,175 | 1,915,025 | 59,229,875 | 7,839,950 | - |

Agriculture expansion: 93% into pasture, 4% into forest, 3% into savannah

*Figure 29: Transition matrix representing the cumulative land use changes (hectares) from 2017 to 2030 in the BAU scenario.*

The expansion of pasture into the forest and savannah (more than 40 million hectares) is mainly linked to predatory land grabbing and livestock. Pasture displacement into Amazon and Cerrado biomes can be associated with the large-scale expansion of soybean into northern ready-cleared areas (Gibbs et al., 2015). The cause-effect relation between the agricultural expansion into existing pasturelands in the southern regions and the deforestation trends in the northern region of Brazil to open new pasture areas, is uncertain and hard to define as indirect land use changes (ILUC).

In the Amazon biome, newly cleared lands will be marginally occupied with productive activities by 2030 and can be mostly explained as quest for land (Miranda et al., 2019). Subsequently, in the mid-term horizon (usually more than 7 years after deforestation (MAPA, 2017)) those lands could be cropped with soybean, for example, or dedicated to cattle ranching activities. The magnitude and rate of these land use transitions are affected by the governmental commitment to preserve Amazonian forest through a full enforcement of the Forest Code and the implementation of penalties for illegal deforestation (Tollefson, 2018).

## 6.3 Country net LULUCF emissions

We considered that the deforestation trend observed since 2012 continues to 2030, which reflects the political support for predatory agriculture and land-grabbing practices under an intermediate environmental governance scenario (Rochedo et al., 2018). This implies increasing losses in carbon stock and net cumulative GHG emissions that can put the country's contribution to the Paris agreement at risk (Table 10).

*Table 10: LULUCF net emissions (Mtons $CO_2$) - BAU scenario*

| Million tons $CO_2$ | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GROSS EMISSIONS** | 755 | 800 | 845 | 892 | 937 | 983 | 1031 | 1080 | 1126 | 1176 | 1222 | 1273 | 1321 |
| - Deforestation | 714 | 755 | 796 | 839 | 880 | 922 | 966 | 1012 | 1054 | 1100 | 1142 | 1189 | 1234 |
| - Other LUC emissions | 41 | 45 | 49 | 53 | 57 | 61 | 65 | 68 | 72 | 76 | 80 | 84 | 88 |
| **REMOVALS** (including CU/IL) | -365 | -368 | -371 | -374 | -377 | -380 | -383 | -388 | -392 | -395 | -398 | -401 | -402 |
| - Regeneration | -17 | -19 | -22 | -25 | -28 | -30 | -33 | -37 | -41 | -45 | -48 | -50 | -52 |
| - Plantation expansion and other LUC removals | -30 | -31 | -31 | -32 | -32 | -32 | -32 | -32 | -33 | -33 | -33 | -33 | -33 |
| - Conservation Units/ Indigenous lands (CU/IL) | -318 | -318 | -318 | -318 | -318 | -318 | -318 | -318 | -318 | -318 | -318 | -318 | -318 |
| **NET EMISSIONS** (not including CU/IL) | 709 | 749 | 791 | 836 | 877 | 920 | 965 | 1011 | 1052 | 1099 | 1142 | 1190 | 1237 |
| **NET EMISSIONS** (including CU/IL) | 391 | 432 | 474 | 518 | 559 | 603 | 648 | 693 | 734 | 781 | 824 | 872 | 919 |

Figure 30 displays the GHG emissions recorded from 1990 to 2017, and the divergence between the National Determined Contribution target (NDC) and the results of our simulation. The NDC curve shows a decreasing trend that falls to ca. 22 million tons $CO_2$ in 2030 (Grassi et al., 2017). In contrast, the LULUCF emissions from the BAU scenario rise after 2017 because of the projected deforestation trends, diverging from the NDC target in 2030 by ca. 900 million tons $CO_2$.

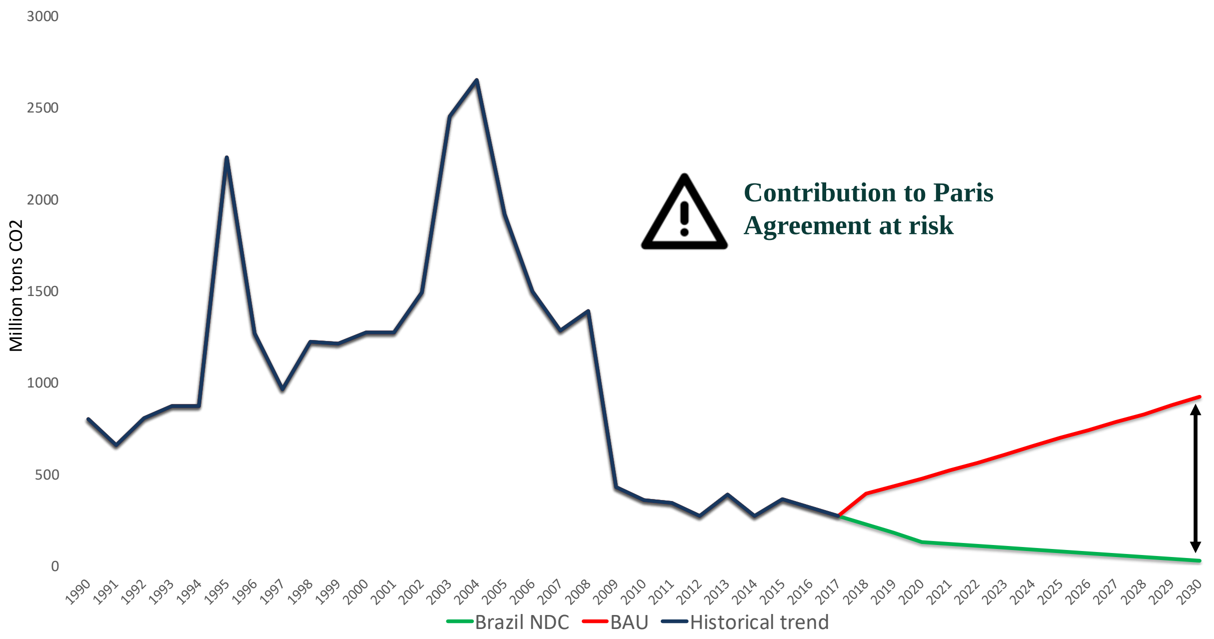



*Figure 30: LULUCF $CO_2$ emissions from changes in biomass and soil carbon stocks. 2017-2030 projections from a BAU scenario versus the country NDC targets (Grassi et al., 2017).*

## 6.4 In depth analysis: sugarcane expansion

### 6.4.1 Sugarcane expansion sorted by state

The largest sugarcane expansion in absolute terms is expected in the State of Sao Paulo (ca. 2,2 million hectares on average), followed by Mato Grosso (0,9 million hectares) and Minas Gerais (0,7 million hectares). Mato Grosso (122%) and Minas Gerais (83%) also record the highest average relative increments[46] (Table 11). A detailed description of the main factors shaping the sugarcane expansion can be found in the Supplementary Information (Annex 5)

*Table 11: sugarcane area in 2017 and projected expansion to 2030, sorted by Brazilian states. Total area (1000 ha) and relative increment (%) vs. 2017 area, under the BAU and POB scenarios*

| | Sugarcane Area (kha) | Sugarcane expansion Area (kha) vs.2017 | | Sugarcane expansion Change (%) vs.2017 | |
|---|---|---|---|---|---|
| State | 2017 | 2030 BAU | 2030 POB | 2030 BAU | 2030 POB |
| Acre | 2.95 | - | - | - | - |
| Alagoas | 411 | 0.7 | 0.80 | 0.2 | 0.20 |
| Amapa | 0.15 | - | - | - | - |
| Amazonas | 5.65 | - | - | - | - |
| Bahia | 121 | 28.6 | 32.4 | 23.7 | 26.8 |
| Ceará | 42.6 | 1.35 | 2.77 | 3.2 | 6.51 |
| Distrito Federal | 0.93 | 1.3 | 1.67 | 140 | 180.4 |
| Espirito Santo | 78.1 | 10.6 | 13.6 | 13.6 | 17.4 |
| Goiás | 730 | 369 | 463 | 50.6 | 63.5 |
| Maranhão | 49.9 | 0.1 | 0.17 | 0.2 | 0.35 |
| Mato Grosso | 229 | 12 | 18.5 | 5.2 | 8.10 |
| Mato Grosso do sul | 778 | 875 | 891 | 112 | 115 |
| Minas Gerais | 905 | 666 | 731 | 73.6 | 80.8 |
| Pará | 13.1 | - | - | - | - |
| Paraíba | 115 | 0.3 | 0.26 | 0.3 | 0.23 |
| Paraná | 652 | 338 | 354 | 51.8 | 54.3 |
| Pernanbuco | 342 | 3.38 | 4.79 | 1.0 | 1.40 |
| Piauí | 15.8 | 0.2 | 0.33 | 1.3 | 2.05 |
| Rio de Janeiro | 105 | 0.5 | 0.46 | 0.5 | 0.43 |
| Rio Grande do Norte | 59.8 | - | 0.02 | - | 0.04 |
| Rio Grande do Sul | 37.0 | 0.4 | 1.02 | 1.1 | 2.76 |
| Rondonia | 4.55 | - | - | - | - |
| Roraima | 0.58 | - | - | - | - |
| Santa Catarina | 12.2 | 0.3 | 0.37 | 2.5 | 3.02 |
| São Paulo | 5395 | 2145 | 2051 | 39.8 | 38.0 |
| Sergipe | 51.7 | 2.375 | 2.69 | 4.6 | 5.20 |
| Tocantins | 26.2 | 0.25 | - | 1.0 | - |

[46] We disregard the Federal District value, since its absolute (ha) contribution to sugarcane area is very low.

| | | | | | |
|---|---|---|---|---|---|
| BRAZIL | 10184 | 4455 | 4570 | 43.7 | 44.9 |

### 6.4.2 Land conversion to sugarcane

Land use conversions to new sugarcane areas from 2017 to 2030 mainly occur in the regions of the Southeast and Midwest (Figure 31).

