Nature-Related Transition Risks and The Climate-Nature Nexus: an Assessment of Capital Stranding Exposure and Financial Vulnerability in Brazil

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Abstract

This work provides a comprehensive analysis of the risks associated with capital stranding and financial vulnerability in Brazil due to nature-related transition risks. Brazil, being one of the largest GHG emitters and a megadiverse country, faces significant transition risks as the world moves towards ecological policies. The study utilizes both Ghosh and Leontief models to assess the cascading propagation effects of transition risks in Brazil's economy, focusing on fossil fuel, agriculture, and forestry sectors. We couple our exposure analysis with a vulnerability assessment based on Minskyian classifications of financial fragility. The findings highlight that both polluting and non-polluting sectors are exposed to capital stranding risks, which can in turn result in financial distress, especially for sectors already in speculative or Ponzi financial positions. In general, the results suggest that there are synergies between climate- and biodiversity-related risks that can amplify capital stranding impacts in Brazil, with significant implications financial stability given the financial fragility of some sectors.

Keywords: Nature-Related Risks, Capital Stranding, Climate-Nature Nexus, Brazil

1 Introduction

Brazil is the major carbon-emitting country in the Latin American and the Caribbean region, ranking as 6th among the largest GHG emitters in 2022 (Crippa et al., 2023). As countries all around the world start to devise and implement new policies for the ecological transition, transition risks are quickly materializing and becoming a matter of increasing concern. The Financial Stability Report of the Brazilian Central Bank (BCB) (BCB, 2022), published in November 2022, showed that around 8% of the National Financial System's credit portfolio is directly exposed to borrowers who may be affected by transition risks taking into account gross emissions, production and export data by sector. This paints a worrying picture of a country that emits high quantities of GHG gases and which is also largely exposed to transition risks.

In accordance with the Greenhouse Gas Protocol Initiative[1], the BCB's report (BCB, 2022) considered Scope 1 and Scope 2 emissions. The former are direct emissions resulting from operations or production process controlled by the issuer; the latter are indirect emissions generated by the energy purchased. However, exposure to transition risks does not depend only on the emission intensity of a sector but also on the emissions of the sectors from which it buys inputs and to which it sells products. A transition shock, such as a new policy constraining the production of a carbon intensive sector, can generate indirect repercussions both downstream, by reducing the supply of inputs to other sectors, and upstream, by reducing the demand of inputs by the directly hit sector. Therefore, the analysis of Scope 3 emissions allows to assess the exposure of a given sector considering all indirect emissions that occur in the value chain, including both upstream and downstream emissions. Moreover, the decarbonization process can lead to a loss of physical capital utilization (i.e capital stranding) (Tong et al., 2019, Pfeiffer et al., 2018), which can propagate downstream and upstream through production network linkages.

Adapting to Brazil and extending the work done by Cahen-Fourot et al. (2021) to consider both downstream (via a Ghosh model) and upstream (via a Leontief model) propagation of transition shocks, in this paper we first explore how a decrease in Brazilian fossil fuel primary inputs and final demand would trigger underutilization of capital stock (i.e capital stranding) in the rest of the Brazilian productive system. In particular, we show that both polluting and non-polluting sectors (e.g *Legal and accounting activities*, *Administrative and support service activities*, *Financial services*) can be exposed to the risk of capital stranding when considering the upstream propagation of a transition shock. Considering the assessment of the financial conditions of a large sample of Brazilian firms in different economic sectors (Modica Scala et al., 2024) we further highlight that transition dynamics could become a source of financial distress for those macro-sectors indirectly exposed that are in a speculative (*Food*, *Wood*, *Chemicals*, *Warehousing*, *Plastic*) or Ponzi position (*Public administration and defense*, *Real Estate*, *Administrative and support service activities*, *Paper*, *Financial services*).

Nevertheless, the ecological transition also entails other aspects apart from the low-carbon transition and climate-related risks. In particular, given its position as the most biodiverse country in the world (Forzza et al., 2012), Brazil faces a complex climate-nature nexus of transition risks, as there are multiple synergies and antagonisms between climate and biodiversity risks. In order to account for this, we also expand the ecological scope of the analysis to incorporate biodiversity loss together with climate change, placing our study in the broader field of Nature-Related Risks. We identify key sectors that pressure biodiversity in Brazil and carry out an exploratory assessment of transition risks and intersections between the cascading effects of a broader ecological transition that tackles carbon emissions and biodiversity loss at the same time.

[1] https://ghgprotocol.org/

In doing so, our paper provides three new contributions to the literature of Nature-Related Risks. Firstly, it proposes a complementary analysis of cascading effects to the one originally made by Cahen-Fourot et al. (2021) by also accounting for upstream indirect effects. Secondly, it proposes an original vulnerability assessment in the NRRs field based on the Minskyian analysis of the Brazilian financial system carried out by Modica Scala et al. (2024). Finally, it also addresses climate and biodiversity risks together in the context of the Brazilian economy, looking for synergies and antagonisms between them. The results cast a light on new paths of research on indirect and cascading effects which are able to account for the multidimensional aspect of the current ecological crisis.

The article is organized as follows. Section 2 presents the framework of nature related risks and discusses the new methodological contributions provided by the paper. Section 3 addresses in detail the climate-nature nexus and transition risks in Brazil. Section 4 describes the methodology employed in the assessment. In Section 5 the results are shown together with discussion, the networks of cascading effects are presented and followed by three different scenarios of transition risks, one focusing on the low-carbon transition, another on biodiversity loss, and the last one on a combined transition scenario. Lastly, Section 6 presents final concluding remarks of the paper.

2 The Framework of nature related risks

Research on Climate-Related Financial Risks (CRFRs) is an established field of research that has received great attention by multiple stakeholders from academia and think-tanks to Central Banks and financial institutions. Motivated by the momentum created by the Paris Agreement in 2015 and the need for a quick and radical structural change towards low-carbon economies, studies on CRFRs advanced towards designing a framework for understanding the sources of climate risks, transmission channels and forms of hazard materialization (NGFS, 2019). More recently, the growing emergence of other aspects of equal importance in the current ecological crisis led the field to adopt a broader scope and framework for risks analysis that incorporates biodiversity loss and ecosystem services provided by nature. The result was the rise of research on Biodiversity-Related Financial Risks (BRFRs), that together with studies on CRFRs, integrate a rising major field of Nature-Related Risks (NRRs) (NGFS-INSPIRE, 2022, NGFS, 2023).

The framework adopted in NRRs studies identifies two major sources of nature risks that are able to pose a threat to macro-financial stability: physical and transition risks. Physical risks are the result of chronic and acute hazards and consist on the risk of reduction of nature contributions to people (NGFS-INSPIRE, 2022, Pörtner et al., 2021). They directly affect the economy in the form of a depletion of ecosystem services that are important for production. Transition risks, conversely, are the result of socioeconomic transformations that challenge existing economic and financial structures and interests (Svarztman et al., 2021). These transformations may take the form of misalignments between economic/financial activities and new policies/regulations (mitigation and adaptation), technological developments and changes in consumer preferences (van Toor et al., 2020).

The materialization of a physical or transition risk lead to direct and indirect impacts affecting the economy. This direct impact is geographically localized and tend to assume a similar pattern for firms that operate in similar business, consequently, it tends to be geographic and sector specific. The directly impacted firms face reductions in output and increasing costs of production, indirectly affecting other firms that are upstream and downstream in the productive chain. Their financial positions is also put at risk, as the reduction of the economic activity may compromise firms' ability to serve their debt and repay the principal (Modica Scala et al., 2024). Together with the direct impact, the chain of indirect and cascading impacts adds up to the macroeconomic level and the financial system, increasing financial fragility and instability, and affecting well-being (OECD, 2023).

The NRRs framework of risk assessment is constructed upon the SREX IPCC Report that divides risk in three main components: hazard identification, vulnerability analysis and exposure analysis (IPCC, 2012). While research on identification and prediction of hazards is yet to be further developed, vulnerability and exposure analysis are commonly carried out in NRRs studies. Vulnerability analysis is usually done at sectoral level by employing the Exploring Natural Capital Opportunities, Risks and Exposure (ENCORE) (Natural Capital Finance Alliance, 2021) or the Biodiversity Impact Analytics – Global Biodiversity Score (BIA-GBS) methodologies (van Toor et al., 2020, Svarztman et al., 2021). These tools provide information and data on dependencies and impacts on nature of the different economic activities. On the other hand, exposure analysis is usually executed by observing the productive network and spotting the channels of indirect and cascading effects (Cahen-Fourot et al., 2021, Godin and Hadji-Lazaro, 2020, Magacho et al., 2023). Starting from the directly affected firms and sectors, by looking at their backward and forward linkages the exposure analysis assesses the length and value of upstream and downstream economic connections exposed to indirect and cascading effects. For this, input-output models have been largely employed given their capacity to apprehend the complex interactions of the productive system.

