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Stakeholder perspectives on cross-border climate risks in the Brazil-Europe soy supply chain

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ABSTRACT

Climate change impacts in one country can lead to impacts in distant locations, for example, via internationally traded crops. Previous work has highlighted a need to include cross-border climate change impacts in climate risk assessments, to describe the exposure and transmission of cross-border climate risk across actors, and understand options for managing this risk. In a case study of the Brazil-Europe soy supply chain, this paper aims to explore how stakeholders perceive past and future shocks, how climate change impacts affect stakeholders differently, and how they might respond. Soy is a key internationally traded commodity and Europe relies on imports for the majority of its soy consumption, used widely in livestock feed. Via 96 semi-structured expert interviews, we found different stakeholder groups are vulnerable to different types of weather shocks, experience different price and supply consequences, and have different capacities to respond. While some responses can reduce risk of impacts across the supply chain (e.g. new soy cultivars, improving transport infrastructure), we also identified examples where responses exacerbate risk for other stakeholders (e.g. export bans, changing demand). A holistic cross-border approach to analysing risk in the soy supply chain can help avoid maladaptation and offer opportunities for more collaborative adaptation.

1. Introduction

Climate risk and adaptation are typically analysed on a national level, but in an interconnected world, a single country focus could miss an important part of the picture. Climate change impacts are not bound by national borders, but can be transmitted through various pathways, leading to impacts in other countries (Carter et al., 2021). Trade is a key pathway of cross-border risk transmission (Benzie et al., 2016) and agri-food supply chains have been identified as vulnerable to climate change impacts (Godde et al., 2021; Jägermeyr et al., 2021; Mirzabaev et al., 2023). Recent events, such as the COVID-19 pandemic and the Russia-Ukraine war, have demonstrated consumer exposure to cross-border impacts in food supply chains (Glauber et al., 2022). However, describing the transmission of cross-border climate change impacts (hereafter referred to as cross-border climate impacts) across actors in international supply chains, and guidance on how to adapt, remain key research gaps (Bednar-Friedl et al., 2022; Mirzabaev et al., 2023).

Emerging work has demonstrated the interdependencies within supply chains in the context of climate change risk and adaptation. The negative financial consequences of extreme weather impacts on suppliers can propagate to customers (Pankratz and Schiller, 2021), and companies' climate risk exposure and adaptive capacity depend on inter-company relationships (Canevari-Luzardo et al., 2020). Regardless of their own resilience measures, companies can be susceptible to climate-change related risks via less resilient stakeholders within their supply chain (Er Kara et al., 2021). The responses of stakeholders to climate impacts can also affect other stakeholders in the supply chain. Whilst responses can promote adaptation, they may have negative consequences on other stakeholders, in worst cases being maladaptive and increasing vulnerability (Barnett and O'Neill, 2010). Recent changes to the IPCC definition of risk recognise the importance of

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including responses in climate risk assessments: risk can arise from the impacts of, as well as human responses to, climate change (Reisinger et al., 2020).

Despite broad evidence for including stakeholders from across the supply chain in analyses of climate risk and adaptation, few studies explore the perspectives of stakeholders in more than one country along a cross-border supply chain. Previous work addressing supply chain stakeholder perspectives on cross-border climate risk has focused on stakeholders within one country (Fleming et al., 2014; Tenggren et al., 2020) or one region (Berninger et al., 2022). Within the food supply chain, previous research has focused on the agricultural production step in both assessing climate risk (Davis et al., 2021) as well as targeting adaptation efforts (Mirzabaev et al., 2023), missing potential opportunities for adaptation in other parts of the supply chain and for understanding the transmission of risk. Furthermore, insufficient attention has been paid to the effects of stakeholder responses to risk on other stakeholders in a supply chain. More work is needed to evaluate trade-offs and synergies between risk management options across stakeholder groups, to avoid situations where risks are shifted to other actors or existing vulnerabilities are reinforced (Fleming et al., 2014; Lager et al., 2021; Sá et al., 2019).

This paper tackles the research gaps outlined above by investigating stakeholder perspectives of cross-border climate risk and their potential responses in a case study of the Brazil-Europe soy supply chain. Using a supply chain perspective, we aim to explore how stakeholders may be impacted by climate shocks, how shocks are transmitted between stakeholders, their potential responses, and how these may impact other stakeholders. In contrast to previous work, we analyse cross-border climate risk and responses for a range of stakeholder groups along an international commodity supply chain.