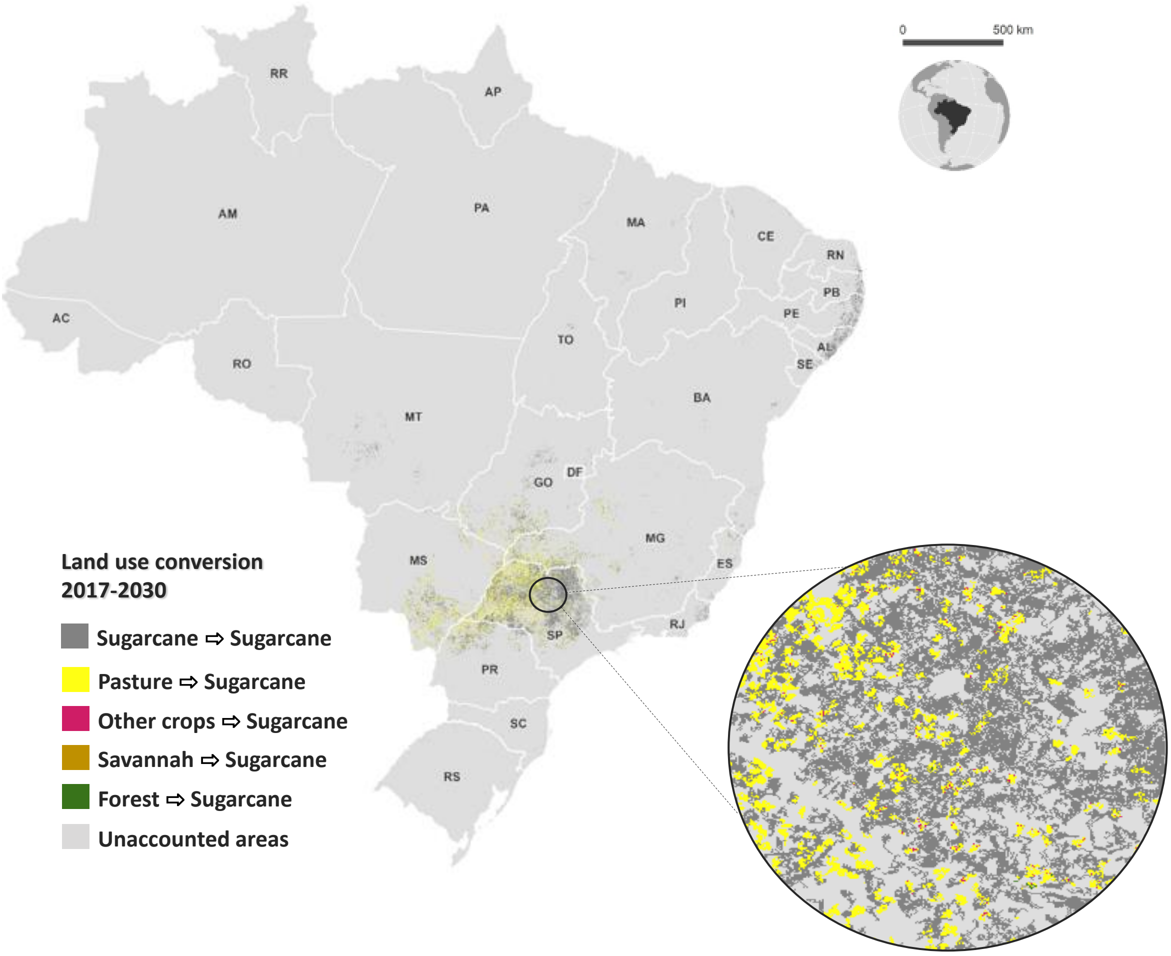



*Figure 31: land use conversions to sugarcane from 2017 to 2030. Example of BAU scenario*

Most of the sugarcane croplands in 2017 continue to be productive in 2030, representing on average 68% of total sugarcane area (Table 12). By focusing only on sugarcane expansion area, we notice that almost the totality of new sugarcane croplands come from the conversion of pastureland (97%), which also account for more than 30% of the total production area. Sugarcane expansion into pasture accounts for ca. 25% of the cumulative expansion of Brazilian agriculture into pasturelands from 2017 to 2030 (4.4-5.2 *versus* 16.4 million hectares).

The conversion of native vegetation and other croplands (including food crops) to sugarcane is very limited, being less than 3% in both scenarios.

*Table 12: land use conversions to sugarcane cropland from 2017 to 2030 under the BAU and POB scenarios.*

| | Area (Mha) | | Conversion ratio (% vs. tot. area) | | Conversion ratio (%vs. tot. expansion) | |
|---|---|---|---|---|---|---|
| TRANSITIONS 2017-2030 | BAU | POB | BAU | POB | BAU | POB |
| Sugarcane permanence | 10.2 | 10.2 | 69.5 | 65.9 | - | - |
| Pasture to Sugarcane | 4.35 | 4.46 | 29.6 | 33.3 | 97.5 | 97.5 |
| Other crops to Sugarcane | 0.03 | 0.04 | 0.23 | 0.28 | 0.76 | 0.82 |
| Savannah to Sugarcane | 0.05 | 0.05 | 0.32 | 0.37 | 1.04 | 1.07 |
| Forest to Sugarcane | 0.03 | 0.03 | 0.19 | 0.21 | 0.63 | 0.61 |
| Total sugarcane area | 14.6 | 14.8 | 100 | 100 | 100 | 100 |
| Total expansion area | 4.46 | 4.57 | - | - | - | - |

We could conclude that the direct impacts on land use arising from sugarcane expansion are very limited, resulting in a small loss of native forest (high carbon stocks) and displacement of other cropping activities. Even though most of the sugarcane expansion is met from pastureland (97%), it is far from certain that new forest clearance in the northern regions is linked to the displacement of pasturelands from the Southeast and Midwest (indirect land use change). Pasture displacement for livestock is not the only solution to meet the steeply increasing demand for meat. In addition to a partial substitution of beef for pig meat, and in particular chicken, in the past, from 1996 to 2008 – sugarcane expansion led to an increased pasture intensification rate (head per hectares) and beef production (Amorim et al., 2010; Kozumi, 2014).

### 6.4.3 GHG emissions from sugarcane cultivation

As mentioned above, the largest expansion of sugarcane crops is expected to be met by pasturelands. This should result in limited GHG emissions from living biomass due to the low carbon content (Mello et al., 2014). However, cultivating degraded pasture demands the use of fertilizer and lime to prepare the soil for farming and achieve the expected sugarcane productivity per hectare, representing an additional source of GHG emissions. Some regions of Brazil, notably in the northern states, rely on burning sugarcane straw to facilitate the manual harvesting by cleaning the fields. A detailed description of the methods and parameters for estimating the GHG budget can be found in MCTI and ONU (2017).

#### *6.4.3.1 Emissions from changes in biomass carbon stock*

Table 13 and Table 14 show the emissions from changes in biomass carbon stocks. Each row represents the progressive transition from a land use type in 2017 to sugarcane in 2030. For example, the forest area in 2017 converted to the sugarcane by 2020 emits ca. 593000 tons of $CO_2$ (usually through a forest to pasture and pasture to sugarcane transition).

*Table 13: GHG emissions (Million tons $CO_2$) from living biomass carbon stock change due to sugarcane expansion from 2017 to 2030. BAU scenario*

| Land use in 2017 BAU scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pasture | 3.22 | 3.20 | 3.19 | 3.20 | 3.17 | 3.16 | 3.16 | 3.13 | 3.12 | 3.10 | 3.08 | 3.07 | 3.07 | 40.89 |
| Forest | 0.76 | 0.60 | 0.59 | 0.59 | 0.57 | 0.52 | 0.60 | 0.52 | 0.49 | 0.37 | 0.27 | 0.30 | 0.08 | 6.24 |
| Savannah | 1.17 | 1.04 | 1.25 | 0.90 | 0.90 | 0.78 | 0.82 | 0.75 | 0.61 | 0.52 | 0.42 | 0.31 | 0.13 | 9.59 |
| Permanent crops | 0.06 | 0.07 | 0.06 | 0.07 | 0.06 | 0.06 | 0.06 | 0.05 | 0.04 | 0.05 | 0.05 | 0.04 | 0.03 | 0.69 |
| TOT | 5.20 | 4.90 | 5.10 | 4.75 | 4.70 | 4.52 | 4.65 | 4.45 | 4.27 | 4.04 | 3.82 | 3.71 | 3.30 | 57.42 |

*Table 14: GHG emissions (Million tons $CO_2$) from living biomass carbon stock change due to sugarcane expansion from 2017 to 2030. POB scenario*

| Land use in 2017 POB scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pasture | 3.30 | 3.29 | 3.27 | 3.27 | 3.25 | 3.25 | 3.22 | 3.22 | 3.19 | 3.19 | 3.17 | 3.14 | 3.13 | 41.89 |
| Forest | 0.93 | 0.69 | 0.69 | 0.59 | 0.76 | 0.56 | 0.44 | 0.48 | 0.42 | 0.36 | 0.27 | 0.27 | 0.14 | 6.61 |
| Savannah | 1.15 | 1.18 | 1.16 | 0.97 | 1.09 | 0.76 | 0.72 | 0.63 | 0.61 | 0.41 | 0.32 | 0.33 | 0.17 | 9.51 |
| Permanent crops | 0.06 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.02 | 0.04 | 0.03 | 0.03 | 0.03 | 0.02 | 0.53 |
| TOT | 5.44 | 5.23 | 5.18 | 4.87 | 5.15 | 4.61 | 4.44 | 4.36 | 4.26 | 3.99 | 3.79 | 3.77 | 3.46 | 58.54 |

### 6.4.3.2 Emissions from changes in soil carbon stock

Table 15 and Table 16 show the emissions from changes in soil carbon stocks. Each row represents the progressive transition from a land use type in 2017 to sugarcane in 2030.

*Table 15: GHG emissions (Million tons $CO_2$) from soil due to sugarcane expansion from 2017 to 2030. BAU scenario*

| Land use in 2017 BAU scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pasture | 0.91 | 1.80 | 2.69 | 3.58 | 4.48 | 5.38 | 6.26 | 7.15 | 8.03 | 8.91 | 9.76 | 10.62 | 11.41 | 80.98 |
| Forest | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.07 | 0.07 | 0.35 |
| Savannah | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.09 | 0.11 | 0.13 | 0.63 |
| Annual crops | -0.01 | -0.01 | -0.02 | -0.02 | -0.02 | -0.02 | -0.01 | -0.01 | 0.00 | 0.01 | 0.02 | 0.04 | 0.05 | 0.01 |
| Permanent crops | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.14 |
| TOT | 0.90 | 1.80 | 2.69 | 3.59 | 4.50 | 5.41 | 6.31 | 7.23 | 8.14 | 9.05 | 9.94 | 10.86 | 11.69 | 82.11 |

*Table 16: GHG emissions (Million tons $CO_2$) from soil due to sugarcane expansion from 2017 to 2030. POB scenario*

| Land use in 2017 POB scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pasture | 0.93 | 1.85 | 2.78 | 3.71 | 4.63 | 5.55 | 6.46 | 7.36 | 8.26 | 9.17 | 10.06 | 10.93 | 11.73 | 83.42 |
| Forest | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.36 |
| Savannah | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | 0.05 | 0.07 | 0.08 | 0.10 | 0.12 | 0.13 | 0.69 |
| Annual crops | -0.01 | -0.02 | -0.02 | -0.02 | -0.03 | -0.03 | -0.02 | -0.02 | -0.01 | 0.00 | 0.02 | 0.04 | 0.06 | -0.05 |
| Permanent crops | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.12 |
| TOT | 0.93 | 1.85 | 2.78 | 3.71 | 4.64 | 5.58 | 6.51 | 7.44 | 8.37 | 9.31 | 10.24 | 11.17 | 12.02 | 84.55 |

### 6.4.3.3 Emissions from fertilizer and lime application

For fertilizing sugarcane areas, an average volume of 100 kg N per hectare per year was considered (MCTIC and ONU, 2017). Table 17 and Table 18 show the emissions ($CO_2$e) from fertilizer application.

