Planet Tracker

DESTROYING BRAZIL'S AirCon

DEFORESTATION THREATENS BRAZIL'S ECONOMY

(No Rain on the Plain - Part 2)

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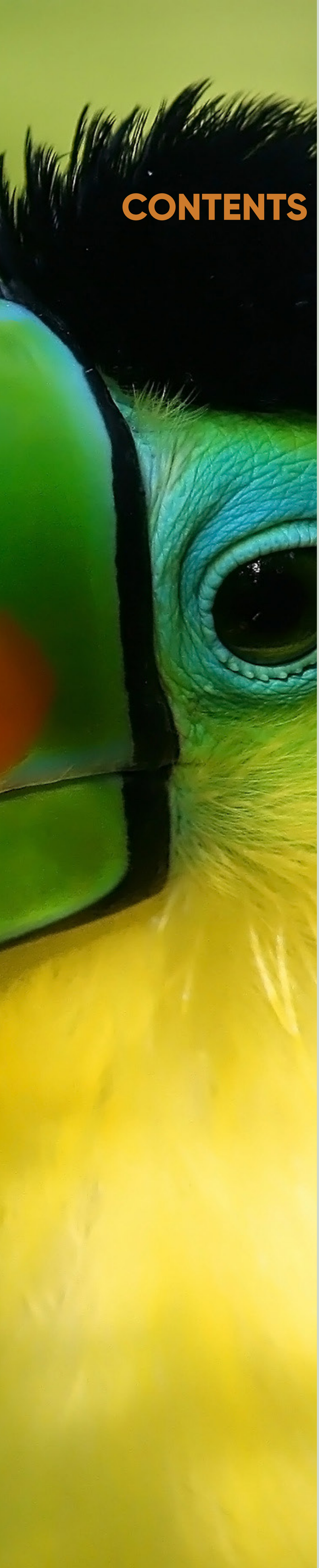

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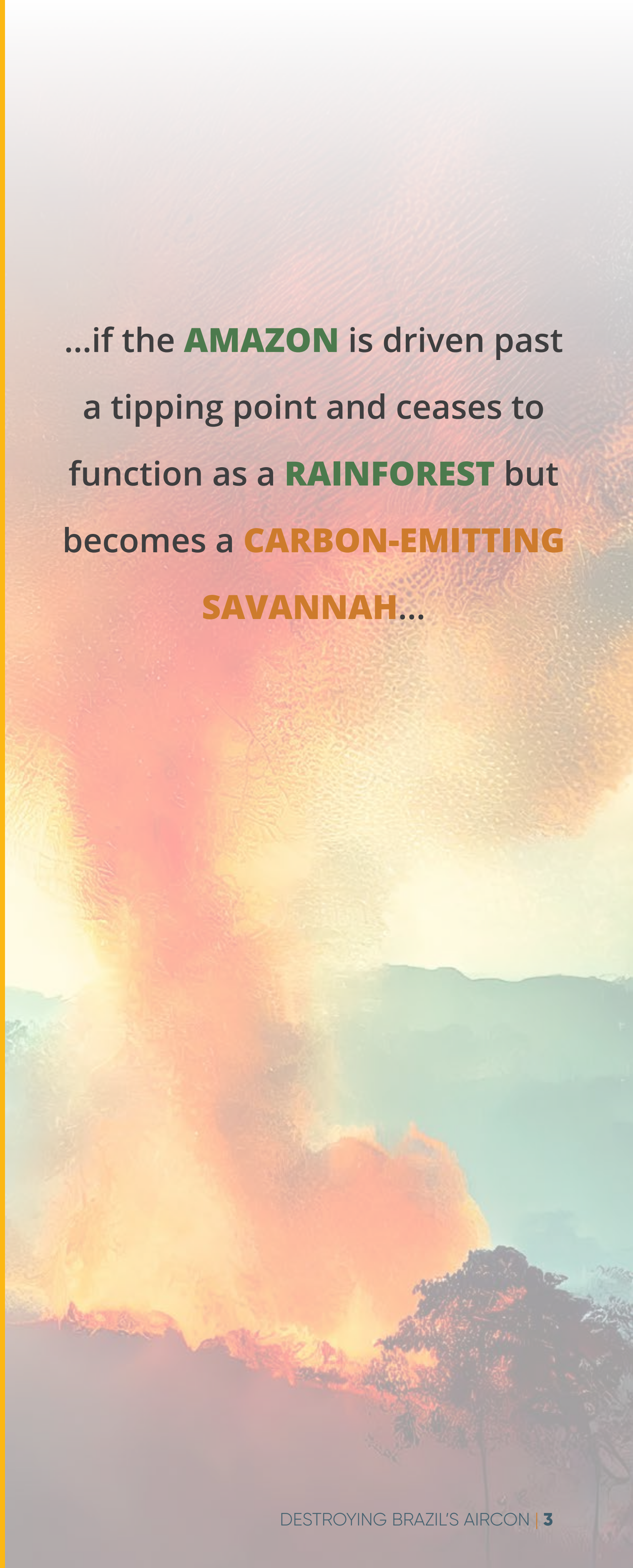
WHY read this report

In No Rain on the Plain we set out the consequences for Brazil's agribusiness sector of continued deforestation and the potential deforestation feedback loop that could drive down the country's agricultural productivity.

In this report, we highlight the material risks to Brazil's wider economy and society that come from the regional climate change driven by continued deforestation. These include the potential for a rapid acceleration of these impacts if the Amazon is driven past a tipping point and ceases to function as a rainforest but becomes a carbon-emitting savannah.

Our analysis has implications for sovereign bond investors exposed to Brazilian bonds and for equity and credit investors and banks exposed to the domestic Brazilian companies that will suffer the direct effects of Brazil's climate becoming more hostile, as well as for investors and banks exposed to the food system companies that are dependent upon Brazil's soft commodity exports (soy, maize, rice, coffee and beef).



...if the **AMAZON** is driven past a tipping point and ceases to function as a **RAINFOREST** but becomes a **CARBON-EMITTING SAVANNAH**...

Executive summary

Deforestation is harming Brazil’s climate

Deforestation is changing Brazil’s local climate, changing rainfall and temperature patterns and threatening Brazil’s economic success.

Brazil’s economy depends upon its benign climate (with predictable weather patterns) and its natural capital (plentiful freshwater and precipitation, productive soil and a predictable range of temperatures). **The Amazon forest in particular acts like a giant air-conditioning unit, cooling the land and providing rainfall across the country.**

Deforestation in Brazil is:

- **Reducing the amount of precipitation** and concentrating it into a shorter rainy season.
- **Increasing the frequency and level 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.
- **Increasing the risk of zoonotic diseases**.

This will have severe impacts on Brazil’s economy

1 **Agriculture** contributes more than a quarter of Brazil’s GDP and 39% of Brazil’s exports. Stable weather patterns and consistent temperatures are essential for the agribusiness sector to continue to thrive.

Local changing climate will impact crop yields and expose more growing areas to weather-related risks threatening soft commodity exports. Soybeans, Brazil’s single largest export product (with exports of USD 28.6 billion in 2020) could experience yield declines of 66% in a moderate climate warming scenario. Yield losses of this scale are possible across all of Brazil’s key agriculture exports (soy, maize, rice and coffee).

2 **Brazil’s energy** security is heavily reliant on a stable local climate – hydropower and biofuels provide 74% of Brazil’s energy.

Brazil has the second largest installed hydropower capacity globally which supplies 66% of Brazil’s electricity. Recent droughts curtailed supply and caused higher electricity costs for customers. Deforestation will exacerbate this trend, risking power shortages and economically harmful price spikes.

Brazil has a large biofuel sector based on a reliable domestic supply of soybeans and sugar cane, which provides nearly a quarter of its transportation fuel. This exposes Brazil’s transport sector (particularly the 65% that goes by road) to the same local climate change risks as the agriculture sector.

These supply-side challenges will be exacerbated by the increasing demand for cooling in a hotter climate, adding additional load on a capacity-constrained system.

3 **Productivity** – higher temperatures and more frequent and persistent periods of extreme heat reduce economic capacity, particularly for outdoor work which provides employment to 18% of Brazil's workforce.

4 **Health** – under more extreme (Amazon tipping point) scenarios risk of death will be a greater threat than reduced productivity for more than 11 million people in Brazil and the city of Manaus (capital of the Amazon region and home to over two million people) could become uninhabitable.

Urban Heat Islands can experience temperatures 10-15ºC higher than surrounding areas and are frequently associated with areas of social deprivation, highlighting that the risk of death will threaten the 16% of Brazil's population living in slums years before it impacts those living in the richer suburbs or rural areas.

5 **Transport** – falling river levels will threaten inland waterway transport. Although this currently only accounts for 6% of Brazil's overall transport volume, it is an important low-cost, reliable transportation method for agriculture, mining and industrial goods. It has significant growth potential, particularly as a more sustainable transport method than the 65% of goods that currently goes by road (which has a CO_2 footprint five times higher than river transport and is heavily dependent upon biofuels as noted above).

6 **Zoonotic diseases** – deforestation brings humans into closer, more frequent contact with animals that can act as vectors for novel diseases against which humans have no resistance. This fat-tail risk is hard to quantify but the recent Covid-19 pandemic illustrates the potential consequences for Brazil (more than 500,000 deaths and over 20 million people infected, and a 4.1% drop in GDP – the steepest fall since 1990).[i]

Investor call to action

Sovereign bond investors

Investors holding Brazilian sovereign bonds are exposed to significant risks from deforestation, particularly those holding longer-dated bonds. To protect the value of their investments they should:

- Engage with the Brazilian government to properly fund monitoring and enforcement measures to prevent deforestation.
- Pressure the Brazilian government to bring forward to 2025 their NDC commitment to stop deforestation by 2030.
- Engage with the Brazilian Central Bank to support its efforts to green the Brazilian financial system.
- Join the Investors Policy Dialogue Deforestation (IPDD) initiative.

Equity investors

Equity investors in domestic Brazilian agribusiness companies are obviously exposed to the macro-economic risks set out in this report, but importantly, so are investors in companies across the Brazilian economy.

Equity investors holding shares in multinational food system companies are also exposed through the supply chains of those companies because of Brazil's significance as a source of key ingredients.

Equity investors should:

- Establish and report the deforestation risk embedded in their portfolios, particularly the risks relating to Brazil.
- Engage with the companies they invest in to pressure them to establish and report on effective zero deforestation supply chain policies with respect to their direct and indirect suppliers to tackle deforestation in Brazil.
- Publish their zero deforestation policies and include their commitments in the fund documentation provided to their clients.
- Monitor and publicly report on their progress towards zero deforestation portfolios.

Bond investors

Local changing climate will impact crop yields and expose more growing areas to weather-related risks threatening soft commodity exports. Soybeans, Brazil's single largest export product (with exports of USD 28.6 billion in 2020) could experience yield declines of 66% in a moderate climate warming scenario. Yield losses of this scale are possible across all of Brazil's key agriculture exports (soy, maize, rice, coffee).

Credit rating agencies

Providers of debt finance should ensure their credit assessment models properly capture the macro-economic threats from deforestation (and do not discount them as 'beyond the investment horizon' or assume they are outweighed by near-term positives).

Credit rating agencies (CRA) need to do more to help their customers understand the specific threats posed by deforestation in Brazil. At present, CRA models focus on the blended average result of a multiplicity of factors and too often assume that climate-related risks are not impactful in the short term, ignoring the threat of tipping points and failing to highlight the 'fat-tail' risks that could result in significant losses.

Banks

Domestic and multinational banks have significant exposure to Brazilian agribusiness companies (including the multinational soft commodity trading companies such as Cargill, Louis Dreyfus, etc), and are obviously also significantly exposed to the wider Brazilian economy and the supply chains that depend upon it.

The latest Forest 500 report shows the extent to which banks are failing to tackle deforestation – continuing to lend to companies without taking any steps to ensure zero deforestation[1].

Banks exposed to deforestation risk in their lending portfolios should:

- Establish and implement strong zero deforestation commitments and policies, covering deforestation, conversion and associated human rights abuses.
- Join multi-stakeholder initiatives to enable cross-sector collaboration.
- Support initiatives focused on funding sustainable agribusiness practices[2].

[1] 93 of the 150 financial institutions most exposed to deforestation do not have a deforestation policy covering their investments and lending to companies in key forest-risk commodity supply chains https://forest500.org/publications/climate-wake-business-failing-hear-alarm-deforestation.

[2] Examples include IFACC (Innovative Finance for the Amazon, Cerrado and Chaco – https://www.tropicalforestalliance.org/en/collective-action-agenda/finance/ifacc and the RCF (Responsible Commodities Facility – https://sim.finance/responsible-commodities-facility).

Evidence that deforestation is changing Brazil's climate

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

The benefits provided by forests

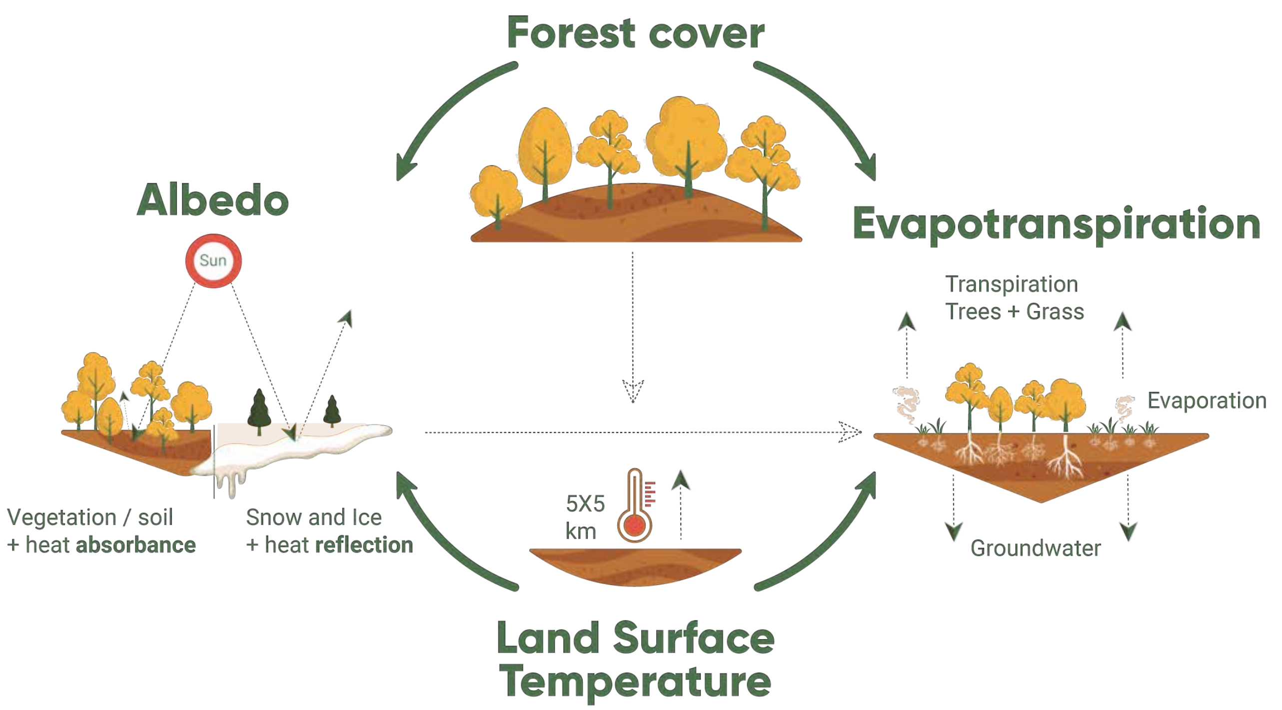


Figure 1: Relationships between forest cover and climatic variables (albedo and evapotranspiration). Source: Impacts of forestation and deforestation on local temperature across the globe.[ii]

Forests are a key component in the water, carbon and energy cycles, and so play a key role in regulating local and regional climate and weather.

- They help 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 precipitation patterns through evapotranspiration. 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 rainforest is so vast, it has a very significant impact on regional weather patterns and is an essential source of water for rivers across South America, particularly the La Plata River basin. 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.

The extent of deforestation

Since large scale deforestation started in the Amazon in the 1970s, 20% of the forest has been lost or degraded. In 1975 the Amazon was 99.4% of its original size but has shrunk and continues to be cleared or degraded through logging and burning, for agriculture, timber and mining - see Figure 2.