We consider the experiences of, and interrelationship between, stakeholders from across the supply chain, drawing on stakeholder theory, originally proposed by Freeman (1984) who argued that firms should be concerned about the interests of their stakeholders, not only their shareholders. Freeman (1984) defined stakeholders as those who affect or are affected by an organisation, though critically not all stakeholders are equal (Cadez et al., 2019). Our study employs a conceptual perspective to consider the perspectives of stakeholders across a supply chain, rather than from a single company's perspective, and draws on stakeholder theory's two main branches (Wagner Mainardes et al., 2011): strategic (the active management of stakeholder interests) and moral (the balancing of stakeholder interests). For our case study, we investigate questions under both branches: how firms can benefit from considering other stakeholders' risk exposure (strategic) and whether there is a 'just' distribution of risk across the supply chain (moral; Lager et al., 2021).

Recent conceptual framings of cross-border climate risk (Carter et al., 2021; Talebian et al., 2023) have outlined cross-border climate risk pathways, and characterised stakeholder responses. Carter et al.'s (2021) framework describes typologies of the initial impact, the downstream consequences propagated through an impact transmission system, and a response transmission system. Building on this initial framework, Talebian et al. (2023) further develop typologies of cross-border climate impacts, responses and actors, to help investigate the appropriateness of responses and governance modalities. We utilise Talebian et al.'s (2023) typologies of responses and response effects to categorise stakeholder responses, analyse their underlying mechanisms and evaluate their effects on other stakeholders along the supply chain.

Drawing on stakeholder theory and Talebian et al.'s (2023) conceptual framework, our study brings together stakeholder perspectives from across the Brazil-Europe supply chain, using data from semi-structured interviews with soy producers, traders, feed producers, livestock farmers and retailers. The Brazil-Europe soy supply chain has been identified as a key cross-border risk for Europe requiring further research due to its reliance on soy imports for livestock feed (Arvis et al., 2020; Berninger et al., 2022; Kuepper and Stravens, 2022; West et al., 2021). In 2020, Brazil was the largest exporter of soy globally, and exported 18.3 million tonnes, or $6.7 billion, of soybean to Europe (Chatham House, 2021). In terms of stakeholder numbers, the supply chain is 'hourglass-shaped', with hundreds of thousands of farms producing soy in Brazil, for an estimated billions of end-consumers globally, connected by a small number of processors and traders (De Maria et al., 2020).

To explore the potential impacts of climate change, we used the terms 'climate shocks' and 'weather-related shocks' with participants. Discussion of climate shocks allows us to explore the perceptions of stakeholders on climate change more broadly, whereas discussion of weather shocks allows us to explore the potential impacts of climate change at a time scale which stakeholders are dealing with on the ground, and which allow us to discuss these impacts in detail. Whilst not every past or future weather-related shock discussed can be attributed to climate change, climate change is projected to increase the frequency and intensity of weather extremes (Pörtner et al., 2022). Stakeholder experiences of extreme weather events, whether or not they are attributed to climate change, can help inform adaptation to extreme weather events which are driven by climate change.

Our study makes the following main contributions to the literature: for an international supply chain, we describe and compare the exposure of different stakeholders to cross-border risks, explore the transmission of shocks between stakeholders, and evaluate trade-offs and synergies between stakeholder responses. We consider stakeholder groups from across the Brazil-Europe soy supply chain, in contrast to a previous focus in the literature on agricultural production. We structure our paper around the following questions.

- How do stakeholders perceive past and future climate risk to the soy supply chain?
- What are the consequences of weather shocks on the soy supply chain for different stakeholders?
- How might stakeholders respond to weather shocks, and how could these responses in turn affect other stakeholders?

In Section 2, we outline the methods for our study's data collection and analysis. In Section 3 we discuss our main results, and in Section 4 we contextualise these within the wider literature and point towards areas of further research. Finally, in Section 5 we present our conclusions.