*Table 17: GHG emissions (Million tons $CO_2$e) from fertilization of sugarcane crops. BAU scenario*

| Mtons $CO_2$e BAU scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct emissions | 2.81 | 2.90 | 2.99 | 3.08 | 3.17 | 3.26 | 3.35 | 3.45 | 3.54 | 3.63 | 3.72 | 3.81 | 3.90 | 43.60 |
| Indirect emissions | 3.33 | 3.44 | 3.55 | 3.66 | 3.77 | 3.88 | 3.99 | 4.10 | 4.21 | 4.32 | 4.43 | 4.54 | 4.65 | 51.87 |
| TOT | 6.14 | 6.34 | 6.54 | 6.74 | 6.94 | 7.14 | 7.34 | 7.54 | 7.75 | 7.95 | 8.15 | 8.35 | 8.55 | 95.46 |

*Table 18: GHG emissions (Million tons $CO_2$e) from fertilization of sugarcane crops. POB scenario*

| Mtons $CO_2$e POB scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct emissions | 2.82 | 2.93 | 3.04 | 3.13 | 3.21 | 3.30 | 3.39 | 3.48 | 3.57 | 3.66 | 3.75 | 3.84 | 3.93 | 44.07 |
| Indirect emissions | 3.35 | 3.48 | 3.61 | 3.71 | 3.82 | 3.92 | 4.03 | 4.14 | 4.24 | 4.35 | 4.45 | 4.57 | 4.67 | 52.34 |
| TOT | 6.17 | 6.41 | 6.65 | 6.84 | 7.03 | 7.23 | 7.42 | 7.62 | 7.81 | 8.01 | 8.21 | 8.41 | 8.60 | 96.41 |

For soil preparation, an average volume of 2 tons of limestone per hectare per year was considered (MCTIC and ONU, 2017). Table 19 shows the GHG emissions from lime application.

*Table 19: GHG emissions (Million tons $CO_2$e) from lime applications*

| Mtons $CO_2$e | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BAU scenario | 1.27 | 1.57 | 1.76 | 1.55 | 1.26 | 2.47 | 1.2 | 1.57 | 1.87 | 2.06 | 1.85 | 1.56 | 2.77 | 22.76 |
| POB scenario | 1.32 | 1.62 | 1.81 | 1.60 | 1.30 | 2.48 | 1.22 | 1.64 | 1.92 | 2.09 | 1.89 | 1.60 | 2.75 | 23.25 |

### 6.4.3.4 Emissions from burning sugarcane straw

The state of Sao Paulo approved the Law n11.241 in 2002, which regulates the burning of sugarcane straw - and will completely remove this practice by 2021. Other producers, notably the northeast states, have not yet defined their position, and continue to use burning as a mean to facilitate manual harvesting. Table 20 shows the emissions from burning sugarcane straw ($CO_2$e).

*Table 20: GHG emissions (Million tons $CO_2$e) from burning sugarcane straw*

| Mtons $CO_2$e | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BAU scenario | 4.45 | 4.32 | 4.21 | 4.08 | 4.16 | 4.22 | 4.26 | 4.29 | 4.31 | 4.29 | 4.26 | 4.21 | 4.16 | 55.21 |
| POB scenario | 4.93 | 4.54 | 4.49 | 4.43 | 4.39 | 4.52 | 4.46 | 4.56 | 4.47 | 4.53 | 4.42 | 4.45 | 4.32 | 58.52 |

### 6.4.3.5 Total GHG emissions

Total GHG emissions are calculated by adding the emissions associated with biomass and soil carbon stock changes (LULUCF), and agricultural practices (Table 21 and Table 22).

*Table 21: total sugarcane area (million hectares) and GHG emissions (million tons $CO_2$) associated with sugarcane production from 2017 to 2030. BAU scenario*

| BAU scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sugarcane area (Mha) | 10.5 | 10.9 | 11.2 | 11.6 | 11.9 | 12.2 | 12.6 | 12.9 | 13.3 | 13.6 | 14.0 | 14.3 | 14.6 | |
| TOT GHG emission (Mtons CO2) | 18.0 | 18.9 | 20.3 | 20.7 | 21.6 | 23.8 | 23.8 | 25.1 | 26.3 | 27.4 | 28.0 | 28.7 | 30.5 | 313 |
| - LULUCF | 6.10 | 6.70 | 7.79 | 8.34 | 9.20 | 9.93 | 11.0 | 11.7 | 12.4 | 13.1 | 13.8 | 14.6 | 15.0 | 140 |
| - Biomass | 5.20 | 4.90 | 5.10 | 4.75 | 4.70 | 4.52 | 4.65 | 4.45 | 4.27 | 4.04 | 3.82 | 3.71 | 3.30 | 57.4 |
| - Soil | 0.90 | 1.80 | 2.69 | 3.59 | 4.50 | 5.41 | 6.31 | 7.23 | 8.14 | 9.05 | 9.94 | 10.9 | 11.7 | 82.1 |
| - Fertilizer and lime | 7.41 | 7.90 | 8.30 | 8.29 | 8.20 | 9.61 | 8.54 | 9.11 | 9.61 | 10.01 | 10.0 | 9.91 | 11.3 | 118 |
| - Burning | 4.45 | 4.32 | 4.21 | 4.08 | 4.16 | 4.22 | 4.26 | 4.29 | 4.31 | 4.29 | 4.26 | 4.21 | 4.16 | 55.2 |

*Table 22: Total sugarcane area and GHG emissions associated with sugarcane production from 2017 to 2030. POB scenario*

| POB scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sugarcane area (Mha) | 11.62 | 11.37 | 11.86 | 12.37 | 12.36 | 12.88 | 12.90 | 13.41 | 13.44 | 14.02 | 14.11 | 14.66 | 14.76 | |
| TOT GHG emission (Mtons $CO_2$) | 19.4 | 19.9 | 21.2 | 21.8 | 22.7 | 24.7 | 24.2 | 25.8 | 26.9 | 28.1 | 28.6 | 29.5 | 31.2 | 323.8 |
| - LULUCF | 6.4 | 7.1 | 8.0 | 8.6 | 9.8 | 10.2 | 10.9 | 11.8 | 12.6 | 13.3 | 14.0 | 14.9 | 15.5 | 143.1 |
| - Biomass | 5.44 | 5.23 | 5.18 | 4.87 | 5.15 | 4.61 | 4.44 | 4.36 | 4.26 | 3.99 | 3.79 | 3.77 | 3.46 | 58.5 |
| - Soil | 0.93 | 1.85 | 2.78 | 3.71 | 4.64 | 5.58 | 6.51 | 7.44 | 8.37 | 9.31 | 10.24 | 11.17 | 12.02 | 84.6 |
| - Fertilizer and lime | 8.10 | 8.25 | 8.73 | 8.81 | 8.51 | 9.99 | 8.75 | 9.45 | 9.75 | 10.27 | 10.11 | 10.15 | 11.35 | 122.2 |
| - Burning | 4.93 | 4.54 | 4.49 | 4.43 | 4.39 | 4.52 | 4.46 | 4.56 | 4.47 | 4.53 | 4.42 | 4.45 | 4.32 | 58.5 |

LULUCF emissions account for less than 50% of total GHG emissions (Figure 32); only ca. 20% came from changes in live biomass carbon stock – e.g, deforestation and other land use transitions. The most relevant $CO_2$ source is associated with fertilization and limestone applications (38%). Burning straw represents ca. 18% of total GHG emissions; this practice is progressively disappearing with the gradual substitution of manual with mechanical harvesting.

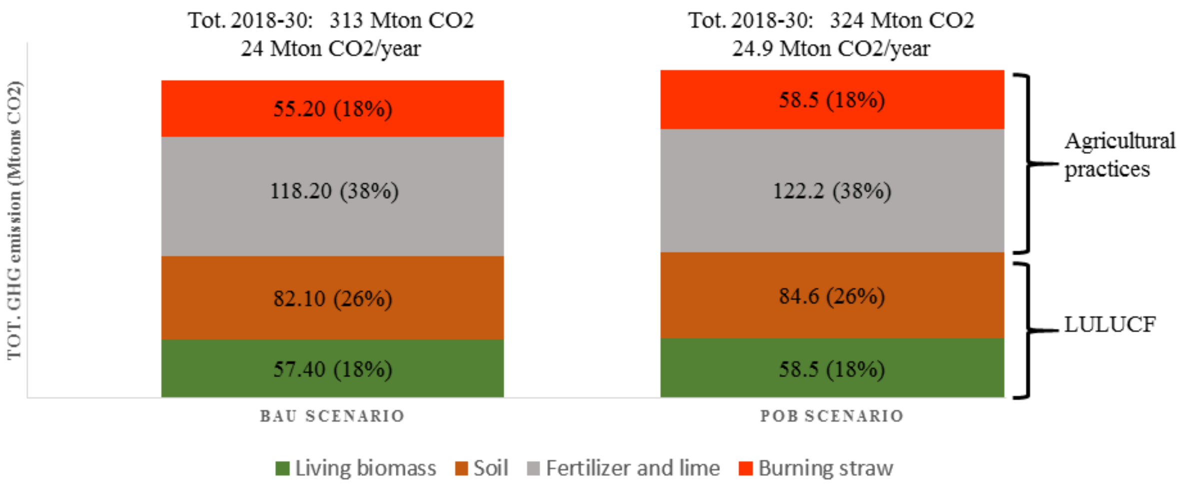



*Figure 32: Profile of the cumulative GHG emissions (million tons $CO_2$) from sugarcane production from 2018 to 2030.*

On average, the GHG emission is ca. 2 tons of $CO_2$ per hectare per year. The LULUCF component can be translated into an equivalent land use change emission per MJ of additional ethanol. The additional annual LULUCF emissions in the POB scenario compared to BAU rise to 0.48 million tons $CO_2$ per year in 2030. The additional ethanol production in the POB scenario compared to BAU amounts to 0.66 billion litres per year. Conventionally, in Europe, LUC emissions are spread over 20 years' of production. Considering also that ethanol has a Lower Heating Value energy content of about 20 MJ per litre, the LUC emissions work out to be about 2g$CO_2$/MJ.

## 6.5 Comparison with soybean expansion

We calculated the LULUCF emissions coming from the expansion of soybean in order to compare the impacts of sugarcane cultivation with the impacts of the largest crop in Brazil.

### 6.5.1 Soybean expansion sorted by states

By comparison, Table 23 displays soybean croplands, sorted by state. This crop is mainly used for animal feed, whilst only a small share (ca. 1% in 2016) of the total production is used for biodiesel (Fuchs et al., 2019).

In absolute terms, according to our projections, the largest expansion occurs into Mato Grosso (ca. 3.5 million hectares), Goiás (ca. 2 million hectares), Mato Grosso do Sul (ca. 1,4 million hectares), Tocantins e Minas Gerais (ca. 1 million hectares). Mato Grosso will be, by far, the largest producer in 2030 (ca. 13 million hectares). Most of these new areas are within the Cerrado and Mata Atlantica biomes. However, three out of the four highest rates of change are observed in the Amazon states, namely Pará (138%), Acre (128%) and Rondonia (69%), even though, in absolute terms, only Pará will contribute with more than one million hectares to 2030 soybean area.

