Planet Tracker

NO RAIN ON THE PLAIN

DEFORESTATION THREATENS BRAZIL'S AGRICULTURAL EXPORTS

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Thematic coverage:
deforestation, soy and maize, double-cropping, climate change
Sector coverage:
Sovereign bonds, Consumer staples, Financials

CONTENTS

KEY TAKEWAYS

- Brazil is deforesting its natural resources - depleting the natural capital on which its agribusiness success depends
- Deforestation is changing Brazil's climate, making it dryer, hotter, and less predictable
- Brazil's success as an exporter of soy (#2 behind the USA) and maize (#3 behind USA and Argentina) depends upon its ability to double-crop - using the same farmland twice in one year
- Double-cropping depends upon a stable climate (consistent rainfall and temperature patterns) and deforestation is destablising it
- The growth of Brazil's soy industry has driven deforestation - and that deforestation will undermine the soy industry
- Sovereign bond investors are at risk as a result but can engage with the Brazilian government to mitigate this risk
- Equity and debt investors in companies across the soy supply chain should take action to stop deforestation as a way to preserve future earnings
- Deforestation-driven destabilization of Brazil's climate threatens its wider economy, creating risks for equity and debt investors far beyond the agribusiness sector

EXECUTIVE SUMMARY

Deforestation is driving a negative feedback loop by changing rainfall patterns which are impacting cropping patterns and yields. If farmers respond by deforesting more land, rainfall patterns will change further, reducing crop yields with a negative impact on farm incomes, state taxes and Brazil's export revenues. **Sovereign bond investors are at risk, as are equity and debt investors supporting companies across Brazil's economy –** see Figure 1.

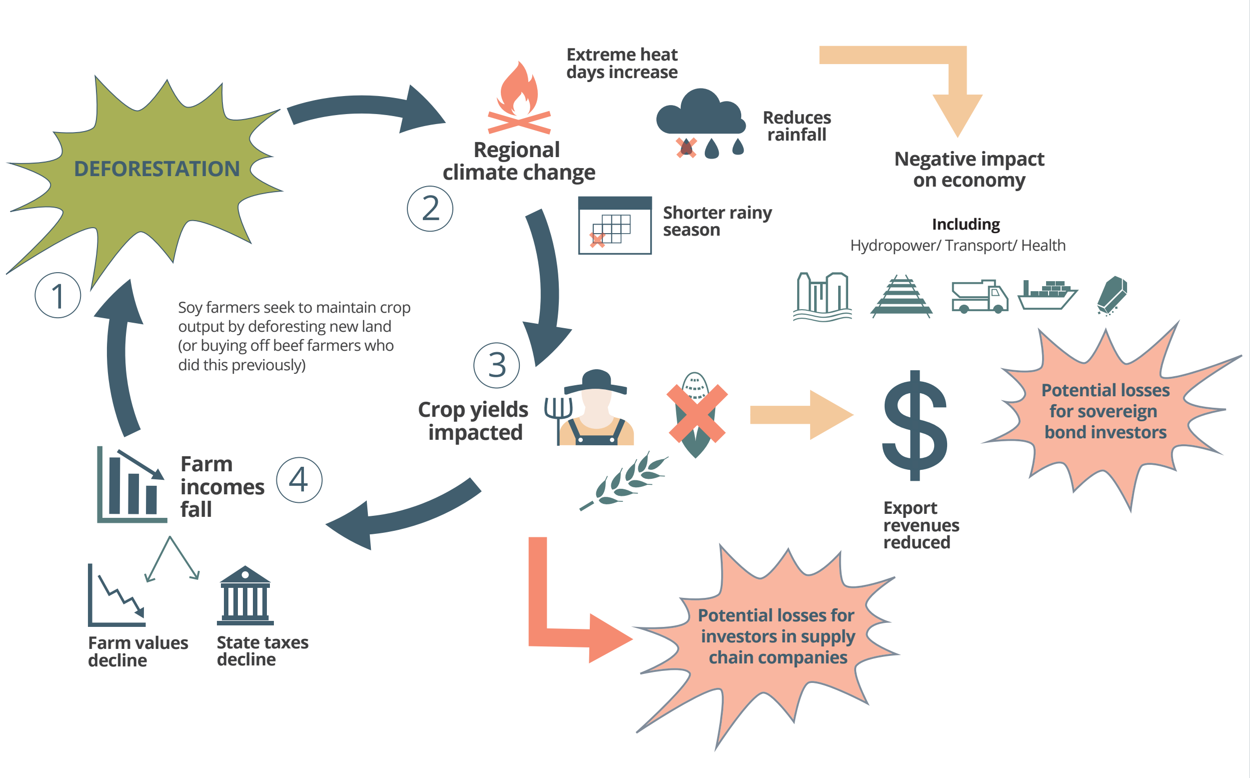

Figure 1: The Deforestation-Rainfall Feedback Loop (Source: Planet Tracker)

The growth of **double-cropping[1] has been an important driver behind Brazil's growth as an agricultural exporter.** Soy and maize have both benefitted from this trend and made up nearly one fifth of total exports in 2018, equivalent to 2.6% of GDP. **Brazil is leveraging its natural capital assets with this technique – using the same soil reserve to produce two crops.** Without double-cropping Brazil would not be able to maintain its position as a leading soy and maize exporter.

Our recent report, 'Brazil – roadmap to sustainable sovereign bonds' set out the ways in which Brazil is depleting its natural capital reserves, particularly through deforestation. This report builds on that framework to analyse the ways that deforestation of the Amazon is affecting rainfall patterns in Brazil, both in terms of quantity of precipitation and duration of the rainy season.

The impact of reduced rainfall quantity on crop yields is obvious. In addition, if the duration of the rainy season is reduced, then the time for a second crop to mature is reduced, with a (further) negative impact on crop yields.

1 'Double-cropping' involves planting a second (usually different) crop on the same land immediately after harvesting the first crop.

If deforestation continues, Brazil's ability to double-crop could be impaired.[2] This will harm farmers' incomes and Brazil's export revenues, particularly from key agricultural states – see Figure 2.

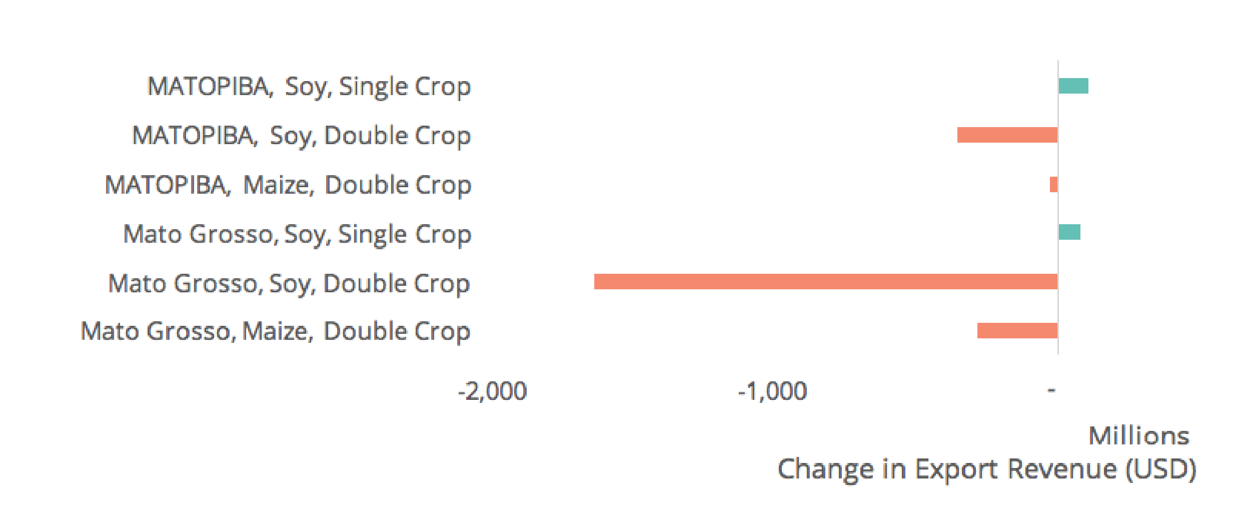

***Figure 2:** Change in Export Revenue for Mato Grosso and MATOPIBA under Climate Change and Reduced Rainfall (Source: Pires et al. (2016)[xxiv], Brumatti et al. (2020)[xxv], Planet Tracker Analysis)*

Losing the maize crop from a soy-maize double cropping system could cost an average sized farm in Mato Grosso one-third of annual farm income.

Brazil's export revenues from Mato Grosso and MATOPIBA[3] could fall by USD 2.1 billion by 2050 (equivalent to 6% of Brazil's total export revenues for soy and maize in 2018).[4]

Soy and maize from Mato Grosso and MATOPIBA form an increasing proportion of Brazil's cash exports and Brazil's dependence on this source of revenue already exceeds the levels it forecast for the FABLE report.[5] This increases Brazil's exposure to deforestation-driven changing rainfall patterns even more.

Deforestation is not just driving global climate change (with all the potential consequences re-emphasised by the recent IPCC report),[i] it is changing Brazil's own climate as well:

- Reducing rainfall and concentrating that rainfall into a shorter rainy season
- Increasing the likelihood of extreme temperature days (impacting human health, crop viability, and worker productivity across all industries, not just agriculture)
- Putting the supply of Brazil's rivers at risk, with negative consequences for water supply, hydroelectric power generation and river transport of commodity exports.

This creates economic risks for Brazil which are compounded by its increasing reliance on soy and maize exports. This threatens returns for sovereign bond investors.

Similarly, **equity and debt investors supporting any Brazilian companies will face increasing risks due to the local climate change effects** outlined above, and **those investing in agribusinesses involved in the soy and/or maize trade are particularly at risk.**

2 Single-cropping is less likely to be affected because the growing season is not constrained by the need to plant a second crop and can shift with the changing rainfall pattern (up to a point).
3 MATOPIBA is the collective term for four Brazilian states: Maranhão, Tocantins, Piauí and Bahia
4 In 2018 Brazil's exports of soybeans and maize amounted to USD 37.30 billion (Source: COMTRADE)
5 Produced by the Food and Land Use Coalition – the report sets out how sustainable food and land-use can contribute to Brazil's sustainable development (discussed in more detail later in this report)

INVESTOR CALL TO ACTION

Sovereign bond investors

Sovereign bond investors should put increased pressure on Brazil to stop deforestation. Joining collective investor initiatives such as the PRI[6] and IPDD[7] is likely to increase the impact of any engagement efforts.

In our recent report 'Brazil – roadmap to sustainable sovereign bonds' we set out specific actions that sovereign bond investors should urge the Brazilian government to take to stop illegal deforestation:

1. **Reverse cuts to the Ministry of Environment** (and related enforcement agencies), and pressuring for more government investment in people and technology to prevent illegal deforestation;
2. **Strengthen current domestic policies, laws and multistakeholder initiatives** focused on preventing illegal deforestation;
3. **Ratify the Escazu Agreement** which Brazil signed in September 2018 (strengthening environmental democracy and protection for Indigenous peoples and those protecting the environment) but has yet to adopt;
4. **Consider issuing a Deforestation - Linked Sovereign Bond** tying coupon payments to success in limiting deforestation.

Sovereign bond investors should support the efforts of the Retail Soy Group in urging the Brazilian National Congress to reconsider the proposal to ratify illegal land occupation in the Amazon which risks accelerating deforestation in the area.[ii]

Equity and debt investors in Brazilian companies and financial institutions

Investors holding equities and corporate debt issued by Brazilian agribusiness companies, and by the regional Brazilian banks supporting them, should press them to adopt sustainable practices that target a deforestation-free approach.

Investors in the companies trading in Brazilian crops (particularly soy and maize), or in the food manufacturers, food retailers, and restaurant chains using products derived from those crops, should ensure the companies they support have published deforestation policies that are enforced.