2. Methods

2.1. Methods overview

We conducted interviews with stakeholders in Brazil and Europe representing a range of organisations involved in the production, transport, trade and use of soy (Table 1). Data collection was carried out in two phases: in Phase A, in-person interviews were conducted in Brazil in 2019; and in Phase B, online interviews were carried out in 2022 (see

Table 1
Number of interview participants per location and stakeholder group. Examples of stakeholder sub-groups provided.

Stakeholder Group	Number and location of participants		Example stakeholder sub-groups
	Brazil	Europe	
Producers	24	1	Soy producer, soy cooperative, seed and inputs company
Intermediaries	47	4	Grain trader, soy processor, storage, trader group
Consumers	0	11	Feed producer, livestock farmer, retailer
Policy and research	6	3	Policymaker, researcher

sections 2.2 and 2.3, respectively).

To identify key stakeholder groups, we conducted a stakeholder mapping exercise (Fig. 1), drawing on prior knowledge and soy supply chain literature (Czaplicki Cabezas et al., 2019; Kuepper and Stravens, 2022). To capture cross-border climate impacts, we defined our system boundaries as the soy produced in Brazil and used for export to Europe. Therefore, our scope does not explicitly include consumption of soy within Brazil, or other sources of soy consumed by Europe (except for one European soy producer stakeholder who provided insight into domestic production as a response).

Based on this mapping exercise, we defined four stakeholder groups: producers (stakeholders involved in the production and initial processing of soy), intermediaries (stakeholders involved in the trade and transport of soy), consumers (stakeholders who import and rely on soy from Brazil) and policy and research (individuals established either in Europe or Brazil, offering an outside perspective on the supply chain as a whole). We recruited 96 participants in total (see Table 1, and sections 2.2 and 2.3 for recruitment methods). Participants were categorised based on their position in the supply chain, and geographical location.

Interviews were semi-structured, allowing questions to be adapted to each stakeholder group and for exploration of topics raised by the participants (Adams, 2015). The interview guides are included in the Supplementary Material.

All participants provided informed prior consent to their involvement and the recording of their data. Ethical approval was granted by the lead author's institution.

2.2. Phase A – interviews in Brazil, 2019

Phase A consisted of in-person interviews with stakeholders located in Brazil, conducted by T.N.P.R. The interviews explored shocks (including climatic shocks) affecting production and trade relations in Brazil's export soy supply chains, as part of a broader scope of research addressing additional questions of trade relationship stability, soy production history and infrastructure decisions (see S.1a, Supplementary Material; Reis et al., 2023). Between July and November 2019, 70 in-person semi-structured interviews were conducted, in Brazilian Portuguese (a further 13 interviews were conducted, but participants chose not to be recorded, and are therefore excluded from this analysis). Key soybean trading hubs were visited within a range of regions involved in the soy supply chain (Reis et al., 2023). Each location was visited for one to two weeks, and semi-structured interviews were conducted with various actors in the soy supply chain, using methods outlined by Patton (2002) and Silverman (2010).

Interviews ranged from 40 to 150 min. Interviewees were identified through a combination of personal acquaintances, contacts with local rural unions and associations, the establishment of a network of gatekeepers and key informants, and snowball sampling (Silverman, 2010). Interviews were recorded and transcribed by a research assistant. Transcripts were translated into English and checked by a native Brazilian Portuguese and English speaker.

2.3. Phase B – virtual interviews, 2022

Phase B consisted of 26 semi-structured online interviews with stakeholders across the whole supply chain (located in both Brazil and Europe), between June and December 2022, conducted by E.S. Purposive sampling was used to recruit the initial interview participants in this phase, with snowball sampling thereafter. Use of multiple starting points reduced the risk of linearity associated with snowball sampling. Interviews took place over Zoom in English, lasting from 30 to 60 min.

Questions were structured into four sections: role and background of the participant; experience of past shocks on the soy supply chain; planning for shocks in the future; and policy responses to shocks (see S.1b, Supplementary Material). Interviews were recorded and transcribed.