*Table 23: Soybean area in 2017 and projected expansion to 2030, sorted by Brazilian states. Total area (1000 ha) and relative increment (%) vs. 2017 area.*

| | Soybean Area (kha) 2017 | Soybean expansion Area (kha) 2030 vs. 2017 | Soybean expansion Change (%) 2030 vs. 2017 | Total area (kha) in 2030 |
|---|---|---|---|---|
| STATE | | | | |
| Acre | 11.2 | 14.4 | 128 | 25.6 |
| Alagoas | - | - | - | - |
| Amapá | - | - | - | - |
| Amazonas | 0 | | - | 0.48 |
| Bahia | 1486 | 601 | 40 | 2087 |
| Ceará | - | 0.03 | 100 | 0.03 |
| Distrito Federal | 60 | 10.9 | 18 | 71 |
| Espirito Santo | - | - | - | - |
| Goiás | 4152 | 1991 | 48 | 6144 |
| Maranhão | 813 | 421 | 52 | 1234 |
| Mato Grosso | 9349 | 3558 | 38 | 12907 |
| Mato Grosso do sul | 2747 | 1399 | 51 | 4146 |
| Minas Gerais | 1830 | | 56 | 2860 |
| Pará | 468 | 646 | 138 | 1114 |
| Paraíba | - | - | - | - |
| Paraná | 4848 | 350 | 7 | 5198 |
| Pernanbuco | - | - | - | - |
| Piauí | 668 | 361 | 54 | 1029 |
| Rio de Janeiro | - | - | - | - |
| Rio Grande do Norte | - | - | - | - |
| Rio Grande do Sul | 4659 | 777 | 17 | 5435 |
| Rondonia | 348 | 239 | 69 | 587 |

| | | | | |
|---|---|---|---|---|
| Roraima | 4.03 | 0.6 | 15 | 5 |
| Santa Catarina | 602 | 154 | 26 | 756 |
| São Paulo | 851 | 452 | 53 | 1302 |
| Sergipe | - | - | - | 0 |
| Tocantins | 1083 | 1066 | 98 | 2149 |
| Brazil | 33981 | 13070 | 38 | 47051 |

### 6.5.2 Land conversion to soybean

Deforestation due to soybean expansion accounts for almost 7% of new croplands (ca. 886450 ha), the second main land conversion after pasture to soy (Table 24). In 2030, the largest share of soybean will be grown on croplands coming from areas already planted with soybean in 2017 (72% of the total area).

*Table 24: Land use conversions to soybean cropland from 2017 to 2030.*

| | Area (Mha) | Conversion ratio (% vs. total area) | Conversion ratio (% vs. total expansion) |
|---|---|---|---|
| TRANSITIONS 2017-2030 | | | |
| Soy to Soy | 33.9 | 72.2 | - |
| Pasture to Soy | 11.3 | 24.1 | 86.9 |
| Other crops to Soy | 0.09 | 0.18 | 0.65 |
| Savannah to Soy | 0.73 | 1.56 | 5.60 |
| Forest to Soy | 0.89 | 1.88 | 6.78 |
| Total Soy area | 47.05 | - | - |
| Total Soy expansion | 13.1 | - | - |

In the period 2009-2016 soybean has been responsible for 1,2% of the loss of Amazon rainforest (GTS, 2018), even though its cultivation in this biome accounts for ca. 13% Brazil's production in 2017 (ca. 4,5 million hectares). Indeed, most of the soybean expansion in the past was met from pasturelands converted from forest before 2008, the reference year of the Soy Moratorium[47]

New land conversion to soybean mainly takes place in the Mid-West and northern states, which presents a worrying trend in terms of the potential threat of soybean expansion into the Amazon rainforest and Cerrado native vegetation (Figure 33). The occupation of pastures in the north of Mato Grosso and Tocantins, Maranhão, Rondonia and Pará could lead to new forest clearance through displacement of pasturelands into the Amazon biome. Moreover, from 2017 to 2030, ca 731,750 ha of native vegetation in the Cerrado will be converted to soybean. Even though in this biome there are large cleared areas suitable for soybean expansion (ca. 42 Mha), these lands are not located in the regions with the most rapid recent growth (Gibbs et al., 2015). The projected large-scale expansion of soybean into the Matopiba region could raise both direct and indirect (i.e, through pasture displacement) land conversion of the native vegetation of Cerrado biome, which is highly vulnerable since it is not safeguarded by the Soy Moratorium. The large-scale expansion of soybean into northern states is driven by the low price of land – in the Matopiba region lands are 50% cheaper than in Mato Grosso (MAPA, 2017).

[47] The Soy moratorium is a voluntary zero-deforestation trade-based agreement implemented in Brazil to avoid the purchase of soybean grown on land deforested after 2008 (the agreement was signed in 2006 by major soybean trades)

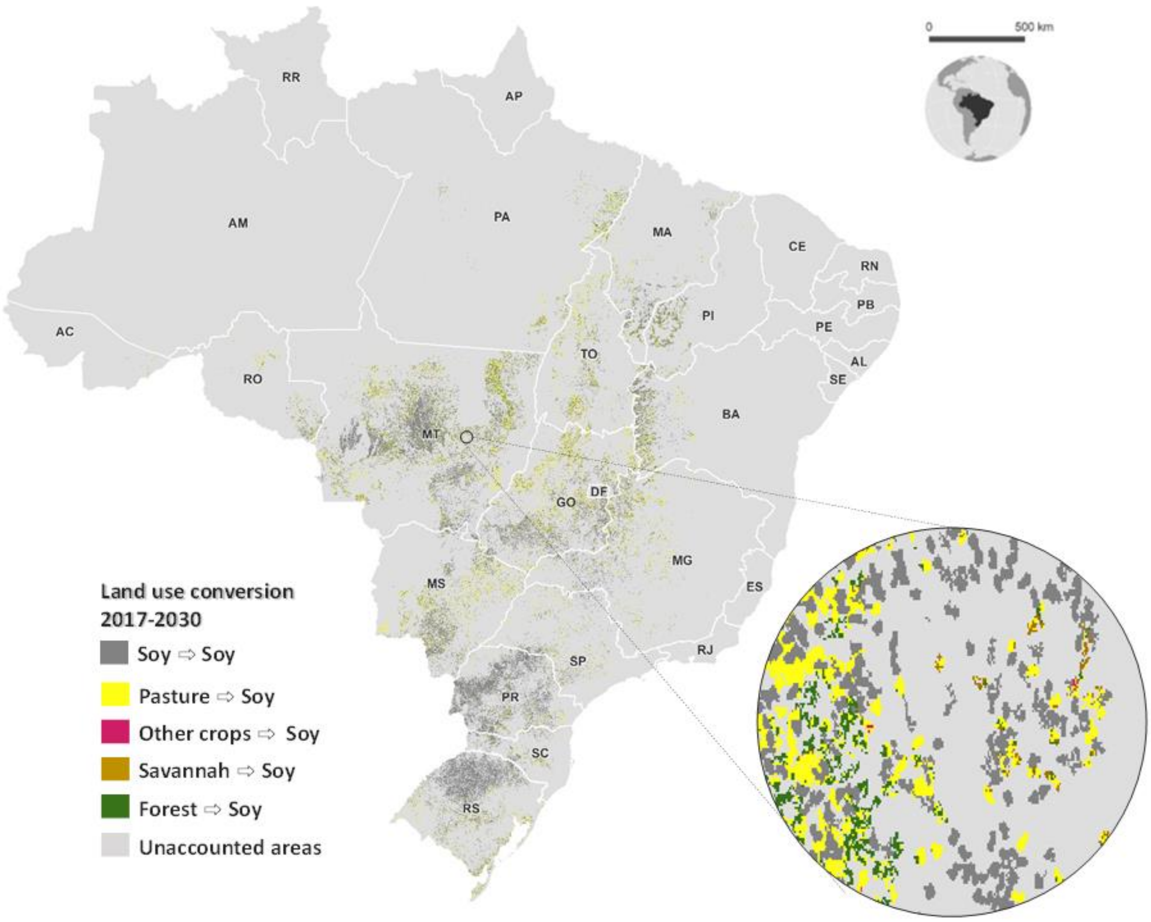



*Figure 33: Land use conversions to soybean from 2017 to 2030.*

### 6.5.3 LULUCF emissions due to soybean production

Table 25 shows the LULUCF emissions due to soybean expansion between 2017 and 2030. We did not calculate emissions from agricultural practices associated with soybean cultivation.

*Table 25: LULUCF emissions (million tons $CO_2$) from soybean expansion from 2018 to 2030.*

| BAU scenario | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soybean area (Mha) | 35.1 | 36.2 | 37.2 | 38.3 | 39.4 | 40.5 | 41.5 | 42.6 | 43.7 | 44.8 | 45.9 | 46.1 | 47.1 | |
| LULUCF emission (Mtons $CO_2$) | 65.5 | 76.9 | 75.7 | 77.6 | 77.8 | 78.9 | 76.8 | 77.0 | 74.9 | 72.6 | 68.3 | 65.6 | 61.9 | 949 |
| - Biomass | 49.6 | 58.4 | 54.7 | 54.0 | 51.7 | 50.3 | 45.6 | 43.3 | 38.7 | 33.9 | 27.1 | 21.8 | 15.6 | 545 |
| - Soil | 15.9 | 18.5 | 21.0 | 23.6 | 26.1 | 28.6 | 31.2 | 33.7 | 36.2 | 38.7 | 41.2 | 43.8 | 46.3 | 405 |

The expansion of soybean into the rainforest and Cerrado native vegetation determines the high values of $CO_2$ emissions from biomass loss. The average LULUCF emission per hectare for soybean is two times larger than that for sugarcane (1.76 ton $CO_2$/ha per year versus 0,85 ton $CO_2$/ha per year). Figure 34 shows the difference between the soybean and sugarcane LULUCF emission magnitudes employing trends from 2018 to 2030.