Investors should continue to support the Amazon Soy Moratorium[iii] and should apply pressure on the companies in their portfolios and watchlists to **establish similar agreements covering other threatened biomes such as the Brazilian Cerrado.**[iv]

INTRODUCTION

The interaction between deforestation and climate change is well understood[8], but the effect on local and regional climate in terms of temperature, wind and rainfall patterns is more complex to investigate and challenging to model.

A number of academic teams have been tackling this challenge with respect to deforestation of the Amazon and other significant forests such as the Cerrado in Brazil. They have identified local climate change effects that constitute a clear risk for the countries allowing the deforestation (such as Brazil) and potentially their close neighbours.

The research findings to date can be summarised as follows:

- Forests are a key component in the water, carbon and energy cycles, and so play a **key role in regulating local and regional climate.**
- **They control local and regional temperatures – so deforestation leads to more frequent extreme temperature days, impacting crop viability, worker productivity and human health.**
- They play an essential role in **controlling local and regional rainfall patterns** through evapotranspiration.[9] Deforestation disrupts this process, leading to changing rainfall patterns and (potentially) less water in the atmosphere in that region (less rainfall there and/or in neighbouring localities).
- Because the Amazon and Cerrado forests are so vast they have a very significant impact on regional weather patterns and are **essential sources of water for rivers across South America**, particularly La Plata River basin.[10] Deforestation puts the supply of these rivers at risk, which would have **negative consequences for water supply, hydroelectric power generation and river transport of commodity exports.**[v]

8 Forests are important carbon stores and also essential tools for sequestering carbon from the atmosphere; deforestation releases stored carbon and impairs (and eventually stops) carbon sequestration

9 Evapotranspiration – the process by which water moves from the earth to the air through evaporation and transpiration (water going from plants into the

10 Brazilian climate scientist, professor Antonio Nobre estimates that the Amazon rainforest pumps 20 billion tonnes of water into the air every day, compared to the 17 billion tonnes transported to the sea on a daily basis by the Amazon river (he describes it as a 'flying river' in an excellent TED talk https://www.ted.com/talks/antonio_donato_nobre_the_magic_of_the_amazon_a_river_that_flows_invisibly_all_around_us?language=en#t-1042739)

In this paper we examine one of these effects: the impact of deforestation on rainfall patterns and the effect this could have on Brazil's enormous agribusiness sector (and the jobs and economic wealth dependent on its success).

Double-cropping

The academic studies we have referred to in the report focus on 'double-cropping' (the process of growing a 2nd crop on land after a 1st crop has been harvested) in two regions within Brazil which are particularly significant to the agribusiness sector: the state of Mato Grosso and neighbouring states of Maranhão, Tocantins, Piauí and Bahia (collectively referred to as MATOPIBA).

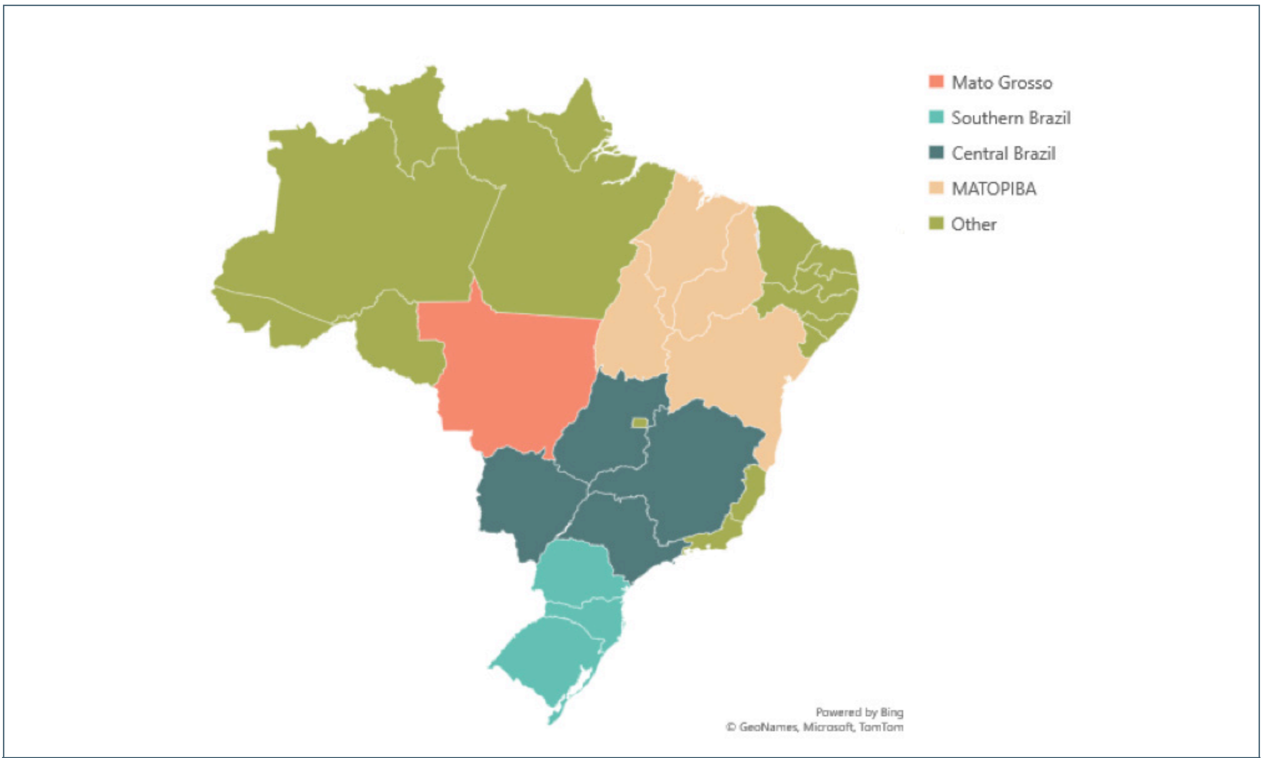

Figure 3: *Map of Brazilian states covered in this report (Source: Planet Tracker)*

Because double-cropping involves growing a second crop on the same piece of land after a first crop has been harvested it allows a farmer to use their land much more efficiently (increasing revenues and potentially profits) but any delay in harvesting the first crop could reduce the yield from the second crop (or even prevent it being successfully sown at all) so the increased returns for the farmer are accompanied by increased risk.

Evapotranspiration – crucial for Brazil's sovereign health

Evapotranspiration is the collective label applied to the process by which water moves from the soil into the atmosphere, either by direct evaporation, or by transpiration when plants draw water up through their roots and pass it out into the atmosphere through their leaves – see Figure 4

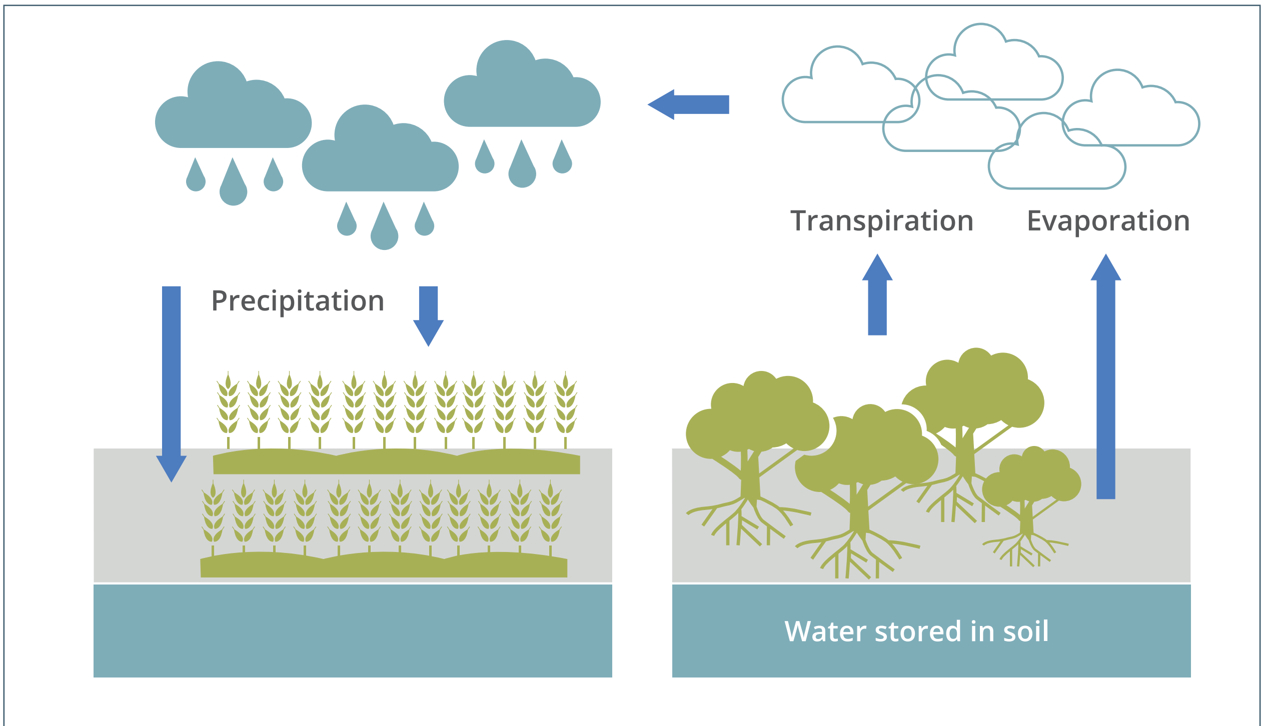

Figure 4: *Evapotranspiration (Source: Planet Tracker)*

Forests such as the Amazon and the Cerrado are vital sources of transpiration. Deforestation disrupts this process.

Refer to the Appendix for further maps showing annual rainfall and average temperatures across Brazil.

Tipping points

The papers we examine in this report do not consider tipping points i.e. the potential for deforestation of the Amazon to reach a point where the various systems within the forest change dramatically and in ways that are hard to predict (and thus hard to model).

Thomas Lovejoy and Carlos Nobre wrote an editorial in Nature in 2018 arguing that if just 20-25% of the Amazon was cut down it could cause systemic changes within the forest's ecosystem so that it would cease to be a rainforest and become a savannah-like ecosystem.[vi] In such a scenario the impact on rainfall in the region would be dramatic because the 'flying rivers' described by Antonio Donato Nobre would be severely disrupted (and potentially cease to function).

Such a scenario would be potentially devastating for Brazil's agribusiness sector and very harmful for Brazil's economy more widely.

SOY-MAIZE DOUBLE-CROPPING

Delays in soy planting can postpone the sowing of second crop maize so that it has less time to grow in the rainy season, which has already been shortening in some areas

Deforestation is shortening the period in which crops can grow

Deforestation of the Legal Brazilian Amazon (LBA) is now at its highest rate since 2008 - see Figure 5.

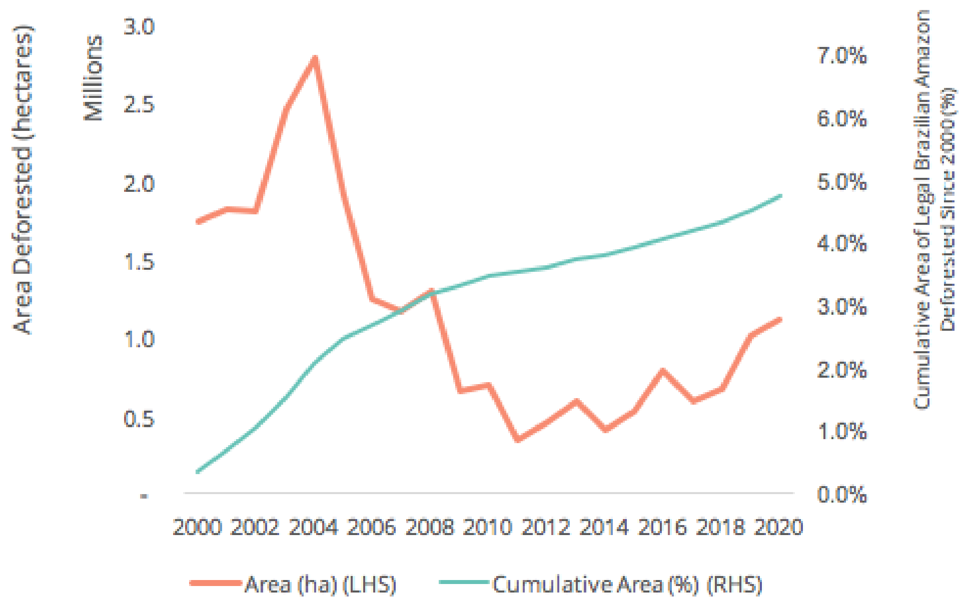

***Figure 5:** Deforestation of the Legal Brazilian Amazon between 2000-2020 (Source: Terra Brasilia)*[vii]

Deforestation of the Amazon reduces evapotranspiration which can reduce rainfall. In turn, changes in rainfall can impact cropping patterns and thus the overall production achieved by farmers.