2.4. Analysis of interview transcripts

Interview participants were anonymised at the transcription stage and given labels representing their stakeholder group (ProX for participants in the producer group, IX for intermediaries, CX for consumers,

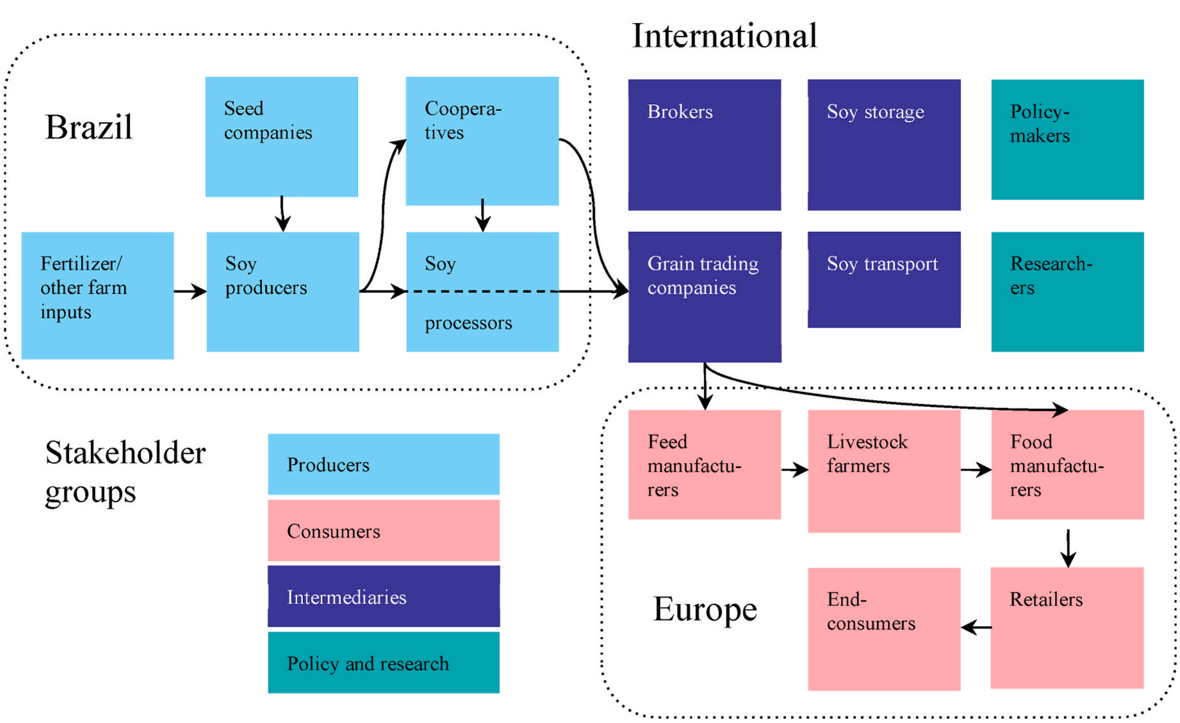

Fig. 1. Stakeholder mapping diagram for the Brazil-Europe soy supply chain case study. Stakeholders grouped by geographic location; colours indicate stakeholder group; arrows indicate soy or material flows. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and PolX for policy and research; interview codes preceded by 'A-' or 'B-' to indicate phase).

We conducted thematic analysis (Braun and Clarke, 2006) and coded transcripts using NVivo version 20.6.1.1137 with both a priori and emergent codes (Elliott, 2018). Five a priori codes were based on the original aims and questions (shocks affecting the soy supply chain in the past; consequences of shocks; responses to shocks; future expected shocks on soy supply chain; policy issues and recommendations), and 51 emergent sub-codes were developed during the coding process from the participants' responses, each categorised within one of the five a priori codes (see Tables S1 and S2, Supplementary Material, section S.2). Emergent codes were refined throughout the coding process, selected based on the recurrence of themes during the interviews, and their relevance to the research questions. The five a priori codes were condensed into three to structure the results section (see Section 3).

In addition to the coding analysis, we applied the conceptual framework for responding to cross-border climate change impacts of Talebian et al. (2023) to analyse our findings within a broader non-sector-specific context and consider the potential repercussions of stakeholders' responses. In particular, we used the authors' categories of response types (based on attributes of the response transmission target and dynamics) to categorise the responses described by participants and response effects (reduce, redistribute or exacerbate risk) to analyse their impacts on other stakeholder groups (see Section 3.3).