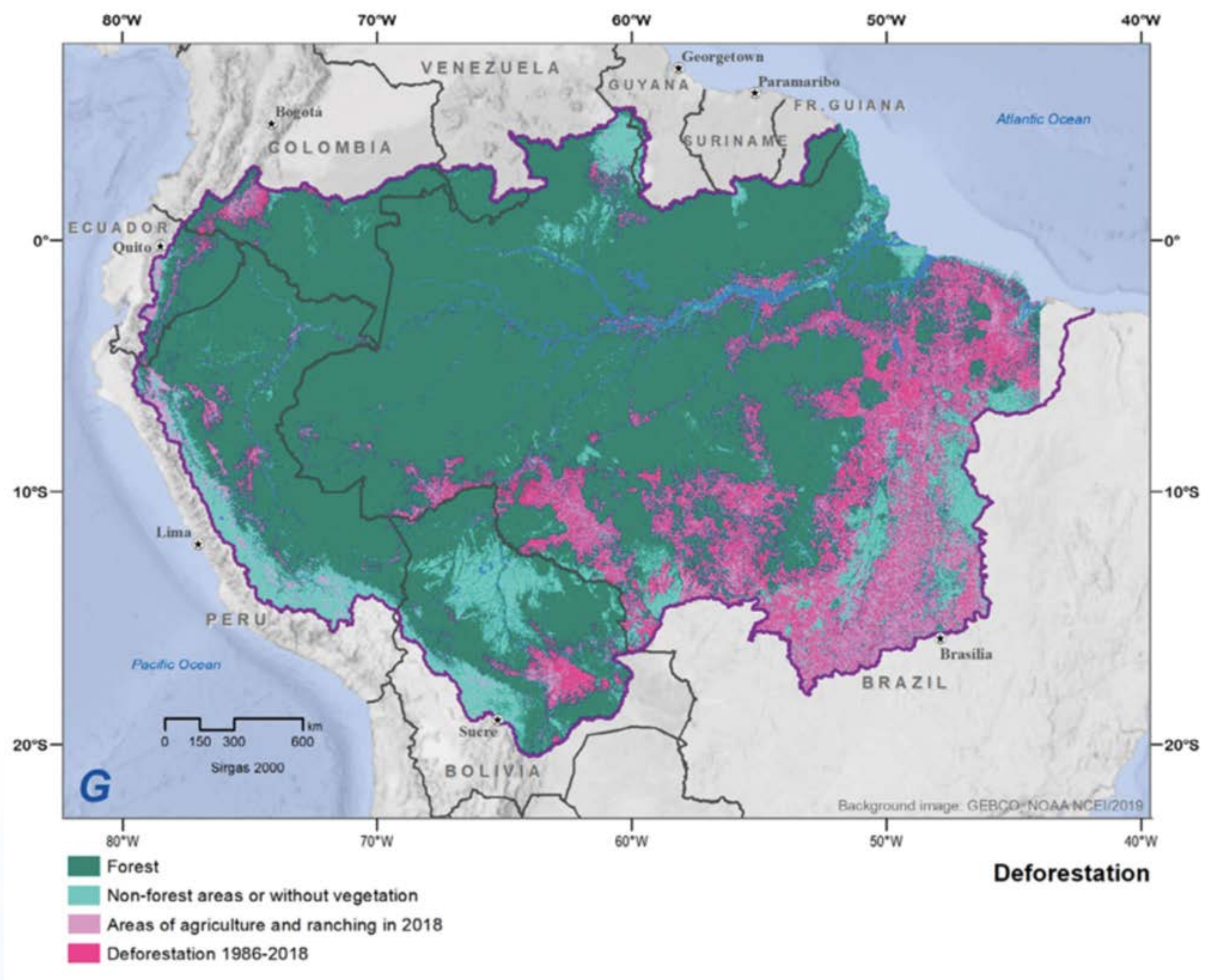
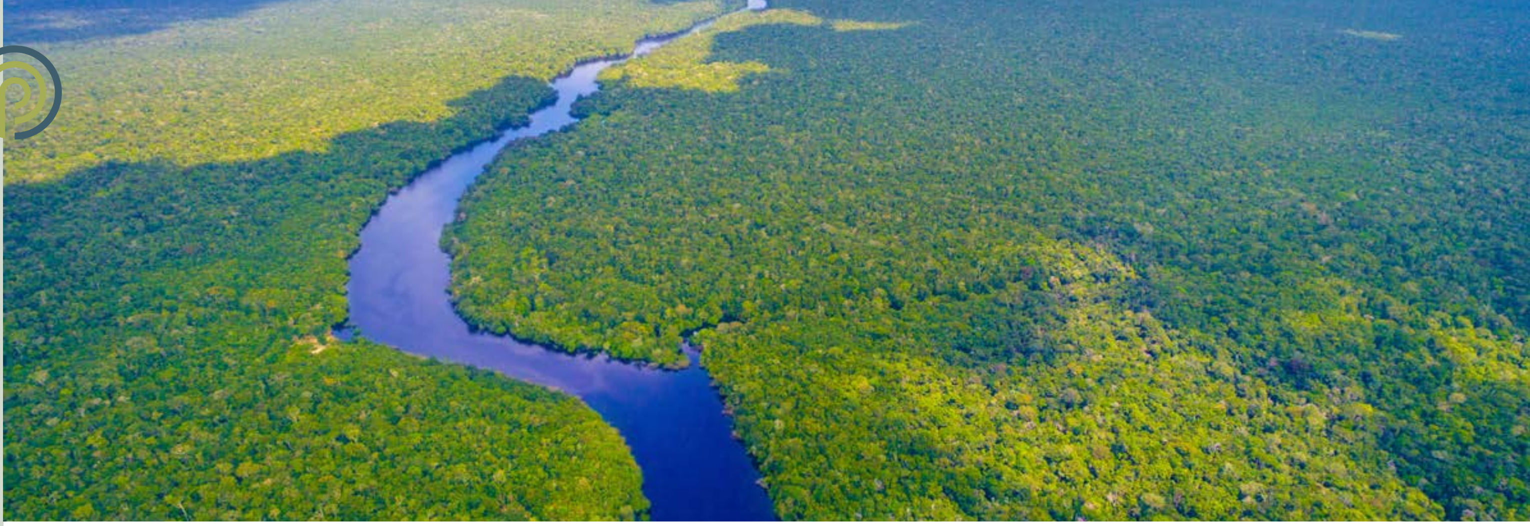


Figure 2: Extent of Amazon deforestation.
Source: The Amazon We Want Science Panel for the Amazon, Chapter 24: In brief resilience of the Amazon Forest to global changes: Assessing the risk of tipping points.[iii]

There is evidence that deforestation is impacting Brazil's hydrological cycle and contributing to changes in the local climate.



Flying rivers

The Amazon River and hydrographic basin contains 20% of the world's available fresh water. Every day, the Amazon pours around 17 billion metric tonnes of water into the Atlantic Ocean. In addition, on a normal sunny day, the trees of the Amazon rainforest recycle a further 20 billion tonnes of water into the air through evapotranspiration which is transported to other parts of the forest and agricultural land as rainfall[iv] – see Figure 3.

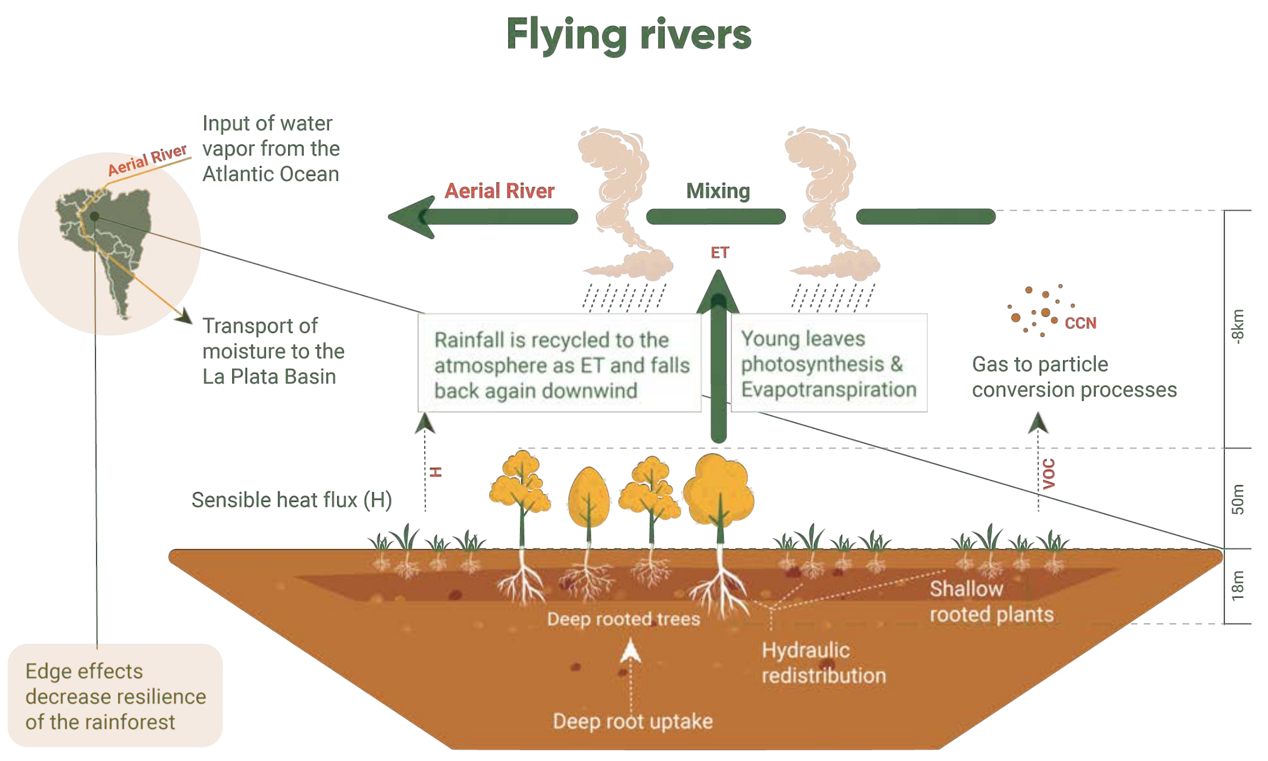


Figure 3: Diagram of the main biogeophysical processes of biosphere-atmosphere interactions in the Amazon.[v]
Source: The Amazon We Want, Chapter 7, Biogeophysical Cycles: Water Recycling, Climate Regulation.[iv]

The impact of deforestation on rainfall

Argemiro Teixeira Leite-Filho et al.'s 2019 paper[vi] concluded that the rainy season is likely to arrive later in the Southern Amazon in areas where deforestation rates are higher, and that there is an increased probability of dry spells early and late in the rainy season. Their correlation analysis indicates a delay in the onset of the rainy season of 0.12-0.17 days for every percentage point increase in deforestation.

This may sound relatively trivial, but the effect is cumulative and builds on the impact from the significant amount of deforestation that has already occurred.

Their analysis highlights the extent to which the dry season has already lengthened and become less predictable due to changes in evapotranspiration and albedo (surface reflection) from the Amazon – see Figure 4.

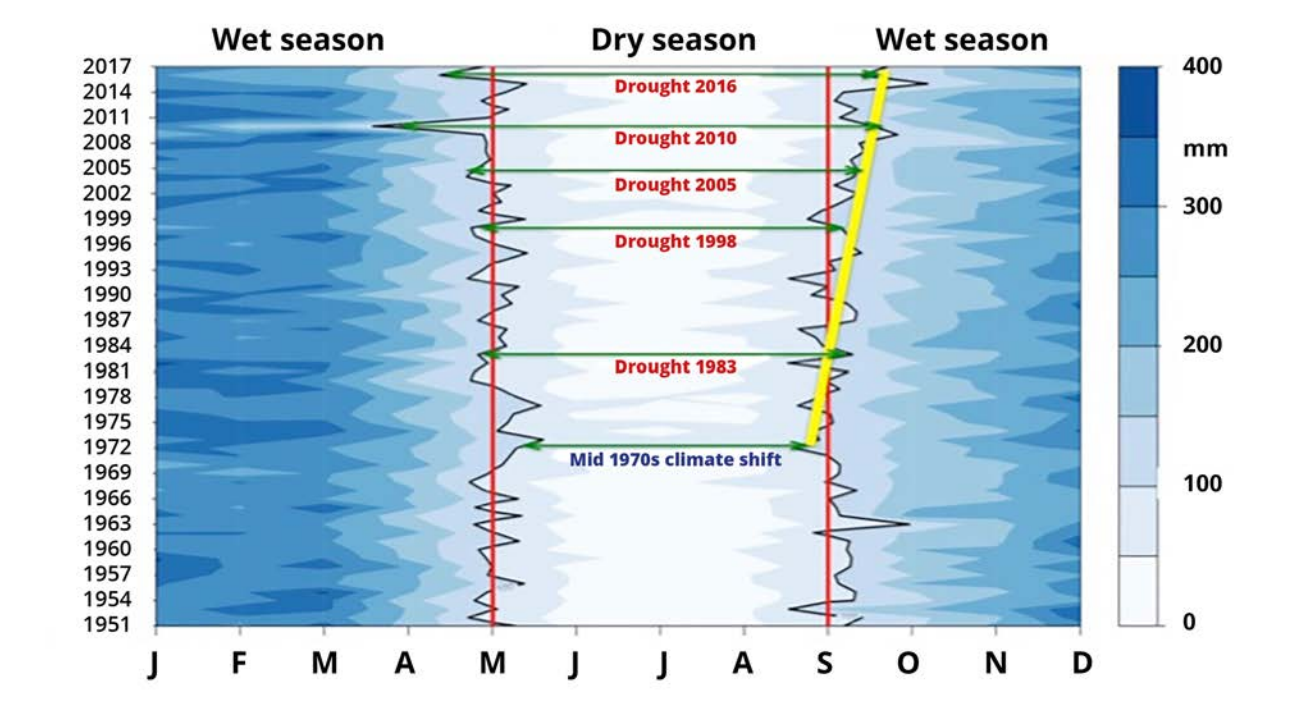


Figure 4: Diagram showing monthly rainfall from 1951 to 2017 for Southern Amazonia (mm/month).[vii] Drought years are indicated with green lines, onset and end of the rainy season with red, tendency for a longer dry season after the mid-1970s with a yellow line.

Further evidence of changing precipitation patterns in Brazil comes from hydrological data from the Brazilian National Electric System operator, ONSE[3], which shows that the precipitation pattern observed in 2021 in the Paraná River basin was the worst in 91 years.[viii]

The precipitation deficit accumulated in the last 10 years in some hydrological basins that are crucial for generating hydropower has reached a value greater than the total rainfall that occurs on average in a year, highlighting the fact that these deficits are unlikely to be restored by future rainfall if this pattern persists – see Figure 5.

[3] Operador Nacional do Sistema Elétrico.

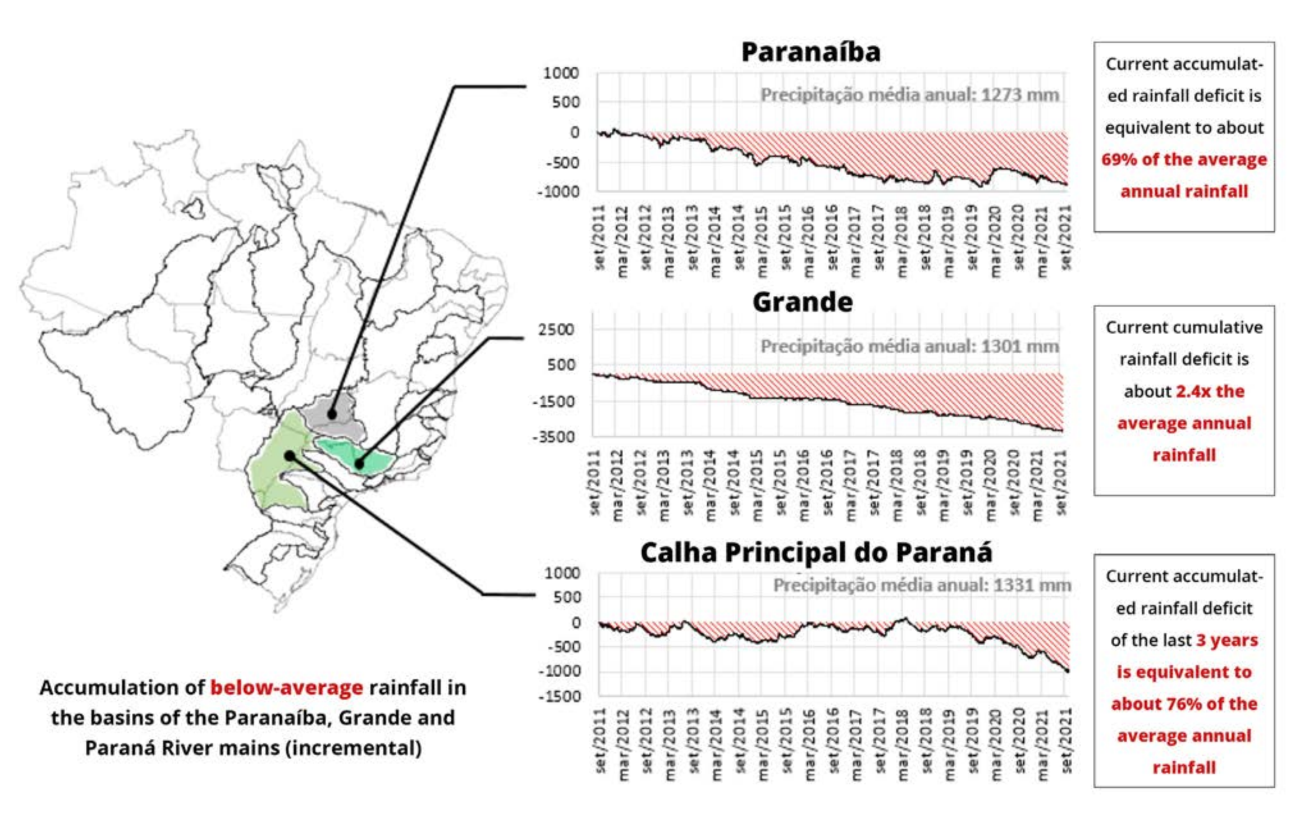


Figure 5: Cumulative below normal rainfall accumulation over 10 years from 2011–2021 in the Paranaíba, Grande and Calha Principal do Paraná River basins).[ix]

The accumulated deficit of precipitation in Paranaíba Basin amounts to 69% of the average annual precipitation. For the Grande, the deficit is equivalent to 2.4 times the normal annual rainfall, and for the Calha Principal do Paraná the deficit is 76% of annual rainfall.