As well as reducing the quantity of rainfall, continued deforestation risks further shortening the rainy season, threatening crop yields and putting pressure on the double-cropping system that has significantly enhanced Brazil's agricultural productivity in recent years.

Recent evidence suggests that the rainy season is shifting in deforested areas of the Amazon. In the state of Rondonia, the onset of the rainy season has shifted, on average, 11 days later over the last three decades. However, where heavy deforestation has not occurred, the onset has not shifted significantly.[viii]

Further evidence of the impact of changing rainfall on double-cropped soy and maize production comes from studies of La Niña[11]. In 2008, there was a dry start to the soy growing season, similar to the one occurring in 2020/21, which delayed the planting of the soy crop. Because maize from double-cropped systems was not the main source of maize at that time, this did not impact the output for the year and both crops saw an increase in yield (6% for soybeans and 10% for maize).

However, in 2018 the La Niña outcome for the maize crop was very different due to the proliferation of double-cropping since 2008. This time the delay in planting soy had a knock-on effect on when it was harvested, and this in turn delayed the planting of maize. The result was that although soy yields were unaffected (and in fact rose 6% as they did in 2008 when the weather conditions were similar), maize yields were impacted by the late planting and fell 10% - see Figure 6.

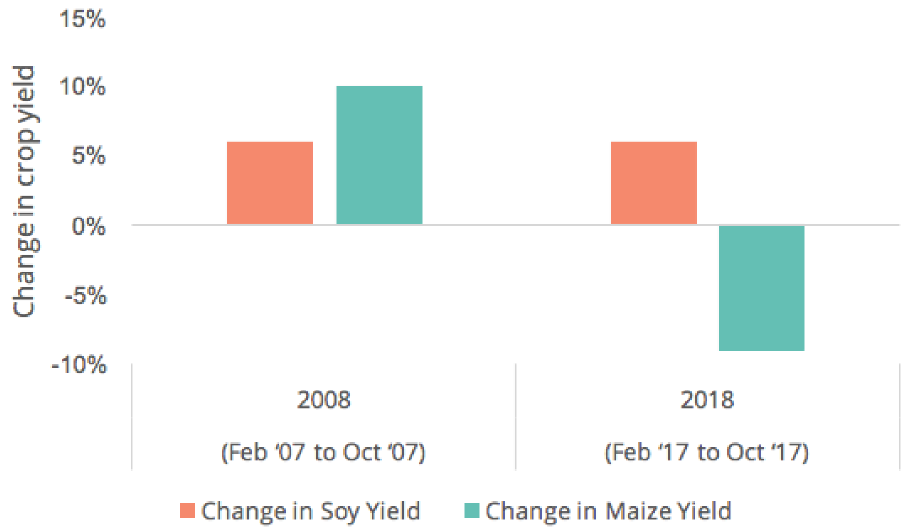

Figure 6: *La Niña Impact on Crop Yields (2008 and 2018) (Source: Gro Intelligence, 2020[ix])*
Change is compared to the previous 15-year average

The La Niña conditions that developed at the end of 2020 saw soybean planting delayed by around 2 weeks in most regions in Brazil due to a lack of rainfall which dropped by as much as 50% in Mato Grosso, the country's largest soybean producing state.[x]

Brazil's maize crop is at risk from a changing climate.

11 La Niña is a climate pattern that describes the cooling of surface ocean water along the tropical west coast of South America

Double cropping in Brazil

In Brazil soy is increasingly being double-cropped with maize and in some places, cotton. The Brazilian states of Bahia, Goiás, Mato Grosso, Mato Grosso do Sul and Paraná represent over 95% of the double-cropped soy area in the country, 37% of the soy production between 2015 and 2018, and 41% of the maize production between 2015 and 2017 – see Figure 7.[xi,xii]

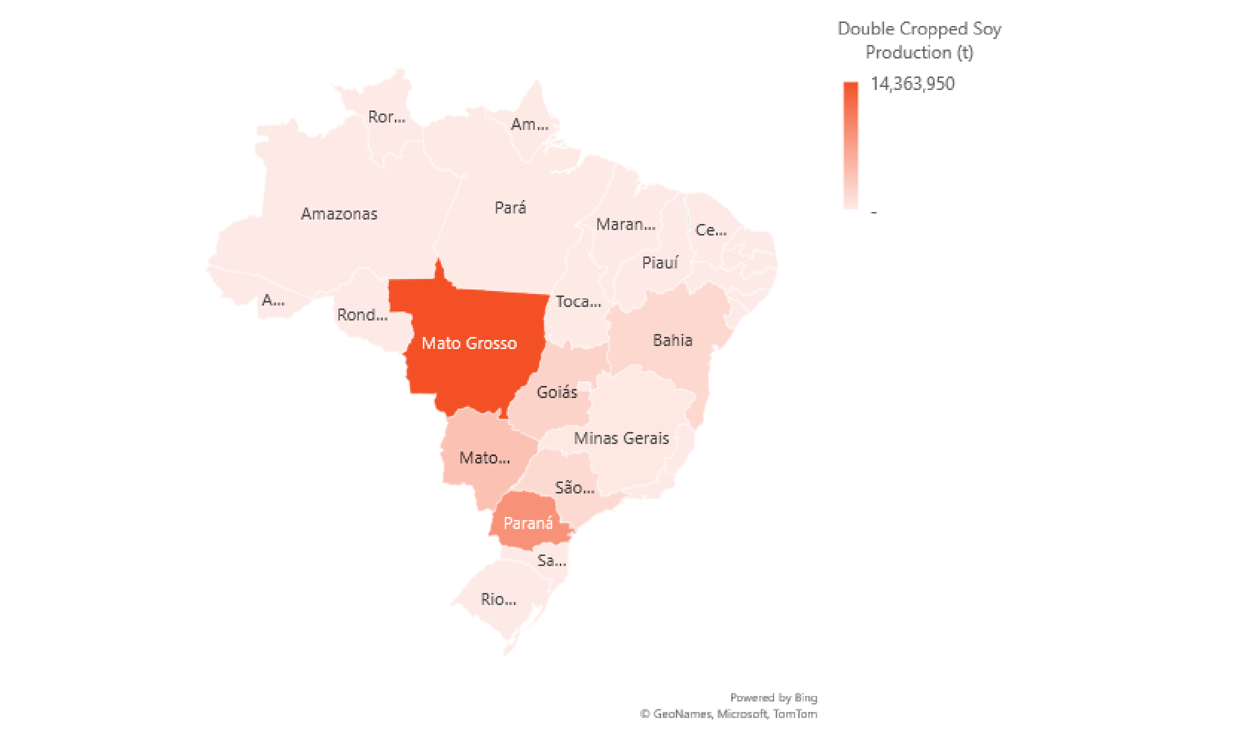

Figure 7: *Annual average soy production from double cropping between 2015 – 2018 (Source: Trase[viii])*

In Mato Grosso 60% of the soy area employed this practice and the production of soy and maize from these systems is estimated at 14.4 and 13.3 million tonnes respectively per year.[vi, iv] Short-cycle cultivar soy is grown in these systems, as opposed to long-cycle cultivars when cropped alone.

Double-cropping systems (either double soy or production of soy and another crop, often maize) has increased in Mato Grosso by over a factor of 10 between 2001 and 2014.[xiii]

Maize from double-cropped systems became the most important maize crop in Brazil from 2012, overtaking maize produced from single cropping systems.[xiv] The value of maize coming from double cropping systems is 2.4x greater than that coming from single cropping systems over 2016 to 2018. Maize produced from such systems accounts for 76% of total maize production in Brazil[xi] – see Figure 8.

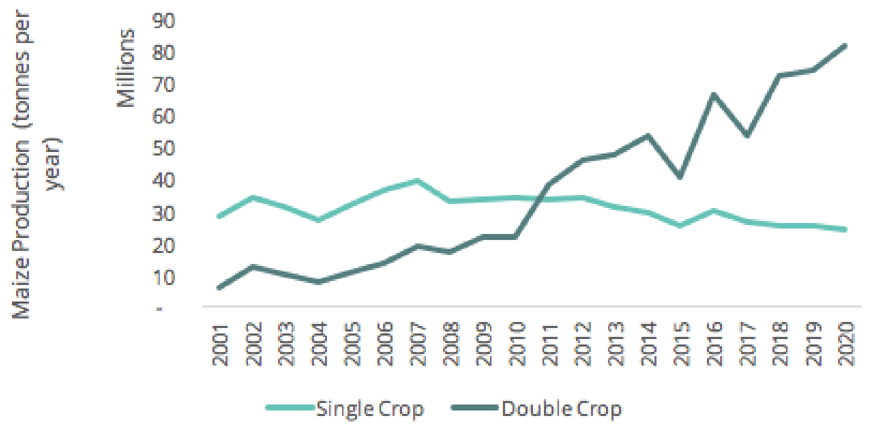

Figure 8: *Production of Maize in Brazil by Cropping Type (Source: Colussi & Schnitkey, 2021[xv])*

The rise of double-cropping has been assisted by the development of genetically modified (GM) short-cycle cultivar[12] soy. In addition to the obvious benefits of growing a second crop on the same plot of land, a study by Xu et al. (2021)[xvi] also found that the shift to soy-maize double cropping has meant that the second maize crop is not competing for port and export capacity with soy during the peak of the soy harvest, potentially reducing costs and delays.

When only a single soy crop is grown, a longer growing season can be utilised and soy can even be planted up until December. In the middle of the calendar year a sanitary break is implemented in Brazil, which dictates that live soybean plants cannot be in the field, which is a measure to control Asian soybean rust. The exact timing of the break can vary from state to state, though generally the break lasts from mid-June until the latter half of September.[xvii]

In double-cropped systems, soy is normally planted earlier in the season, around September and October. This allows maize to be planted earlier in the following year, around January and February. Table 1 shows a simplified crop calendar, illustrating the way in which a second crop (maize) can be grown after the first crop (soy) has been harvested.

Table 1: *Soy and Maize Crop Calendars for Mato Grosso (Source: AMIS)*

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Soy	G	H	LH	LH		S	S	S	S	P	G	G
Maize (2nd)		P	G	G	G	H	H	LH	LH			
Season	Rainy				Dry				Rainy			

Periods*: **P**: planting* ***H****: harvesting* ***LH****: late harvesting* ***G****: critical growing period* ***S****: sanitary break*
Shading*: Lighter shaded cells indicate an early or late period. Darker shades indicate peak periods*

12 Short-cycle cultivar – a breed of crop that has a shorter growing season allowing an earlier harvest

Double-cropping has obvious financial benefits for the farms concerned, since their land yields two crops per annum instead of one. If the maize crop is lost from soy-maize double cropping systems, then the expected income loss from an average sized farm (of 332 ha) in Mato Grosso is over USD 18,500 per annum, or one-third of annual farm income.[xix]

Evidence is mixed about the yield benefits of double-cropping soy and maize in Brazil. One study (van Benthem, 2013) found that when grown in rotation, both soy and maize yields can increase (providing an additional benefit). When maize is grown after soy, yields are 9% higher, and when soy is grown after maize, yields are 5% higher compared to growing the same crop in successive seasons. Reasons given for this surprising effect include the decreased influence of pests and diseases on crop losses and increased nutrients in the soil resulting from the double cropping.[xx]

However, another study (Xu et al., 2021)[xi] suggests that the yield of maize from double-cropped systems is lower than single cropped ones due to a shorter growing season.