3. Results

3.1. Stakeholder perceptions of past and potential future shocks

Participants reported a wide range of different geopolitical, economic and weather-related past shocks, the majority occurring in the past ten years (Fig. 2; Table S3, Supplementary Material, section S.3). This highlights that weather impacts on the soy supply chain occur alongside other geopolitical and financial disruptions, and experiences of all these shocks informed participants' responses during the interviews. As explained by B–C7 (an aquaculture producer), supply chains are so 'tight' currently, it makes responding to any individual shock more difficult; if climate shocks occur in the future *"there's not so much space around to find replacements."*

In terms of past weather shocks, participants mostly reported drought or excess rain (mentioned by 43 and 35 participants, respectively; see Table 2). The particular timing of weather shocks during the growing season matters (A-Pro5): soy is most vulnerable to drought during the flowering to grain filling stage (B-Pro5), and heavy rainfall has the most negative impact during planting or harvesting. Participants also highlighted examples of concurrent or compounding weather shocks. For example, 10 of the 26 Phase B interviewees mentioned the 2021–2022 growing season, in which southern Brazilian states experienced drought followed by excess rainfall which delayed harvesting and damaged part of the crop (B-Pol1).

The impact of weather on the transport of soy in the past was mentioned less frequently than impacts to soy yields (see Table 2), or seen as less important than impacts to production (B-Pol2). Whilst B–I1 and B–I3 recognised that weather could affect waterways, they were sceptical about its potential to cause large disruption to roads or railways. B–I1 and B-Pol4 explained that weather disruption may increase transport costs, but does not generally disrupt the flow of soy because alternative routes are possible.

Some participants (mostly intermediary and consumer stakeholders)

Table 2
Participant perceptions of how weather shocks can affect soy production, transport and infrastructure. Number of interviewees in brackets.

Shock	Impacts on soy production	Impacts on soy transport & infrastructure
Drought	Reduces soy yields (43)	Reduces waterway transport of soy (6) Reduces hydroelectric power generation (1)
Excess rain	Delays soy planting (3) Delays soy harvesting (6) Damages soy quality, increases risk of disease (e.g. soybean rust) (21) Unspecified harvest loss (7) Leaches potassium from soil, less light for photosynthesis, lower yields (1)	Delays loading at ports (1) Causes flooding on [unpaved] roads (10) Increased sedimentation in rivers, blocking waterways (1) Damage to soy in storage (1)
Storms	None mentioned	Can damage loading facilities or boats on the water, divert ships and delay docking (2) Can damage railways and bridges (1)
Extreme cold	Frost can damage plants and cold can slow germination (4)	None mentioned
Extreme heat	High temperatures can damage plants (2)	Increase of vermin affecting soy storage (1)

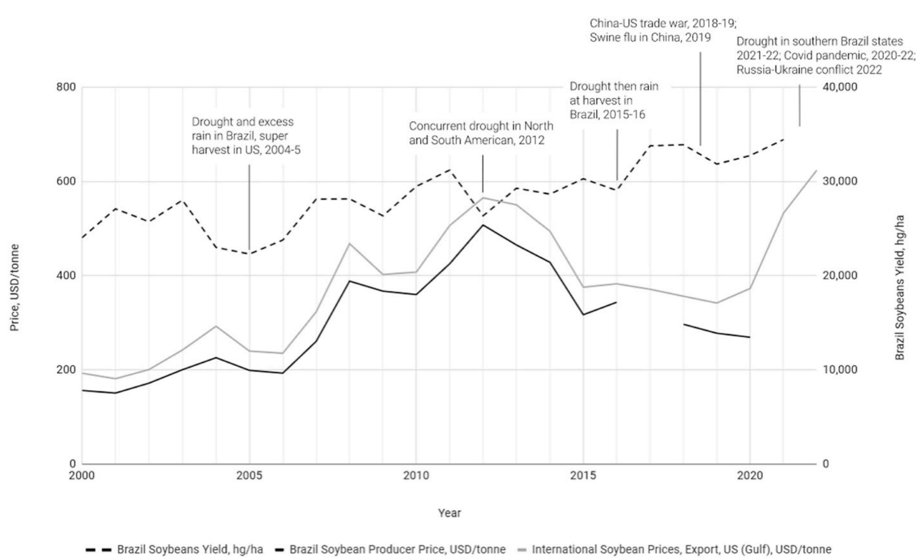

Fig. 2. Timeline of annual Brazil producer price, mean international export price and Brazil soy yield, 2000–2020. Major shocks mentioned by participants are labelled. Sources: FAO, 2023a; FAO, 2023b. Data for 2017 unavailable in producer price data.