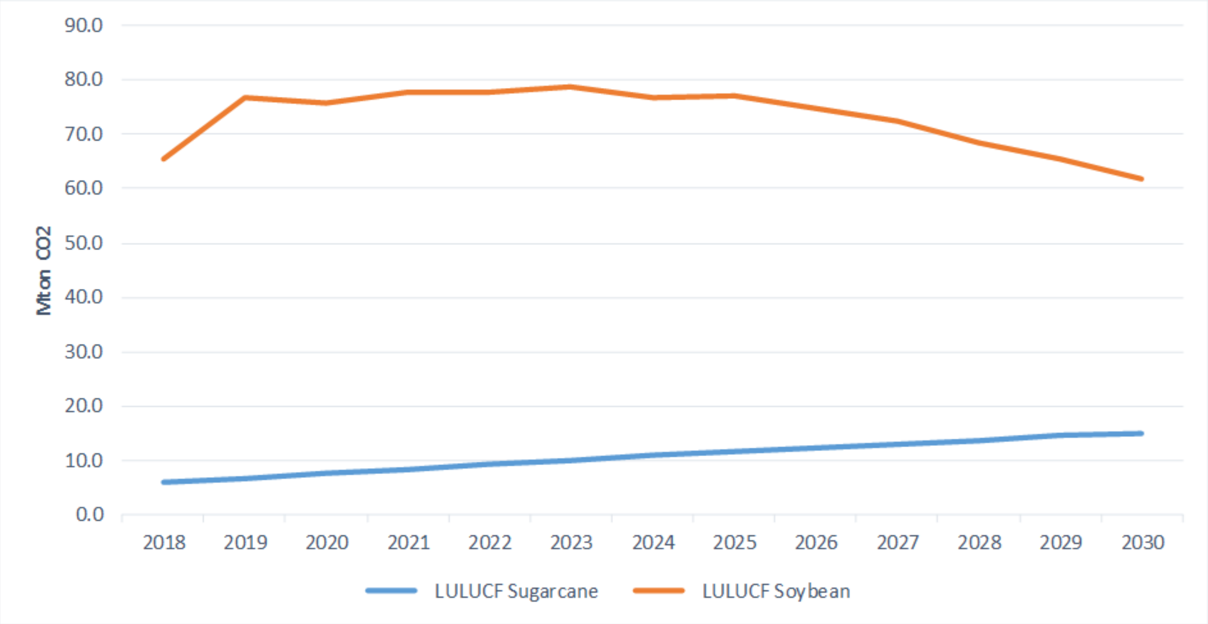



*Figure 34: soybean and sugarcane LULUCF emission trends from 2018 and 2030*

The LULUCF emissions per hectare of soybean expansion can be translated roughly into the equivalent land use change emissions per MJ of soya biodiesel that could be produced from that land. Between 2017 and 2030, this expansion results in 949 million tons of $CO_2$. Conventionally, in Europe, land use change emissions are divided by the production on the land over 20 years; then the emissions attributed to a ton of additional annual soybean production work out to be 1.06 tons of $CO_2$ per ton of soybean per year. Considering the energy content of soybean (ca. 20 MJ/kg at 13% moisture), and the slight energy losses in the processing to biofuel, the emissions per MJ of biodiesel that could be made from the additional soybean correspond to 56g$CO_2$/MJ.

# 7 Conclusion

To achieve its decarbonisation targets and boost the bioeconomy, the EU will inevitably consume more biomass. Part of the demand will be met by EU resources, but this will also require sustained access to third country markets. In order to reconcile its economic growth with the goal of mitigating climate change and promoting globally sustainable development, the EU trade agreements with third countries should be conditional to strict social and environmental criteria. This is of particular importance for Brazil, the largest exporter of agricultural products to the EU. In 2017, the EU-Mercosur trade-talks failed to conclude a political agreement on a few sensitive agricultural products – including ethanol. Guaranteeing the competitiveness of European farmers and concerns about the environmental sustainability of Brazilian ethanol feedstock supply, have long been key-issues during the negotiations. This study provides insights about the potential impacts on land use change and associated greenhouse gas (GHG) emissions from sugarcane cropping, and assesses its compliance with the European environmental criteria for biofuel feedstock production.

Our projections to 2030 show that sugarcane expansion into the Amazon and Cerrado native vegetation could be marginal (less than 2%) if Brazil upholds its ban on growing sugarcane in the Amazon, and hence would entail limited forest biomass loss and associated GHG emissions (Figure 35). The conversion of other croplands – including food crops – to sugarcane would also be negligible (less than 1%), thereby avoiding significant indirect land use changes elsewhere or affecting other crop markets. Although most of the sugarcane expansion occurs at the expenses of pasturelands (97%) - because ranching is in general economically less competitive than sugarcane - it is difficult and very uncertain to forge a direct link between new forest clearance in the northern regions (Amazon and Cerrado) and the displacement of pasturelands from the Southeast and Midwest. Converting pasture to sugarcane and achieving the expected yield demand a substantial application of lime and fertilizers, which represents the largest source of GHG emission from sugarcane cropping (ca. 35%). However, these emissions are far lower than the emissions from deforestation to open new areas for crop expansion, making this transition an opportunity for the Brazilian sugarcane industry to meet the rising demand for ethanol and sugar while achieving country sectoral mitigation targets and the compliance with the EU's environmental criteria. Nevertheless, this solution also requires investments in cattle ranching intensification to yield land for agricultural expansion, especially in regions with easy access to grain production given that improved and supplemental feeding both on pasture and in feedlots is essential to beef intensification.

This study did not assess the potential impacts of varying ethanol import quotas on European producers of biofuels that would come under pressure. We only judged the environmental sustainability of Brazilian sugarcane feedstock production within different scenarios, showing that its potential impacts on GHG emissions through land use changes could be considered limited even under conditions of high EU demand - which represents a small share of Brazilian total supply.

| IMPACT | SUGARCANE: MAIN OUTCOMES, 2017-2030 | COMPLIANCE WITH EU ENVIRONMENTAL CRITERIA |
|---|---|---|
|  | Marginal expansion (<2%) into forest (high carbon stock lands) and savannah native vegetation | ✓ |
|  | Marginal expansion (<1%) into other croplands (including food crops). Negligible displacement of farming activities and associated ILUC | ✓ |
|  | 97% of expansion into pasturelands in the Southeast and Midwest. Uncertain link between sugarcane expansion in the south and pasture displacement into northern regions (and associated forest clearance) | ✓ ⚠ |
|  | Converting pastureland to sugarcane demands the application of lime and fertilizers. It represents the largest source of GHG emission (>35%) from sugarcane production – but far lower than emissions associated with the conversion of native vegetation to croplands | ✓ |
|  | • 24.5 Mtons CO2/year<br>• 2 tons CO2/ha year and 2 gCO2/MJ<br>• Cumulative emissions 2018-2030: ca. 312-323 Mton CO2<br>• GHG emission profile: 1) Agricultural practices 56% (38% from fertilizer and lime application; 18% from straw burning); 2) LULUCF 44% (26% from carbon stock change in soil; 18% from carbon stock change in biomass). Straw burning should be gradually dismissed | ✓ |

*Figure 35: main outcomes about potential impacts of sugarcane expansion from 2017 to 2030. The GHG emission profile includes LULUCF emissions and emissions from agricultural practices. The check mark identifies the compliance with the environmental criteria set by the EU REDII, whilst the caution sign draws attention to warning bells that could require further analysis*

By comparison, soybean – the largest crop in Brazil with expected 48 million hectares in 2030 – will expand considerably into the Amazon (ca. 7% of total expansion i.e. 0.9 Mha) and Cerrado native vegetation (ca. 6%, i.e. 0.7 Mha), resulting in high GHG emissions from loss of biomass and soil carbon (Figure 36). This crop is mainly used for animal feed and only 1% of total production is currently used for biofuel.

The lower land prices in the Matopiba region has the potential to drive large-scale expansion of soybean into northern areas. This soybean growth on pasturelands of Mato Grosso, Tocantins, Maranhão, Rondonia and Pará could lead to further forest clearance through displacement of pasturelands into the nearby Amazon and Cerrado biomes. While a strict enforcement of the Soy Moratorium could halt the expansion of soybean into forested areas of the Amazon biome, the Cerrado's native vegetation remains highly vulnerable to soy conversion due to the absence of effective environmental governance for this biome.

| IMPACT | SOYBEAN: MAIN OUTCOMES, 2017-2030 | COMPLIANCE WITH EU ENVIRONMENTAL CRITERIA |
|---|---|---|
|  | Significant expansion into forest (high carbon stock lands, ca. 7% = 0.88 Mha) and savannah native vegetation (ca. 6% = 0.73 Mha). | ⚠ |
|  | Marginal expansion (<1%) into other croplands (including food crops). Negligible displacement of farming activities and associated ILUC | ✓ |
|  | 87% of expansion into pasturelands mainly in the Midwest and northern regions. Soybean large-scale occupation of northern pasturelands could displace pasture into Amazon and Cerrado biomes (with associated new forest clearance) | ⚠ |
|  | Only LULUCF emissions:<br>• 73 Mton CO2/year<br>• 1.8 ton CO2/ha year and 56 gCO2/MJ<br>• Cumulative emissions 2017-2030: ca. 950 Mton CO2<br>(By comparison, sugarcane LULUCF: ca. 11 Mton CO2/year and 0.85 CO2/ha year; cumulative emissions: ca. 140 Mton CO2)<br>• Soybean LULUCF emissions (ton CO2/ha year) are two times larger than the sugarcane ones (higher conversion of forest and native vegetation to croplands) | ⚠ |

*Figure 36: main outcomes about potential impacts of soybean expansion from 2017 to 2030 and compliance with the environmental criteria set by the EU REDII (Note: only a small share of soybean (1% in 2016) is dedicated to biofuel production – the REDII criteria should be applied only to this volume). The GHG emission profile only includes LULUCF emissions. The check mark identifies the compliance with the environmental criteria set by the EU REDII, whilst the caution sign draws attention to warning bells that may require further analysis*

The overall land use changes – due to the allocation of all projected supplies of the main agricultural commodities, wood, together with deforestation and forest regeneration rates to 2030 - imply increasing LULUCF net cumulative emissions that put the Brazilian contribution to the Paris Agreement at risk. The LULUCF emissions in both scenarios rise rapidly as we move to 2030, which contradicts the decrease foreseen by Brazil's NDC targets (ca. 22 million tons of $CO_2$). This additional emission (ca. 900 million tons of $CO_2$) is mainly due to our assumption that the deforestation rising trends since 2012 continue unabated to 2030, with a growing support for predatory agricultural and land-grabbing practices and the lax enforcement of the Forest Code (Figure 37).

| IMPACT | COUNTRY CUMULATIVE LAND USE CHANGES: MAIN OUTCOMES, 2017-2030 | CONTRIBUTION TO PARIS AGREEMENT |
|---|---|---|
|  | The difference between the country's Nationally Determined Contribution (NDC) targets by 2030 (ca. 22 million CO2 tons) and our results is approximately an additional 900 million CO2 tons. Deforestation is the main source of the additional LULUCF emissions – we assumed that the deforestation rates observed since 2013 continue to 2030 (weakened environmental governance scenario) | ⚠ |

*Figure 37: impacts of cumulative land use changes in Brazil from 2017 to 2030 on LULUCF emissions, which could put the country contribution to the Paris Agreement at risk.*

From 2005 to 2012, Brazil was able to curb deforestation and substantially reduce its GHG emissions with strong improvements in environmental governance. However, with the dismantling of Brazil's environmental protection, there is no safeguard that deforestation will be under control in the near future. Making trade negotiation with Brazil conditional on strict environmental criteria for agricultural commodities could be an effective way to promote sustainable development and avoid further deforestation directly or indirectly linked to farming and ranching activity expansion.