What is clear is that the later the maize crop is planted, the lower the yield is expected to be, owing to increasing water stress in critical growing periods.[xxi]

Maize is a valuable crop that is at risk of being lost from double-cropping systems if rainfall patterns change.

The Value of Soy and Maize

Soy and maize combined account for 61% of planted agricultural area – see Figure 9.

Domestic agriculture

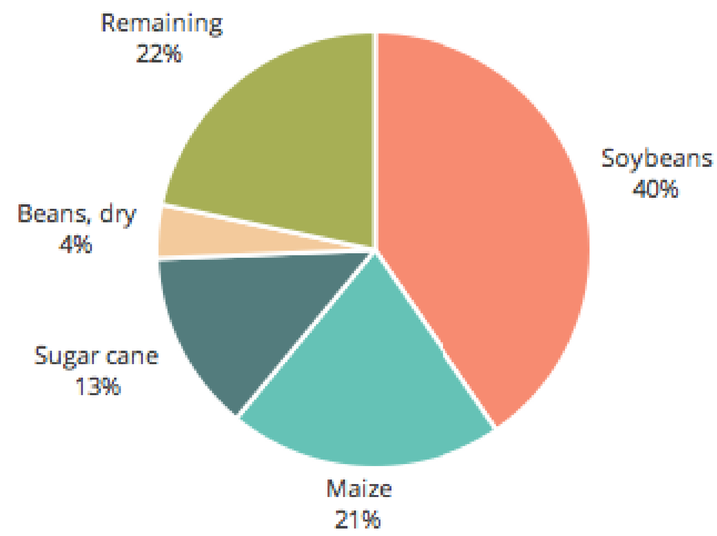

Figure 9: *Proportion of Agricultural Land Used for Major Crops in Brazil between 2016 and 2018 (Source: FAOSTAT, 2021)*

Two states, Mato Grosso and Paraná, account for 39% of soy production and 46% of maize production – see Tables 2 and 3.

Table 2: *Top 5 Soy Producing States in Brazil (total production between 2015 and 2018) (Source: Trase[xxii])*

Rank	State	Production (tonnes)	Share (%)
1	Mato Grosso	95,654,867	22%
2	Paraná	71,838,280	17%
3	Rio Grande Do Sul	65,036,142	15%
4	Goiás	40,769,900	10%
5	Mato Grosso Do Sul	29,412,888	7%

Table 3: *Top 5 Maize Producing States in Brazil (total production between 2015 and 2017) (Source: Trase[xviii])*

Rank	State	Production (tonnes)	Share (%)
1	Mato Grosso	66,635,402	27%
2	Paraná	46,410,774	19%
3	Goiás	25,313,689	10%
4	Mato Grosso Do Sul	24,320,809	10%
5	Minas Gerais	18,484,067	7%

Exports

Soy and maize constitute a significant portion of Brazil's soft commodity exports. From a natural capital perspective, our analysis of COMTRADE data shows that natural capital dependent exports totalled USD 107 billion in 2018 – see Figure 8.

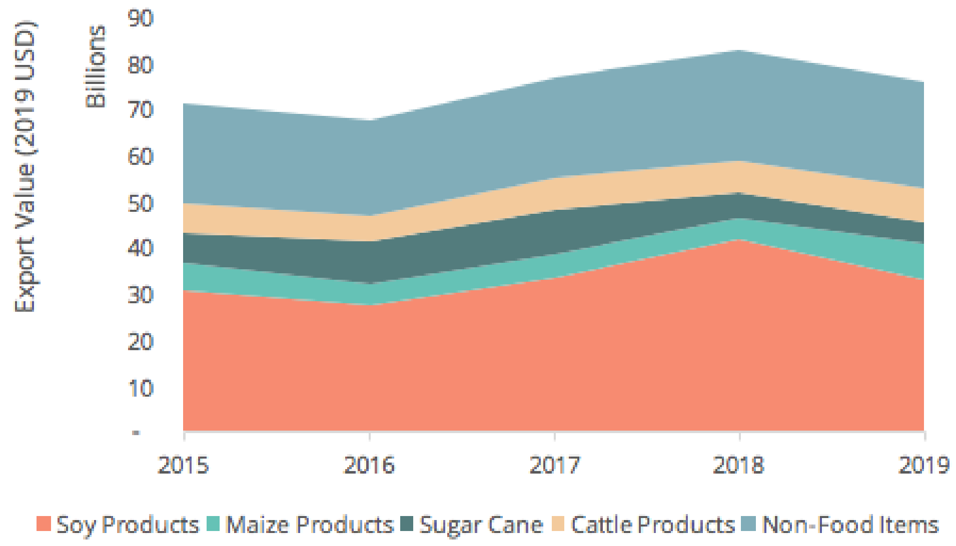

Figure 10: *Top 5 Natural Capital Dependent Exports from Brazil (Source: COMTRADE[xxiii])*[13]

13 Non-food items are mainly textiles, paper and timber products

The five categories in Figure 9 represent between 71% to 77% of exported natural capital dependent goods each year. Soy and maize exports – including its flour, meal and oil made up 16.6% and 1.8% of total exports in 2018 by value. Soy and maize production are forecast to increase by 33% and 20% over the next ten-years to 2029, while exports are also expected to increase by 42% and 33% respectively (MAPA, 2019)[xxiv]. Over the period 2015 to 2019, 44% of Brazil's exports were directly dependent on renewable natural capital for their production.[14]

When analysed together with its imports the data show that in the recent past Brazil has been a net exporter of such natural capital dependent products – see Figure 11.

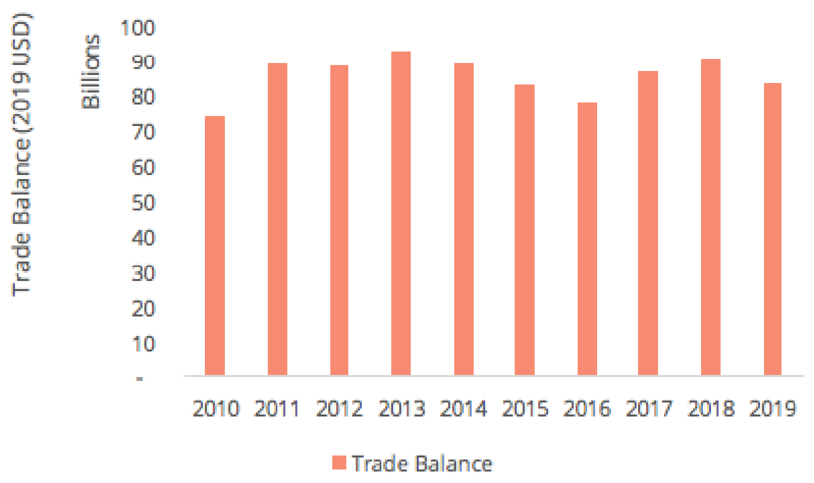

Figure 11: *Brazil's Trade Balance of Goods Dependent upon Renewable Natural Capital (Source: COMTRADE[xx], Planet Tracker Analysis)*

Brazil's overall GDP was USD 1,885 billion in 2018.[xxv] Soy exports were equivalent to 2.3% of GDP and maize exports were equivalent to 0.25%.

Brazil is dependent on natural capital for its export revenue and Mato Grosso is an important agricultural producer and natural capital user.

14 'Renewable natural capital' means renewable natural resources such as agricultural goods. 'Natural capital' would normally include non-renewable natural resources such as oil and minerals.

SUSTAINABLE PATHWAYS

Brazil has set targets to increase soybean yields by 1.6x and maize yields by 2.7x so it can meet the SDGs by 2050

Transformations are needed in Brazil's food system to meet the SDGs

Brazil is a member of the FABLE Consortium[15] and (with the other 19 member countries) has developed 'national pathways' that are consistent with the UN's Sustainable Development Goals (SDGs) and the objectives of the Paris Agreement. The pathways work back from the 2050 targets to shed light on the major transformations that countries need to implement to achieve sustainable land-use and food systems. As part of the development process, each national pathway is co-ordinated with the others to align with the global FABLE targets and ensure they are consistent - see Figure 12.

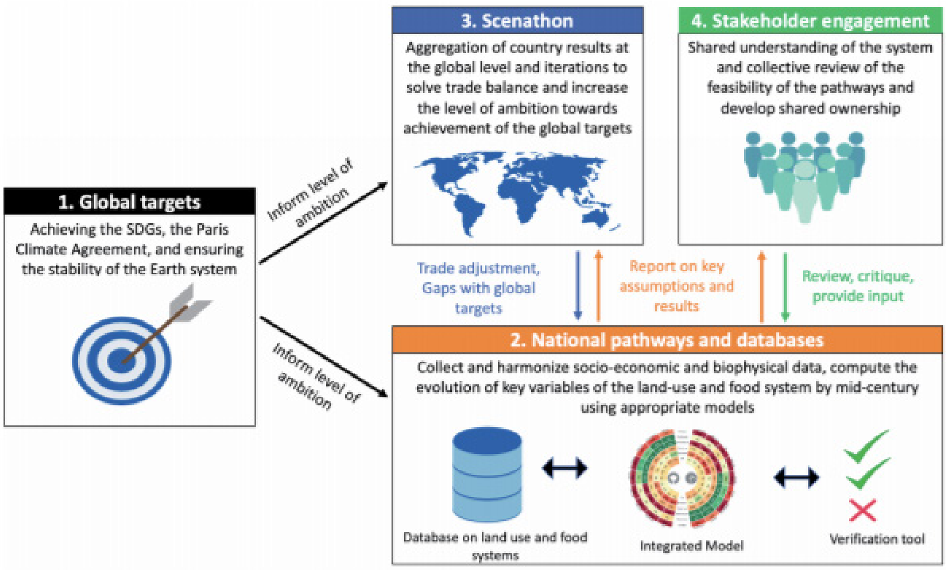

Figure 12: *FABLE Methodology (Source: Food and Land Use Coalition)*

As part of the FABLE consortium, Brazil has set out the assumptions underpinning two pathways to 2050 – 'current trends' and 'sustainable high ambition pathway'. Under both scenarios Brazil is expecting soy and maize yields to increase.

15 The Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is convened as part of the Food and Land Use Coalition (FOLU)

The key FABLE Pathway assumptions are summarised in Table 4.

***Table 4:** FABLE 2050 Scenario Analysis Results for Brazil*
(reference year = 2010) (Source: Food and Land Use Coalition[xxii])

Category	Current Trends	Sustainable Pathway	Comparison
Land	No constraint on agricultural land expansion	No deforestation after 2030	*Much tighter restriction on deforestation*
	No afforestation expected	Afforestation of 27 Mha	*Additional 27 Mha of afforestation*
Biodiversity	30% of total land protected	32% of total land protected	*Additional 2% of land to be protected*
Production (maize and soy)	**Maize** productivity increases from 5.8 t ha^{-1} to 8.5 t ha^{-1}	**Maize** productivity increases from 5.8 t ha^{-1} to 15.9 t ha^{-1}	*Target for **maize** productivity increase is 147% (vs 47% increase)*
	Soybean productivity remains constant	**Soybean** productivity increases from 3.2 t ha^{-1} to 5.2 t ha^{-1}	*Target for **soybean** productivity increase is 63% (vs no change)*
	Post-harvest losses reduced by 50%		*No change*
Trade	Maize exports increase from 43 Mt to 69.7 Mt per year	Maize exports decrease from 43 Mt to 39.2 Mt per year	*Maize exports decrease by 9% (vs 62% increase)*
	Soybean exports increase from 74 Mt to 95.5 Mt per year	Soybean exports decrease from 74 Mt to 58.5 Mt per year	*Soybean exports decrease by 21% (vs 29% increase)*

Meeting the FABLE targets depends on stable rainfall patterns

On its current trajectory, Brazil should have no trouble meeting its 2050 FABLE targets for soy and maize production suggesting that its FABLE 'sustainable pathway' scenario is achievable.