Even more evidence of shifting rainfall patterns across Brazil comes from INMET, the Brazilian National Institute of Meteorology. A comparison of annual average rainfall over the last 30 years (1991–2020) to the prior 30 years (1961–1990) shows that the North and, in particular, the East of the country are receiving less rainfall, while areas to the South and Northwest are receiving more rainfall – see Figure 6.

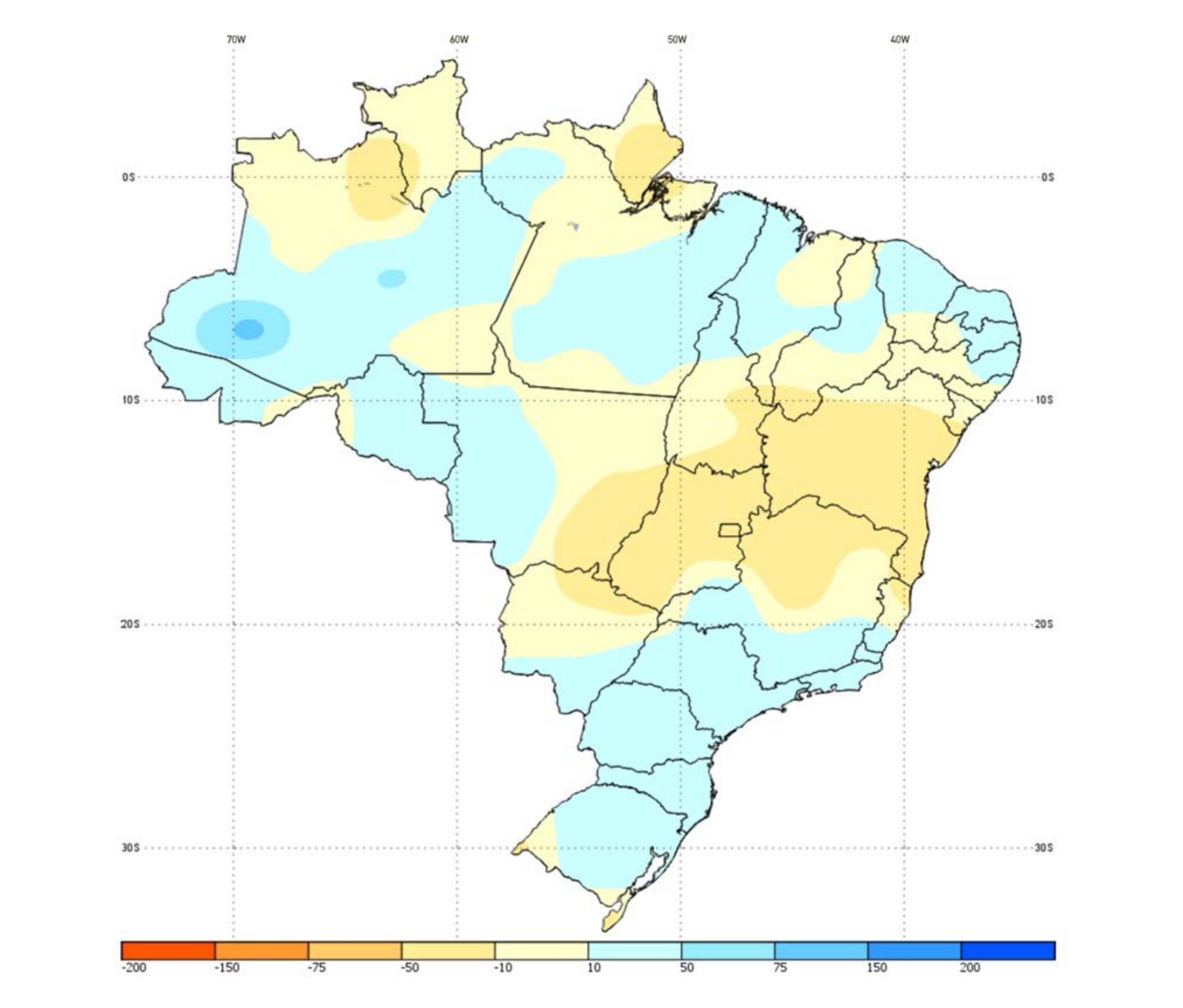


Figure 6: Difference between normal accumulated precipitation of Brazil (1991–2020 – 1961–1990).[x]

The impact of deforestation on temperature

Forests have a local cooling effect since heat is more readily absorbed by forests[4] in contrast to other surfaces such as concrete or pasture, which reflect the heat back into the atmosphere, warming the air above them. This cooling effect is magnified by the evapotranspiration from the forest because the water vapour released transports the heat into the upper atmosphere creating a cooling effect at ground level (not dissimilar to an air-conditioning unit).

Deforestation of the Amazon is destroying the equivalent of Brazil's air-conditioning unit. It disrupts the cooling effect contributing to further warming in the region and increasing the likelihood of more frequent and intense heatwaves.

[4] The reflective quality of a forest (or any other surface) is referred to as its 'albedo'. The more reflective a surface is the higher the albedo value.

A study by Prevedello et al.[xi] examined the impact of deforestation on local temperatures and concluded that tropical forest cover losses of c.50% are associated with increased local land surface temperatures of 1.08°C as a result of changed albedo and reduced evapotranspiration.

Prevedello's study also looked at two future deforestation scenarios for Brazil out to 2050. The first, a 'business-as-usual' scenario[5] of continuing deforestation with little in the way of control against the illegal clearing would increase local land surface temperatures by up to 1.45°C.[xii]

This increase would be in addition to temperature rises due to global climate change meaning that local temperature increases by 2050 could exceed 3°C even in a situation where the global average rise was in line with the Paris target of 1.5°C.

Their second scenario assumes full implementation of the Brazilian Forest Code (a national law passed in 1965 intended to reduce illegal deforestation) and assumes no illegal deforestation as well as restoration of forests in legal reserves, amnesty for previous deforestation on small farms and the enforcement of the Atlantic Forest Law. In this scenario, there are 79,000 km^2 of deforestation and reforestation of 110,000 km^2 of previously illegally deforested land. In this scenario, they expect land surface temperature to rise an average of 0.02°C in addition to warming from global climate change.

Figure 7 shows the results of their scenario modelling.

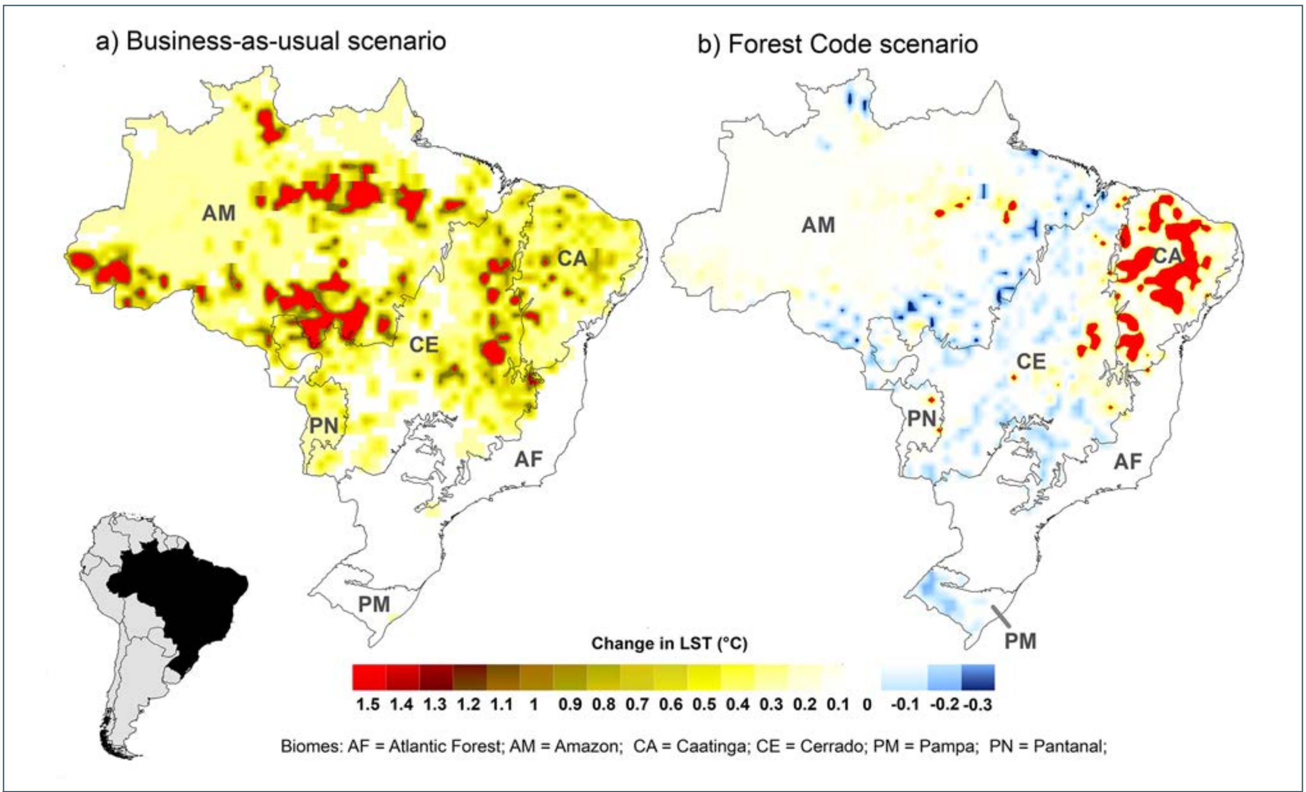


Figure 7: Predicted future changes in annual land surface temperature (LST) for Brazil from 2010 to 2050.[xiii]

The Prevedello paper assumes that the Amazon continues to function as a rainforest in spite of the extent of the deforestation – other studies have challenged this assumption and examined what could happen if the Amazon crossed a 'tipping point' as a result of deforestation and climate change.

[5] This scenario assumes 606,000 km^2 of deforestation between 2010 and 2050, equivalent to 15,000 km^2 per year. By way of reference, deforestation of the Legal Amazon 1988–2021 totalled 440,000 km^2, equivalent to 13,000 km^2 per year.

Amazon tipping point – eco-disaster (200GT of CO_2 released)

Tipping point theory

The Amazon biome requires a specific climate – a range of temperature and moisture that allows the forest to self-sustain.

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 initiate a chain of self-reinforcing consequences which would bring about profound changes to the climate and hydrological cycle of the region. This in turn would cause systemic changes within the forest's ecosystem so that it would cease to be a rainforest and become a savannah-like ecosystem.

Already, there are parts of the rainforest which have been unable to regenerate after fire, and in some remote parts of the Amazon, far from the agricultural frontier, floodplain forests have been replaced by white-sand savannas containing dry-affiliated vegetation.[xv]

Regional climate change feedback loop

Although deforestation is regarded as a key driver that could lead the Amazon to a tipping point, regional climate change could also have this effect. M. Hirota et al.[xvi] outlines a wider variety of drivers highlighting the potential for regional and global climate change to breach tipping point thresholds for the Amazon rainforest:

- Annual rainfall totals below 1,000-1,500 mm/year
- Dry season length longer than seven months
- Cumulative water deficit values exceeding 200-350 mm/year
- An increase of 2°C of the equilibrium temperature of the Earth
- Deforestation of the whole basin surpassing 20-25%

Given the Amazon's significance for Brazil's climate, there is a significant risk that global and regional climate change combine with local deforestation to drive a feedback loop where the Amazon ceases to function as a rainforest and this in turn leads to more dramatic changes in Brazil's climate, which in turn will cause more harm to the Amazon – see Figure 8.

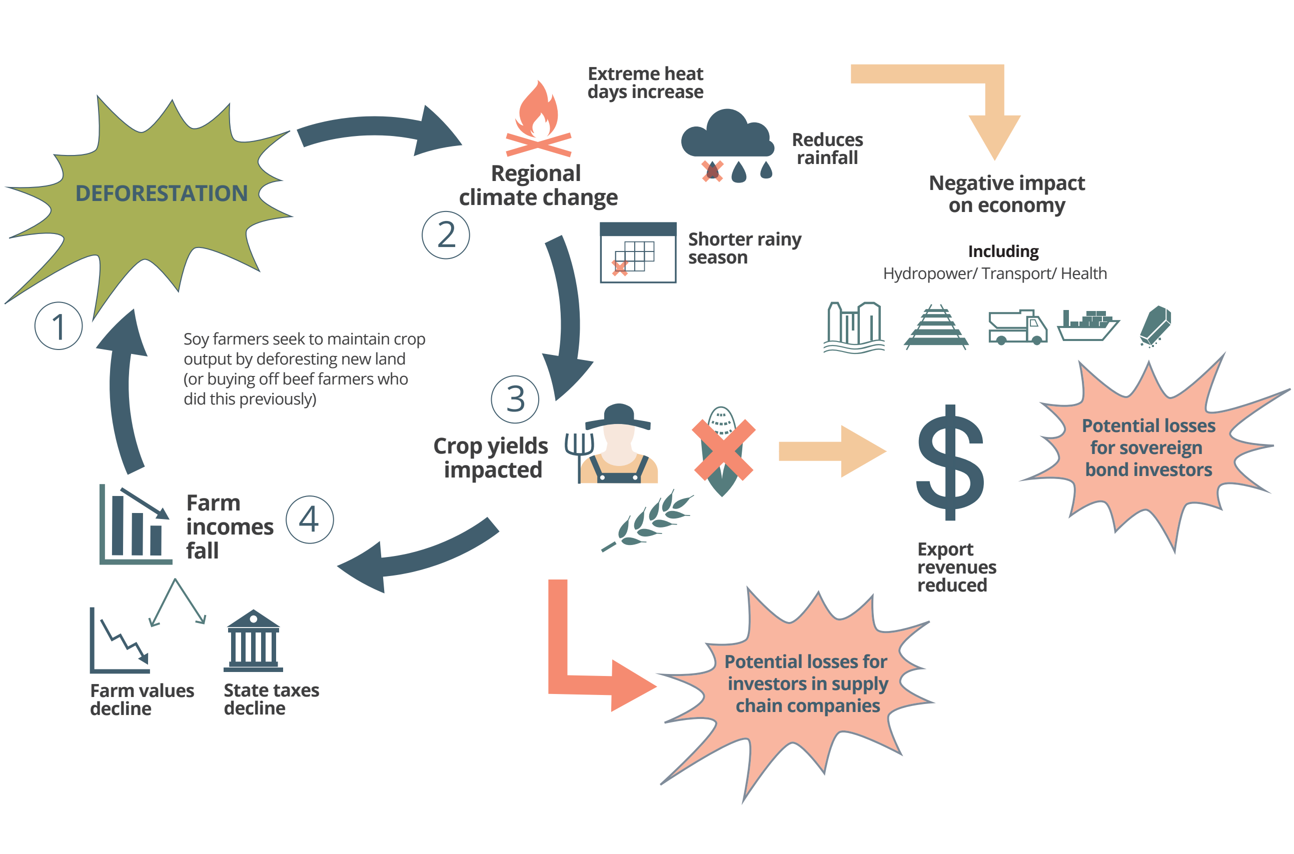


Figure 8: The deforestation/regional climate change feedback loop. Climate change then leads to natural deforestation. Source: Planet Tracker.

Tipping point consequences

Passing this tipping point could have dire consequences for the forest and for the climate of both Brazil and the rest of the world.