In this paper we provide three new contributions to the NRRs framework of risk analysis. Considering the exposure assessment, we complement the transition risks analysis of downstream capital stranding made by Cahen-Fourot et al. (2021) through the means of an input-output Ghosh model with an upstream capital stranding analysis carried out with a standard Leontief model. Following Modica Scala et al. (2024), the second contribution consists on an original vulnerability assessment based on the analysis of companies' financial fragility under the well-known cash flow taxonomy introduced by Minsky (1975, 1986) which categorizes firms into hedge, speculative or Ponzi position based on a comparison between the cash inflows generated by firms into a specific period and interest and principal payments obligations. Lastly, the third contribution consists in addressing climate change and biodiversity loss transition risks together through the lenses of a climate-nature-society nexus, something never done before in the NRRs literature.

3 Brazil, the Climate-Nature nexus and transition risks

3.1 The Brazilian emissions profile

With 44.8% of its energy mix composed of renewable energy sources, Brazil stands out as a global reference in green energy when compared to the global average of only 14.7%. Data on the electricity mix reinforces this position as 84.8% of the Brazilian electricity is produced by renewable sources, mostly by hydroelectric plants (61.9%), compared to the global average of 28.1% (Brasil, 2023).

This prominence, however, strongly contrasts with the Brazilian position as the 6th largest GHG emitter in 2022, accounting for 2.44% of total global annual emissions in that year (Crippa et al., 2023). A closer look at the Brazilian emissions profile reveals that, in 2020, 23.2% of total Brazilian GHG emissions came from the energy sector, adding to a total of 389,484 Gg of CO2 equivalent emissions. From this total, 95.1% of the emissions were generated by activities of burning fossil fuels, indicating a large responsibility of mineral fossil fuels activities on the total Brazilian emissions (Brasil, 2022).

Together with the energy sector, the activities of "agriculture and farming", and of "land use, land use change and forestry" top the GHG emissions in Brazil, amounting to 28.5% and 38.0% of the total Brazilian emissions in 2020, respectively. For "agriculture and farming", 57.0% of the emissions come from the process of digestive enteric fermentation of ruminant animals, and 31.0% come from direct and indirect emissions stemming from activities related to soil use such as fertilization and animal waste deposition. For the activities of "land use, land use change and forestry", 93.6% of the emissions are the result of land use and conversion associated with deforestation and timber activities, most of them taking place in the Amazon Rainforest and the Brazilian Cerrado (Brasil, 2022).

3.2 Drivers of biodiversity loss and the Climate-Nature nexus in Brazil

Often labeled as the “most biodiverse country in the world”, Brazil is recognized as one of the 17 megadiverse countries in the world, hosting the greatest richness of terrestrial plant species on the planet and around 200.000 animal species. The country also has one of the highest percentage of endemism - species that only exist in the country - for inland countries; a result of its extensive singular biomes and ecosystems (Forzza et al., 2012). Being the home of 30% of all species of vascular plants, vertebrates and arthropods, and of 13% of all trees of the world, the Amazon Rainforest is the ecosystem with the highest species density on Earth (Guayasamin et al., 2021, Zapata-Ríos et al., 2021). While the Amazon usually unequivocally receives most of the global attention as it is approaching its tipping point of savannization (Lovejoy and Nobre, 2018), the Atlantic Rainforest (Mata Atlântica) and the Cerrado are also huge spots of biodiversity, being the both of them considered biodivesity hotspots that exhibit exceptional concentrations of endemic species and which are experiencing exceptional loss of habitat (Forzza et al., 2012).

Biodiversity loss in Brazil is directly driven by habitat conversion, soil degradation, deforestation, wildlife exploitation, climate change, introduction of invasive species, and soil, water and air pollution (Joly et al., 2019). These direct drivers are the result of sociopolitical and economic development conditions, governance systems, and the political and institutional context that determines laws and decision-making processes related to the environment and biodiversity, the so-called indirect drivers. Together with urbanization, the economic activities of agriculture, farming and forestry lead nature impacts through land use and change, especially through deforestation of biomes, causing habitat conversion and fragmentation processes that result in biodiversity loss (IPBES, 2019).

There is an intricate climate-nature nexus of reinforcing synergies between climate change and biodiversity loss characterized by a key geospatial component that connects local biodiversity loss effects with global climate change effects (Pörtner et al., 2021, NGFS-INSPIRE, 2022). In the past, rapid climate change has been a key driver of previous mass extinction events on Earth and it is estimated to be capable of eliminating up to 90% of all species (Benton, 2018, Bond and Grasby, 2017, Dunhill et al., 2018, Foster et al., 2018, Song et al., 2021). In addition to the direct mutual impact on each other, climate change and biodiversity loss also impact other factors that drive these phenomena. For instance, climate change is bound to trigger alterations in temperature and rainfall patterns that will prompt main drivers of biodiversity loss such as deforestation, soil degradation and habitat conversion. On the other hand, regional biodiversity loss may release CO2 from carbon sinks and also trigger regional changes in the water cycle causing indirect impacts in global climate dynamics.

The mutual reinforcing dynamics of the climate-nature nexus takes place in multiple facets in Brazil. The rising temperatures caused by climate change directly threatens species living close to their upper thermal limits and the ecological functioning of wetland ecosystems (Pörtner et al., 2021). The documented impacts in equatorial reefs located in the northeast part of Brazil (Lucas et al., 2023) and in Pantanal, the largest wetland in the world (Thielen et al., 2020), are some examples of it. Climate change induced shifting isotherms also causes species migration, increasing the occurrence of invasive species in Brazilian ecosystems. For instance, African invasive grass species are expected to substitute Amazon native grass species given their substantial adequability area in contexts of rising temperatures (Mano et al., 2023). Moreover, together with the rising temperatures and changes in the hydrological cycle, the increased recurrence of extreme events caused by climate change are also generating large scale processes of land conversion and pushing Brazilian ecosystems towards their tipping points of no return (Joly et al., 2019, Flores et al., 2024).

Ecosystem and biodiversity loss, in turn, reinforces climate change through releasing CO2 to the atmosphere that was previously stored in carbon sinks. The Amazon rainforest was recently found to shift from a global carbon sink to a global carbon source due to increasing stress from fires, deforestation and climate change effects (Basso et al., 2023, Gatti et al., 2021). The example of the Amazon also reveals how regional changes in the water cycle triggered by biodiversity loss affects global climate patterns. New studies show that Amazon savannization will lead to severe climatic changes in South America, reducing rainfall, increasing dry season length and temperature extremes (Ruv Lemes et al., 2023, Bottino et al., 2024). Furthermore, anthropic actions of land conversion in Brazil are usually carried out with the goal of employing the area for agriculture and farming, activities associated with high GHG emissions (Joly et al., 2019).

3.3 The climate-nature-society nexus of transition risks in Brazil

The interconnections between climate change and biodiversity loss in Brazil translate into synergies and trade-offs associated to transition risks (Pörtner et al., 2021). The need to embark in a process of ecological transition characterized by structural change towards a catching-up low-carbon sociobiodiversity economy (Semieniuk et al., 2020, Abramovay et al., 2021, Magacho et al., 2023, Lasso et al., 2023) strongly contrasts with the Brazilian economic dependence on economic activities that are behind the main drivers of GHG emissions and biodiversity loss. The fact that the sectors of agriculture and farming and the extractive industry led Brazilian GDP growth and exports in 2023 is very illustrative of this condition. The sector of agriculture and farming grew by 15.1% and was responsible by 23.9% of all Brazilian exports in the period. If the industrial activities related to the agricultural sector are also considered, the aggregated agribusiness sector added to 49% of all Brazilian exports. Similarly, the extractive industry grew by 8.7% last year and, led by crude petrol extraction, amounted to 23.2% of all Brazilian exports in the period (Amitrano and Araujo, 2024, Ministério do Desenvolvimento, Indústria, Comércio e Serviços, 2024).