However, **the FABLE scenarios do not take into account any changes to Brazil's climate** (including changing rainfall patterns) caused by deforestation.

Furthermore, the data show that Brazil's agribusiness sector is becoming more concentrated on soy and maize than forecast in the FABLE scenarios, increasing the risks if that sector were to be disrupted by changing rainfall patterns.

Five-year average yields for soy have increased 9.1% per five-year period from 1970 to 2014. This is equivalent to an annualised rate of 1.8%. For Brazil to meet its Sustainable Pathway soybean yield target it only needs to achieve a 1.5% increase in yield per year from 2018 to 2050.

Projecting the historic rate of improvement to 2050 (and ignoring any deforestation-driven climate changes in Brazil) means soybean yields would reach 5.45 t ha^{-1}, or 5% above the Sustainable Pathway target yield of 5.2 ha-1 set out in Brazil's sustainable pathway – see Figure 13.

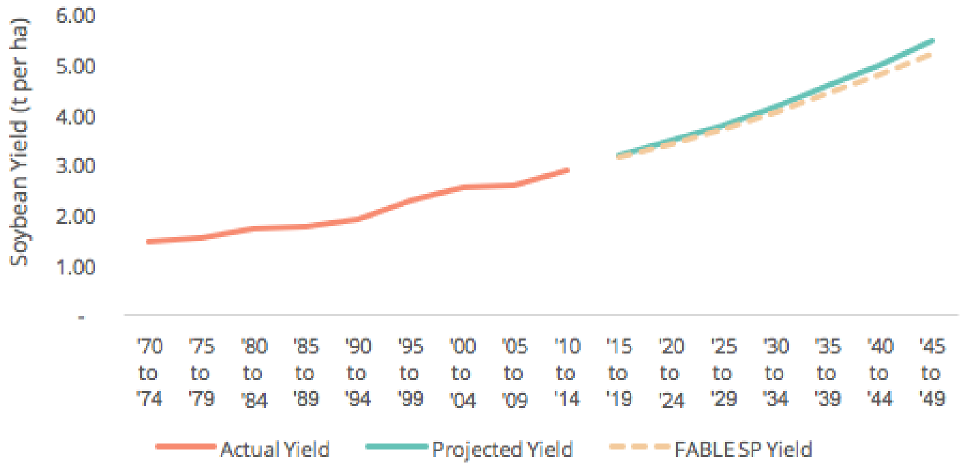

Figure 13: *Projecting Soybean Yield Growth (Source: FAO[xxvii])*

Five-year average yields for maize have increased 19.8% per five-year period from 1990 to 2019. This is equivalent to an annualised rate of 4.0%. For Brazil to meet its Sustainable Pathway maize yield targets it only needs to achieve a 3.7% increase per year to 2050 compared to a historical annual improvement of 4.0%.

Projecting the historic improvement rate forward to 2050 implies that maize yields would reach 19.7 t ha^{-1}, or 24% above the sustainable pathway target yield of 15.9 t ha^{1} – see Figure 14.

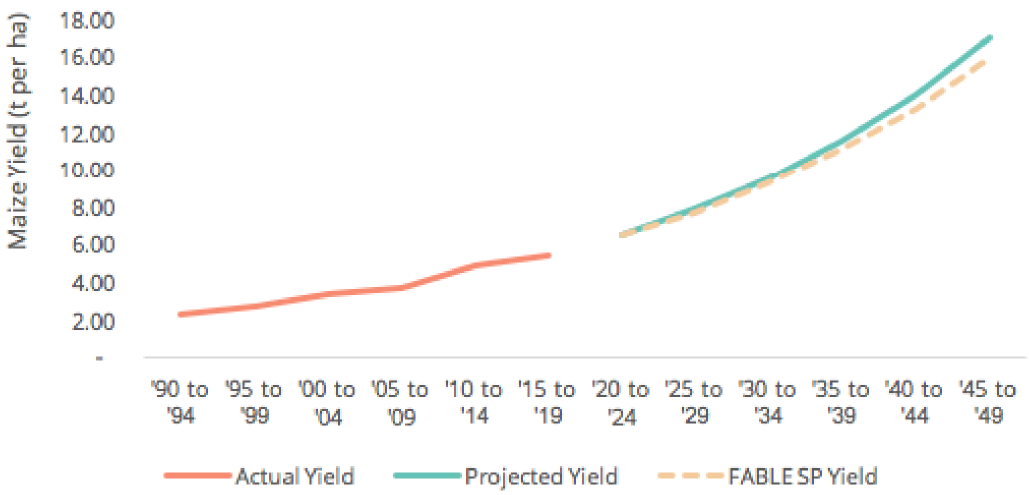

Figure 14: *Projecting Maize Yield Growth from (Source: FAOSTAT[xvii])*

Brazil's agricultural economy is becoming more concentrated

The FABLE authors calculate that Brazil's soft commodity exports and imports are currently moderately or highly concentrated (soy and maize dominate export, and wheat dominates imports), whereas its cultivated area is classified as moderately concentrated.

Under the current trends scenario the authors calculate that Brazil's economy will be more concentrated in 2050 than it is today (in terms of its exports, its imports and its cultivated area), increasing Brazil's dependence on soy and maize. Under the Sustainable Pathway scenario, Brazil's cultivated area, exports and imports are expected to become more diverse (reducing its natural capital risk) – see Figure 15

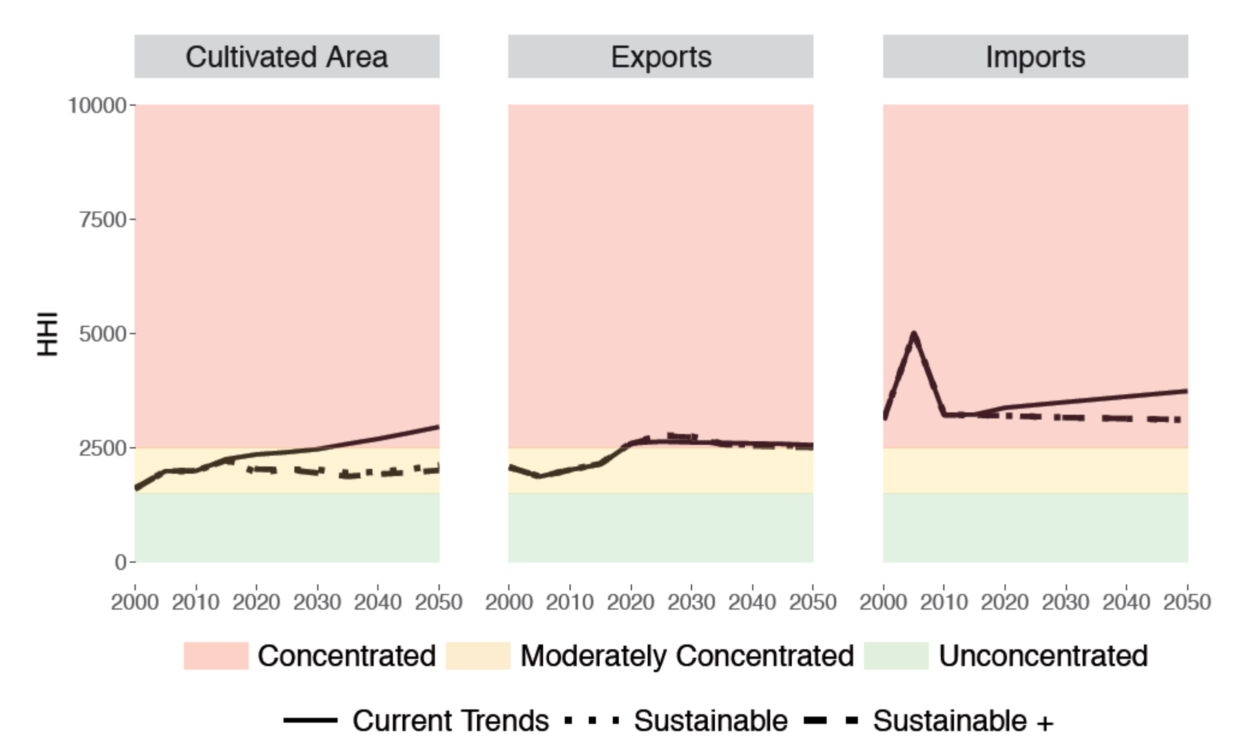

Figure 15: *FABLE Projections of Concentration of Brazil's Cultivated Area, Exports and Imports (2000-2050) (Source: Food and Land Use Coalition)[xxii] HHI = The Herfindahl-Hirschman Index, a common measure of market concentration.*

However, Brazil's export data show that this **concentration is happening even faster than Brazil forecast in its FABLE Pathways**. Brazil is currently exceeding the export levels assumed under both the current trends and sustainable pathway scenarios for both soy and maize. Exports for soybeans in 2019 exceeded 74 million tonnes, 9% above the current trends pathway - see Figure 16.

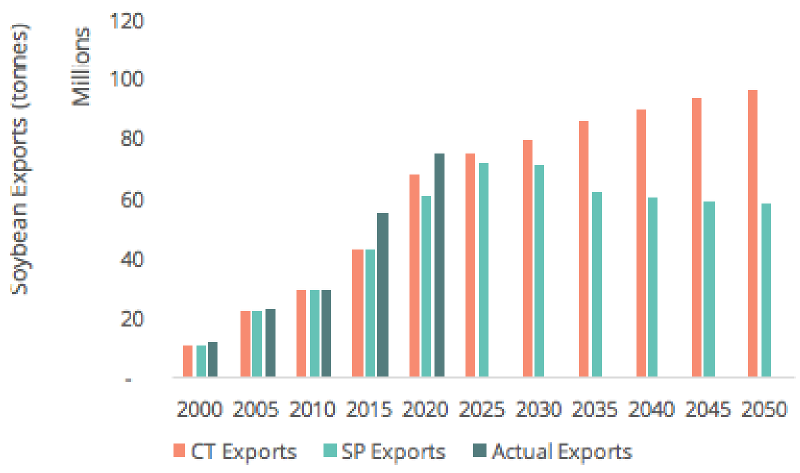

Figure 16: *Projected Soybean Exports to 2050 Aligned with a Current Trends (CT) and Sustainable Pathway (SP) Scenario (Source: Food and Land Use Coalition[xxii], FAOSTAT[xvii])*

Exports for maize were 42 million tonnes, even higher (22%) above the current trends pathway than soy (see Figure 17)

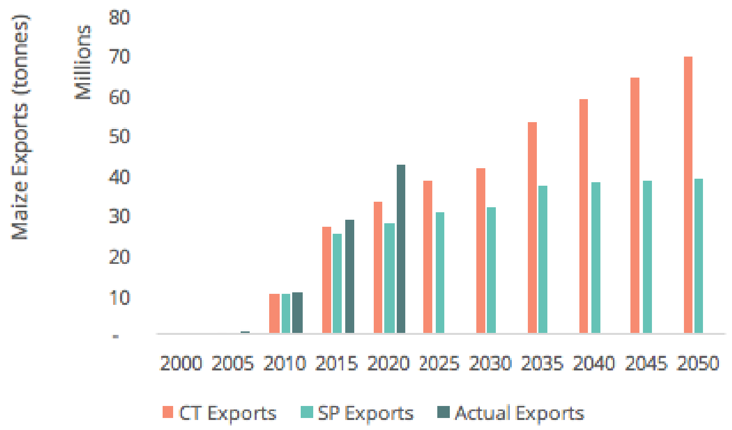

Figure 17: *Projected Maize Exports to 2050 Aligned with a Current Trends (CT) and Sustainable Pathway (SP) Scenario (Source: Food and Land Use Coalition [xxii], FAOSTAT[xvii])*

The FABLE scenarios discussed above (and Brazil's ability to meet or exceed those targets) depend upon a stable climate in Brazil. A number of academic studies have begun to investigate the links between regional climate change (in terms of temperature and precipitation) and deforestation, and the risks this poses for Brazil's agribusiness sector. In the next section we discuss these links.