Climate

The regional climate effects of deforestation discussed earlier in this report would be the same under a tipping point scenario but would occur more rapidly and be more extreme. The Amazon's evapo-transpiration system would alter dramatically under a tipping point scenario, impacting regional rainfall patterns, reducing total rainfall, lengthening the dry season, and increasing the likelihood of more frequent and intense drought. The weakening of the local cooling effects of evapotranspiration will also lead to further local warming which could increase the likelihood of more frequent and intense heatwaves.

Modelling local temperatures under the Amazon tipping point (savannisation) scenario

De Olivera et al. published a study in 2021[xvii] which examined how savannisation of the Amazon Basin would influence the occurrence of heat stress under two climate change scenarios (RCP4.5 and RCP8.5).

Their methodology looks separately at the effects of global climate change and deforestation, taking a 'worst case' deforestation scenario, that the entire Amazon is replaced by savannah.

To assess heat stress in the scenarios they analysed, they calculated wet bulb globe temperatures (WBGT) combining air temperature and humidity. When WBGT exceeds 26°C, an hourly rest period during heavy work is recommended. At WBGT 34°C, suspension of work activities is recommended. Under more extreme conditions, a WBGT >40°C could endanger life for people with conditions making them vulnerable to heat stress.

The scenario combining the effects of deforestation with global warming presents the most extreme levels of in-shade WBGT heat stress risk in most of the Amazon region, showing an increase of up to 11.5°C under the RCP8.5 scenario by the end of the twenty-first century relative to the present conditions.

For most of South America apart from the Amazon Basin region, their model showed average maximum daily in-shade WBGT values increased by 2-5.5°C during the hottest months for 2073–2100 compared with present conditions. They found that the effects of climate change under the more extreme RCP8.5 scenario were comparable in magnitude to the local effects of deforestation on creating heat stress. The combined effects of deforestation with global climate change produced the most extreme heat stress in Northern Brazil where the expected heat stress could exceed the limits of human adaptation by 2100.

Biodiversity loss in the Amazon

The negative impact on biodiversity would be considerable. The Amazon rainforest is home to an estimated 390 billion trees, containing at least 30,000 species of plants, 1,300 species of birds and 300 species of mammals. Some studies have estimated that the Amazon ecosystem harbours between 10% and 15% of land-based biodiversity.[xviii]

Attributing a value to this biodiversity is extremely difficult but the option value associated with the potential for currently unidentified plants and animals within the Amazon biosphere to be discovered to be valuable sources of medicinal drugs (as just one example) must be significant – and this value will be lost to the Brazilian economy if the species disappear.

In addition to this, habitat destruction on this scale is likely to have other hard-to-predict consequences for the ecology of the country, raising the potential threats from issues such as **zoonotic diseases**[xix] (and the recent Covid pandemic shows the economic and social destruction that can result from such incidents).

CO_2 release

Should the Amazon Rainforest cross the tipping point, the amount of CO_2 that could be released from the trees and soil as the forest dies is colossal and would severally threaten our efforts to limit planetary warming.

Nobre et al. estimate that the Amazon rainforest stores 150-200 Gt (gigatonnes) of CO_2 which would be at risk of entering the atmosphere if the forest dies.[xx] This would use up half of the remaining carbon budget for a 50% chance of limiting warming to 1.5°C (420 $GtCO_2$) by 2050[xxi] and would be equivalent to over three times the current annual anthropogenic emissions (58.1 $GtCO_2e$[6]).[xxii]

Social consequences (Indigenous Peoples)

In addition to the impacts outlined above, destroying the Amazon will threaten the livelihoods and the very existence of the numerous Indigenous People groups that live there, destroying thousands of years of irreplaceable culture.

[6] This figure includes the effect of land use change, the estimated figure excluding LUC is 51.5 $GtCO_2e$.

Economic consequences of regional climate change

Agribusiness consequences

Agriculture is fundamental to the Brazilian economy. In 2021, the sector contributed 27.6% of GDP when combining the contributions from farming inputs[7], farming, livestock, industry and agricultural services[xxiii] and provides employment for 20% of Brazil's total occupied population, which is equivalent to 18.2 million people. 45% work directly in primary production.[xxiv]

Agriculture is also the largest component of Brazil's external trade, with agricultural products responsible for 39% of total exports in 2020 (OEC World).[xxv]

Globally, Brazil is the largest exporter of soybeans, coffee, frozen beef and fruit juices and the third largest exporter of maize (OEC World).[xxvi]

Climate is key to the success of Brazil's agriculture sector. Brazil's climate provides ample freshwater, predictable precipitation and temperatures that support growing conditions. As we discussed in No Rain on the Plain,[xxvii] it has allowed Brazil to grow more than one crop on the same plot of land in the same year ('double-cropping').

Climate change will impact Brazil's agricultural productivity in two ways:

1 Crop yields may be reduced.

2 The area of land suitable for growing particular crops may be reduced.

Extreme weather over the past decade highlights how sensitive agricultural output can be to drought conditions.[xxviii]

- In 2012 production of beans and corn crops experienced losses exceeding 40% in the Caatinga region. The Pampa biome also experienced production losses of 38% in the soybean crop that year.
- In 2015, the Coastal Zone experienced losses of 60.9% in the wheat crop.
- 2012 featured extremely dry conditions in north-eastern Brazil and in 2015 most of Brazil suffered a wide and severe rainfall deficit.

Figure 9 highlights how rainfall has varied over the past decade.

[7] E.g. Producers of fertilizers, farm machinery, etc.

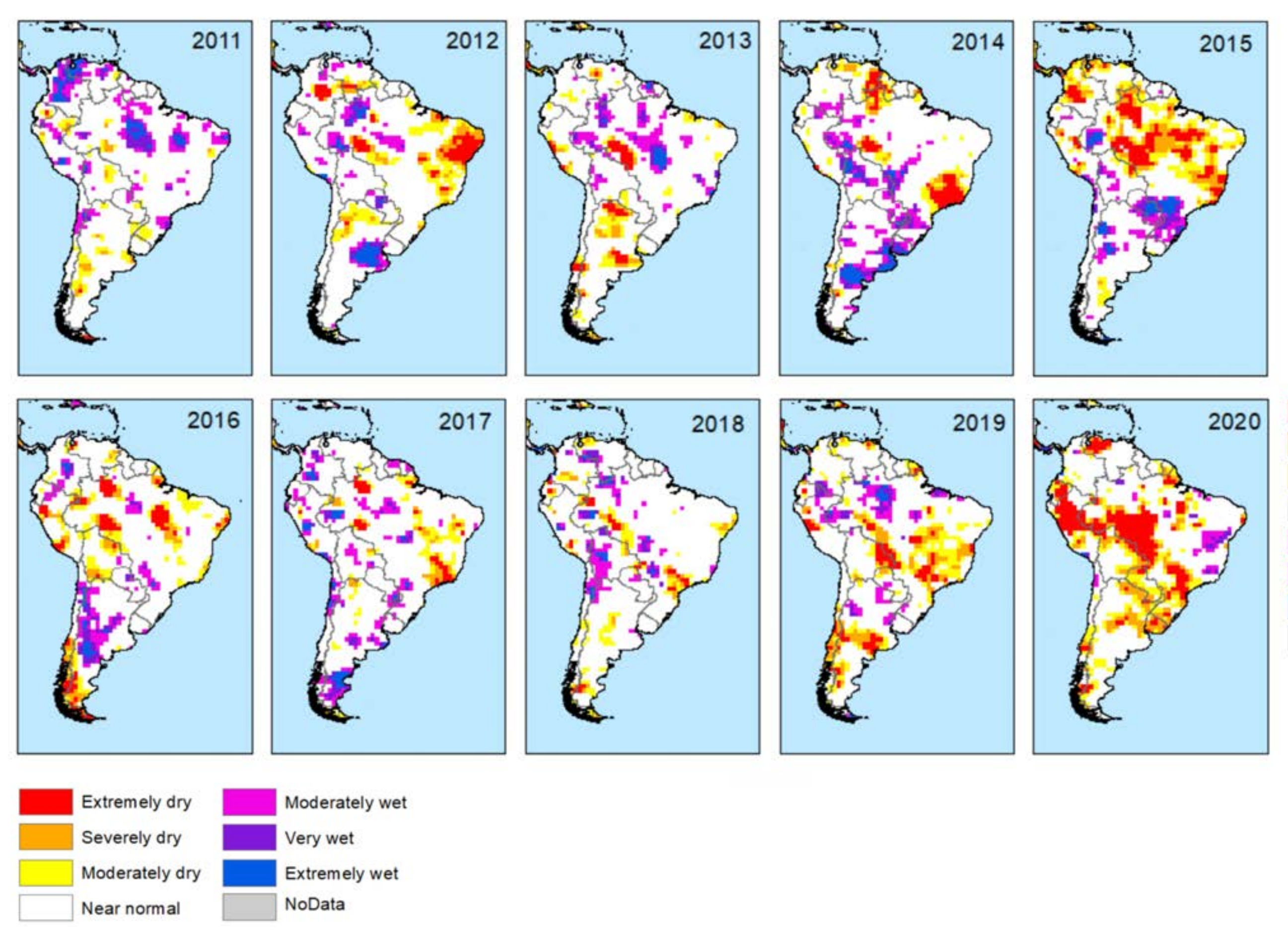


Figure 9: Rainfall in South America – 10 years overview 2011–2020.[xxix]

Academics have examined the potential impact of climate change on Brazil's soft commodity output by 2050. Examples of their conclusions include:

- Soy and maize yields could fall by more than 66% and 50% respectively
- 'Low risk' areas for growing soy could shrink by 65%
- 'Low risk' areas for growing coffee could shrink by 76%

We summarise these findings in the following sections.

Soy and maize yields could fall by more than 50%

The impact on agricultural production in Brazil from climate change has been the subject of several academic studies which have examined the potential change in productivity for Brazil's key crops and livestock products.[xxx]

The following is a summary of modelled climate impacts on key crops for Brazil, published in a 2012 report for LCSAR and The World Bank[xxxi] – see Table 1. The study considers how two climate scenarios would impact crop productivity through rainfall and temperature. The two scenarios are:

Scenario A1b represents a 'high', (business as usual) emissions scenario and

Scenario B1 represents their 'low' scenario of greenhouse gasses stabilising (in CO_2 equivalent at 550 parts per million)[8].

Table1: Modelled climate impacts on key crops for Brazil.[xxxii]

Product	Productivity Average 2008-2017 (t/ha)	Projected Productivity 2050 (t/ha) A1B	Projected Productivity 2050 (t/ha) B1	Variation (%) A1B	Variation (%) B1
Soybeans	2.9	0.6	1	-79.6	-66.2
Wheat	2.5	1.3	1.8	-46.2	-26.1
Maize	4.7	1.5	2.2	-68.4	-53.44
Rice	4.9	4.2	4.4	-15.2	-11.1

In the 'high' emissions scenario, crop yields could be significantly reduced by climate change for soybeans (-80%), maize (-68%) and wheat (-46%). Even in the 'low' (or stabilising) emissions scenario soybeans and maize yields fall by more than 50%.

Rice shows less downside risk than other crops, both in terms of productivity and risk of production. Rice has higher thermal requirements than other crops, so its production generally benefits from increases in temperature; however, in Brazil, the thermal conditions for photosynthesis are already close to the ideal, leading to a modelled reduction in yield.

Changing climate is likely to have further consequences for agricultural output as rainfall patterns change and become increasingly variable and leading to less reliable production.

[8] For reference, in 2021, atmospheric CO_2 reached 414.7 parts per million (NOAA). Based on the Transient Climate Response (TCR) estimated from IPCC AR5, the estimated concentration of CO_2 at 1.5°C and 2°C are 507 ppm and 618 ppm respectively. Source: 'How much CO_2 at 1.5°C and 2°C?', Met Office, https://www.metoffice.gov.uk/research/news/2018/how-much-co2-at-1.5c-and-2c.

'Low risk' crop growing areas for soy could shrink by 65%

A study by the Ministry of Science, Technology, Innovations and Communications (MCTIC) in 2016[xxxiii] examined how areas considered 'low-risk' for key crops could change by 2050 under two climate scenarios, SWL2 and SWL4 (Specific Warming Level) for key crops for Brazil. This is summarised below in Table 2.

For soy, there could be a large decrease in 'low-risk' production areas, potentially declining by 65.7% in the SWL2 scenario and by 81.2% in the SWL4 climate scenario. The actual soy yield would not be forecast to decline by this amount; this just highlights that under such warming scenarios, water deficits will be more likely and crop yields will be less predictable unless there is large-scale investment in irrigation infrastructure that would maintain water availability comparable to the base scenario[9]. From the farmer's perspective this increase in risk will equate to higher costs and lower profits.

*Table 2: Change in low risk soy growing areas under two different climate scenarios.[xxxiv] Source: MCTI, 2016. *first crop **second crop*

Crops	The total low-risk area in the base year (2012) (million ha)	Heat level			
		Low-risk areas in SWL2		Low-risk areas in SWL4	
		Total (million ha)	Variation in relation to the base year (%)	Total (million ha)	Variation in relation to the base year (%
Rice	2.41	2.23	-7.5	2.08	-13.9
Beans*	1.96	1.06	-45.6	0.84	-57.1
Beans**	1.02	0.40	-61.2	0.29	-71.9
Corn*	7.60	6.65	-12.5	5.91	-22.2
Corn off-season crop**	7.47	1.13	-84.9	0.20	-97.3
Soybean	24.98	8.56	-65.7	4.69	-81.2
Wheat	1.91	1.60	-16.5	1.46	-23.8

[9] Currently only 3% of agricultural land is irrigated and there is limited potential to increase this – see page 26.

'Low risk' crop growing areas for coffee could shrink by 76%

Brazil is the largest exporter of coffee globally.[xxxv] A paper by Roman Grüter et al.[xxxvi] examines the impacts of climate change on coffee production under three climate scenarios to 2050:

- RCP 2.6 (low emissions);
- RCP4.5 (intermediate emissions); and
- RCP8.5 (high emissions).

Similar to Fernandes et al. 2012, this study models how temperature and rainfall in three future climate scenarios to 2050 will impact the suitability of growing areas for coffee production. Suitable coffee growing areas globally and in main producing countries are divided into four categories: S1: highly suitable; S2: Moderately suitable; S3: Marginally suitable; and N: Unsuitable, for current (2000) and future (2050) conditions under the three scenarios – see Table 3.

Table 3: Modelled climate impacts on growing suitability areas for coffee [xxvii]

Suit Class	2000 (km2)	RCP 2.6		RCP 4.5		RCP 8.5	
		2050 (km2)	Δ (%)	2050 (km2)	Δ (%)	2050 (km2)	Δ (%)
WORLD TOTAL							
S1	36,240	16,540	-54.4	16,777	-53.7	14,678	-59.5
S2	5,709,608	3,951,207	-30.8	3,679,863	-35.5	3,369,550	-41.0
S3	14,709,645	15,118,407	2.8	13,995,976	-4.9	12,787,405	-13.1
N	104,044,240	105,413,581	1.3	106,807,118	2.7	108,328,100	4.1
BRAZIL							
S1	5,934	1,421	-76.1	1,268	-78.6	161	-97.3
S2	1,822,032	1,311,548	-28.0	1,161,921	-36.2	1,040,958	-42.9
S3	2,430,089	2,536,454	4.4	2,427,693	-0.1	1,939,711	-20.2
N	4,099,828	4,508,459	10.0	4,767,001	16.3	5,377,052	31.2

Brazil currently has the largest global share of suitable areas for coffee production (S1 & S2). However, in all future climate scenarios the most suitable areas (S1) could be reduced by 76% and S2 by 28%, even in the least demanding climate scenario – see Figure 10.