Brazilian sectors that are linked to climate change and biodiversity loss drivers are also significant sources of wages and employment in the country. In a study on the macroeconomic exposure of developing economies to the low-carbon transition, Magacho et al. (2023) classify Brazil as a socioeconomically exposed country to the low-carbon transition due to its large national dependence of wages and employment on high-emission industries. In the same vein, biodiversity products are fundamentally important for income generation of the poorest ones living in Brazilian rural areas, and the over-exploitation of these products, together with biodiversity loss, directly affects some of the most economically vulnerable communities that had been previously subsisting in more harmonious forms with the ecosystems (Joly et al., 2019).

The large economic relevance of activities linked to climate change and biodiversity loss paints the picture of a complex climate-nature-society nexus in Brazil (Pörtner et al., 2021). As a consequence, the country is largely exposed to climate and nature transition risks that are bound to materialize and negatively affect society. The propagation of indirect effects through the productive network resulting from the materialization of transition risks in Brazil, not only will generate significant impacts in terms of loss of capital and asset stranding, but will also spread to the financial system.

In an exploratory case study carried out by the NGFS (2023) on transition risks stemming from an European Union (EU) policy to ban the consumption of non-deforestation-free products , it was found that the Brazilian economy is exposed to a reduction in total output of the magnitude of 1.6 billion EUR in case of a 15% reduction in EU imports for all Brazilian Forestry, Agriculture, Livestock, and Mining sectors. Considering financial transition risks, in a study that adheres more to the NRRs framework, Calice et al. (2021) found that 46% of the total non-financial corporate loan portfolio and 20% of the total credit portfolio of Brazilian banks are in the hands of non-financial corporates that operate in sectors highly or very highly dependent on one or more ecosystem services. From the total exposed value of BRL 811 billion, BRL 254 billion consists in credit to establishments that could be operating in protected areas. This exposure could increase to BRL 437 billion (25 percent of the corporates credit portfolio) should conservation gaps close, and to BRL 664 billion (38 percent of the corporates credit portfolio) should all priority areas become protected.

4 Methodology

In order to perform a comprehensive assessment of Brazilian sectors' exposure to capital stranding, we combine two approaches. First, we initiate the analysis through exploring the downstream propagation of a transition shock by adapting to Brazil the study of Cahen-Fourot et al. (2021). The study originally developed a methodology rooted in the Ghosh model (Ghosh, 1958) to compute 'marginal stranding multipliers' and provide an estimate of the monetary value of the sectoral capital stock at risk of becoming idle due to a 1$ reduction of primary inputs used by a given originating sector. In particular, we conducted the analysis by considering *Mining fossil extraction* (similar to Cahen-Fourot et al. (2021)) as well as *Agriculture* and *Forestry* as sectors directly impacted by the shock, with the latter two being key in tackling carbon emissions and biodiversity loss at the same time. Second, we extend Cahen-Fourot et al. (2021) to consider the upstream propagation of a transition shock using the Leontief model to compute 'marginal stranding multipliers' (Leontief, 1991), which in this case provide an estimate of the monetary value of the sectoral capital stock at risk of being unemployed in production due to a 1$ reduction of final demand for the sector of *Mining fossil extraction*, *Agriculture* and *Forestry*. In both approaches, similar to Cahen-Fourot et al. (2021), we construct cascading networks to study how fossil, agriculture and forestry stranding propagates within the international production system. As a final step, we assess the financial vulnerability of Brazilian sectors indirectly exposed to capital stranding by building upon the well-known Minskyian taxonomy of cash flows following the methodology developed by Modica Scala et al. (2024).

In the next subsections we first present the data sources. This is followed by a brief introduction to the basics of a Multi-Regional Input-Output model. Then, we present the methodology used to compute the matrix of 'marginal stranding multipliers' and the 'stranding cascades' in the Ghosh and Leontief models. Finally we show the methodology based on Modica Scala et al. (2024) to assess the sectors' financial fragility.

4.1 Data

In alignment with Cahen-Fourot et al. (2021), the main source of data used for the analysis is the World Input-Output database (WIOD) which is a Multi-Regional Input-Output (MRIO) database comprising 43 countries plus a Rest Of the World (ROW) region and 56 productive sectors classified according to the NACE level 2 categories. The rationale for using WIOD lies in the fact that it is the only database offering sector-specific values for physical capital stocks. However, it presents an aggregated mining sector that includes both fossil fuels and minerals extraction activities. Therefore, to accurately represent a shock on Brazilian fossil fuels, the mining sector is split using the OECD Inter-Country Input-Output (ICIO) database, where the mining sector is disaggregated into three subsectors: 'Mining and extraction of energy-producing products' (NACE sectors B05 & B06), 'Mining and quarrying of non-energy producing products' (NACE sectors B07 & B08), and 'Mining support service activities' (NACE sector B09). In this paper we rely on the most updated version of ICIO (OECD, 2020[2]) which covers 76 countries plus a ROW region and 45 productive sectors. The resulting WIOD table with a disaggregated mining sector is then balanced using a two-stage RAS (TRAS) procedure (Gilchrist and Louis, 2004) to ensure consistency between the new mining sub-sectors and the original aggregate WIOD mining sector (Cahen-Fourot et al., 2021). For the details on the procedure followed to split and rebalance the WIOD table refer to Cahen-Fourot et al. (2021).

[2]https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm

4.2 The Technical Coefficients Matrix, the Leontief Inverse and the Ghosh Matrix

An MRIO model is composed of three main matrices, which are the matrices of intermediate consumption, value added and final demand[3], and an output vector. The intermediate consumption matrix is a squared matrix containing information about all selected sectors[4] of each country/region. If read vertically, each column displays which inputs a sector employs in its production process. Other factors that also contribute to the final value of the produced good, such as wages, taxes and consumption of fixed capital, are seen in the value added matrix, which is positioned under the intermediate consumption matrix. If read horizontally, each row shows which sectors purchase the output of a specific sector. What is not bought by other sectors is consumed directly by households, government or becomes investment; these values are displayed in the final demand matrix that is positioned on the right of the intermediate consumption matrix.

By adding the columns of the intermediate consumption and value added matrices together, it is possible to obtain a vector of total inputs that displays total production value of each sector calculated from inputs. When all of its values are summed it represents the total output of the economy from a "supply perspective". On the contrary, if all the rows of the intermediate consumption and final demand matrices are added together, we can find the total output of the economy from a "demand perspective". Given this information, it becomes possible to calculate the technical coefficients of production. For this, one needs to divide each value of intermediate goods employed in the production of a specific sector by its total output calculated from the supply perspective. The resulting values, the technical coefficients of production, represent the amount of direct inputs from other sectors needed to produce one unit of final product in the analyzed sector. Therefore, they show how much a sector is directly dependent on other sectors to produce its final output. In mathematical terms, the technical coefficients a are calculated by dividing the intermediate consumption Z of an industry j - represented in one column - from another sector i - represented in a row - by the total output value of sector j:

$$a_{i,j} = \frac{z_{i,j}}{x_j} \tag{1}$$

Instead of calculating each technical coefficient individually, it is possible to operationalize the whole matrices to find a matrix A with all technical coefficients by multiplying the intermediate consumption matrix Z by the inverse of the diagonalized output vector x:

$$A = Z\hat{x}^{-1} \tag{2}$$

However, it should be considered that each one of the sectors that offers direct inputs to a particular sector j also receive direct inputs from other sectors. From the sector j perspective, this means that its production depends not only on the direct inputs that it is directly consuming, but also on indirect inputs that are consumed by the chain of sectors that provide for the sectors that are producing the

[3]The matrices of value added and final demand may be of only one row or column and, thus, vectors.

[4]The words "sector" and "industry" are employed hereas synonyms.

direct inputs of sector j. For instance, imagine three sectors j, i and k. Sector j needs direct inputs from sector i. Sector i, in turn, needs direct inputs from sector k. In this example, sector k only provides indirectly to sector j, as sector j depends on sector k providing for sector i in order to obtain the amount of products from sector i that it needs. Now, imagine that sector k also needs direct inputs from sector j and sector i. From sector k's perspective, this means that it is directly dependent on sector i and indirectly independent on sectors i, k and on itself. In order to find the values of direct and indirect inputs for each sector, we must find the total requirements matrix, or the so-called "Leontief inverse" L. This requires some mathematical manipulation. Starting from equation 2, it is possible to isolate the Z matrix:

$$Z = A\hat{x} \tag{3}$$

As already explained, by reading the MRIO table horizontally it is possible to find that intermediate consumption plus final consumption equals the output vector. Being f the column vector of final demand:

$$Z_i + f = x \tag{4}$$

By substituting equation 3 into 4 and isolating the vector x we can find the Leontief inverse:

$$Ax + f = x \tag{5}$$

$$(I - A)\, x = f \tag{6}$$

$$x = (I - A)^{-1} f \tag{7}$$

$$L = (I - A)^{-1} \tag{8}$$

In the Leontief inverse matrix, each coefficient represents the total output of a sector i that is needed by sector j to produce one unit of final demand. In other words, as mentioned before, the coefficients account for the direct and indirect inputs needed by sector j to produce its final output. Together with the A matrix, the L matrix can be employed for upstream analysis of the different sectors, providing information about the direct and indirect inputs that enter an industry.