Unless deforestation is stopped, and if Brazil's agriculture and export economy continues to become more reliant on soy and maize exports, it will become more exposed to environmental shocks driven by regional climate change.[16]

16 Our recent report 'Deforestation-Linked Sovereign Bonds' sets out how Brazil could add weight to any commitments to halt illegal deforestation by issuing a sovereign bond with coupon payments linked to its success in meeting these commitments

CLIMATE AND RAINFALL SCENARIOS

Global climate change and local deforestation will impact soy and maize production across Brazil, putting exports at risk

Single and double cropped areas experience different environmental impacts

We have based our analysis of the potential impact of deforestation on rainfall patterns in Brazil on two studies: Pires et al. (2016)[xxviii] and Brumatti et al. (2020)[xxix]. Pires et al. (2016) consider soy from double cropping systems and Brumatti et al. (2020) consider maize from double cropping systems.

We have divided their analysis into two scenarios:

1. **Scenario 1 (GCC) – the impact of global climate change (GCC) on soy and maize production**
2. **Scenario 2 (GCCR)– the impact of global climate change and a reduction in rainfall (GCCR) caused by further deforestation of the Amazon and Cerrado**

A reduction in rainfall, increasing carbon dioxide concentration, a shortening of the rainy season as well as other factors are considered in the studies' calculations.

Soy

We use the study by Pires et al. (2016) to calculate the decrease in soy yields from single- and double-cropped systems in four regions of Brazil:

- MATOPIBA, which consists of the states of Maranhão, Tocantins, Piauí and Bahia
- Mato Grosso
- Central Brazil, which consists of the states of Goiás, Mato Grosso do Sul, Minas Gerais and São Paulo
- Southern Brazil, which consists of the states of Paraná, Rio Grande do Sul and Santa Catarina

A drop in soy yields is calculated for short cycle cultivar soy, associated with double-cropping systems, and an optimum soy cultivar planted later in the growing season, associated with single-cropping systems. Yields for both of these varieties are analysed under the two climate change scenarios mentioned above, GCC and GCCR.

Maize

We use the study by Brumatti et al. (2020) to calculate the decrease in maize yields from double-cropped systems in MATOPIBA and Mato Grosso only (their study did not consider Central or Southern Brazil).

The authors calculate the impact on maize yields using the same two climate scenarios mentioned above. Seventeen maize planting dates were considered in the analysis.

Three variations within each climate change scenario were also analysed:

- **No adaptation** – maize sowing dates remain unchanged to 2050
- **10-day sowing delay** – sowing dates are delayed due to the later onset of the rainy season
- **20-day sowing delay** – an even later onset of the rainy season is assumed[17]

An average of 100 days is used as the time it takes for soybean plants to reach full maturity (phenological cycle), whereas 120 days is the average used for maize. Alternative cultivars were also included in the analysis, where a 90-day phenological cycle is used for soy, and two alternatives of 100 and 90 days for maize. These are used to reflect the introduction of new GM cultivars which are yet to be developed.[18]

Instead of presenting all the possible combinations and outcomes from the study we have used the median change in maize yield across all sowing dates for each of the possible scenarios.

The authors find that even the best-case scenario (using the best sowing dates and short cycle cultivars) was not enough to maintain the revenue generated by these activities in all study regions when there are high deforestation levels.

17 Deforestation in Rondonia (another state in Brazil) showed that the rainy season had shifted by 11 days as a result of deforestation ('Evidence that deforestation affects the onset of the rainy season in Rondonia, Brazil', Butt et al 2011)

18 GM soy and maize is already used extensively in Brazil so there is little capacity to increase existing GM crop usage (the area of GM soy planted in Brazil was between 94% to 97% over 2015 to 2018, and 85% to 89% for maize over the same period - ISAA, PT analysis)

CONSEQUENCES FOR SOY AND MAIZE PRODUCTION

Without change Brazil could lose billions in export revenue from soy and maize. If Brazil can achieve its sustainable pathway goals, it could transform those losses into gains. Scenario 1: Global Climate Change (GCC)

SCENARIO 1:
GLOBAL CLIMATE CHANGE (GCC)

Double-cropped soy and maize

For double-cropped soy, the outcome of the scenario is negative for all the regions except Southern Brazil which (based on the Pires model) experiences an uplift in output. As a result, the model shows that without technological improvements Brazil will miss the targets for soy production that are embedded in its Current Trend pathway in two of the four regions.

No regions will meet the yield targets in the Sustainable Pathway. Three regions experience significant declines in production – see Table 5.

Maize results are similar as Mato Grosso and MATOPIBA experience losses in all scenarios. No regions will meet any of the FABLE yield targets.

Table 5: *Changes in Soybean and Maize Yield for Double-Cropped Areas due to Global Climate Change (Source: Pires et al. (2016)[xxiv], Brumatti et al. (2020)[xxv], Planet Tracker Analysis). CT: Current Trend; SP: Sustainable Pathway.*

Area	Crop	Scenario	Cropping Type	Production Change		2050 Yield (tonnes per ha)	CT	SP
				tonnes	%			
MATOPIBA	Soy	Climate change	Double Cropping	-746,000	-40.0	2.50	x	x
Mato Grosso				-1,600,000	-11.1	2.96	x	x
Central Brazil				-366,000	-4.3	3.33	✓	x
Southern Brazil				1,029,000	11.9	3.40	✓	x
MATOPIBA	Maize	GCC – No adaptation	Double Cropping	-51,000	-5.3	3.04	x	x
Mato Grosso				-560,000	-4.2	5.30	x	x
MATOPIBA		GCC – 10-day delay		-137,000	-14.2	2.98	x	x
Mato Grosso				-1,534,000	-11.5	5.06	x	x
MATOPIBA		GCC – 20-day delay		-826,000	-22.1	2.53	x	x
Mato Grosso				-1,508,000	-17.0	5.07	x	x

Brumatti et al. (2020) found that combined double-cropping annual gross revenue from soy and maize could decline by USD 1 billion in MATOPIBA and by USD 2.3 billion in Mato Grosso by 2050.

From an export revenue perspective, Brazil could lose USD 645 million in soy exports in the GCC scenario as a result of the impact on double-cropping systems.[19] For maize, Brazil could lose USD 392 million in export revenue.[20]

19 Includes Mato Grosso, MATOPIBA, Central Brazil and Southern Brazil
20 Includes Mato Grosso and MATOPIBA only

Assuming the cropping area stays constant until 2050, most scenarios show that the Brazilian regions will not meet the goals outlined in the FABLE scenarios under the Current Trends pathway. All regions fail to meet the yield targets in the Sustainable Pathway.

Single-cropped soy

When the single-cropped soy crop is analysed, the outcomes are positive across all four regions. This is because farmers are assumed to be able to shift their planting and harvesting in response to changing weather patterns thus mitigating those effects to some extent.

However, even though yields are higher this is not sufficient to enable Brazil to meet its sustainable pathway yield targets in any of the regions – see Table 6.

Table 6: *Changes in Soybean and Maize Yield for* ***Single-Cropped*** *Areas due to Global Climate Change (Source: Pires et al. (2016)[xxiv], Planet Tracker Analysis). CT: Current Trend; SP: Sustainable Pathway.*

Area	Crop	Scenario	Cropping Type	Production Change		2050 Yield (tonnes per ha)	CT	SP
				tonnes	%			
MATOPIBA	Soy	GCC	Single Cropping	782,000	10.8	2.96	x	x
Mato Grosso				757,000	7.9	3.27	✓	x
Central Brazil				1,606,000	9.1	3.59	✓	x
Southern Brazil				4,209,000	14.9	3.69	✓	x

In single-cropping systems Brazil could gain USD 2.8 billion in soy export revenue in the climate change scenario. Most of these gains (79%) are in Central and Southern Brazil. But as illustrated earlier this is still a net loss to Brazil due to the impact on the more economically important double-cropping system.

Mato Grosso is at a significant loss due to climate change

Mato Grosso stands to lose more from deforestation than it would gain. The loss to soy production in double-cropping systems could be as much as 1,600,000 tonnes, and the loss of maize production from double-cropping systems up to 1,534,000 tonnes.

For single-cropped areas Planet Tracker only have data available for soy production, which shows that Mato Grosso could gain up to 757,000 tonnes soy production by 2050 from the impacts of climate change. In terms of soy that equates to a net loss of 843,000 tonnes for Mato Grosso.

SCENARIO 2: GLOBAL CLIMATE CHANGE + RAINFALL CHANGE (GCCR)

Double-cropped soy and maize

As in scenario 1, the outcome of the scenario is negative for all the regions except Southern Brazil, which the model shows as experiencing some uplift in soy production compared to scenario 1. Brazil's performance in relation to its FABLE targets for soy and maize is also the same as scenario 1. A small difference for maize in this scenario is that MATOPIBA experiences a slight production benefit in two of the six scenarios, but still falls below the production yield expected in both the Current Trends and the Sustainable Pathways – see Table 7.

Table 7: *Changes in Soybean and Maize Yield for* ***Double-Cropped*** *Areas due to Global Climate Change and a Reduction in Rainfall due to Deforestation of The Amazon and Cerrado (Source: Pires et al. (2016)[xxiv], Brumatti et al. (2020)[xxv], Planet Tracker Analysis) . CT: Current Trend; SP: Sustainable Pathway.*

Area	Crop	Scenario	Cropping Type	Production Change		2050 Yield (tonnes per ha)	CT	SP
				tonnes	%			
MATOPIBA	Soy	GCCR	Double Cropping	-932,000	-50.0	2.44	x	x
Mato Grosso				-4,325,000	-30.0	2.60	x	x
Central Brazil				-1,005,000	-11.8	3.25	✓	x
Southern Brazil				1,349,000	15.6	3.43	✓	x
MATOPIBA	Maize	GCCR - No adaptation	Double Cropping	83,000	8.6	3.12	x	x
Mato Grosso				-187,000	-1.4	5.39	x	x
MATOPIBA		GCCR - 10 - day delay		2,000	0.2	3.07	x	x
Mato Grosso				-1,854,000	-13.9	4.98	x	x
MATOPIBA		GCCR - 20 - day delay		-168,000	-4.5	2.96	x	x
Mato Grosso				-1,712,000	-19.3	5.02	x	x

Brumatti et al. (2020) found that double-cropping gross revenue from soy and maize combined could decline by USD 1 billion in MATOPIBA and by USD 2.8 billion in Mato Grosso by 2050.

From an annual export revenue perspective, Brazil could lose USD 1.9 billion of soy exports[21] and USD 316 million of maize exports from its double-cropping systems.[22]

Single-cropped soy

Under the GCCR scenario, when single-cropped soy was considered, all four regions showed an increase in soy production in this scenario. Mato Grosso and MATOPIBA produce less soy than in the GCC scenario, whereas Central and Southern Brazil actually increase their output – see Table 8. However this must be placed in context of the overall productivity loss from the ability of other regions to double crop.

21 Includes Mato Grosso, MATOPIBA, Central Brazil and Southern Brazil
22 Includes Mato Grosso and MATOPIBA only

Table 8: *Changes in Soybean and Maize Yield for Single-Cropped Areas due to Global Climate Change and a Reduction in Rainfall due to Deforestation of The Amazon and Cerrado (Source: Pires et al. (2016)[xxiv], Planet Tracker Analysis). CT: Current Trend; SP: Sustainable Pathway.*

Area	Crop	Scenario	Cropping Type	Production Change		2050 Yield (tonnes per ha)	CT	SP
				tonnes	%			
MATOPIBA	Soy	GCCR	Single Cropping	282,000	3.9	2.82	x	x
Mato Grosso				211,000	2.2	3.19	x	x
Central Brazil				1,659,000	9.4	3.56	✓	x
Southern Brazil				4,435,000	15.7	3.76	✓	x

In single-cropping systems Brazil could gain USD 2.5 billion in soy export revenue in the climate change and rainfall reduction scenario. Again, most of these gains (93%) are in Central and Southern Brazil and in the overall scenario would still represent a loss to Brazil and its sovereign health due to the impact on the more economically important double-cropping system.