struggled to think of any weather-related examples of past shocks on the soy supply chain (B–C3, B–C4, B–I6, B-Pol4, A-I13). B–C4 explained: *"I think it's gonna be very difficult to pinpoint a climate shock that has impacted the entire industry for such massively produced commodities as soy and palm oil."* Whilst B–I3 acknowledged historical examples of drought reducing yields, they stated *"it's not a massive crop failure"*, and that other producers could step in to fill gaps in supply. Some participants also argued that soy was less affected by bad weather than crops such as coffee or fruit (B-Pro1), and that other countries (in particular, Argentina) experienced worse weather and larger soy harvest losses than Brazil (B-Pol4, B–C1, B–C6, A-Pro13).

As with past shocks, a wide range of possible future shocks were described by participants, including geopolitical, economic, demand-related and climate-related (see Table S4, Supplementary Material, section S.3, for further detail). Some participants suggested that climate change may be a bigger risk than other potential shocks, due to its longevity and irreversibility (B–I3), and the difficulty of finding solutions (B-Pol4). There was generally a strong expectation that climate change would impact the soy supply chain, but it was not always clear exactly how (B–I6, B–C10, B–C7, B-Pol4, A-I16); *"we all think we know what climate change is, but we don't really understand it"* (B–I6). However, some participants gave specific examples, including negative impacts on transport, storage and processing, often identified by those involved in grain trading (B–I3, B–I4, B–I5); *"how to move the cargo is going to be broadly the next big challenge. I am very worried that in 10 years we will not have this river, or the other river […] Because that implies a complete change of flow inside the country and of course on the economics behind"* (B–I4). Participants at the trader and consumer end of the supply chain also identified climate-induced legislation and regulation as a risk to the soy supply chain (B–I3, B–C10, B–C6, B–C8, B–C9, A-I18).

Certain participants portrayed optimism about the supply chain's ability to withstand future shocks: *"if you ask [Brazilian soy farmers] about the future shocks and the possibilities that something could break their harvest, they would say that they are not concerned about this, because now they are earning a lot of money […] so they will see the future when the future comes"* (B-Pol1). Participants were also optimistic about the future of soy due to strong persistent demand, such as the rise of Indian demand for meat (A-I11, A-I13, A-I15, B–C2, B-Pro2). However, B–C3 suggested that optimism may come from the fact that many supply chain actors *"are from a generation where everything was available in large quantities. And I think we enter a new era, let's say, where we will face a lot more disruptions.*

Participants had different definitions of a shock and were concerned by different aspects of supply chain performance. For some participants, a shock represented a physical disruption to supply, whilst other participants were primarily concerned about changes to the price of soy. For example, participant B–I6 was optimistic about the supply chain's ability to withstand shocks due to historical continuity of supply: *"we've never seen the supply chain broken. There's never been a disruption in the continuity […] in the pandemic, when we saw negative prices for oil, most ships were abandoned because there was no demand. Supply of soymeal kept working like a Swiss clock."* Ultimately, supply and price are closely related: interruptions in supply cause prices to increase. Some stakeholder groups 'suffer' from a disruption in supply but not from an increase in prices (grain traders, those involved in the transport of soy), whilst other stakeholder groups are affected by higher prices (those who buy soy as an input for their industry, and stakeholders who buy their products).

3.2. Consequences of weather-related shocks for different stakeholders

For soy producers, the consequences of weather-related shocks mainly relate to harvest losses, which could have direct impacts via loss of potential income (B-Pol1, B–I5, B-Pro4). It is common for soy farmers to sell 30–70% of their expected harvest in advance, to protect themselves from the risk of lower future soy prices (6 participants), but not selling 100% in case of a harvest loss or a higher future soy price (12). If soy farmers are unable to fulfil a contract they have already agreed to, there are several potential consequences: the contract will be renegotiated (11 participants), and soy farmers could face debt (6), pay a fine or the cost of soy on the market (12), the contract may be rolled over to the following year (8), or farmers could face a court process (3). Where the harvest is damaged or fails to meet certain standards, traders purchase the soy with a discount (A-I36, A-Pro17, A-I31, A-Pro16). In some cases, soy producers may take multiple years to recover financially (A-Pro3, B–I1, A-Pro6, A-I41).