A different angle of analysis focused on the downstream side of production chains may rely on the so-called Ghosh model (Ghosh, 1958). By reading the MRIO table horizontally, it is possible to spot the distribution of a given industry i output across other industries that purchase inter-industry inputs from i. In this sense, instead of dividing each column by the total output as in the technical coefficients case, to find the so-called "allocative coefficients" b each row of the Z matrix should be divided by the gross output of each industry. An allocative coefficient b can be read as the share of industry's i output that is used by industry j. In order to operate the whole matrix at once and obtain the B matrix of output allocative coefficients one should multiply the inverse of the diagonalized output vector x by the Z matrix:

$$B = \hat{x}^{-1} Z \tag{9}$$

	Matrix S	Country 1		Country 2		Stranding exposure
		Sector A.1	**Sector B.1**	**Sector A.2**	**Sector B.2**	
Country 1	**Sector A.1**	$s_{A1,A1}$	$s_{A1,B1}$	$s_{A1,A2}$	$s_{A1,B2}$	Total A.1 stranding exposure
	Sector B.1	$s_{B1,A1}$	$s_{B1,B1}$	$s_{B1,A2}$	$s_{B1,B2}$	Total B.1 stranding exposure
Country 2	**Sector A.2**	$s_{A2,A1}$	$s_{A2,B1}$	$s_{A2,A2}$	$s_{A2,B2}$	Total A.2 stranding exposure
	Sector B.2	$s_{B2,A1}$	$s_{B2,B1}$	$s_{B2,A2}$	$s_{B2,B2}$	Total B.2 stranding exposure
Stranding multiplier		Total stranding from A.1	Total stranding from B.1	Total stranding from A.2	Total stranding from B.2	

Figure 1: Matrix S - (Cahen-Fourot et al., 2021)

Following the same logic underlining the Leontief inverse, an industry i not only provides directly to an industry j, but also provides indirectly to many other industries as industry j relies on the output coming from industry i to also produce output that will be purchased by other industries. Therefore, we can find the "Ghosh inverse" matrix G - or the "output inverse matrix" in which each value indicates how important a sector is in providing direct and indirect inputs to others. In a similar fashion to the Leontief inverse, considering the Value Added row vector v and the transposed output vector x', the Ghosh inverse matrix G can be obtained in the following way:

$$x'B + v = x' \tag{10}$$

$$x'(I - B) = v \tag{11}$$

$$x' = v(I - B)^{-1} \tag{12}$$

$$G = (I - B)^{-1} \tag{13}$$

4.3 The matrix of "Sectoral stranding multipliers" and Cascade networks

Starting from the Ghosh approach, which explores the downstream propagation of a transition shock (from suppliers to customers), we transpose the G matrix (G^T) (used for convenience by Cahen-Fourot et al. (2021) to read the effects of changes in sectoral primary inputs over the columns of G^T similar to the Leontief matrix L), and combine G^T with sectoral data of physical capital stocks k. Defininining $k_i = k_i/x_i$ as the capital intensity of sector i, where x is the total output of the sector, we find the matrix S of asset stranding multipliers $S = \hat{k}G^T$ by multiplying the diagonalised form of the vector of capital intensities by G^T. Therefore, each element s_{ij} of S defines the monetary value of capital stock of a sector i (e.g. A.1) that could become stranded because of a 1$ decrease in the primary inputs used in the production of goods and services of a sector j (e.g. B.1, fossil fuels). Figure 1 shows a stylised representation of the S matrix.

On the one hand, column sums of matrix S represent the monetary value of the capital stock at risk of becoming idle in the whole economy as a consequence of a marginal decrease of primary inputs in a given originating sector (Cahen-Fourot et al., 2021). On the other hand, rows sums can be interpreted as the monetary value of the capital stock at risk of becoming idle in a given sector due to a marginal decrease of primary inputs in all the sectors of the economy (Cahen-Fourot et al., 2021). In addition, to investigate how stranding propagates through the economic system, distinguishing the direct effects of the initial impulse from the following indirect interindustry responses, we follow (Cahen-Fourot et al., 2021) and perform a *stranding layer decomposition* analysis rewriting the matrix S as a power series to disentangle the direct and subsequent indirect stranding effects caused by a fossil supply shock:

$$S = \hat{k}G^T = \lim_{n \to \infty} \hat{k} \left(I + B + B^2 + ... + B^n\right)^T \tag{14}$$

Each successive term in the power series approximation represents the magnitude of the round-by-round of a change in primary inputs on sectoral capital stock. Focusing on the first few rounds of effects (short-term), we identify the most important stranding channels by sequentially isolating the strongest linkages from round to round to construct graphs that can be interpreted as weighted directed networks. In particular we build for Brazil what Cahen-Fourot et al. (2021) define a *Cascade network* to explore how an initial shock in the *Fossil/Agriculture/Forestry* sector propagates through the economic system by isolating the dominant stranding cascades it creates. We put the focus sector (i.e the Brazilian *Mining fossil, Agriculture* or *Forestry* sector) at the origin of the network and assume a marginal unitary decrease in its primary inputs as the initial stranding shock. Then we identify the sectors most directly affected by this shock (i.e. in the first round of the stranding power series), given by the highest values of the originating fossil sector's column in the $\hat{k}B^T$ matrix. Only the top q sectors are retained and placed in the first layer of the network. The next layer is obtained by repeating this procedure for each sector of the first layer. We show the value of total stranding taking place in each sector in a specific round (corresponding to the sum of incoming edges for the case in which q is set equal to the total number of sectors) to the node labels. Following (Cahen-Fourot et al., 2021), we focus on the first few rounds of the power series (i.e three layers) and set q equals to 3 to isolate the most important stranding channels[5]. Given the arbitrary component in choosing the q parameter, we also consider the total stranding in each sector of the economy due to a marginal shock hitting one the focus sectors and compared the results.

Regarding the Leontief approach, which explores the upstream propagation of the transition shock (from customers to suppliers), instead of considering 1$ reduction of primary inputs, we consider 1$ reduction of final demand for the *Mining fossil*, *Agriculture* and *Forestry* sectors. Consequently, *total stranding multipliers* (i.e column sums of matrix S) represent the monetary value of the capital stock at risk of becoming unutilised in all sectors of the economy due to a marginal loss of final demand in a given originating sector. Conversely, *total stranding exposures* show the monetary value of the capital stock at risk of becoming unutilised in a given target sector due to a marginal loss of final demand in all sectors of the economy. Formally, we rewrite the matrix S of asset stranding multipliers substituting the transpose of the Ghosh matrix G^T with the Leontief inverse $S = \hat{k}L$ and we modified the stranding

[5] Refer to (Cahen-Fourot et al., 2021) for a more detailed description of the procedure followed to build the network.

layer decomposition analysis accordingly:

$$S = \hat{k}L = \lim_{n\to\infty} \hat{k}\left(I + A + A^2 + ... + A^n\right) \tag{15}$$

4.4 The Minskyan analysis

The risk faced by a sector depends not only on its capital stranding exposure but also on its vulnerability to shocks. The vulnerability level reflects the characteristics of each sector and is a function of its ability to cope and adapt to the climate and nature stress. The analysis of a firm's ability to generate enough inflows to meet its interest and principal payment obligations provides a measurement the firm's economic vulnerability to capital stranding stemming from materialized climate and nature risks. In order to perform this analysis, we rely on Modica Scala et al. (2024) who adopted the cash-flow taxonomy introduced by Minsky (1975, 2008), and further developed by Davis et al. (2019), to categorized Brazilian firms into hedge, speculative or Ponzi positions. In particular, income statements, cash flows, and balance sheet data for Brazilian publicly listed firms are taken from Economatica. Being S the firm's cash inflows, I interest payments and P principal repayments, formally we define as hedge firms with $S - I - P > 0$; speculative if $S - I - P < 0$ but $S - I > 0$, and Ponzi if $S - I < 0$. The analysis evaluates the number and percentage of firms that are categorized in each position withing sectoral clusters (Modica Scala et al., 2024). This aggregation approach leverages the clustering properties depicted by the 2018 OECD Input-Output tables for Brazil (Modica Scala et al., 2024) and acknowledges that adverse climate shocks often spread through production networks represented by input-output tables. It recognizes that shocks affecting specific sectors will predominantly be transmitted to sectors that are closely linked to those initially impacted. Consequently, sectors within the same tightly connected community are likely to exhibit similar levels of exposure to various types of climate shocks that may affect the economy. We define as:

- Hedge those clusters with a share of hedge firms larger or equal 50%;
- Speculative those clusters with a share of speculative firms larger or equal 50%;
- Ponzi those clusters with a share of Ponzi firms larger or equal 50%.
- Hedge-speculative clusters if the share of hedge plus speculative firms is larger or equal to 50%.
- Speculative-Ponzi clusters if the share of speculative plus Ponzi firms is larger or equal to 50%.