Mato Grosso loses 170% more soy when deforestation occurs

Mato Grosso stands to lose an *extra 2.7 million tonnes* of soy production from double-cropping areas from deforestation compared to scenario 1. The total loss to Mato Grosso's soy production in double-cropping systems could reach 4.3 million tonnes, and the loss of maize production from double-cropping systems up to 1.9 million tonnes. For single-cropped areas Planet Tracker only have data available for soy production, which shows that while Mato Grosso could gain up to 0.2 million tonnes soy production by 2050 that does not offset the projected loss

Summary

Estimating the impact of deforestation on rainfall patterns and the resulting impact on crop yields is complex and the studies we have examined give mixed results.

The flexibility allowed by the single-cropping process (in terms of planting and harvesting) means that farmers using this approach are likely to be able to cope with changing rainfall patterns and may even benefit.

The studies demonstrate that **farmers using double cropping systems will find deforestation-driven changes in rainfall patterns a challenge to cope with.**

As noted in the Introduction, what these studies have not considered is all the other negative impacts from climate change and the potential effect on worker health from the more frequent occurrence and severity of extreme temperature days and thus the ability of farms to function during those periods.

In all the scenarios examined Brazil would fail to meet the targets set out in its FABLE Sustainable Pathway. Significant technological improvements will be needed if Brazil is going to come close to meeting these targets – see Figure 18.

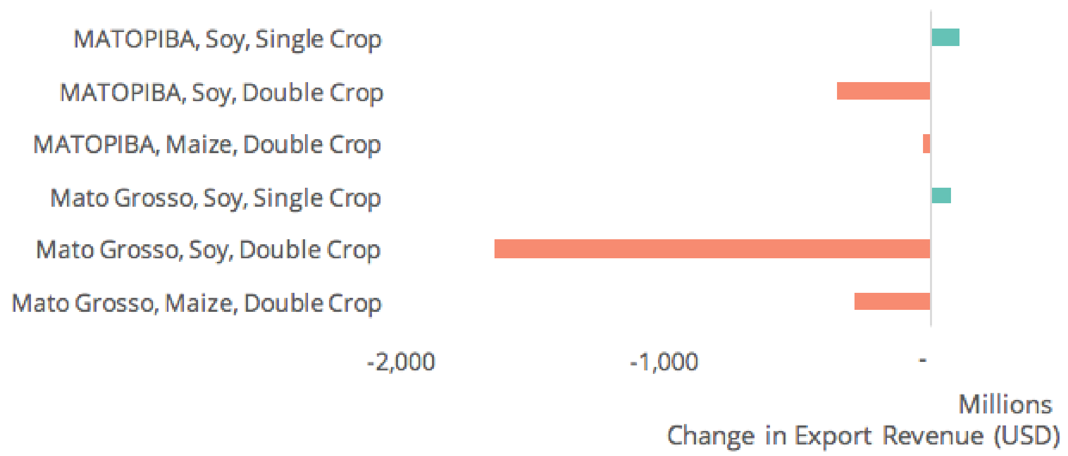

Figure 18: *Change in Export Revenue by 2050 for Mato Grosso and MATOPIBA under Climate Change and Reduced Rainfall (Source: Pires et al. (2016)[xxiv], Brumatti et al. (2020)[xxv], Planet Tracker Analysis)*

Combining the results for Mato Grosso and MATOPIBA, the net loss to Brazil's export revenue by 2050 is between USD 701 million and USD 2.1 billion per year,[23] increasing the risks for sovereign investors (as well as those exposed to Brazil's agribusiness sector and the banks supporting it).

23 In 2018 Brazil's exports of soybeans and maize amounted to USD 37.30 billion (Source: COMTRADE) c.15% of Brazil's total exports (USD 251 billion).

DOUBLE-CROPPING IS VITAL FOR BRAZIL'S AGRICULTURAL PRODUCTIVITY

As we discussed earlier in this report, **Brazil's ability to grow more than one crop in a year on the same plot of land has been a significant factor in its emergence as one of the world's largest agricultural producers and exporters.**

It is clear that any reduction in Brazil's ability to exploit double-cropping would have a significantly negative impact on the incomes of the farms affected and also on Brazil's export income.

As noted earlier, if the maize crop is lost from soy-maize double cropping systems, then the expected loss in income from an average sized farm (of 332 ha) in Mato Grosso is over USD 18,500 per annum, or one-third of annual farm income.[xxx]

In addition, achieving the FABLE Sustainable Pathway yield targets will be challenging if Brazil's ability to continue double-cropping is impaired by rainfall changes driven by continued deforestation.

The deployment of short-cycle cultivar soy and maize is one of the main ways that the soy-maize double-cropping system can continue under the various climate scenarios discussed above. Reductions in the time taken for the plants to reach maturity are needed if the maize crop is to survive a shortened rainy season, but GM soy and maize is already widespread in Brazil so developing crops with even shorter growing cycles may be difficult.[24]

The dilemma (balancing risks and rewards) faced by Brazil's farmers (and ultimately feeding through to Brazil's economy) is illustrated in Table 9.

Table 9: *The farmer's dilemma – risk vs reward*

	Single crop	Double crop
Advantages (rewards)	Greater flexibility regarding planting and thus harvesting will allow adaptation to shifting rainfall patterns (up to a point)	Much more efficient use of the available land Significantly greater income (if successful)
Disadvantages (risks)	Significantly less income than double-cropping	Any delay planting and therefore harvesting the first crop risks pushing the timetable for the second crop beyond its ideal planting and harvesting calendar, so that the crop might be impaired or lost entirely

24 Modelling by Hampf et al. (2020) suggest that advances in technology and crop management could offset the negative effects from climate change, lower precipitation and higher temperatures but this relies on historic innovation trends continuing into the future. The paper does not explain why this should be the case.

THE DEFORESTATION FEEDBACK LOOP

The obvious solution for farmers suffering a fall in crop yield is to compensate by expanding the amount of land they use, but this may be difficult.

As an example, Mato Grosso accounted for 85% of the soy production in the Amazon biome in 2014 and production was reaching its limitations. Only 2% of properties in Mato Grosso contained sufficient legal reserves[25] to allow for expansion to offset any reduction in yield.[xxxi]

This suggests that for 98% of properties in Mato Grosso any further expansion of farmland would require illegal deforestation. That might be tempting in the short term for the individual farmers concerned, however as the studies covered in the report show, there is a significant risk that such deforestation would lead to a negative feedback loop, further reducing the rainfall which is essential for Brazil's agriculture.

Deforestation can also have an impact on temperature and extreme heat events. A study by Flach et al. (2021)[xxxii] found that agriculture that is within 50km of recently deforested areas in Brazil experienced increase in temperatures and an increased occurrence of extreme temperature days, which damages crops. The impact on soy production from this effect is thought to cost between USD 1,550 and USD 1,650 per hectare in terms of lost annual revenue by 2050 and each day where the temperature surpasses 30˚C, soybean yields can be expected to decrease by 1% to 5%.

The model outputs from the two studies we have examined in this paper imply that while the impact of this feedback loop would be negative for farmers using double-cropping in Mato Grosso, MATOPIBA[26] and Central Brazil',[27] the short-term outcome for farmers in Southern Brazil[28] might be less negative, since rainfall patterns will not be impacted in the same way. However, as noted earlier, these studies ignore the other important factors arising from climate change, particularly the impact of more frequent and severe extreme temperature days preventing workers from operating and thus the ability of farms to function during those periods – see Figure 19.

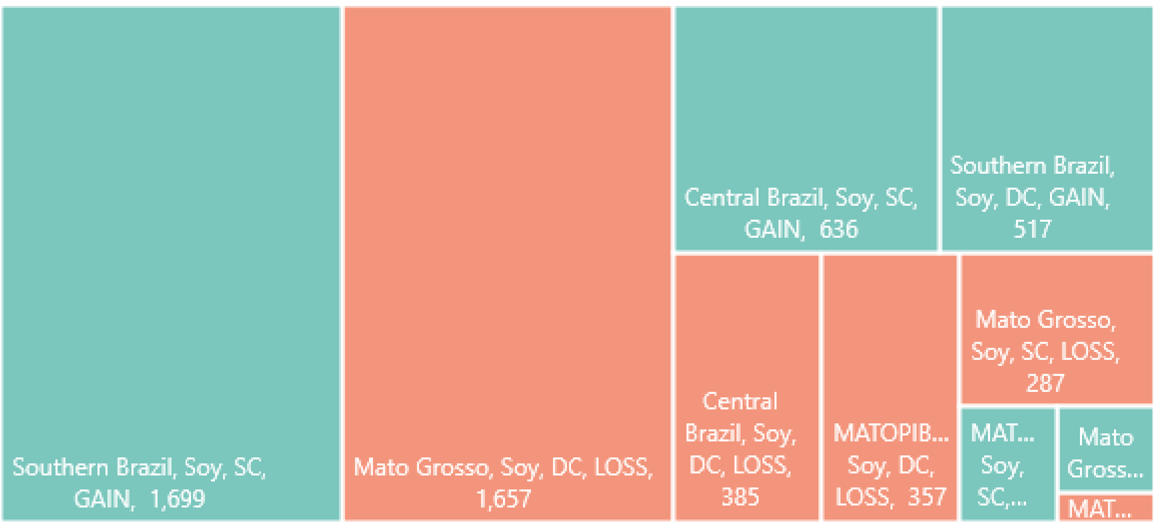

Figure 19: *Change in Export Revenue by 2050 for All Regions under Climate Change and Reduced Rainfall Scenario (Source: Pires et al. (2016)[xxiv], Brumatti et al. (2020)[xxv], Planet Tracker Analysis) USD millions*

DC*: double-cropping system* ***SC****: single-cropping system*

25 i.e. expansion of farms through legally permitted deforestation
26 Maranhão, Tocantins, Piauí and Bahia
27 Goiás, Mato Grosso do Sul, Minas Gerais and São Paulo
28 Paraná, Rio Grande do Sul and Santa Catarina

From the perspective of sovereign bond investors, this would represent a significant (and potentially disruptive) shift in Brazil's agricultural economy from more productive states to less productive ones, with a significant impact on jobs, local incomes and even potentially politics.

Individual States within Brazil could also find their finances challenged as a result of lost tax income from farming businesses impacted by deforestation-driven climate change. Since the majority of their debt is provided by the central government, this will feed through to government finances.

INCREASED RISK FOR AGRIBUSINESS FROM CLIMATE VOLATILITY

The analysis and modelling in the studies we have examined necessarily results in outputs that are smoothed and implies a greater degree of certainty than would be the case in reality.

In a situation where deforestation is allowed to continue, not only are rainfall patterns and local temperatures likely to be altered, but they are also likely to become less predictable and more extreme, and push Brazil's ecosystem dangerously closer to potential tipping points with the commensurate risk of widespread and very harmful systemic changes to Brazil's climate and economy

For farmers and the agribusiness sector more broadly this combination will be very challenging – the risks they face will increase significantly without any commensurate increase in potential returns. These new market characteristics will feed through to investors as well.

CONCLUSIONS

Deforestation is an act of economic self-harm by Brazil

While deforesting the Amazon might appear at first sight to be a cheap way for individual Brazilian farmers to expand their agricultural capacity, the studies discussed in this report clearly show that **there is a strong probability that further deforestation activities will shorten the rainy season and reduce precipitation in Brazil, making it highly likely that the production of soy (and other crops such as maize) will fall in existing farmed areas,** offsetting any perceived short-term gains from newly deforested land.

Deforestation will drive local climate change in the agriculturally important areas of Mato Grosso and MATOPIBA, damaging Brazil's important agribusiness sector, destroying jobs and livelihoods, and impairing Brazil's ability to earn essential export income.

Agricultural land further south, which is less suitable for soy double cropping and thus less productive, currently is less likely to be impacted by the deforestation-rainfall feedback loop because of its greater distance from the Amazon. While increased temperatures from global warming and increased carbon dioxide concentrations might have some potentially beneficial impact on the growth of soy plants this is no guarantee that soy production would benefit in these areas because of the other effects of climate change, particularly the increased incidence and severity of extreme temperature days and their impact on farm productivity. As a result, from Brazil's perspective (and that of sovereign investors in its bonds) this effect will not compensate for the overall effect of increased risk and the much stronger negative effects of deforestation impacting the more productive regions of Mato Grosso and MATOPIBA.