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## List of abbreviations and definitions

| | |
|---|---|
| BAU | Business as usual scenario |
| EEA | European Environmental Agency |
| EPE | Brazilian Ministry of Energy (Energy Research Office) |
| FAO | Food and Agriculture Organization (UN) |
| GHG | Greenhouse gas |
| ILUC | Indirect Land Use Change |
| LUC | Land Use Change |
| LULUCF | Land Use, Land Use Change and Forestry |
| MAPA | Brazilian Ministry of Agriculture |
| MMA | Brazilian Ministry of Environment |
| MCTIC | Brazilian Ministry of Science, Technology, Innovation and Communication |
| NDC | Nationally Determined Contributions |
| POB | Phase out biodiesel scenario |
| REDII | Renewable Energy Directive (EU, 2018) |
| SDGs | Sustainable Development Goals |
| TQR | Tariff Rate Quota |

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# 9 Supplementary Information

## 9.1 Annex 1: MAGNET model

The economic analysis of this research is conducted using the global neoclassical computable general equilibrium (CGE) simulation model MAGNET (Modular Applied GeNeral Equilibrium Modelling Tool) (Woltjer and Kuiper, 2014). As a principal source of data, the MAGNET model is calibrated to the Global Trade Analysis Project (GTAP) database (Aguiar et al., 2016), which has a coverage of 57 commodities and 140 regions. The most recent version (version 9) with a 2011 benchmark year, includes detailed national accounts information from statistical offices, as well as gross bilateral trade flows by commodity, with associated international transport costs and trade protection data.

In the accompanying standard GTAP model (Corong et al., 2017), the behavioural equations characterising economic agents (i.e., producers, households, investors) follow the theoretical tenets of constrained optimization (cost minimization, utility maximization). Producers operate under conditions of perfect competition and constant returns to scale, whilst further market clearing and accounting equations ensure that supply equals demand in all markets and national-income, -expenditure and -output flows are equal within each country's circular flow. A series of price linkage equations with exogenous tax (or tariff) variables capture the market distortions on domestic and imported markets. The propensity to save in each economy is a fixed share of regional income, whilst regional investments are allocated based on a regional rate of return mechanism. A neoclassical ‘closure’ rule is assumed which implies that imbalances on the capital account (i.e., regional savings less investment) are compensated by the current account (exports minus imports), such that the balance of payments nets to zero.

For multiregional impact assessments, the standard GTAP represents a solid point of departure. For the purposes of the current work, it does not, however, include an explicit treatment of bioenergy, whilst explicit modelling of relevant EU biomass policies is lacking. The MAGNET model remedies both of these omissions. MAGNET has been used widely in the area of natural resource, agricultural and environmental economics, in the academic (e.g., Banse et al., 2008; Rutten et al., 2013; Nelson et al., 2014; Schmitz et al., 2014; Boulanger and Philippidis, 2015, Philippidis et al, 2018, 2019) and policy literature (Boulanger and Philippidis, 2014; Philippidis et al., 2016; Boulanger et al., 2016; M'barek et al., 2017).

As an advanced ‘biobased’ derivative of the standard GTAP database, the MAGNET data incorporates further biomass and bio based activity sector splits from the 'parent' sector definitions of the GTAP database. The coverage of bioenergy includes conventional and advanced biofuels and biokerosene. Aside from 'traditional' gas and coal fired stations, electricity generation also includes a biobased technology, as well as renewable (solar, wind, hydroelectric) and nuclear alternatives. To service the bioenergy activities within MAGNET, non-standard additional lignocellulose biomass sources are also included within the data (i.e., crop and forestry residues, energy crops, pellets). The characterisation of the trade-offs and synergies relating to biomass usage is further enhanced through explicit recognition of biodiesel and bioethanol biofuel animal feed by-products (oilcake and DDGS, respectively), as well as further sector splits to characterise specific feed and fertiliser activities.

With a rich treatment of sectoral detail beyond the standard GTAP database coverage, the MAGNET model is able to characterise differentiated technologies for livestock and crop activities. Furthermore, the modelling of agricultural factor markets recognises immobilities in land transfer between alternative agricultural and non-feed/food activities, labour wage and capital rent differentials between agricultural and non-agricultural sectors, and changes in agricultural land supply to reflect abandonment or uptake. In addition, explicit biofuel, EU domestic policy, and greenhouse gas emission modules are 'activated' to enrich the design of the baseline scenario (see next section).

Further details of the biobased variant of MAGNET can be found online in Philippidis et al., 2018.

For this study, the chosen data disaggregation (Table 26) encompasses lignocellulose biomass sources (i.e., residues, energy crops, pellets), agriculture, food, animal feed, conventional biofuel technologies, advanced biofuels (including biokerosene) and biochemical biomass conversion technologies, and bioelectricity. Non bio-based energy markets are represented by crude and processed fossil fuels and several electricity technologies (fossil, nuclear and non-biological renewables). The regional disaggregation includes an EU28 aggregate region, whilst non-EU regions cover 'large' third-country distributors of raw and processed biomass products on world markets and a European residual region of EU neighbours.

*Table 26: Study disaggregation of commodities and regions.*

| **Commodity Disaggregation (66 Commodities):** |
|---|
| **Arable and horticulture (9):** paddy rice, wheat; other grains; oilseeds; raw sugar; vegetables, fruits and nuts; other crops; plant fibers; crude vegetable oil |
| **Livestock and meat (7):** cattle and sheep; wool; pigs and poultry; raw milk; cattle meat; other meat; dairy |
| **Fertilizer (1):** fertilizer |
| **Other food and beverages (4):** sugar processing; rice processing; vegetable oils and fats; other food and beverages |
| **Other 'traditional' bio-based (5):** fishing; forestry; textiles, wearing apparel and leather products; wood products; paper products and publishing |
| **Bio-mass supply (10):** energy crops; residue processing; pellets; by-product residues from rice; by-product residues from wheat; by-product residues from other grains; by-product residues from oilseeds; by-product residues from horticulture; by-product residues from other crops; by-product residues from forestry |
| **Bio-based liquid energy (5):** 1st generation biodiesel; 1st generation bioethanol; 2nd generation thermal technology biofuel; 2nd generation biochemical technology biofuel; bio-kerosene |
| **Bio-based industry (4):** lignocelluose sugar; biochemical (fermentation) conversion of sugar biomass to polylactic acid chemicals; biochemical (fermentation) conversion of bioethanol to polyethylene chemicals; thermochemical conversion of biomass to chemicals |
| **Bio-based and non-bio-based animal feeds (3):** 1st generation bioethanol by-product distillers dried grains and solubles (ddgs); crude vegetable oil by-product oilcake; animal feed. |
| **Renewable electricity generation (3):** bioelectricity; hydroelectric; solar and wind |
| **Fossil fuels and other energy markets (10):** crude oil; petroleum; gas; gas distribution; coal; coal-fired electricity; gas-fired electricity; nuclear electricity; electricity distribution; kerosene |
| **Other sectors (5):** chemicals, rubbers and plastics; other manufacturing; aviation; other transport; other services |
| **Regional Disaggregation (8 Regions):** |
| EU28; Rest of Europe; North America; Brazil, Rest of Central and South America; African continent; China, Rest of Asia and Oceania. |

## 9.2 Annex 2: OTIMIZAGRO

We used the spatially explicit land use model Otimizagro[48] to assess the impacts of future demands for crops on direct and indirect land use changes (LUC and ILUC) and LULUCF $CO_2$ emissions. The model has a national coverage and simulates land use change, forestry, deforestation, regrowth and associated carbon emissions under various scenarios of agricultural land demand and environmental policies (Rochedo et al., 2018). The model framework is structured into four spatial levels: i) Brazilian biomes; ii) micro-regions, as defined by the Instituto Brasileiro de Geografia e Estatistica (IBGE); iii) Brazilian municipalities, and iv) a raster grid with a 25 ha pixel resolution. Otimizagro models nine annual crops (soybean, sugarcane, corn, cotton, wheat, beans, rice, manioc and tobacco), including multiple cropping, four permanent crops (coffee, oranges, bananas and cocoa) and plantation forests. The demands for crops, wood and meat, and the deforestation/forest regrowth rates are exogenous to the model. The crop-expansion module calculates the productive area (ha or $Km^2$) to satisfy the demand for a commodity (tons or litres); concurrent allocation of crops at pixel level is a function of a suitability map, defined on the basis of crop climate suitability and profitability (calculated using regional selling prices, production and transportation costs) When available land in a given region is insufficient to meet the specific land allocation, Otimizagro reallocates the distribution of remaining land demands to neighbouring regions, creating a spill over effect.

The allocation of productive areas in 2012 (simulation starting point) was based on official datasets on cropped areas at municipality level (IBGE, 2012)[49]and forest plantations at State level (ABRAF, 2012)[50]. To improve the delimitation of soybean, sugarcane and corn croplands, the agriculture maps of Canasat (2016)[51] have been used. Further details of the Otimizagro framework and modules can be found in Soares-Filho et al., (2016), Rochedo et al. (2018) and online[52].

## 9.3 Annex 3: Integrated modelling framework

The modelling framework (Figure 38) includes 3 different components that aim at:

1) Projecting the EU demand for commodities under socioeconomic and policy scenarios to 2030 (through the MAGNET model), and the total country supply. This step prepares all the inputs for OTIMIZAGRO, including the projections of the other 13 cropping activities (e.g, soybean and corn), plantations, forest regrowth and deforestation to 2030.
2) Allocating the cropland areas to satisfy the projected demands from 2018 to 2030, and calculating land use changes (through the OTIMIZAGRO model). The selected spatial resolution is 25 hectares and the temporal resolution is 1 year.
3) Estimating the GHG emissions due to LULUCF and farming practices (through the OTIMIZAGRO model).