The choice of response from the grain trader depends on the size and type of producer: with a family farm they may roll the contract to the following year, *"because it makes no sense to go against someone who is not going to be able to solve it"* (B–I4). However, with a larger corporation, they would be asked to comply with the commitment or pay the price difference for buying the same volume of soy on the market. A-Pro16 also stated that due to their good relationship with the trader, they did not have to pay the required fine when they broke their contract due to a harvest loss: *"it depends on the relationship you have with the company.*

Participants specified that the impact on producers also depends on how widespread the shock is: *"depending on the kind of shock, the prices are going to go back to the producer, or to the client"* (B–I4). If it affects a small area, the affected producers are more likely to shoulder the cost personally (B-Pro1, B–I4). However, if soy yields decreased over a larger region, governments may step in to support farmers (B-Pro1), and soy prices will increase (due to reduced soy supply), leading to a slight balancing effect for producers with a harvest (B–I4). B–I4 gave the example of the ongoing drought in Argentina, where a reduction in the loads soy barges were able to carry increased export costs. Other producers of soy (Brazil, US, Paraguay) did not have the same problem, therefore buyers were not willing to pay the increase in transport costs and, as a result, Argentinian farmers absorbed the increased freight costs via lower soy prices.

Multiple participants suggested that shocks to soy production would not have negative financial consequences for large traders, and that soy price rises could increase their profitability (B–I2, B-Pol2, B–I5). However, other participants stated that, in the case of a drop in production, traders may absorb costs and wait for the next harvest (A-I16, A-I30), and could incur costs for not filling, cancelling or delaying ships (A-I35, A-I8, A-I37). B-Pol3 also stated that *"any uncertainty on the price […] any response through crisis adjustments to a shock is creating a situation of uncertainty where everybody loses"*, which specifically included traders.

Shocks to soy *transport* were highlighted as having clear negative consequences for traders: by buying soy in advance, traders are vulnerable if transport costs increase between buying and receiving the soy (B–I1, B–I3, B–I4, A-I2). As B–I3 stated, *"if there's a diesel price increase, that's something we [...] the processors or the movers of physical goods would have to absorb and there's only little leeway in fact to price it on further in the chain."* Transport and logistics costs for grain traders can also increase indirectly as a result of crop failure: lower yields can mean having to unexpectedly shift sourcing areas, which leads to an increase in transport and infrastructure costs (B–I3). This normally occurs every year to some extent as supply shifts from North America to South America, but it is exacerbated by crop failures (B–I3).

Many participants agree that the effects of rising soy prices would be felt by consumer stakeholders (including intermediate consumers, such as feed producers and livestock farmers) of the supply chain (B–I2, B–C5, B-Pol4, B–C1). An increase in soy prices leads to a big increase in input costs for the feed sector. For example, Brazil's harvest loss in the 2021–2022 season *"affected the feed sector because soya prices rose from £350 a tonne to £500 a tonne"*, and droughts affecting the transport of soy in Argentina led to *"a noticeable increase in cost"* for the feed producing sector in the EU (B–C1).

There is considerable heterogeneity in how livestock farmers may be affected by an increase in feed prices. Depending on the animal, feed can make up a huge proportion of production costs for livestock farmers: up to 70% for chicken (B–C3), and 60–80% for fish (B–C9, B–C7), whereas sheep and cattle are less dependent on feed as they can be grass-fed (B–C2). Price-setting mechanisms also vary. For example, B–C10, from a dairy cooperative, explained that milk prices are set and evaluated monthly, involving the farmers, and would reflect increases in inputs such as feed. B–C11 described the contrasting example of the Norwegian salmon industry where prices are set by the government annually, so sudden short-term increases in feed costs can negatively impact salmon farmers as the system is not flexible. A livestock farmer's ability to withstand shocks is also partly linked to size, as larger companies have more power when it comes to contracts: *"if you are small [livestock] farmers and you are alone, you have zero power in terms of with these big player traders of raw materials, soybean, all around the world"* (B–C5).