Brazil's Sustainable Pathway FABLE scenario assumes increasing yields and no deforestation beyond 2030, but Brazil's current deforestation trend implies that this 2030 target is unlikely to be met, casting doubt on its ability to meet its FABLE crop production targets.

So not only is preserving the Amazon essential for the health of humanity at large (as a store of carbon and a significant biodiversity reserve as well as a significant factor in global weather patterns) but **Brazil has a strong domestic motive for halting deforestation** as well, since failure to do so will likely impair its export revenues and the livelihoods of Brazilian farmers in Mato Grosso and the MATOPIBA states.

Deforestation is leading to significant hard-to-model risks for investors

Stopping deforestation is essential for Brazil's sovereign health.

Sovereign bond investors are clearly exposed to the risks arising from the deforestation-rainfall feedback loop. Brazil's agribusiness sector is an essential source of export revenues that has been growing consistently since the 1960's but deforestation is putting this at risk, both in terms of threatening to reduce the absolute quantity of crops Brazil can produce but also by increasing the volatility of Brazil's output and thus export revenues. Not only that, but **the local climate changes deforestation is likely to bring about threaten Brazil's economy more broadly.**

The increased incidence and severity of extreme temperature days will impact worker productivity and the health of the population as a whole across Brazil, and the impact on Brazil's river systems could severely affect its ability to generate hydroelectricity and to transport goods cheaply from the interior to the sea.

Equity and debt investors are also clearly exposed to these effects through their holdings in and lending to the Brazilian companies that will be directly affected, and also indirectly through their investments in Brazil's banks and insurance companies (which could see an increase in loan defaults and insurance claims relating to physical, financial and health-related losses).

Brazil's alternative – a roadmap to a sustainable future

There is an alternative path for Brazil as we discussed in 'Brazil – roadmap to sustainable bonds'. Sovereign investors have much to gain if Brazil enhances its sovereign health by focusing on restoring its natural capital wealth, but much to lose if it fails to do so and continues to allow extensive deforestation.

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APPENDIX

MAPS OF BRAZIL'S CURRENT CLIMATE AND RAINFALL

This report focuses on four regions in Brazil:

- Mato Grosso
- MATOPIBA, which consists of the states of Maranhão, Tocantins, Piauí and Bahia
- Central Brazil, which consists of the states of Goiás, Mato Grosso do Sul, Minas Gerais and São Paulo
- Southern Brazil, which consists of the states of Paraná, Rio Grande do Sul and Santa Catarina

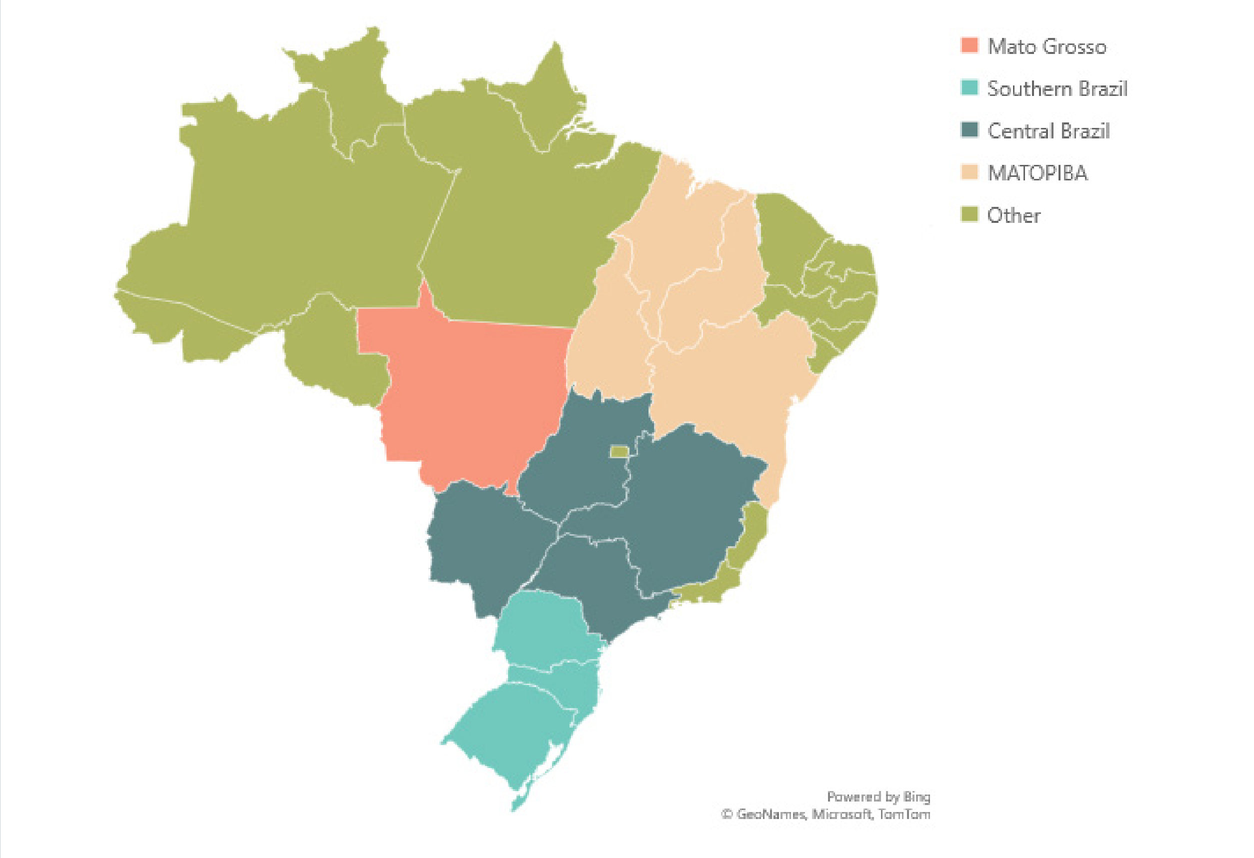

Figure 20: *Map of Brazilian states covered in this report (Source: Planet Tracker)*

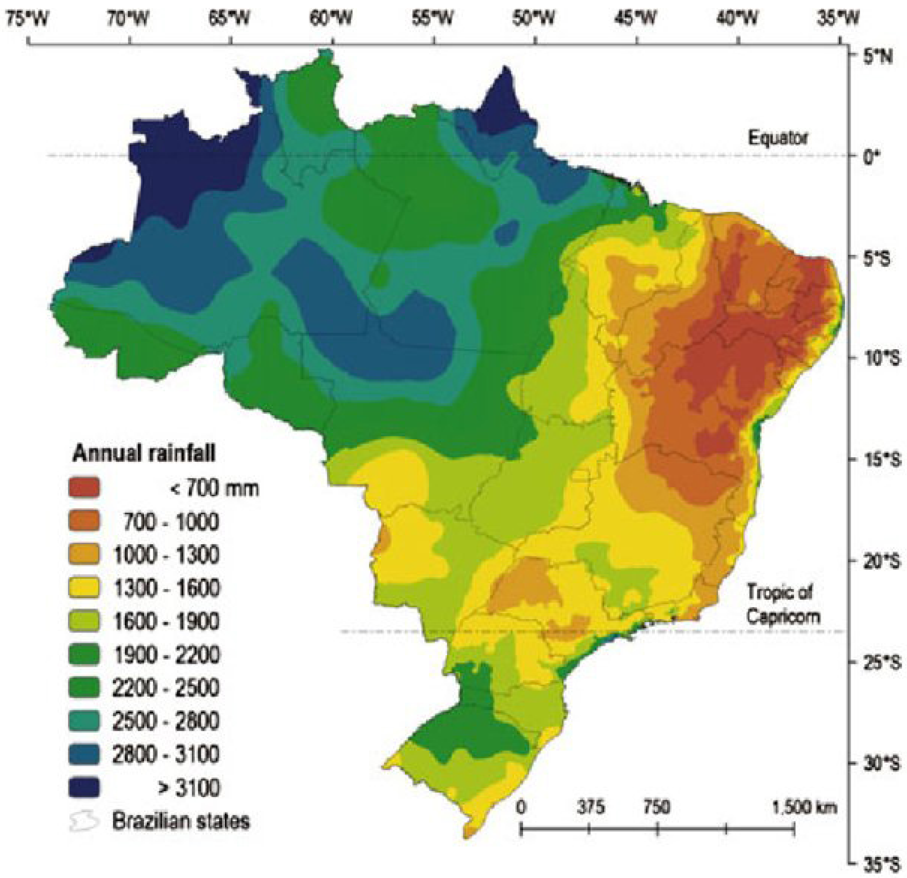

Figure 21: *Annual rainfall in Brazil (source: Alcarde Alvares, Clayton & Stape, Jose & Sentelhas, Paulo & Gonçalves, José & Sparovek, Gerd. (2013). Köppen's climate classification map for Brazil. Meteorologische Zeitschrift. 22. 10.1127/0941-2948/2013/0507.)*

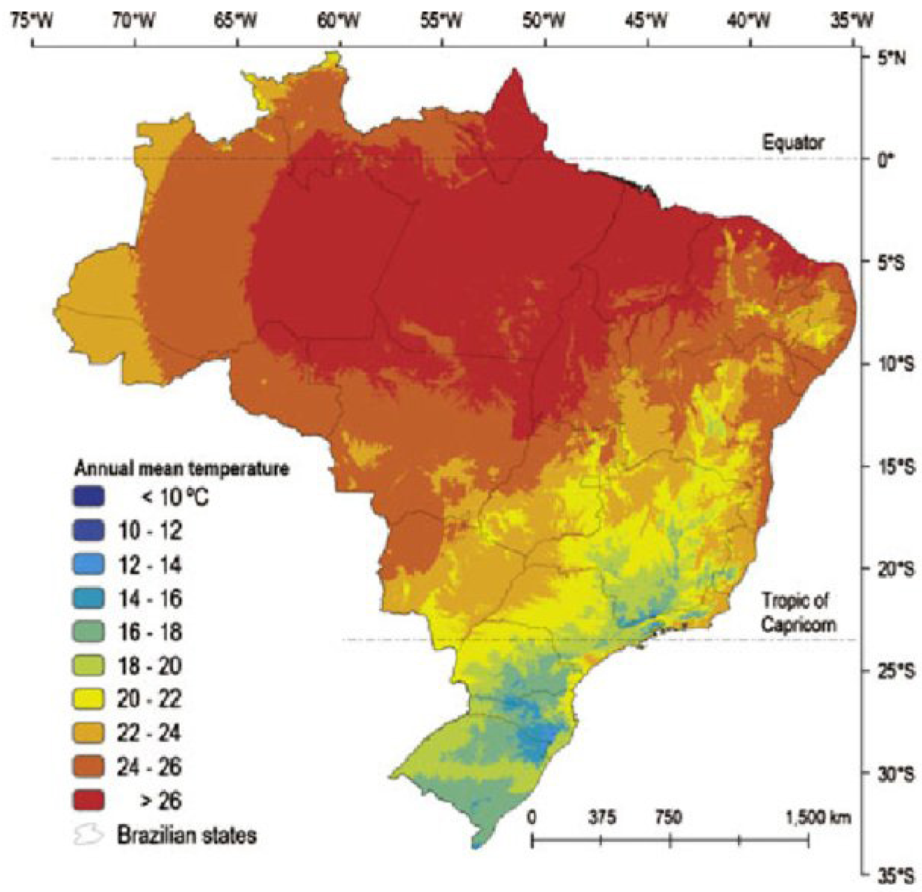

Figure 22: *Annual mean temperature in Brazil (source: Alcarde Alvares, Clayton & Stape, Jose & Sentelhas, Paulo & Gonçalves, José & Sparovek, Gerd. (2013). Köppen's climate classification map for Brazil. Meteorologische Zeitschrift. 22. 10.1127/0941-2948/2013/05*

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