[48] https://csr.ufmg.br/dinamica/otimizagro/
[49] Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: http://www.sidra.ibge.gov.br
[50] Associação brasileira de produtores de florestas plantadas.
Available at: http://www.ipef.br/estatisticas/relatorios/anuario-ABRAF12-BR.pdf
[51] Monitoramento da cana de açúcar por imagens de satélite (Program for monitoring sugar cane areas through remote sensing images). Available at: www.dsr.inpe.br/laf/canasat.
[52] https://csr.ufmg.br/otimizagro/

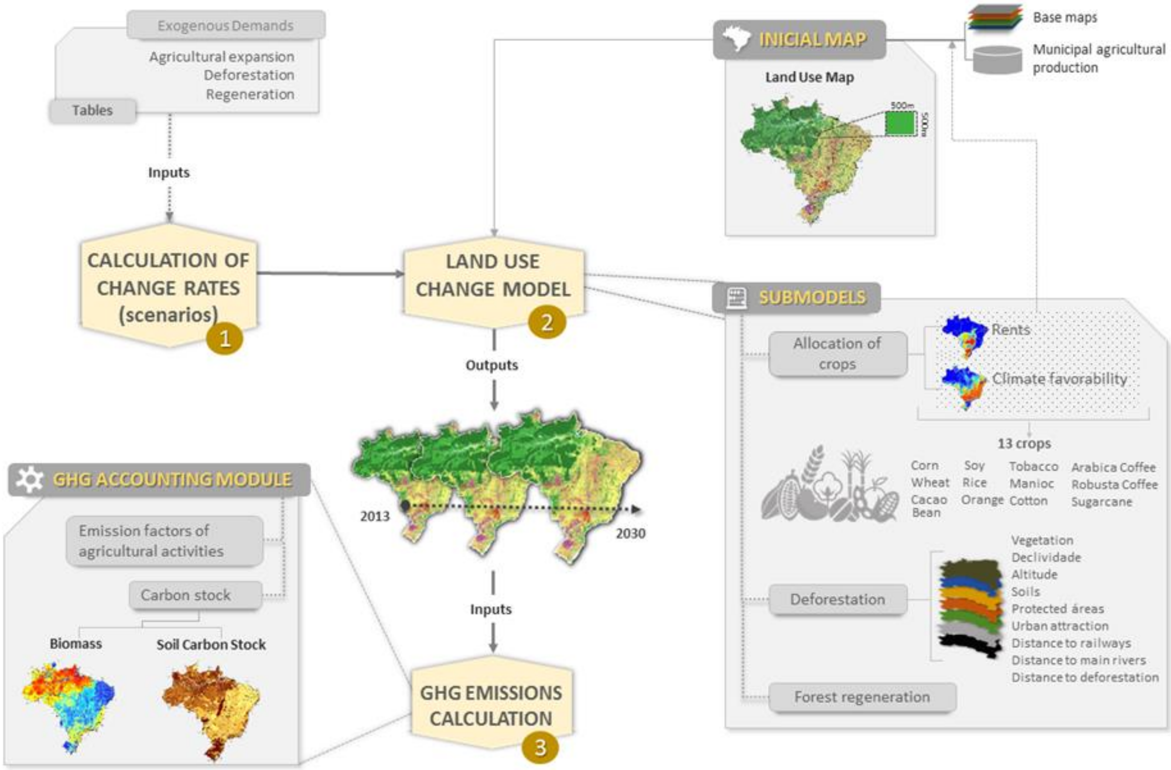


*Figure 38: modelling framework developed for the Brazil case-study. Steps: 1) Projection of EU demand for ethanol to 2030 (with MAGNET model); projections of the other crops' growth to 2030 (MAPA, 2017). 2) Allocation of all productive croplands (with OTIMIZAGRO model) and calculation of land use changes. 3) Estimation of GHG emission from LULUCF and farming (with OTIMIZAGRO model).*

## 9.4 Annex 4: land use transition matrix from POB scenario

Figure 39 shows the land use transition matrix from 2017 to 2030 in the POB scenario.

| | | 2017 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Categories of land use** | **Pasture** | **Savannah** | **Forest** | **Regeneration** | **Agricultural area** | **Planted forest** | **Landuse 2030** |
| 2030 | **Pasture** | 209,113,950 | 20,302,250 | 22,083,050 | 0 | 2,410,000 | 0 | **253,909,250** |
| | **Savannah** | 0 | 96,710,625 | 0 | 0 | 0 | 0 | **96,710,625** |
| | **Forest** | 0 | 0 | 378,365,250 | 0 | 0 | 0 | **378,365,250** |
| | **Regeneration** | 4,194,275 | 223,300 | 526,700 | 1,915,025 | 16,300 | 0 | **6,875,600** |
| | **Agricultural area** | 16,541,283 | 826,467 | 952,046 | 0 | 56,759,579 | 0 | **75,079,375** |
| | **Planted forest** | 1,162,650 | 12,125 | 14,875 | 0 | 38,250 | 7,839,950 | **9,067,850** |
| | **Landuse 2017** | **231,012,158** | **118,074,767** | **401,941,921** | **1,915,025** | **59,224,129** | **7,839,950** | |

*Figure 39: Transition matrix representing the cumulative land use changes (hectares) from 2017 to 2030 in the POB scenario.*

## 9.5 Annex 5: Main factors shaping sugarcane expansion

Land use maps show little difference between BAU and POB scenarios, due to the limited increase of sugarcane croplands (by 1% from BAU to POB). In both cases, the largest expansion of sugarcane is expected in the regions of the Southeast and Mid-West - notably in the state of Sao Paulo, Minas Gerais and Mato Grosso do Sul. Therefore, it seems reasonable to suppose that the main drivers shaping sugarcane distribution are the same.

### *Distribution of logistic infrastructure and ethanol plants*

The concentration of sugar and ethanol mills in the southeast regions, especially in Sao Paulo State, together with the well-developed multimodal system for transportation of ethanol (Logum system[53]), makes this region more attractive for the sugar sector due to reduced transportation and production costs (Figure 40). This trend is expected to continue in the near future since most of the projects for new ethanol plants appear close to existing road infrastructure in the southern regions. The development of the railway *Norte-Sul* and *Centro Atlântica* should improve the transport links with the northern regions of the country making their ethanol production more competitive in the future (EPE, 2018).

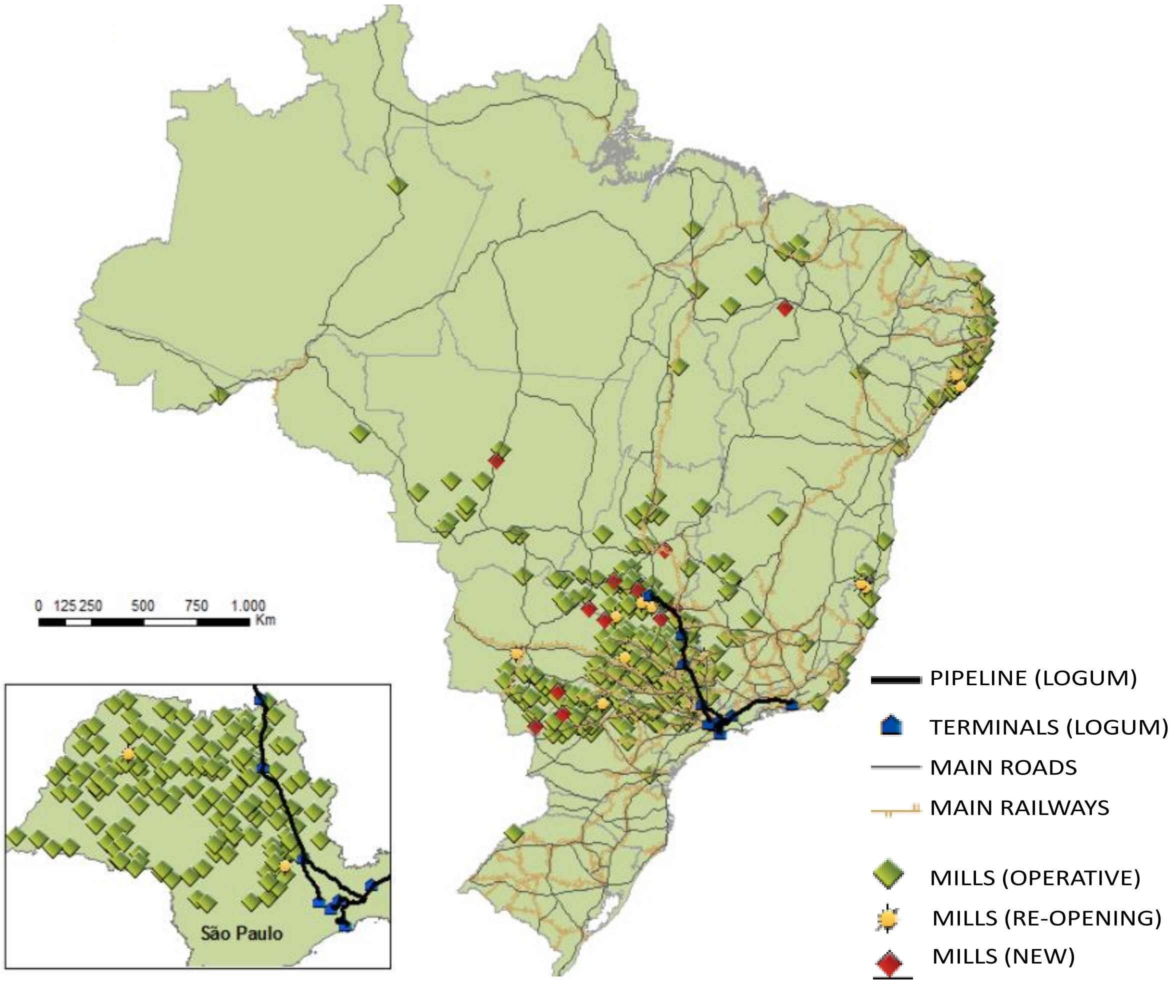


*Figure 40: distribution of ethanol plants and main logistic infrastructure used for ethanol transportation in Brazil. Source: EPE, 2018.*

### *Legislation and Agro-Ecological Zoning*

The limits of the available areas for the expansion of sugarcane in Brazil have been set by the Agro-Ecological Zoning (AEZ) in 2009 (Figure 41). That means ca. 64 million hectares of suitable land out of which only 10 million hectares have been already used for sugarcane in 2017. Almost all the viable land is located in the southern and mid-west regions, and, to a lesser extent, along the northeast coastline. Since then, there were several unsuccessful attempts to extend its limits into the Legal Amazon (Senate bill

[53] www.logum.com.br/

PLS626/2011[54] ) - the last one at the end of 2018. It is important to stress than even the Brazilian Sugarcane Industry Association (UNICA) reinforces its commitment to adhere to the AEZ in order to comply with national and international environmental standards. Indeed, the new National Policy on Biofuels (Renovabio) limits the lands for sugarcane expansion within the demarked AEZ and avoids the production of biofuel feedstock on lands converted from forest areas after December 2017.