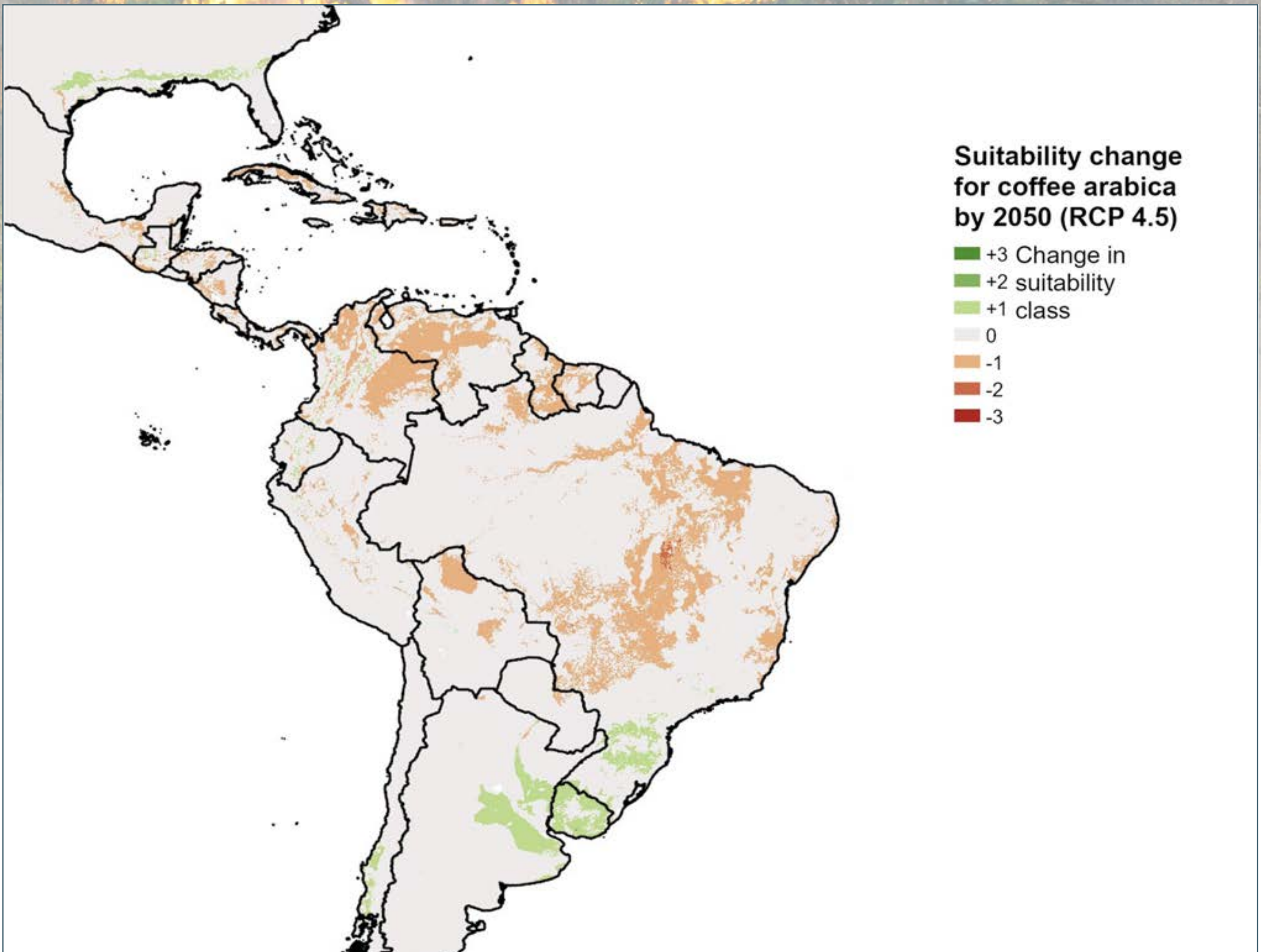


Figure 10: Map showing the impact of climate the suitability of areas for coffee growing in Brazil (intermediate scenario).[xxxviii]

Shrinking areas suitable for crops could drive further deforestation

For all of Brazil's key crops, climate change will shrink the land area that can be regarded as 'low risk' for agriculture; indeed, some areas will become unsuitable for cultivation without investment in irrigation infrastructure. To meet the expected demand of a growing domestic population and to meet demand in the export market farmers could be tempted to deforest new areas to expand the planted land area for crops to maintain output in a lower-yielding environment. This is the deforestation feedback loop discussed in Planet Tracker's report from September 2021, No Rain on The Plain – see Figure 11.

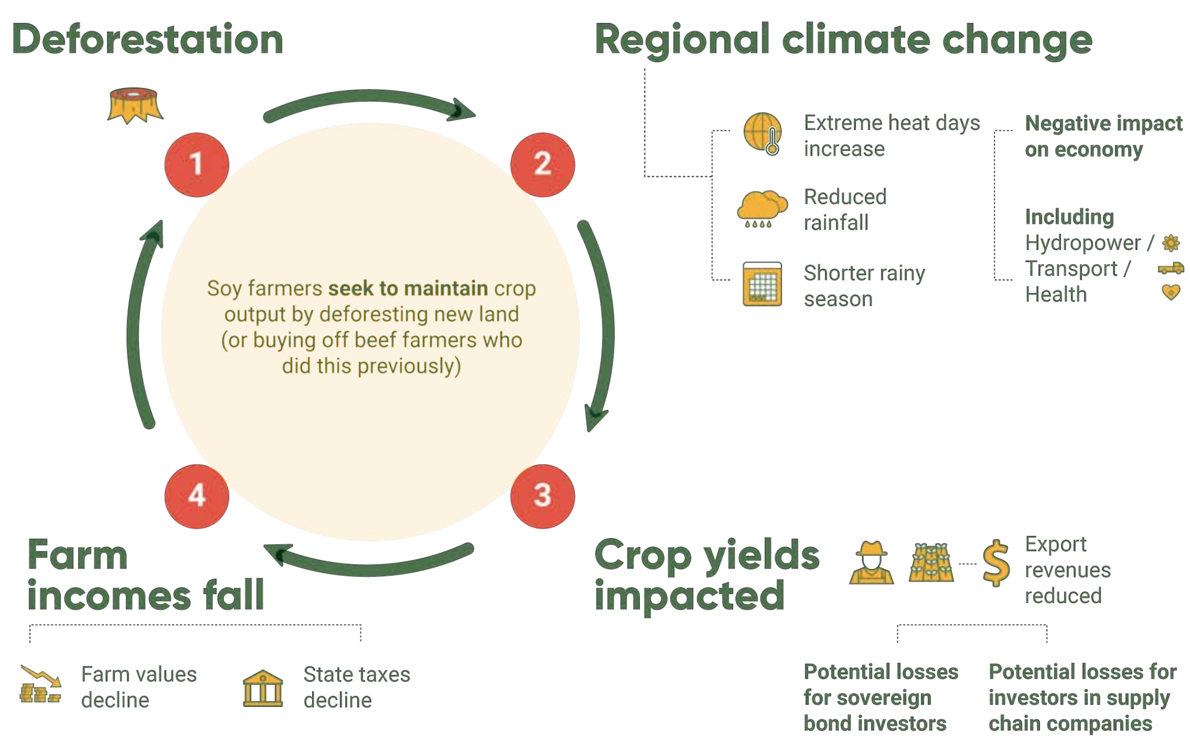


Figure 11: The Deforestation-Rainfall Feedback Loop.[xxxix]

The potential increase in planted area just to meet Brazil's domestic demand under a lower yield, higher production risk environment is significant. Figure 12 illustrates the increase.

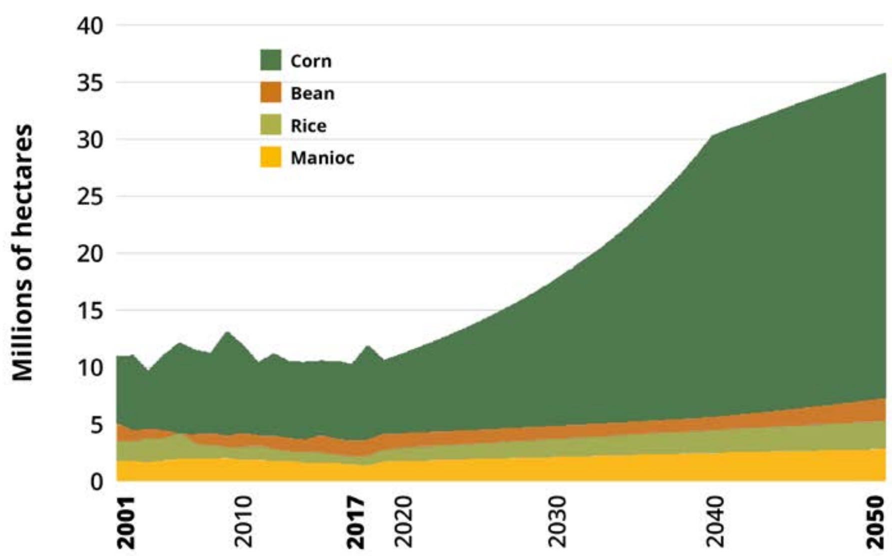


Figure 12: Potential increase in planted area in a lower yield, higher risk environment.[xl]

Increased irrigation could help but not if water is scarce

Currently only 3% of agricultural lands in Brazil are irrigated,[xli] leaving most areas reliant on natural rainfall and therefore vulnerable to a deficit in rainfall during critical periods in the growing cycle. The area irrigated has increased significantly – from 1.5 million hectares in 1980 to 7 million hectares in 2015 – and is projected to reach 10 million hectares by 2030.

However, significantly expanding the area under irrigation beyond this will be challenging, as an increase in agricultural use would be at the expense of other users of water, most importantly potentially reducing the supply of water available downstream for the hydropower sector which already faces its own challenges in a drier climate (discussed in the next section).

The potential impact on crop yields outlined above does not consider any additional adaption that could help maintain productivity as climate changes. There will likely be opportunities for farmers to use novel genotypes of crop as they are developed that will preserve yield as water availability is reduced and temperatures shorten the growing cycle. However, these crops are not yet available and there is no guarantee that they will be developed (or, if they are, that they will be as profitable).

Infrastructure will be threatened

The agribusiness sector will be most at risk from regional climate change, but other sectors of the economy will also be threatened.

In a research paper in 2017, Mikosz estimated that out of all the economic losses suffered due to climate between 2005–2015, 67% of the total economic losses were in the agriculture and livestock sector, but damage to infrastructure was the second most significant category, representing 16% of the total losses.[xlii]

Energy security

Brazil's energy system is dependent on a predictable, reliable climate. Renewable sources make up 83% of Brazil's electricity mix, predominantly hydropower (66%) with a growing contribution from biomass, solar and wind – see Figure 13.

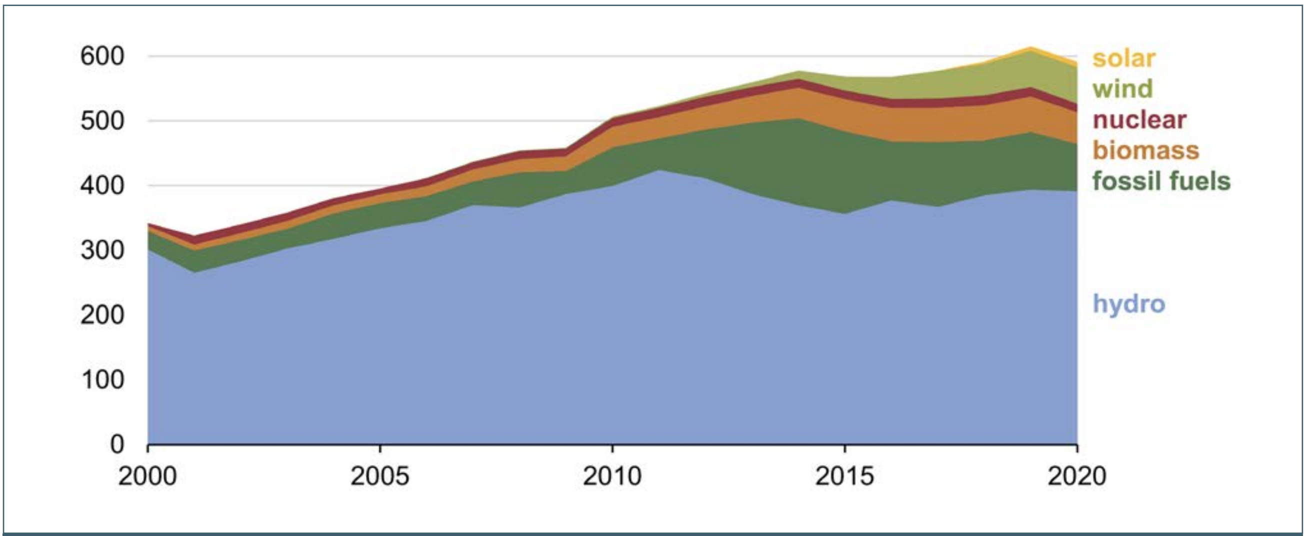


Figure 13: Brazil's changing electricity supply mix 2000–2020.[xliii]

The climate also provides conditions that have allowed Brazil to develop a biofuel industry which in 2018 supplied 23% of its transportation fuel using ethanol (19%) and biodiesel (4%).[xliv]

Sugarcane is the main raw material used for ethanol production and soybeans are the main raw material for biodiesel in Brazil.

Hydroelectricity is dependent upon precipitation

A reliable, cost-effective electricity supply is essential for the entire Brazilian economy. Industrial demand is responsible for 36.5% of electricity consumption, residential 27.6% and commercial 23.6%.[xlv]

Brazil's extensive use of hydroelectricity means that it is reliant on precipitation for 2/3 of the country's electricity and its hydroelectricity capacity is concentrated in three river basins, with approximately 73% of Brazil's hydropower plants located in the Paraná River, São Francisco and Tocantins River basins, further increasing the risk.[xlvi]

These three regions provide some diversification across different hydrographic regions with distinct wet and dry periods which theoretically complement each other via a long-distance transmission network that facilitates delivery of excess power from one area to another region that is experiencing low water levels.

However, it is worth noting that the Paraná River basin is the location for the main 'regularisation reservoirs' which account for 53% of the storage capacity of the entire national electricity network[xlvii] and are capable of guaranteeing energy in the dry periods to compensate for the lack of power being generated by the hydroelectric plants installed in the North region of the country. Regional climate change will threaten these 'regularisation reservoirs' and thus Brazil's ability to balance electricity flows.

Recent droughts highlight the risks for hydroelectricity

Severe droughts in recent years highlight the vulnerability of the electricity system to local climate change.

In 2021 a severe drought reduced water levels to the extent that power output was constrained. In such circumstances, it was necessary for thermoelectric power plants to operate as baseload capacity along with other higher cost energy sources while the output from hydropower plants was constrained.

This episode highlights the potential cost consequences of a hydropower sector that experiences reduced flows more frequently or for longer periods. In 2021, electricity tariffs increased to compensate for the higher cost to produce electricity while hydropower output was constrained. Increases in power prices in 2021, due to climate contributed 0.67% to inflation, overshooting the Central Bank of Brazil's inflation target.

Higher costs and price volatility threaten Brazil's economy

Higher cost and more volatile power prices could erode the competitiveness of the Brazilian economy, particularly for industries that are intensive users of electricity. We would highlight this as a risk for Brazil's metal producers (steel and aluminium), food producers, chemical, mining and pulp and paper sectors which we estimate to equate to approximately 30% of the Bovespa Index[10] by market capitalisation – see Figure 14 for a sectorial breakdown of industrial electricity demand.

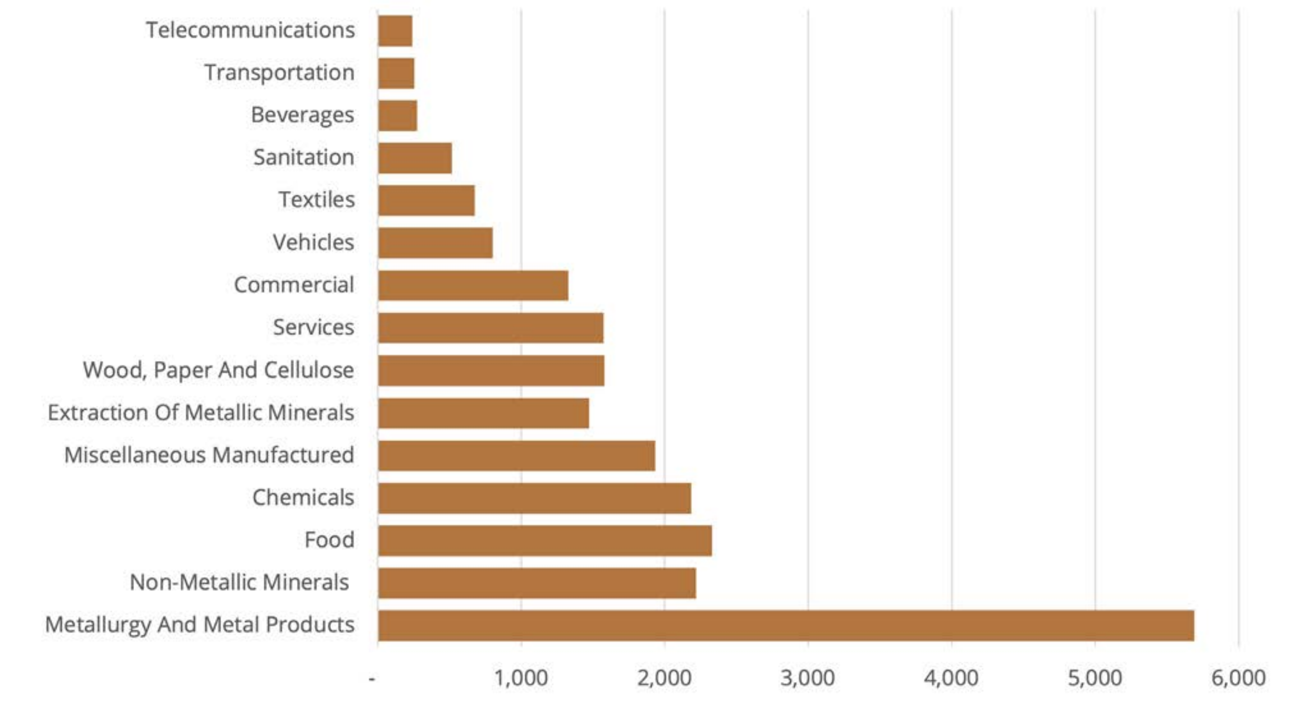


Figure 14: Electricity use by industry.[xlviii] Industrial use 2 weeks from 07/01 to 07/15/2022 MW – Data CCEE.