One can interpret that clusters classified in hedge position are composed of firms that are able to generate enough inflows of liquidity to meet their cash commitments. The speculative position is composed by firms that have cash flows enough to pay for the interest payments, but not for the principal. Therefore, the clusters classified as speculative are more fragile in front of adverse fluctuations in financial markets. Ponzi clusters are composed of firms that do not generate enough inflows to pay both interest and principal payments, remaining in a condition of continuous acquirement of more debt. Sectoral clusters that do not meet the the "hedge", "speculative" and "Ponzi" criterias are placed in the in-between categories of "hedge-speculative" and "speculative-Ponzi".

5 Results and Discussion

5.1 Cascading Network of Impacts

5.1.1 Downstream Cascading Effects

The sectors of *Mining and Extraction of Fossil Fuels* (MINfos), *Crop and animal production, hunting and related service activities* (AGRagr), and *Forestry and logging*(AGRfor) are placed at the top of the Figures 2, 3, 4, 5, 6 and 7 to indicate the origin of the shocks. The results in Figure 2 indicate that an initial reduction of $1 dollar in primary inputs on the MINfos sectors generates a $5.16 worth of capital stranding in the same sector. The first layer of indirect effects is composed of the Brazilian sector of *Coke and refined petroleum products* (MANref) and the Brazilian and Chinese sectors of *Electricity, gas, steam and air conditioning* (PWR+). The cascading effects take place in two main clusters, one affecting the Brazilian economy and the other affecting the Chinese economy. In the Brazilian cluster, the sectors affected in the second round of effects are *Land transport and transport via pipelines* (TRAinl), *Mining and quarrying of non-energy producing products* (MINoth), *Crop and animal production, hunting and related service activities* (AGRagr), and *Public administration and defence; compulsory social security* (PUB+). In the third round, the effects again cascade towards other countries, as the Japanese PWR+ sector and the Chinese sector of *Food, beverages and tobacco products* (MANfoo) are affected. In the Chinese cluster the second and third cascading effects spread mostly through manufacturing sectors.

Results of downstream effects for a shock applied to the *Crop and animal production, hunting and related service activities* (AGRagr), and *Forestry and logging* (AGRfor) sectors display a different set of industries affected by cascading effects. From the AGRagr sector, a $1 dollar reduction in inputs generates a $1.59 worth of capital stranding in the same sector (Figure 3). The first round of cascading indirect effects spreads towards the Brazilian and Chinese sectors of *Food, beverages and tobacco products* (MANfoo) and the Brazilian industry of *Chemicals and chemical products* (MANche), generating again two different clusters of cascading effects in Brazil and in China. When the initial shock is applied to the AGRfor sector, a $1 dollar reduction in inputs generates a $2.35 worth of capital stranding in the same sector. Following what is displayed in figure 4, the first round of cascading effects remains inside the domestic economic, affecting the Brazilian sectors of *Paper and paper products* (MANpap), *Wood and products of wood and cork, except furniture* (MANwoo), and *Crop and animal production, hunting and related service activities* (AGRagr).

5.1.2 Upstream Cascading Effects

The upstream impacts display a different picture from the downstream impacts, as a different selection of industries are affected through cascading effects. Starting with a shock in MINfos (Figure 5), a 1$ reduction of final demand for the sector would spread first to the sectors of *Mining and quarrying of non-energy producing products* (MINoth), *Legal and accounting services; Activities of head offices; management consultancy activities* (PROleg), and *Administrative and support service activities* (ADM+). The second and third round of cascading effects shows that the shock might spread

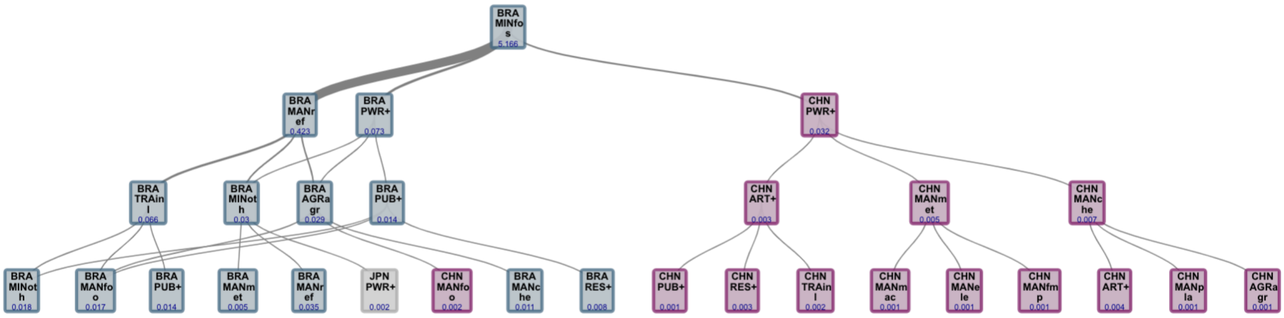

Figure 2: Downstream Cascading Network of a Shock in the Brazilian Sector of Mining and Extraction of Fossil Fuels

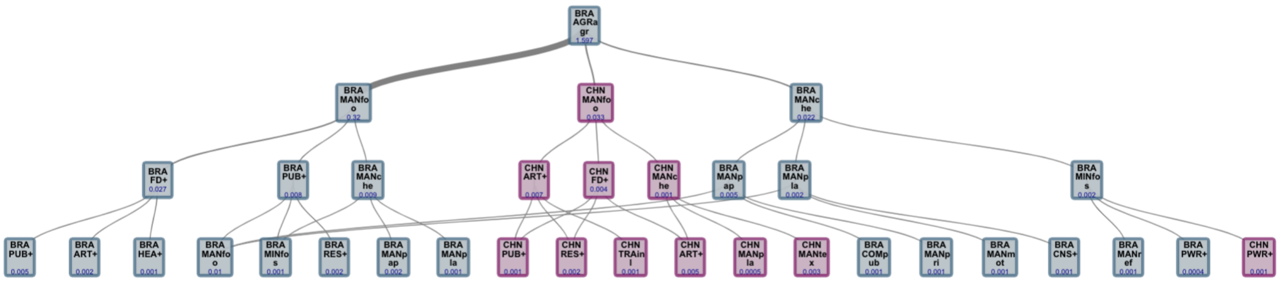

Figure 3: Downstream Cascading network of a shock in the Brazilian Sector of crop and animal production, hunting and related service activities

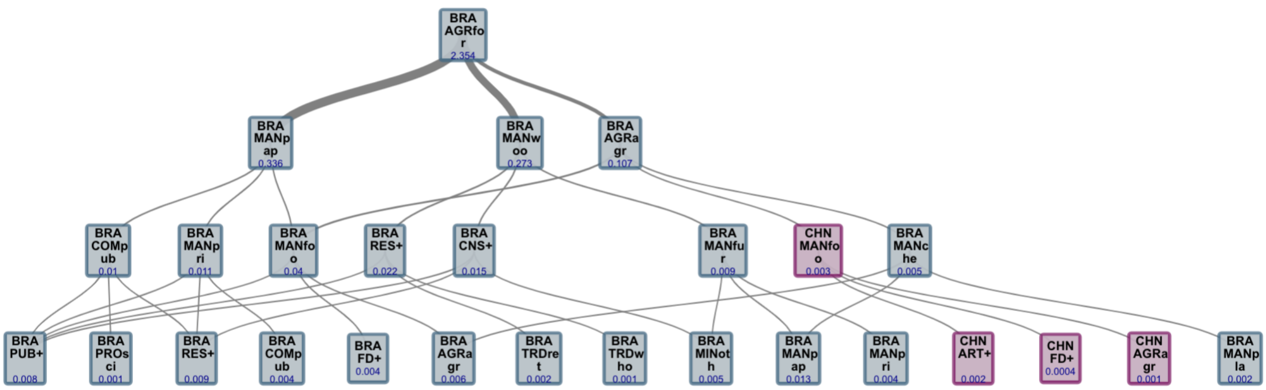

Figure 4: Downstream Cascading network of a shock in the Brazilian Sector of agriculture, forestry and fishing