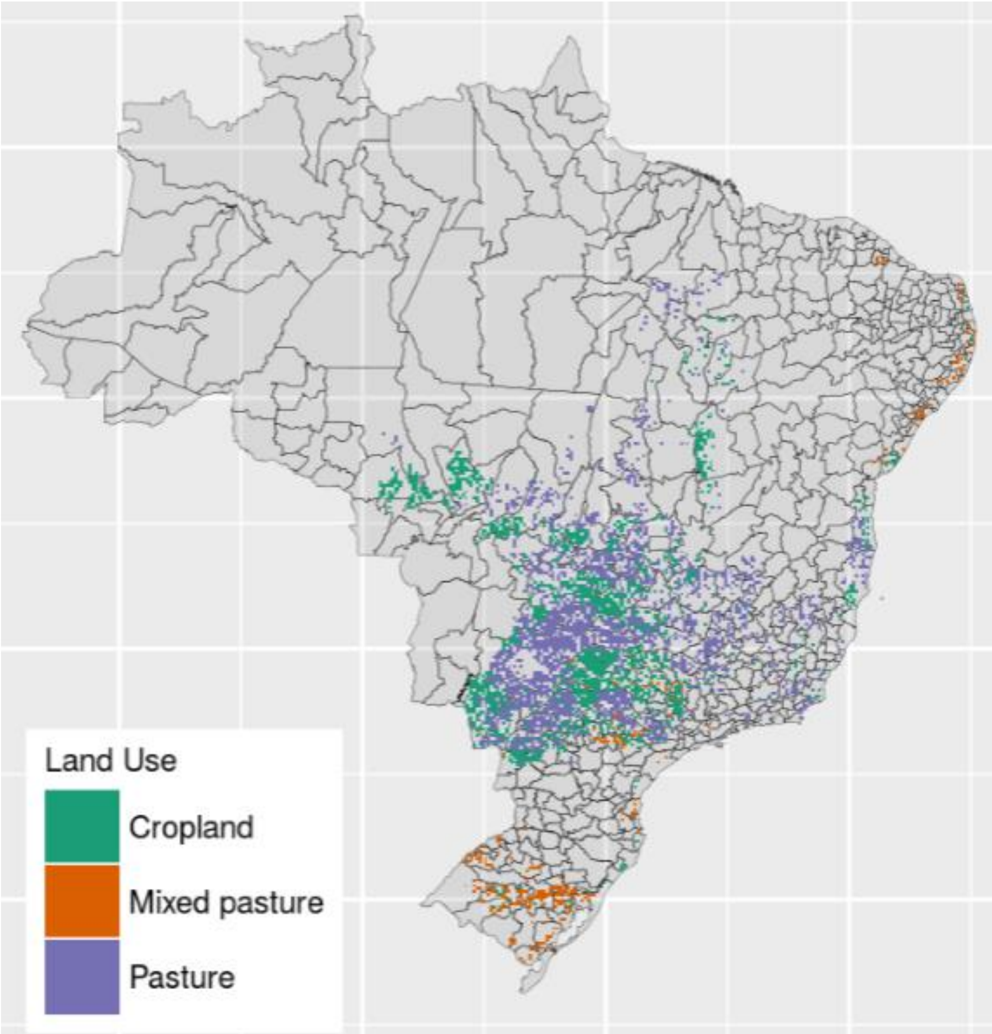


*Figure 41: distribution and land use categories of the areas identified by the AgroEcological Zoning for the expansion of sugarcane in Brazil. Source: Jaiswal et al., 2017.*

Even though the sugarcane production in the Northeast has dropped off in the past, more recently it has risen again and it could benefit from new governmental programs aimed at boosting the sugar sector in this region (e.g., *Programa Renovar*[55]). Moreover, the Brazilian legislation (law 9363/96, Art.70[56]) states that the volume of ethanol for export to preferential markets must be produced in the Northeast – one of the poorest areas of the country – as a means to promote the social and economic growth of rural areas. This law is in line with the EU commitment of promoting sustainable development through its trade policy (EP, 2016).

[54] https://www25.senado.leg.br/web/atividade/materias/-/materia/102721
[55] https://asplanpb.com.br/2018/03/14/programa-renovar-promete-revitalizar-cultura-da-cana-de-acucar-no-nordeste-e-recuperar-empregos-perdidos/
[56]https://presrepublica.jusbrasil.com.br/legislacao/107933/lei-9362-96

### ***Land tenure***

In the Southern and Northeastern municipalities, there is a high share of private pastureland under no legal obligations (Figure 42), as defined by the Brazilian Forest Code – the principal law regulating forest conservation in private properties. This privately held land can be converted into agriculture and cattle production. However, in most cases, the progressive degradation of pasturelands has decreased traditional extensive ranching, leaving the door open for more lucrative sugarcane expansion.

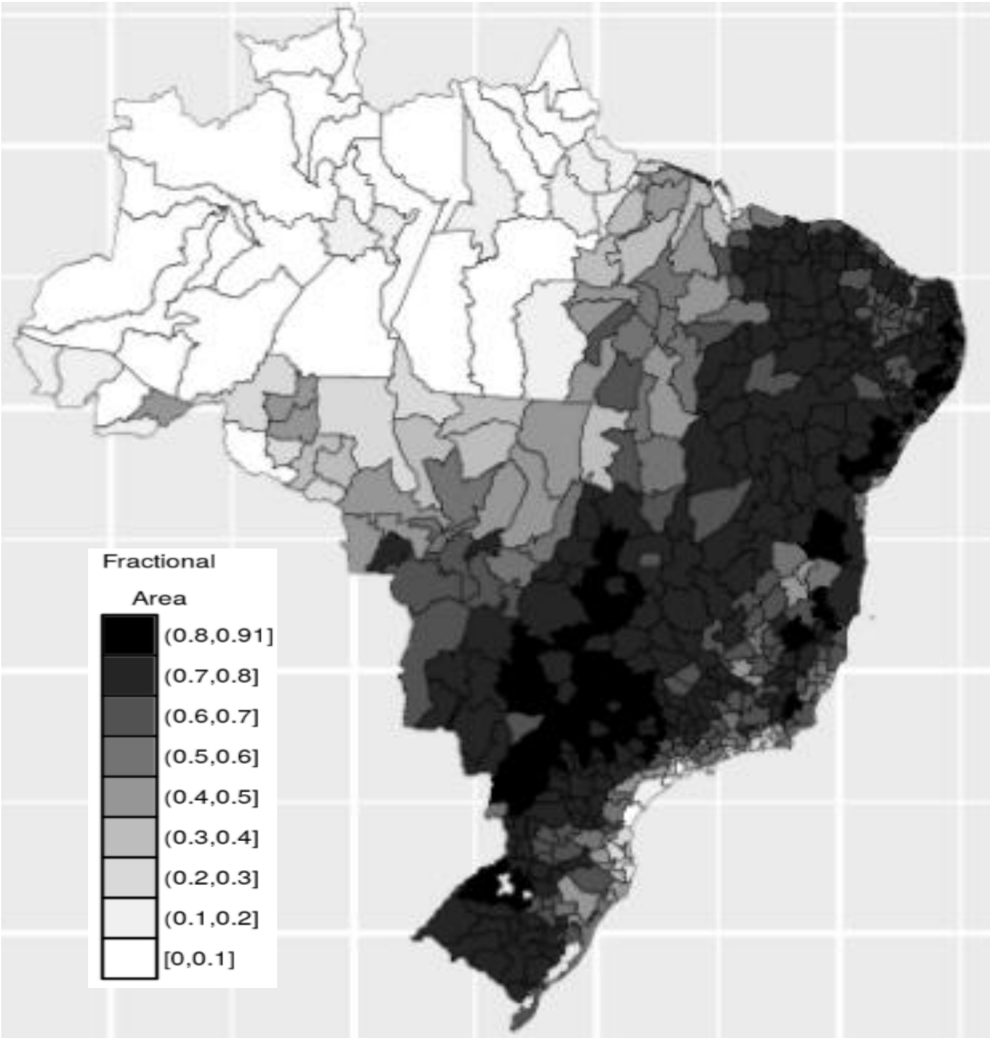


*Figure 42: total private land under no legal obligations (share of municipality area). Source: Jaiswal et al., 2017.*

### ***Climate favourability***

Maps delimiting the climate suitability for each crop have been calculated taking into consideration the relationship between observed occurrences of the crop and the spatial variability of climate attributes – i.e, average annual temperature and rainfall – and the soil moisture deficit and surplus, as detailed by (MCTIC and ONU, 2017). Figure 43 shows the probability of successful sugarcane growth under current and near future climates. It fits reasonably well with the results of Assad et al., (2013) that projected the impacts of climate change to 2030 on the viable agricultural area for the main crops, including sugarcane. Our study only considered rainfed crops, without including the possibility of extending the suitable agricultural areas through irrigation (as an adaptation measure to counteract negative impacts of longer droughts).

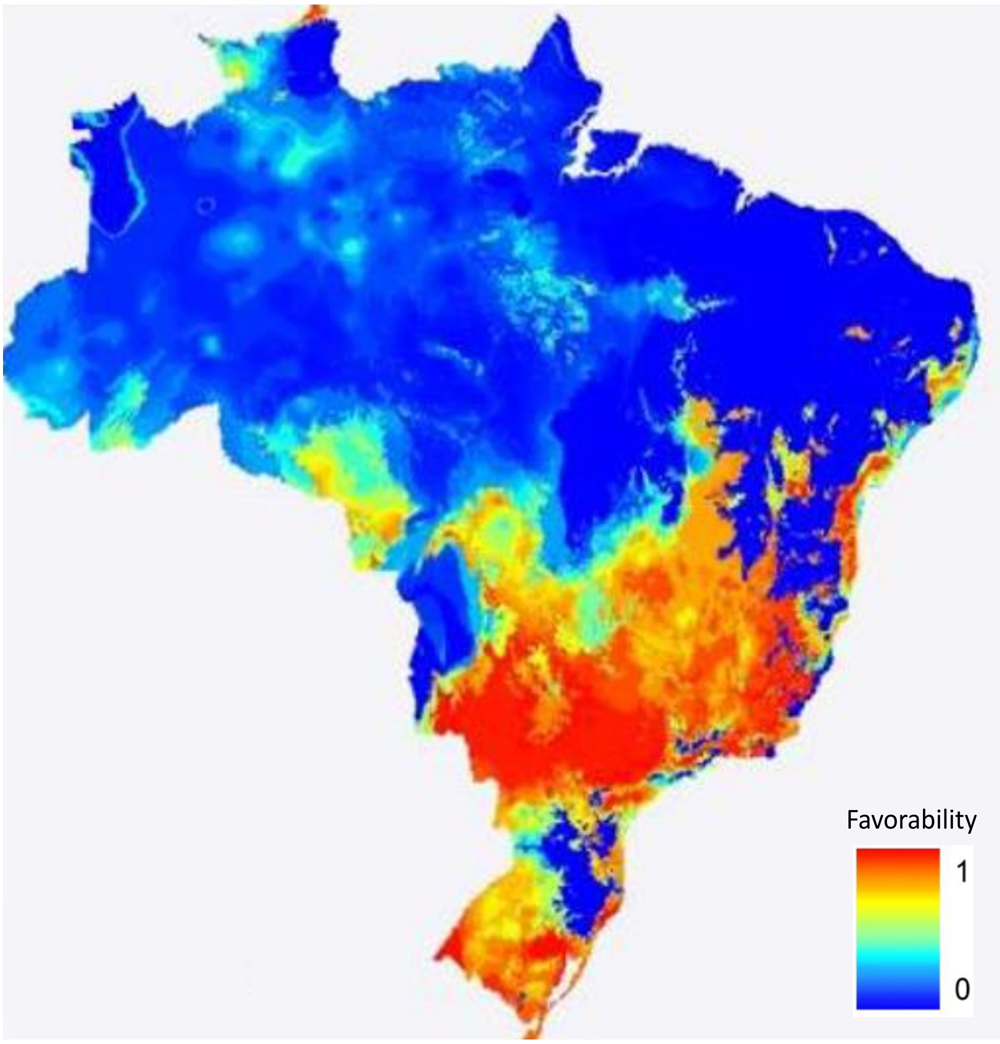


*Figure 43: climate favorability map for sugarcane. Source: MCTIC and ONU, 2017.*

Jaiswal et al., (2017) assesses the impacts of mid-term climate change projections to 2045 on Brazilian ethanol production, showing that significant losses are expected in the north, whilst the southern regions record smaller losses and even limited increases.

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