[10] The Bovespa Index (Portuguese: Índice Bovespa) is the benchmark index of about 84 stocks traded on the B3 (Brasil Bolsa Balcão).

Brazil's MCTI's Fourth National Communication of Brazil to the UNFCCC provides a study on change in the supply of hydroelectric generation and impact on the electricity grid undertaken by SIN (Brazilian Interconnected System operator (Sistema Interligado Naciona) which used Ribeiro et al.'s hydrological analysis.

The study considered two climate models to demonstrate how hydroelectric generation could be impacted in two Specific Warming Level (SWL) scenarios (SWL2 and SWL4) compared to a reference scenario based on the Brazilian Government's 10-year plan for the sector (PDE 2026). The results of the study are summarised in Table 4 and Figure 15.

Table 4: Summary of potential climate impacts modelled on hydro power availability (SIN).[xlix]

Climate Model	SWL2	SW4
Eta-HadGEM2-ES	-27%	-41%
MIROC5	-6%	-10%

Their study also highlighted that the Northern and Central Western systems are most impacted under both scenarios.

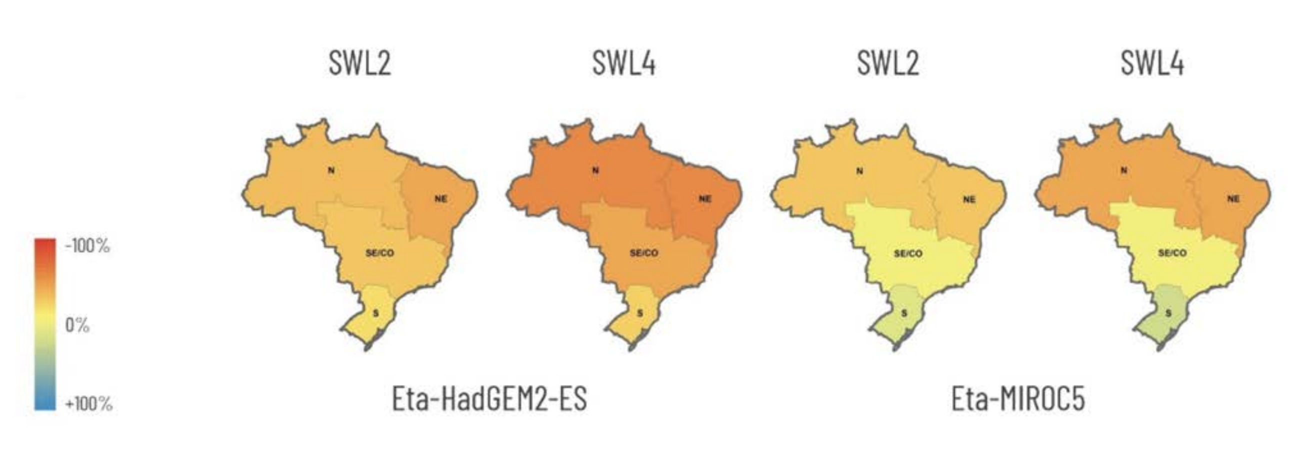


Figure 15: Map showing potential climate impacts modelled on hydro power availability (SIN).[l]

Regional climate change will drive up electricity costs

The analysis also highlights the marginal energy cost implication under both scenarios, SWL 2 and 4, compared to the 10-year plan reference supply mix. Higher costs under both warming scenarios are directly linked to lower water availability as the model opts for the next lowest cost alternative compared to hydro to compensate for energy loss due to reduced flow to meet demand.

Based on this analysis, power prices would likely be 13-25% higher under a SWL2 climate scenario and 25-50% higher in a more extreme SWL4 climate scenario – see Figure 16.

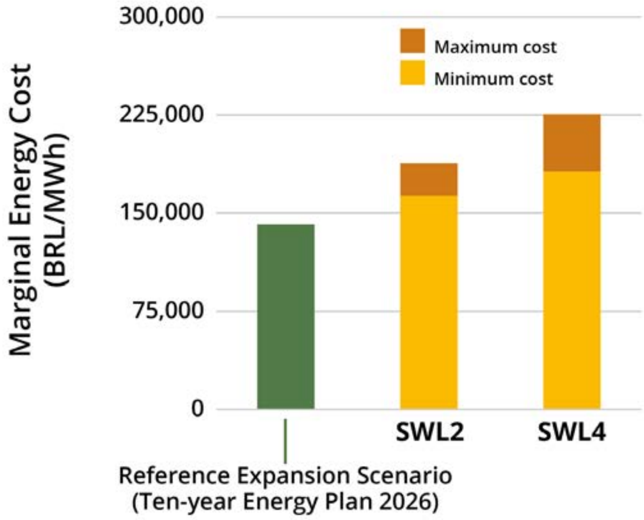


Figure 16: Marginal cost of generation sources under climate warming scenarios SWL2 and SWL4 (SIN).[li]

Climate change will increase the demand for cooling

Brazil's electricity supply faces a climate-driven pincer movement: regional climate change will reduce supply just at the point that rising temperatures and increasingly common Extreme Heat Days lead to an increase in demand for cooling.

A study by OECD and IEA (2018)[lii] estimated that Brazil's Cooling Degree Days[11] (CDD's) could increase by 25% compared to 2016 over the next 30 years (to 2046) and that electricity system peak loads for cooling could increase from 7.6% in 2016 to 20.5-30.8% of peak electricity loads by 2050.

The combination of an expected increase in peak electricity load of 20-30% and a hydropower supply that is reduced due to lower water supply is an important vulnerability for the Brazilian economy and will increase price and availability risks, particularly for energy intensive sectors.

[11] Cooling Degree Days (CDD) is a metric to quantify the potential demand for energy required to cool buildings the number of degrees that a day's average temperature is above 65ºF or 18ºC, calculated as a sum of the daily average temperature less 65F / 18C with negative values set to zero.

Biofuels

In 2018, biofuels accounted for 23% of Brazil's transportation fuel. The majority of this was ethanol from sugarcane (19%) and the balance (4%) came from biodiesel derived from soybeans.[liii]

Brazil has probably reached the limit of its ability to increase its hydroelectricity capacity, so any expansion of renewable energy will have to come from other sources such as biofuels, wind and solar.

As discussed in the section on the climate threat to the agribusiness sector, Brazil's crop yields are likely to fall. This in turn will reduce the supply for biofuels, increasing their prices and limiting the extent to which they can assist Brazil in its transition away from fossil fuels.

Ethanol uses sugarcane as its feedstock. The largest areas of sugarcane production for ethanol are in the Central-South region, with 93% of the average harvests from 2014 to 2018 used to produce ethanol and São Paulo, where almost half of the harvest is used to produce ethanol.[liv]

The main feedstock for biodiesel is soy and the main regions producing soy for biodiesel are Mato Grosso, Paraná and Rio Grande do Sul, which account for 28%, 18% and 16% respectively of the production in Brazil.

A changing climate will threaten the production of the feedstocks required to produce biofuels: sugarcane and soy.

The combination of an expected increase in peak electricity load of 20-30% and a hydropower supply that is reduced due to lower water supply is an important vulnerability for the Brazilian economy and will increase price and availability risks, particularly for energy intensive sectors.

Ethanol (sugarcane)

Ethanol from sugarcane accounts for 19% of the fuel for transport. Sugarcane production is sensitive to climate and the occurrence of droughts can significantly impact the harvest. In 2014, drought in São Paulo and Minas Gerais reduced yields by 8% in the South-Central region compared to the prior year and 12.1% in São Paulo.

Zullo et al.[lv] studied the vulnerability of ethanol production to climate change, looking at how sugar production in the Cerrado and Atlantic Forest biomes (where 76% of Brazil's ethanol production is located) could be impacted under two climate change scenarios, the GCM of the 5th IPCC report and the representative concentration pathway (RCP) 8.5 model.

Their analysis shows that over the next 25 years, sugar production areas that are at low risk from climatic change could shrink from 46% in the reference scenario to 31% and 28% in the MIROC-5 and HadGEM2-ES scenarios respectively.

In areas classed as medium and high risk, cultivation would depend on increasing irrigation, highlighting their vulnerability to droughts. The outcomes of the study are summarised in Table 5.

Table 5: Summary of climate model impact on sugar production risk for ethanol.[lvi]

Scenario	Low	Medium	High
Base	46%	36%	18%
MIROC-5	31%	42%	27%
HadGEM2-ES	28%	42%	30%

Sugarcane will face an increasing challenge to maintain production as the climate warms and will also need to compete with other water uses to secure enough water for irrigation to maintain production.

Biodiesel (soy)

Soy is used as the feedstock for c.75% of Brazil's biodiesel[lvii] putting a significant portion of this fuel at risk from climate change.

Assad et al.[lviii] analysed the outlook for soy production in the two biomes where 84% of Brazil's biodiesel plants are located, the Cerrado and the Atlantic Forest. Their analysis considered soy production under three alternative climate scenarios: global warming of 1.5°C, 2°C and 4°C compared to a baseline (data from 1961–1990).

Their study found that high-risk areas for soy production increase in both biomes.

In the Cerrado biome, 92% of the production area in the baseline period is classed as low-risk; however, with warming, this area reduces to 41% for the SWL1.5, 37% for the SWL2 and 10% for the SWL4 scenario.

In the Atlantic Forest biome, 48% of the area is categorised as low-risk in the baseline period, reducing to only 5% for the SWL1.5 and 2% for the SWL2 scenarios, indicating that climate change would likely impact the supply of soy used to produce biodiesel – see Table 6 and Figure 17.

Table 6: Summary of climate model impact on sugar production risk for ethanol.[lvi]

	Baseline	SWl1.5	SWL2	SWL4
Cerrado	92%	41%	37%	10%
Atlantic Forest	48%	5%	2%	0

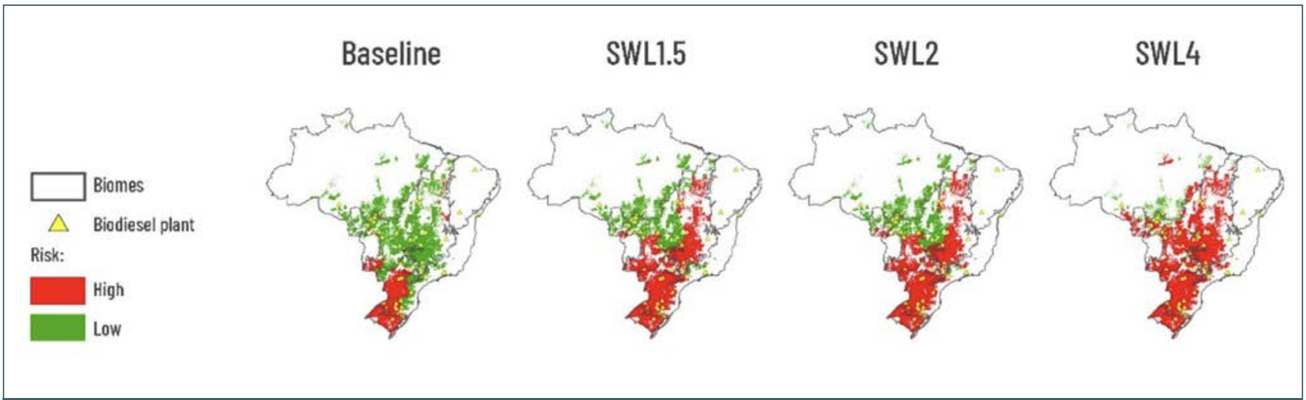


Figure 17: Summary map of climate model impact on soy production risk for biodiesel).[lix]

Productivity/health – extreme heat

Outdoor workers will be most at risk

Extremes of heat have increased due to climate change and the impacts of deforestation on regional temperatures. These events will occur more frequently and become more intense as global temperatures rise and further deforestation adds to regional warming.

Prolonged exposure to extreme temperatures poses a serious risk to human health, causing cardiovascular and respiratory complications, renal failure, electrolyte imbalance and harm to foetal health.[lx]

Life and work in Brazil will need to adapt to limit exposure to extreme temperatures and avoid the potential impacts on health, which will reduce the overall capacity to work, particularly for occupations that are primarily outdoors. For Brazil, this has potential to impact a significant proportion of employment. In 2020, nearly 18% of employment (15.2m jobs) were in agriculture, mining, construction, provision and maintenance of utilities[lxi] – see Table 7.

Table 7: Summary of employment by sector in Brazil with high exposure to outdoor working.[lxii]

Sector	Total (000)	% of total employment
Brazil total employment all activities	**85,923**	
Agriculture & forestry	8,005	9.3%
Mining & quarrying	431	0.5%
Electricity & gas supply	237	0.3%
Water, waste & remediation activities	506	0.6%
Construction	6,016	7.0%
Total high exposure to outdoor working	**15,195**	**17.7%**

From an investor perspective these sectors represent a similar proportion of the Brazilian market – approximately 18% of the Bovespa Index by market capitalisation – so the threat to portfolios (particularly for domestic investors) arising from the impact on the profitability of companies in these sectors could be material.

Heat stress is already impacting Brazilian productivity

Academic studies have analysed the economic impact of extreme heat events for different countries and regions; these studies can help quantify how periods of extreme heat impact Brazil's economy already and how it could affect the economy in warming scenarios that consider the effects of global warming and the warming impacts of deforestation.

A study from 2019 by the International Labour Office[lxiii] estimates that heat stress caused a 0.44% loss in working hours in Brazil in 1995, showing that outdoor workers are already exposed to heat stress. They estimate that by 2030, even if the world was on track for a 1.5°C increase by 2100,[12] this loss in working hours would increase to 0.84%, equivalent to 850,000 full-time jobs, with the most significant impact in the agricultural and construction sectors.

The ILO's estimate of an 0.84% loss of working hours due to heat stress by 2030 provides a baseline for the reduction in productivity that Brazil will experience as a result of deforestation-driven regional climate change.

De Olivera et al. published a study in 2021[lxiv] which examined how savannisation of the Amazon Basin would influence the occurrence of heat stress. Under such a high emission scenario, they estimate that 'more than 11 million people will be exposed to heat stress that poses an extreme risk to human health' (implying that worker productivity might be less of a concern that mortality).

[12] A more benign path than the most recent IPCC estimate ('Global surface temperature will continue to increase until at least mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades') - IPCC AR6.

Extreme Heat Days could be fatal, particularly in the Amazon region

De Olivera's model suggested maximum temperatures during Extreme Heat Days in the Amazon region could be 11.5°C higher than present conditions by 2100.

Figure 18 illustrates this effect by adding 11.5ºC to the average maximum temperatures observed in the Amazonas region in Brazil between 1991 and 2020. Under this simple scenario analysis, Extreme Heat Days could exceed the 'risk of death' threshold in every month.