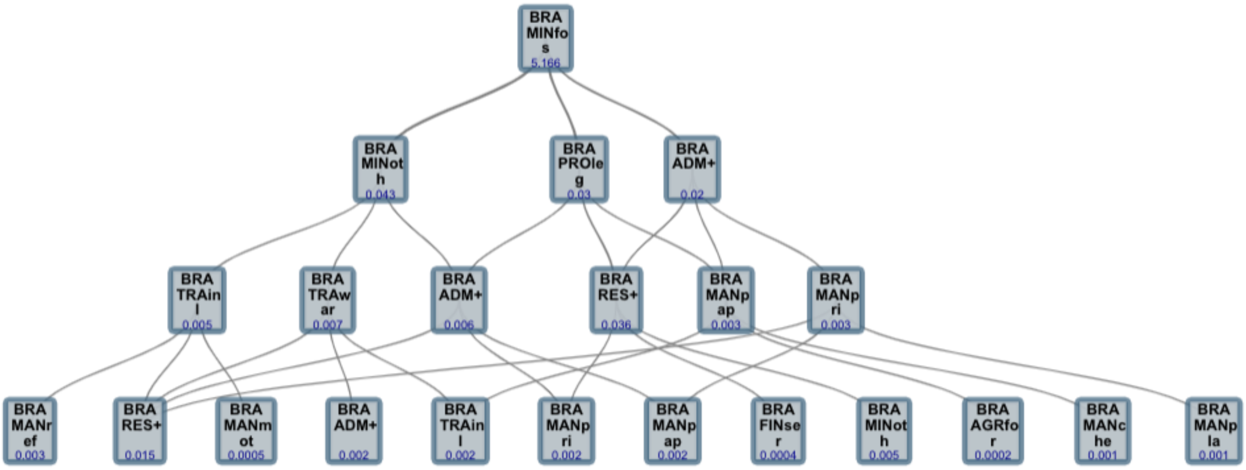

Figure 5: Upstream Cascading Network of a Shock in the Brazilian Sector of Mining and Extraction of Fossil Fuels

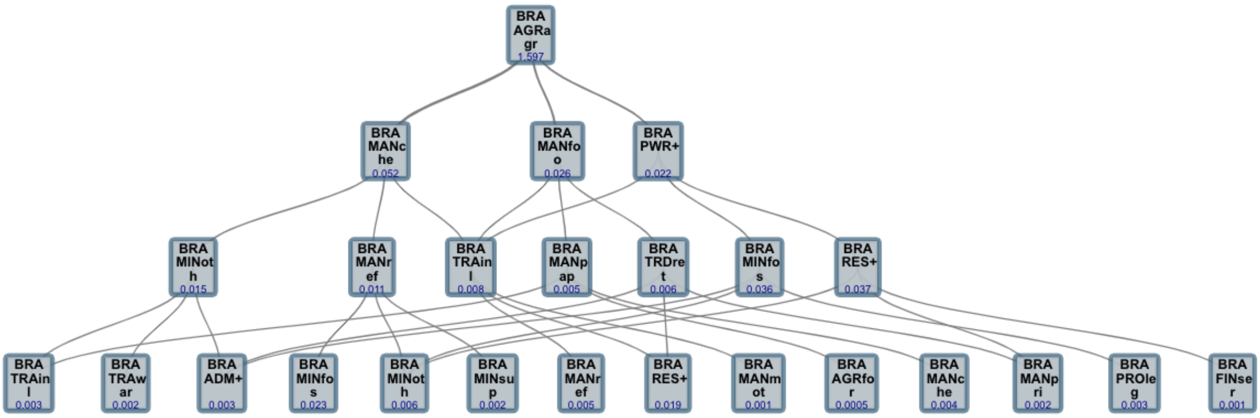

Figure 6: Upstream Cascading Network of a Shock in the Brazilian Sector of crop and animal production, hunting and related service activities

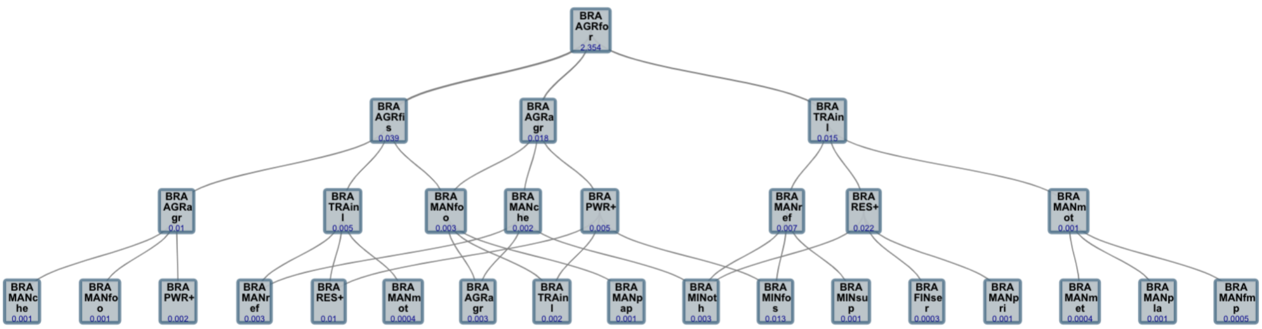

Figure 7: Upstream Cascading Network of a Shock in the Brazilian Sector of forestry and logging

towards a vast selection of industries, including transport sectors, real state and multiple manufacturing sectors.

In the case of a shock of 1$ reduction of final demand in the sector of *Crop and animal production, hunting and related service activities* (AGRagr), the first round of cascading effects is composed of the Brazilian sectors of *Chemicals and chemical products* (MANche), *Food, beverages and tobacco products* (MANfoo), "Electricity, gas, steam and air conditioning" (PWR+). The second and third rounds of cascading effects spreads towards multiple manufacturing, mining and transport, and services sectors. For a shock on *Forestry and logging*, the first round of upstream cascading effects showcases the sectors of *Fishing and aquaculture* (AGRfis), *Crop and animal production, hunting and related service activities* (AGRagr), and *Land transport and transport via pipelines* (TRAinl). The second and third rounds of upstream cascading effects also spreads towards a large variety of sectors ranging from energy, manufacturing and agriculture.

5.1.3 Analysis, modeling limitations and mitigation factors

The results presented for the downstream cascading effects of an initial shock in the MINfos sector are in alignment with the ones found by Cahen-Fourot et al. (2021). The sector is a major upstream sector in the Brazilian economy, providing direct and indirect inputs not only to multiple domestic sectors, but also to foreign sectors, particularly to China. The upstream cascading results, conversely, showcase sectors in the first rounds of propagation that are not highly emitting ones, such as the PROleg and ADM+ sectors. These results highlight the importance of accounting for both upstream and downstream scope 3 analysis of ecological effects and nature-related risks, as a transition policy affecting the MINfos sector may critically impact service sectors that are not directly emitters of GHG equivalents.

When it comes to the sectors that are the main drivers of biodiversity loss in Brazil, the cascading effects behave in a different way when stemming from the AGRagr or from the AGRfor sector. The AGRagr is characterized by a longer upstream chain than a downstream one, as it demands inputs from energy and manufacturing sectors related to chemicals and food, while it provides downstream more to final goods sectors, such as food manufacturing both in Brazil and China. On the other hand, similarly to the MINfos sector, the AGRfor sector has longer downstream chains than upstream ones, as it is a key supplier of manufacturing industries of paper and wood, which in turn are large suppliers of multiple service sectors. This highlights the importance of the position occupied by a sector in the productive network when it comes to the analysis of nature related risks. In general, the longer the upstream and downstream connections of a sector, the higher the exposure of the economy to capital stranding resulting from materialized transition risks affecting this sector. However, it should be noted that stranding cascading effects are, equally, an effect of both the capital intensity of the sector and its importance in the upstream/downstream production network measured with the coefficients of the Leontief/Ghosh Inverses. This is a result of the linear assumption of the Leontief and Ghosh models that can be observed in equations 14 and 15 where the S matrices of asset stranding multipliers were built.

Moreover, results of the cascading network analysis showcase a picture of the exposure of the economy to a particular shock stemming from the materialization of a transition risk affecting certain selected sectors. Nevertheless, it should be expected upstream cascading effects to be more certain to effectively materialize than downstream ones, as they are the result of a reduction in final demand taking place in the Economy that leaves sectors without the possibility to sell their output (NGFS, 2023). While final demand is not "replaceable", downstream cascading effects in the form of a reduction of the inputs provided to the economy consists in a problem that is more feasible to be mitigated. It is well known that economies operate below full capacity utilization (Gahn, 2023, Gallo and Barbieri Góes, 2023) which allows for import substitution of inputs in the short-run and, consequently, lead to a mitigation of downstream cascading effects (Oosterhaven, 1988).

5.2 Scenarios of financial and capital stranding exposure to transition risks

We present now three scenarios of financial and capital stranding exposure to transition risks. The initial shocks of \$1 dollar reduction in final demand for the upstream effects and of \$1 dollar reduction in primary inputs for the downstream effect are now applied at the same time. Instead of looking at the cascade network of propagation of the shock, now we focus on the more aggregate macroeconomic effects of capital stranding. Following the industry clusters proposed by Modica Scala et al. (2024), we cross the financial information of theBrazilian clusters with the exposure to capital stranding. Table 3 shows the correspondence between the WIOD sectors' label, the two-digits NACE core code Rev. 2 and the clusters based on Cahen-Fourot et al. (2021) and Modica Scala et al. (2024). The results for the scenarios are summarized in Tables 1 and 2.

5.2.1 Scenario 1: Climate transition risks

The first scenario is labeled as the "low-carbon transition" one and the initial shock is concentrated in the MINfos sector. Table 1 displays total downstream effects while Table 2 the upstream ones. Concerning the downstream effect in the whole economy, a \$1 dollar reduction in primary inputs results in a \$6.60 dollar worth of capital stranding in the economy. The most exposed clusters of sectors are *Mining-energy*, *Electricity, gas and steam supply*, *Food*, and *Land transport*. When it comes to the upstream effects, the effects of a \$1 dollar reduction in final demand in MINfos add up to \$5.69 dollars in the whole economy. The clusters of *Mining-energy*, *Mining no-energy*, *Real estate, entertainment*, and *Publishing, professional activities* are the main exposed ones. While the *Mining-energy* cluster remains in a hedge position, the clusters of *Electricity, gas and steam supply* and of *Mining no-energy* are in hedge-speculative positions. Even more appalling are the speculative condition of the *Food* cluster and the "Ponzi" position of the cluster on *Real estate, entertainment*.

5.2.2 Scenario 2: Nature/Biodiversity transition risks

The second scenario is named as "Biodiversity protection transition" and consists on a combined shock in both AGRagr and AGRfor sectors. The downstream effects of a \$1 dollar reduction in primary inputs is of \$6.21 dollar worth of capital stranded in the economy. *Food*, *Paper, water transport*, *Wood,* *machinery*, and *Chemical, plastic* are the most affected clusters of sectors. The upstream effects of a combined shock in AGRagr and AGRfor of a $1 dollar reduction in final demand add up to $5.16 dollars, with the most affected clusters being *Food*, *Mining-energy*, and *Real estate, entertainment*.

Similarly to Scenario 1, the clusters of *Mining-energy*, *Food* and *Real estate, entertainment* appear as the main affected ones. Again, the "Ponzi" and "speculative" positions of the *Real estate, entertainment* and *Food* clusters raise multiple concerns of financial fragility. In addition, this scenario also affects the clusters of *Paper, water transport*, *Wood, machinery*, and *Chemical, plastic*, which are classified with "Ponzi", "speculative", and "speculative" financial positions, respectively.

5.2.3 Scenario 3: Combined Climate + Nature transition risks

The third and final scenario is labeled as "Climate + Nature transition" and consists in a combination of Scenarios 1 and 2. The initial shock is applied at the same time on the MINfos, AGRagr and AGRfor sectors. The downstream results of a $1 dollar reduction in primary inputs for these sectors is of $12.82 dollars worth of capital stranding, meaning that the shock amplifies up to 12 times in function of the downstream connections of these sectors and the capital intensity of the sectors positioned ahead of them. Upstream-wise, the effect of a $1 dollar reduction in final demand in the three sectors add up to $10.85 dollars worth of total capital stranding in the economy, an amplification factor of 10.8 as a result of the upstream network of production.

The financial risk is mostly concentrated in highly exposed "Ponzi" clusters, such as *Paper, water transport*, *Finance and insurance, IT, public administration*, and *Real estate, entertainment*. Clusters in "speculative" position, such as *Food*, *Chemical, plastic*, *Wholesale and retail*, and *Wood, machinery* are also clusters that can face great financial stress in front of a combined transition policy targeting climate change and biodiversity loss at the same time.

5.2.4 Scenarios discussion: main takeaways and limitations

The scenario exercises reveal important insights on the effects of materialized nature-related risks affecting the Brazilian sectors that are major GHG emitters and biodiversity loss inducers. The larger share of exposure to capital stranding takes the form of direct and indirect effects over the primarily affected cluster of sectors (*Mining-energy* and *Food*). In terms of financial vulnerability, while the Minskyian analysis showcases a hedge position for the *Mining-energy* cluster of sectors, the cluster of *Food* is characterized by a speculative position, which indicates that food industries are expected to be lack sufficient cash flows to mitigate and cope with capital losses stemming from materialized risks.

Indirect effects affecting other sectors also consist on a relevant parcel of the total effects. They are particularly important as multiple indirectly exposed clusters of sectors are currently in Ponzi or speculative financial positions. For instance, the clusters of *Real estate, Entertainment* and *Paper, Water transport* are the two clusters that receive most of the indirect impact in the low-carbon transition and biodiversity protection transition scenarios, respectively, while facing Ponzi financial positions.

While the results display impacts in terms of stranding capital, it should be noted that the clusters of *Mining-energy* and *Food* are deeply entangled in the Brazilian climate-nature-society nexus. As highlighted before, the sectors that compose these two clusters are highly relevant for the Brazilian economy in terms of employment, wages, fiscal revenues and for the generation of foreign exchange reserves. Moreover, they are important providers of basic final demand needs of the Brazilian society such as food and energy. The shortage of the products provided by these sectors may lead to catastrophic social and economic problems related to health and basic subsistence.

In addition, it should be remembered that our scenarios are highly stylized and assume that the shocks affect only one or two particular industries at a time. In reality, as already mentioned, we could expect nature and climate risks to take place together, specially because the cluster of Food is both a major driver of biodiversity loss and GHG emissions in Brazil. Furthermore, the volume or size of the shock is an important factor to be taken into consideration, as particular macro-financial dynamics shall be triggered only at a particular level of materialized direct and indirect effects, being the Minskyian financial analysis an illustration, as larger effects may lead to the complete collapse of financially fragile sectors.

Cluster	Low-carbon transition ($)	Biodiversity protection transition ($)	Climate/Nature transition ($)	Financial position in 2020
Mining-energy	5.80131	0.02299	5.82429	Hedge
Food	0.11399	4.82957	4.94356	Speculative
Paper, Water transport	0.03989	0.45144	0.49133	Ponzi
Wood, Machinery	0.01227	0.35235	0.36462	Speculative
Chemical, Plastic	0.04932	0.10159	0.15091	Speculative
Mining-no energy	0.09182	0.05411	0.14593	Hedge-Speculative
Electricity, gas and steam supply	0.12780	0.00697	0.13478	Hedge-Speculative
Land transport	0.10471	0.00787	0.11258	Hedge
Finance and insurance, IT, Public administration	0.04861	0.06155	0.11016	Ponzi
Accommodation, Food services, Air transport, Other services	0.02424	0.07747	0.10171	Hedge-Speculative
Construction, Non metal products	0.03516	0.04488	0.08004	Ponzi
Real estate, Entertainment	0.02475	0.04475	0.06950	Ponzi
Wholesale and retail	0.03049	0.03788	0.06837	Speculative
Publishing, Professional activities	0.01976	0.03308	0.05284	Hedge-Speculative
Motor vehicles	0.01787	0.02301	0.04088	Hedge
Textiles	0.00683	0.02342	0.03024	Ponzi
Health	0.01084	0.01645	0.02729	Hedge-Speculative
Telecommunication, Administration, Education	0.01095	0.01002	0.02098	Ponzi
Real estate, Entertainment (R) - Accommodation, etc. (S)	0.01049	0.00922	0.01971	R (Ponzi), S (Hedge-Speculative)
Warehousing	0.00620	0.00257	0.00877	Speculative
Water and Waste	0.00607	0.00199	0.00806	Hedge-Speculative
Other transport equipment	0.00208	0.00338	0.00545	Ponzi
Electrical equipment	0.00220	0.00052	0.00272	Speculative
Computer	0.00096	0.00103	0.00198	Speculative
Postal and courier	0	0	0	Hedge
Total stranding	**6.59861**	**6.21809**	**12.81670**	