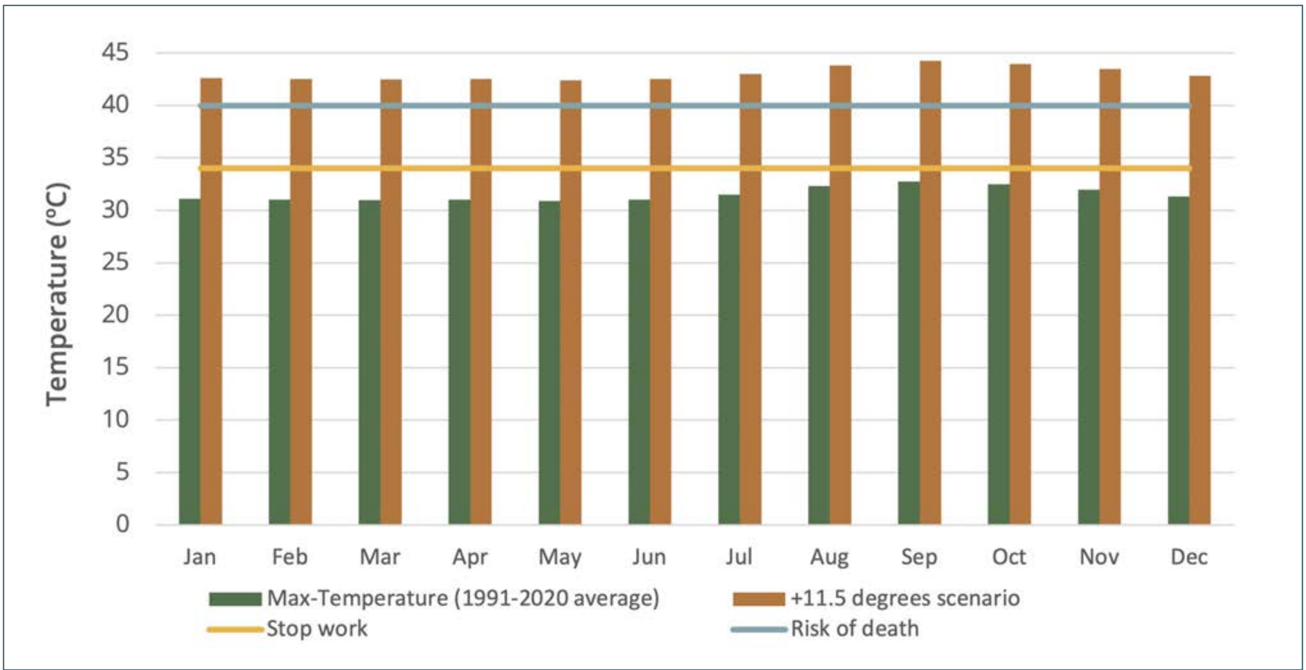


Figure 18: Illustration of Extreme Heat Days scenario.[lxv] Source: World Bank data, Planet Tracker analysis.

Such an extreme heat scenario would obviously drive further changes in the Amazon region's ecosystem but would also constitute a severe threat to the region's economy. Manaus, the region's capital city which has a population of over two million people (it is the seventh largest city in Brazil), is a significant inland port for the region and Manaus airport[13] ranks third in Brazil for cargo handling.[lxvi]

Rendering a city the size of Manaus uninhabitable would have severe economic and social consequences for the rest of Brazil, as the city's industries closed down and its two million residents sought homes and work elsewhere[14]. As noted previously, De Olivera et al. estimated more than 11 million people could be at severe risk in a savannisation scenario.

[13] Vinci Airports SA took over operation of Manaus airport in January 2022 under a 30-year concession.

[14] This movement of people could amount to an internal refugee crisis, particularly for the poorer, more vulnerable, sections of society.

City hot spots – 10-15°C hotter

Urban areas experience higher temperatures than non-urban areas and specific localities within urban areas can experience even higher temperatures than nearby streets.

A 2022 study by Lorenzo Mentaschi et al.[lxvii] for the EU's Joint Research Centre found that this Surface Urban Heat Island (SUHI) effect can result in specific SUHIs experiencing temperatures 10-15ºC higher than surrounding, cooler, parts of the city – see Figure 19.

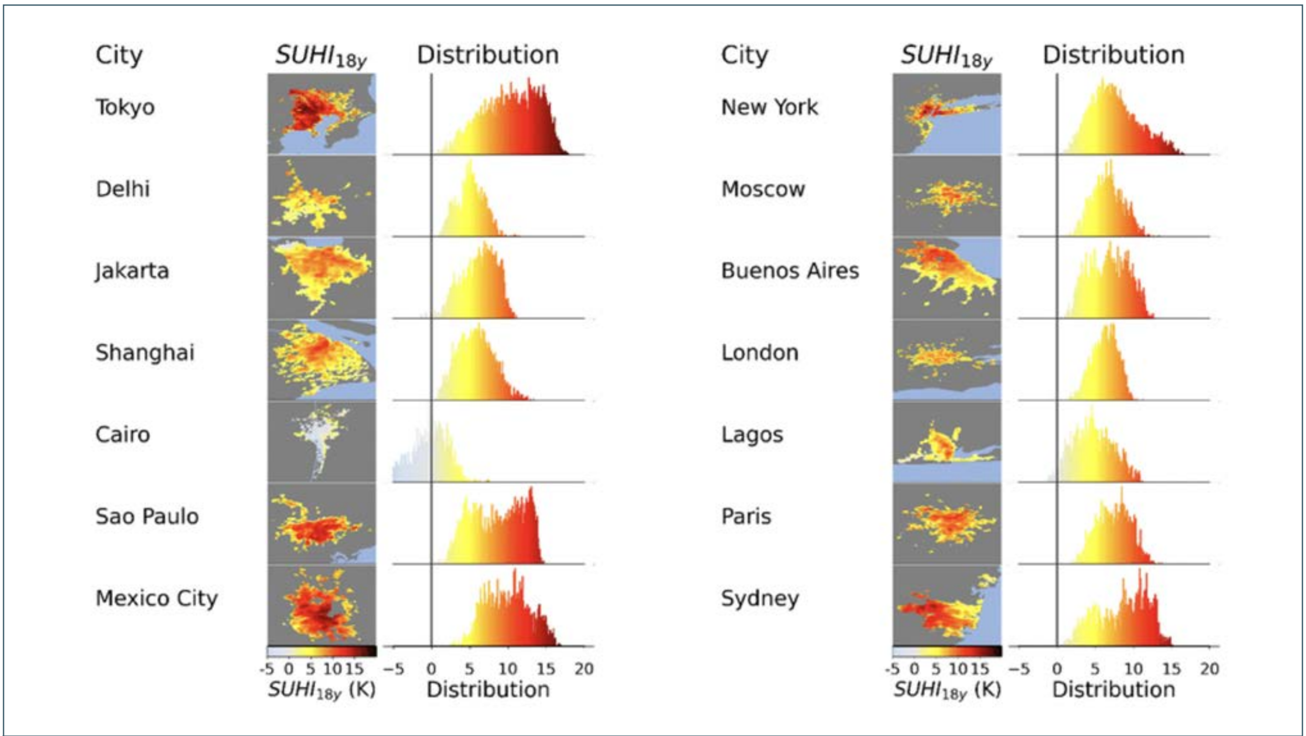


Figure 19: Surface Urban Heat Island extremes – sample cities.
Source: L Mentaschi et al., 2022. Distribution of warm-season extreme SUHI in megacities. Maps (left panels) and histograms (right panels) of warm-season 3-day SUHI maximum over the 18 years analysed (SUHI18y). Considered are all urban pixels within the Functional Urban Areas for each of the 14 world megacities.

A number of studies, including this one, highlight the point that Surface Urban Heat Islands are usually found in the most deprived areas of cities since these are the most crowded and are often furthest from green spaces such as parks. As Mentaschi et al. put it:

'This corroborates the link between the chaotic, dense and unregulated urbanisation typical of slums and intense heat exposure (Wang et al., 2019a). Combined with poverty, poor housing conditions and little access to cooling options this poses serious health threats to people (Teare et al., 2020).'

In Brazil, 89% of the country's entire population live in urban areas, 16% in slums.[lxviii] The urban population is growing by 1.1% each year – see Figure 20.

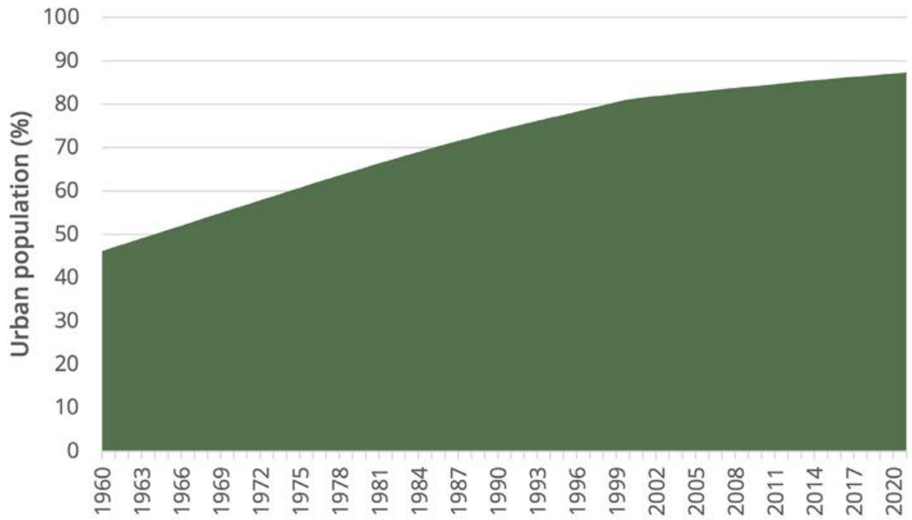


Figure 20: Urban proportion of Brazil's population (1960–2021). Source: World Bank data, Planet Tracker analysis.

This combination of extreme urbanisation and the number of people living in deprived areas that are typically Specific Urban Heat Islands with Extreme Heat Day maximum temperatures that can be over 10ºC higher than cooler parts of the city, means that the threat of death due to heat extremes will impact poor Brazilians years earlier than those living in the rich suburbs or many rural areas, creating significant social challenges for the country.

Transport – inland waterways

Brazil has 60,000 km of waterways of which 13,000 km are used to carry around 45 million tonnes of freight annually. According to ANTAQ[15], the system could potentially handle 180 million tonnes as a high capacity, low cost transportation alternative to roads – four times its current utilisation.

Transportation by waterway represents only 5% of Brazil's freight market, with road and rail taking significantly larger shares (65% and 15% respectively) – see Figure 21.

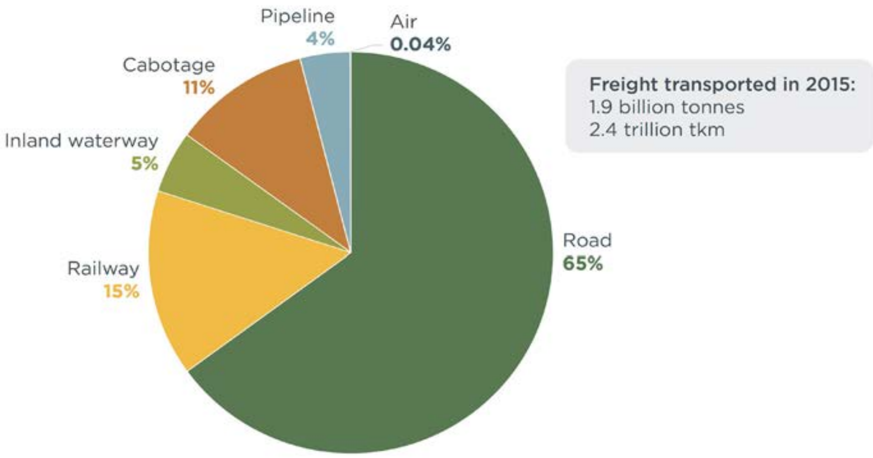


Figure 21: Freight transportation mode share in Brazil 2015 (percentage of total tonnes).[lxix]

[15] Agência Nacional de Transportes Aquaviários – Brazil's National Water Transport Agency.

Reduced precipitation threatens inland waterways

Over the past decade, as droughts impacted hydrological conditions on key stretches of waterway, shipping activity was temporarily reduced or suspended until hydrological conditions improved.

In 2021, reduced water levels caused reduced navigation capacity on several major waterways which increased transport time and costs for corn, iron ore and oilseeds as cargos had to move onto more expensive road and rail options.[lxx]

- The Paraná River Basin in central Brazil experienced its worst water crisis in 91 years, with flows in June 2021 only 55% of the historical average for the month.
- The Tiete-Paraná sub basin, which transports grains and oilseeds from Brazil's crop belt to export terminals came close to halting operations for the first time since a severe drought in 2014. Water levels in a key stretch of the waterway – Avanhandava – fell below the minimum required for navigation.
- The Paraguay-Paraná waterway, which is used to transport iron ore, reduced capacity as water levels fell to their lowest levels since 2010.
- The Madeira River in the southern Amazon region, which is used to transport grains and oilseeds, also faced issues as drought conditions caused the waterway to dry out earlier than usual.

Regional climate change will limit Brazil's sustainable transport opportunities

In an environment of warmer and drier conditions, river transportation will likely face challenges similar to 2021 which could mean that Brazil fails to capture the opportunity to achieve a more sustainable transportation mix by shifting freight from road to rail and expanding the utilisation of its inland waterways.

According to data from the Climate Observatory, CO_2 emissions per tonne-kilometre generated by road transportation are between 4.3 and 12.8 times higher than emissions from rail transport, depending on the product being moved, and may be up to 20 times higher than for short-sea coastal shipping ('cabotage') – see Figure 22.

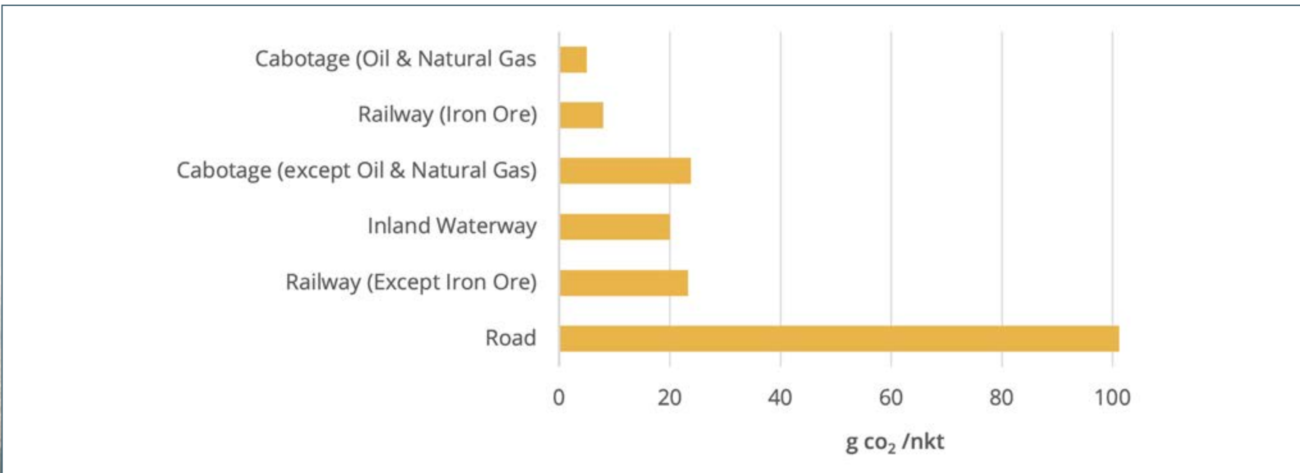
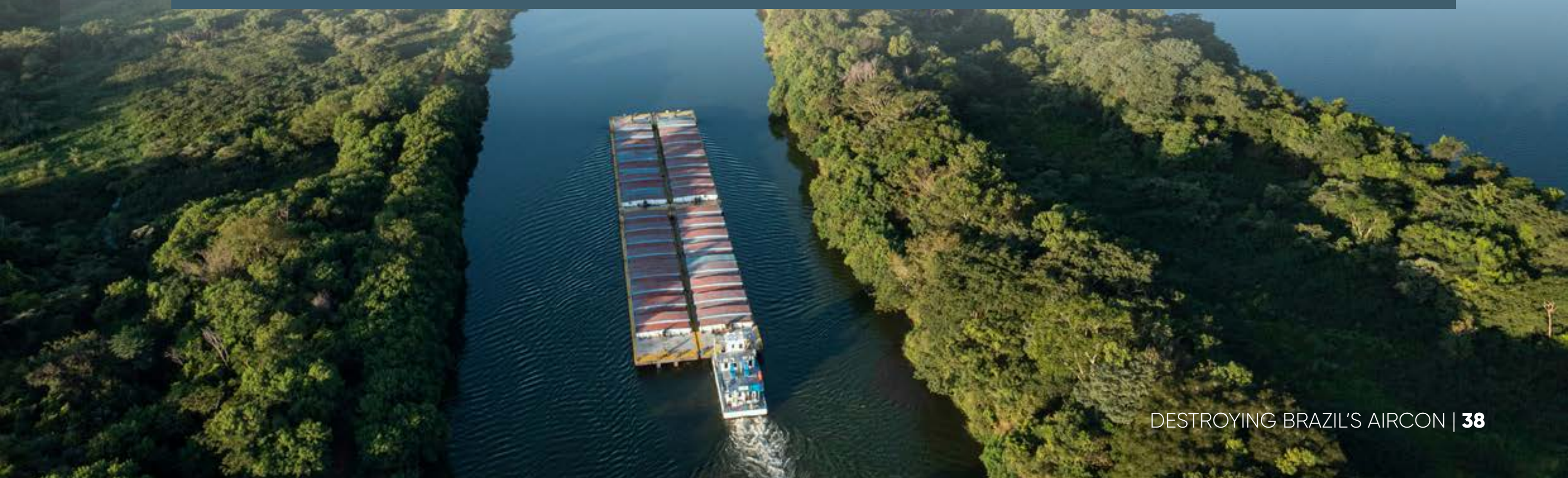


Figure 22: Comparing the emissions of different transport methods in Brazil.[lxxi]



A study by de Freitas Junior et al., comparing the costs of waterway cargo transportation between Brazil and the US in 2016,[lxxii] provides an indication of the opportunity to save costs that will be lost if Brazil is unable to make the most of its inland waterways for transport.