Table 1: Downstream effects of Scenarios 1, 2 and 3

Cluster	Low-carbon transition ($)	Biodiversity protection transition ($)	Climate/Nature transition ($)	Financial position in 2020
Mining-energy	5.24287	0.19820	5.44107	Hedge
Food	0.00707	4.29673	4.30380	Speculative
Real estate, Entertainment	0.07413	0.11541	0.18954	Ponzi
Publishing, Professional activities	0.06236	0.05553	0.11789	Hedge-Speculative
Mining-no energy	0.08475	0.06087	0.14562	Hedge-Speculative
Chemical, Plastic	0.01467	0.08732	0.10199	Speculative
Wholesale and retail	0.01816	0.07805	0.09621	Speculative
Electricity, gas and steam supply	0.00714	0.05939	0.06653	Hedge-Speculative
Paper, Water transport	0.03156	0.03449	0.06605	Ponzi
Land transport	0.02515	0.04975	0.07490	Hedge
Telecommunication, Administration, Education	0.03210	0.02089	0.05299	Ponzi
Finance and insurance, IT, Public administration	0.02088	0.02467	0.04555	Ponzi
Warehousing	0.02773	0.01675	0.04448	Speculative
Wood, Machinery	0.01574	0.01619	0.03193	Speculative
Accommodation, Food services, Air transport, Other services	0.00691	0.00304	0.00995	Hedge-Speculative
Real estate, Entertainment (R) - Accommodation, etc. (S)	0.00274	0.00341	0.00615	R (Ponzi), S (Hedge-Speculative)
Motor vehicles	0.00214	0.00403	0.00617	Hedge
Water and Waste	0.00301	0.00357	0.00658	Hedge-Speculative
Health	0.00208	0.01474	0.01682	Hedge-Speculative
Construction, Non metal products	0.00506	0.01264	0.01770	Ponzi
Textiles	0.00101	0.00226	0.00327	Ponzi
Electrical equipment	0.00069	0.00085	0.00154	Speculative
Computer	0.00039	0.00021	0.00060	Speculative
Other transport equipment	0.00010	0.00016	0.00026	Ponzi
Postal and courier	0	0	0	Hedge
Total stranding	**5.68844**	**5.15916**	**10.84759**	

Table 2: Upstream effects of Scenarios 1, 2 and 3

6 Concluding Remarks

In this paper we sought to provide three new methodological contributions to the NRRs literature: (1) the study of upstream cascading effects through a standard Leontief model, complementing the analysis proposed by Cahen-Fourot et al. (2021), (2) the Minskyian framework of assessment for financial fragility is employed as a new measure of vulnerability for the different sectors of the economy, and (3) climate and biodiversity issues are addressed together for the first time in a NRR assessment.

Brazil provides a great case for the study of the climate-nature nexus. The analysis of cascading effects indicate that both polluting and non-polluting sectors are exposed to capital stranding effects given the implementation of a transition policy. When looking at the Scenarios and the macro impact of a marginal reduction of inputs or final demand for particular sectors, the results indicate that $1 dollar of direct impact can be generate a value worth of stranded capital up to 10x to 12x times higher. In particular, some of the most exposed sectors are also particularly financially vulnerable as they integrate clusters of "Ponzi" and "speculative" positions.

Following studies could focus on other variables such as employment, wages, foreign currency revenues, state revenues, etc, in order to bring a larger picture of the a climate-nature-society nexus of risks faced by Brazil. Moreover, the financial analysis could be improved with more granular data and employed to build new indexes that could guide future transition policies.

Acknowledgments

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Supplementary Materials

Sector label	NACE code	Sector description	Cluster
AGRagr	A01	Crop and animal production, hunting and related service activities	Food
AGRfor	A02	Forestry and logging	Food
AGRfis	A03	Fishing and aquaculture	Food
MINfos	B05-06	Mining and extraction of energy producing products	Mining-energy
MINoth	B07-08	Mining and quarrying of non-energy producing products	Mining-no energy
MINsup	B09	Mining support service activities	Mining-energy
MANfoo	C10-12	Food, beverages and tobacco products	Food
MANtex	C13-15	Textiles, wearing apparel, leather and related products	Textiles
MANwoo	C16	Wood and products of wood and cork, except furniture	Wood, Machinery
MANpap	C17	Paper and paper products	Paper, Water transport
MANpri	C18	Printing and reproduction of recorded media	Paper, Water transport
MANref	C19	Coke and refined petroleum products	Mining-energy
MANche	C20	Chemicals and chemical products	Chemical, Plastic
MANpha	C21	Basic pharmaceutical products and pharmaceutical preparations	Health
MANpla	C22	Rubber and plastic products	Chemical, Plastic
MANmin	C23	Other non-metallic mineral products	Construction, Non metal products
MANmet	C24	Basic metals	Mining-no energy
MANfmp	C25	Fabricated metal products, except machinery and equipment	Mining-no energy
MANcom	C26	Computer, electronic and optical products	Computer
MANele	C27	Electrical equipment	Electrical equipment
MANmac	C28	Machinery and equipment n.e.c.	Wood, Machinery
MANmot	C29	Motor vehicles, trailers and semi-trailers	Motor vehicles
MANtra	C30	Other transport equipment	Other transport equipment
MANfur	C31-32	Furniture and other manufactured goods	Wood, Machinery
MANrep	C33	Repair and installation services of machinery and equipment	Wood, Machinery
PWR+	D	Electricity, gas, steam and air conditioning	Electricity, gas and steam supply
WATwat	E36	Natural water; water treatment and supply services	Water and Waste
WATwst	E37-39	Sewerage services; sewage sludge; waste collection, treatment and disposal services	Water and Waste
CNS+	F	Constructions and construction works	Construction, Non metal products
TRDmot	G45	Wholesale and retail trade and repair services of motor vehicles and motorcycles	Wholesale and retail
TRDwho	G46	Wholesale trade, except of motor vehicles and motorcycles	Wholesale and retail
TRDret	G47	Retail trade services, except of motor vehicles and motorcycles	Wholesale and retail
TRAinl	H49	Land transport and transport via pipelines	Land transport
TRAwat	H50	Water transport	Paper, Water transport
TRAair	H51	Air transport	Accommodation, Food services, Air transport, Other services
TRAwar	H52	Warehousing and support activities for transportation	Warehousing
TRApos	H53	Postal and courier activities	Postal and courier
FD+	I	Accommodation and food service activities	Accommodation, Food services, Air transport, Other services
COMpub	J58	Publishing activities	Publishing, Professional activities
COMvid	J59-60	Motion picture, video and television production, sound recording, broadcasting	Publishing, Professional activities
COMtel	J61	Telecommunications	Telecommunication, Administration, Education
COMcom	J62-63	Computer programming, consultancy; Information service activities	Finance and insurance, IT, Public administration
FINser	K64	Financial services, except insurance and pension funding	Finance and insurance, IT, Public administration
FINins	K65	Insurance, reinsurance and pension funding services, except compulsory social security	Finance and insurance, IT, Public administration
FINaux	K66	Activities auxiliary to financial services and insurance services	Finance and insurance, IT, Public administration
RES+	L	Real estate activities	Real estate, Entertainment
PROleg	M69-70	Legal and accounting services; Activities of head offices; management consultancy activities	Publishing, Professional activities
PROeng	M71	Architectural and engineering activities; technical testing and analysis	Publishing, Professional activities
PROsci	M72	Scientific research and development	Publishing, Professional activities
PROadv	M73	Advertising and market research	Publishing, Professional activities
PROoth	M74-75	Other professional, scientific and technical activities; Veterinary activities	Publishing, Professional activities
ADM+	N	Administrative and support service activities	Telecommunication, Administration, Education
PUB+	O	Public administration and defence; compulsory social security	Finance and insurance, IT, Public administration
EDU+	P	Education	Telecommunication, Administration, Education
HEA+	Q	Human health and social work activities	Health
ART+	R-S	Arts, entertainment and recreation	Real estate, Entertainment (R) - Accommodation, etc. (S)

Table 3: Correspondence between NACE sectors and clusters. Source: Cahen-Fourot et al. (2021), Modica Scala et al. (2024)

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