While the specific cost comparisons presented in the paper are now dated (costs from 2012), the magnitude of the cost differential between road and waterway transportation likely remains relevant. Road transport in Brazil is over four times more expensive than water transport – see Table 8.

Table 8: Cost comparison of transport modes US vs Brazil.[lxxiii]

	Brazil		USA	
	% TKU	US$/Mil TKU	% TKU	US$/Mil TKU
Roadway	67	133	31	310
Railway	18	22	37	29
Waterway	11	30	10	10
Pipeline	3	25	21	9
Airway	0,04	1060	0,30	1,107

Having said that, capturing the opportunity to increase the use of inland waterways will require better government co-ordination. A presentation in 2015 by ANTAQ illustrates that, in spite of a clear awareness of the benefits of waterway use as part of a more sustainable transport mix, there is a lack of ambition to increase waterway use this decade – see Table 9.[lxxiv]

Table 9: Advantages of switching transport to inland waterways and Ministry of Transportation.[lxxv]

Advantages of Navigation	
MORE	LESS
+ Fuel efficiency + High capacity transport + Lifetime of infrastructure + Useful life of equipment and vehicles + Load security and tax control	- Fuel consumption - Pollutant emissions (climate change and greenhouse gases) - Traffic - Infrastructure Cost - Number of accidents - Operational cost - Environmental impact - Noise emission

Multimodal Transport Distribution in Brazil (2015-2031) TKU (%)					
Type of transport	2015	2019	2023	2027	2031
Roads	44	40	39	38	38
Railway	36	36	42	43	43
Inland Waterways	6	6	6	6	6
Cabotage	7	7	9	9	9
Pipes	7	7	4	4	4

Supply chain implications – key exports

In 2020, Brazil's agriculture exports of USD 84.4 billion (OEC) contributed to its overall trade surplus of USD 54 billion in 2021. As we have discussed in this report, deforestation and climate change pose significant risks to agricultural production which, in turn, would impact exports of these products, potentially putting 39% of Brazil's exports at risk.

Given the scale of Brazil's role in the global supply chain of key commodities, countries and companies that depend upon imports of these commodities are exposed to significant direct and indirect risks as a result of the harm that regional climate change driven by continuing deforestation could do to agricultural output in Brazil.

Events in Ukraine this year have highlighted the importance of food security to the global community. Commodity prices have moved sharply higher on the reduced ability of Ukrainian commodities to reach export markets and sanctions reducing Russian commodities' access to the global market.

Figure 23 illustrates how prices have increased over the past year for commodities where Ukraine's exports represent a significant proportion of the global trade in that commodity.

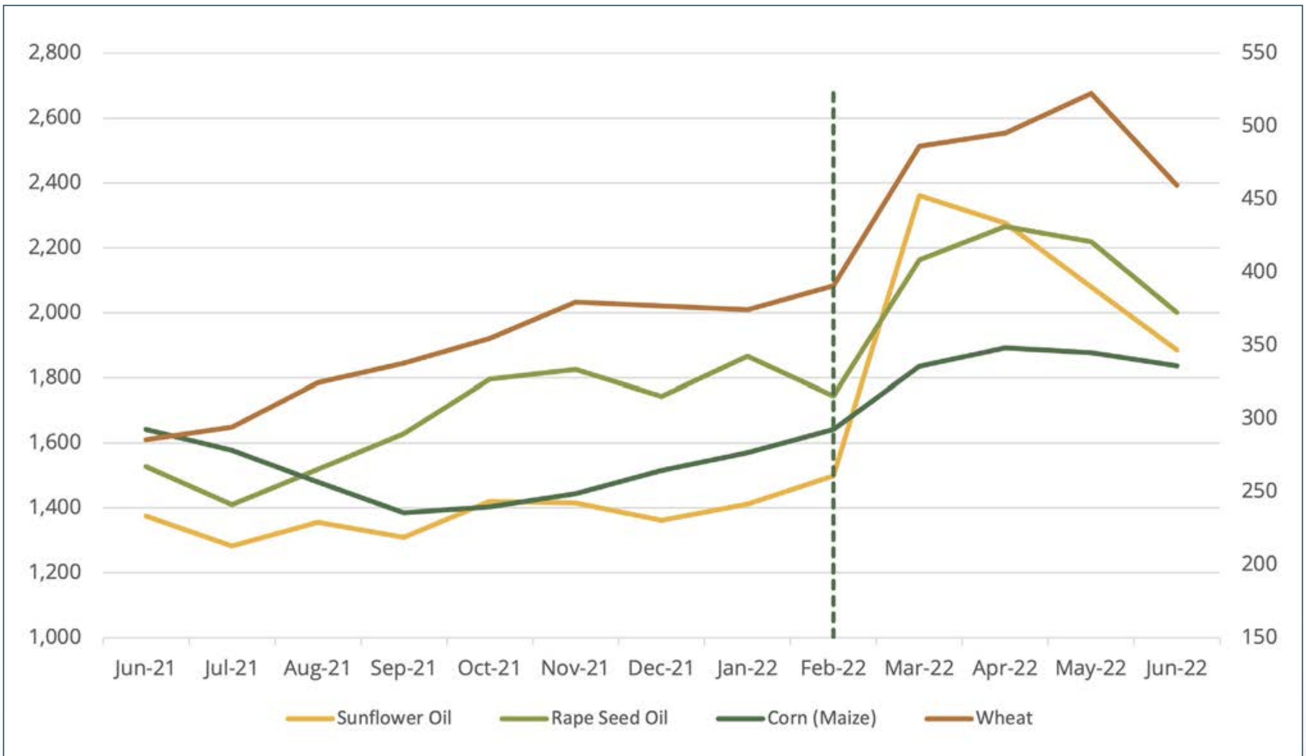
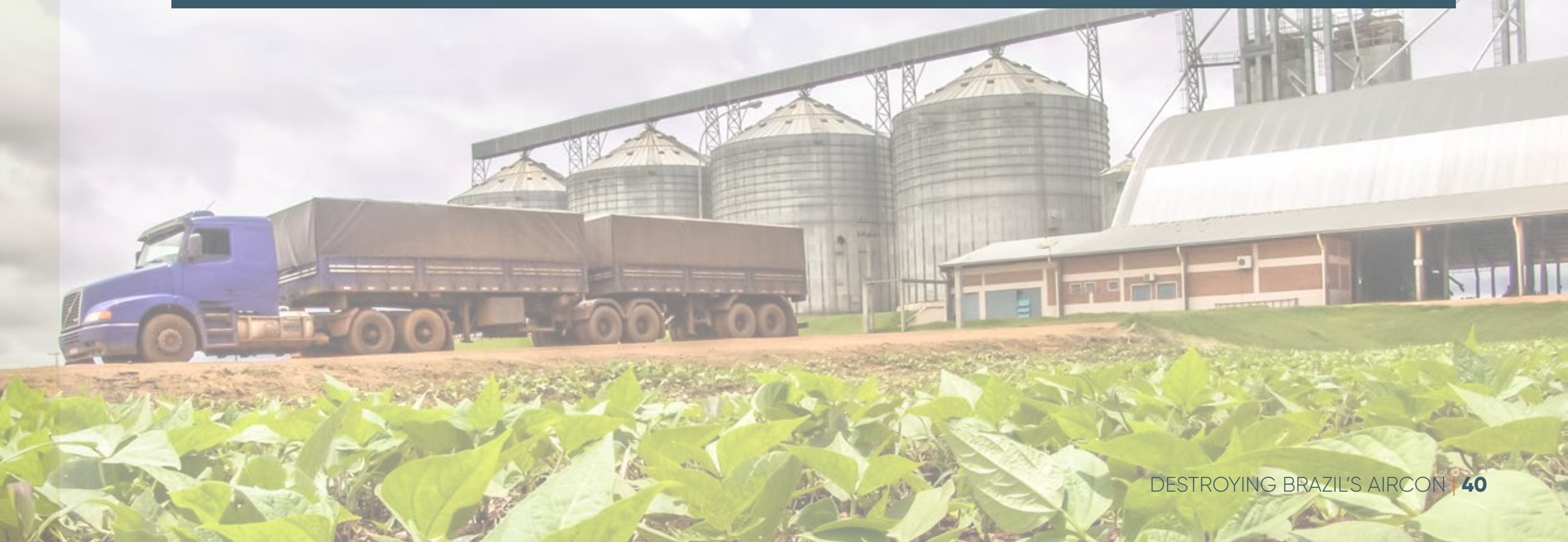


Figure 23: Commodities exposed to supplies from Ukraine.[lxxvi]



In 2020, Ukraine's sunflower oil, corn, wheat and rapeseed exports were 52.2%, 12.8%, 9% and 9.2% respectively of the global export market for those commodities. The price reaction for wheat and rapeseed oil highlights the fact that even disrupting exports from a country that accounts for less than 10% of the global market still impacts global prices.

Given this fact, both Brazil and its partners should be aware of the climate-related supply chain risks arising from continuing deforestation. Brazil's key agricultural exports are a significant proportion of the global export market for those commodities. As discussed in this report, regional climate change could severely impact Brazil's ability to satisfy the demand for these commodities, with serious implications for global food security and the supply chains of the food producers and retailers that are dependent on these commodities – see Table 10.

Table 10: Summary of Brazil's key agricultural export products. 3 year average sales (2018–2020). Source: Comtrade.[lxxvii]

Commodity	Significance to Brazil (exports)	Significance to world markets	Supply chain significance (imports)	Significance of Brazil to key importers
Soy	In 2020, Brazil exported $28.6 billion of soybeans and another $6 billion of soybean meal. This is Brazil's single, largest export product.	Brazil is the largest exporter of soybeans globally with 44.7% of the total export market.	China is the largest buyer ($20.9 billion), followed by Netherlands ($1.1billion), Spain ($942 million), Thailand ($916 million), and Turkey ($726 million).	Brazil supplies 55.9% of China's soy imports and 45% of the imports to the Netherlands.
Sugar	This is Brazil's 4th largest export product with sales of $8.95 billion in 2020.	Brazil is the largest exporter of Raw Sugar globally with 35.8% share of the export market.	The main buyers are the US ($1.95B), China ($1.86B), Indonesia ($1.46B), Italy ($732m), Bangladesh ($725M).	Brazil supplies 15.3% of sugar imports to the US, 69.3% of China's, 32% of Indonesia and 86.6% of Bangladesh's imports.
Beef	Beef is Brazil's 5th largest export ($6.69 billion frozen and $700 million of fresh beef) in 2020.	Brazil is the largest exporter of Beef globally with 24.8% share of the global market.	The main destinations for frozen beef are: China ($4.04B), Hong Kong ($808M), Egypt ($395M), Russia ($185M), and Italy ($145M).	Brazil supplies 44.8% of China's frozen beef imports, 35.3% of HK's, 53% of Egypt's, 27.5% of Russia's and 53.3% of Italy's imports.
Coffee	In 2020, Brazil's coffee exports totalled $5.08 billion, equivalent to nearly 3% of its total exports by value.	Brazil is the largest exporter of coffee globally with a 16.5% share of the market.	Europe and North America are the main destinations for three quarters of the trade.	Brazil supplies 28.3% of Germany's coffee imports, 5.4% of France's, 27.4% of Belgium's, and 17.3% of the US's.
Maize	In 2020, Brazil's maize exports were worth $5.95 billion, equating to nearly 3% of Brazil's exports by value.	Brazil is the third largest exporter of maize globally with a 15.6% share of global trade.	The largest markets for Brazil's maize are MENA (Iran $745m, Egypt $552m) and Asia (Japan $712m , Vietnam $633m, S. Korea $418m).	Brazil supplies 68.2% of Iran's maize imports, 29.5% of Egypt's, 26.3% of Japan's, 30% Vietnam's, and 20.7% S. Korea's maize imports.

Implications for investors

The economic fallout for an economy as exposed as Brazil is to climate change will be wide ranging. With more than a quarter of GDP linked to agriculture and an electricity system that is 2/3 hydropower, all sectors of the Brazilian economy face some risk.

Domestic (Brazilian) companies

In terms of domestic Brazilian companies (Bovespa Index[16] constituents), we estimate that:

- c. 30% by market capitalisation require significant electric power in their manufacturing or processing and are therefore exposed to the risk of higher electricity prices and supply problems.
- 18% of the Bovespa Index by market capitalisation rely on a significant proportion of their workforce working outdoors in construction, mining, transportation, agriculture or forestry and will experience lower worker productivity during periods of extreme heat.
- 48% of the index could be exposed to the risk of changed rainfall patterns, either as utilities requiring river flow to generate electricity or their manufacturing process requiring access to large quantities of fresh water.
- Banks and insurers represent 25% of the Bovespa by market capitalisation and will have exposure to climate-linked risks across their portfolios either directly to farmers experiencing reduced yields or more broadly, to companies that are exposed to climate through their processes or inputs.

Sovereign bond holders

As discussed in this report, deforestation-driven regional climate change has the potential to have significant negative impacts on Brazil's economy. The threat of environmental tipping points that are hard to predict, but have potentially severe economic and social consequences, should materially increase the risk premium required to invest in Brazilian bonds.

The regional climate change scenarios examined in this report all lead to a deterioration in the outlook for the agriculture sector which will impact Brazil's exports, threatening its balance of trade and ability to fund its sovereign debts. The inflationary pressures of rising energy costs will impact on longer term economic prospects and government budgets will be impacted by job losses and less productive employment in parts of the country with more exposure to extreme heat.

The government will likely have to provide additional support to the incomes of farmers reliant on crops which will more frequently fail or suffer from weather extremes, increasing the expense of rural income protection schemes.

The increased frequency and severity of Extreme Heat Days and the potential for more frequent and longer duration droughts will lead to significant social disruption and potentially material internal migration, with the associated increased risk of political instability.

[16] The **Bovespa Index** (Portuguese: *Índice Bovespa*), best known as **Ibovespa** is the benchmark index of about 84 stocks traded on the B3 (Brasil Bolsa Balcão), accounting for the majority of trading and market capitalisation in the Brazilian stock market. It is a weighted measurement index.

Foreign companies relying on Brazilian products or services

Company disclosures often fail to provide the clarity and detail required to analyse the exposure of a specific company to Brazil in terms of soft commodities used in production and/or services provided by Brazilian suppliers.

However, the ongoing war in Ukraine provides a timely reminder that global markets for food ingredients can experience significant disruption to supplies and prices if a major supplier suffers disruption. Given Brazil's dominance as a source for key food ingredients, it is clear that even companies that do not source directly from Brazil will be threatened if Brazil's exports are disrupted by regional climate change, so any food system company with a product portfolio involving soy, sugar, coffee, maize and/or beef will be at risk.

Conclusions

Brazil depends upon its natural resources for its present economic success and the future wellbeing of its growing population. Deforestation is putting this at risk.

Brazil's forests are the equivalent of a giant air-conditioning unit, moderating temperatures across the country and providing plentiful and consistent rainfall.

Deforestation is the equivalent of smashing this aircon unit.

If this destruction continues, Brazil is likely to go beyond the point of no return, with potentially catastrophic social and economic consequences.

Brazil has the capability to achieve zero deforestation and has committed to do so by 2030 in its Nationally Determined Contribution under the Paris Agreement. It should accelerate these efforts to ensure the wellbeing and future prosperity of its people.

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ABOUT PLANET TRACKER

Planet Tracker is a non-profit financial think tank producing analytics and reports to align capital markets with planetary boundaries. Our mission is to create significant and irreversible transformation of global financial activities by 2030. By informing, enabling and mobilising the transformative power of capital markets we aim to deliver a financial system that is fully aligned with a net-zero, nature-positive economy. Planet Tracker proactively engages with financial institutions to drive change in their investment strategies. We ensure they know exactly what risk is built into their investments and identify opportunities from funding the systems transformations we advocate.

FOOD AND LAND USE TRACKER

Programme goal: to align capital markets with a sustainable global food system. Before 2050, Planet Tracker's Food and Land Use Programme will highlight the investment risks and opportunities associated with the just and equitable transformation of the global food system that eliminates negative externalities with respect to climate, nature, and health so that it is fit to feed the world's growing population within planetary boundaries. By highlighting these risks and opportunities, Planet Tracker's Food and Land Use programme will influence financial markets actors to actively support and fund this transformation.

This report is the second in a series examining the problems faced by the Amazon due to extensive deforestation. The first, No Rain on the Plain, was named winner of the Environmental Finance Sustainable Investment Awards 2022.

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