It is not always possible for livestock farmers to pass on increasing costs down the supply chain (B–I6, B–C3, B–C7, B–C5, B–C11). Several participants (B–C3, B–C7, B–C11) highlighted that the small number of large retailers meant they had *"huge bargaining power"* (B–C7), making it difficult for poultry producers and the aquaculture industry to pass on increased costs. The *"super fresh"* nature of chicken also reduces poultry producers' bargaining capacity (B–C5).

B–C4, a UK retailer, suggested that retailers may not feel shocks as much as feed producers or livestock farmers: *"I don't really see the case for a shock which would impact us. [… Retailers have] so many thousands of suppliers who source from all over the world […] I think that that kind of flexibility is built into the system, certainly at the far end of the supply chain that we operate in"*. For B–C8, retailers would hardly notice the increase in the price of soy as a result of a drought: *"you just shift your supply […] if you calculate what the actual influence is of a rise in the prices for soy in the end product as sold in retail it's so marginal that it's actually negligible […] I guess the biggest burden there is to be borne by the producers themselves."* However, other participants disagreed and suggested that retailers and consumers do see an increase in prices: retail prices for salmon increased in 2022, likely driven by higher feed and energy costs (B–C9).

The impact of shocks on end-consumers was not explored in detail, but participants did highlight that the relative wealth of the EU meant that consumers could afford an increase in the cost of food, and soy supply would continue even if prices increase (B–I6, B–I4, B-Pol3, B-Pol4). In the case of participant B-Pol3, speaking in the context of the wider EU food system, they were *"not sure we have a real shortage or a big threat to food supply – yes, feed supply, yes, but food supply, […] I'm not sure we are in such a dramatic situation with this kind of thing."*

3.3. Responding to and preparing for weather-related shocks

The topic of climate risk to the soy supply chain for traders and 'consumer' stakeholders is still an early internal discussion (B–I1, B–C3), and conversations in the sector are currently more focused on reducing greenhouse gas emissions (B–I1, B–C9, B–I5, B–C10). Existing policy addressing shocks in the soy supply chain is rare (B–C5, B-Pol2), and several participants described a lack of plans for responding to future climate disruption to the soy supply chain (B–C7, A-I16, A-I18). One approach of responding proactively to shocks may therefore be to raise awareness of these risks within the sector(s) (B–C3).

However, many participants did identify responses to potential shocks, and these are summarised in Table 3, categorised by response type and response effects as defined by Talebian et al. (2023). Where responses could fit within multiple types, we have chosen the most appropriate. In this section, we outline the main responses described by participants, their response types and response effects. Further detail on the responses can be found in the Supplementary Material, section S.4.

According to Talebian et al. (2023), the 'domestic adaptation' response type is defined as responses at the location of the recipient. In our study, recipients are located both in Brazil and Europe, and we divided 'domestic adaptation' responses by country. In Brazil, participants reported multiple 'domestic adaptation' responses, though many require farmers to pay high costs, which can be a barrier to implementation. For example, low uptake of soy farmer insurance in Brazil (uptake varies by region) is in part due to its high costs, but also due to a perception that weather is relatively stable in some regions (B-Pro1, A-Pro4), and because insurance only covers severe losses (B-Pro4, B-Pol2). Participants also mentioned responses which the Brazilian government can implement: export bans (to protect domestic soy consumption from high prices) and loans for farmers (these tend to be offered in times of widespread harvest loss, B-Pro1).

In Europe, 'domestic adaptation' responses mentioned by participants were mostly government actions. Financial support from governments and the EU depends on the 'long-term' nature of the shock. For example, the EU would respond differently to an isolated shock, compared to recurrent shocks which might challenge the idea that production was viable in the long-term (B-Pol3). This underlines the importance of monitoring and projecting markets and production under climate change and other risks (a 'system-wide adaptation' response), which is done by many actors, including the EU, the FAO, the OECD,

Table 3
Potential responses to shocks identified via interviews, and response effects on stakeholder groups (excluding costs of implementation). Green = reduces risk, orange = redistributes risk, red = exacerbates risk. 'X' represents the main implementing group, and absence of an 'X' indicates it is implemented by stakeholders outside of the labelled stakeholder groups. Stakeholder groups: Pro = Soy producers in Brazil; I = Intermediaries; C = Consumer sectors in Europe. Response type and response effects defined by Talebian et al. (2023).

Response type	Response name	Response effect: Pro	Response effect: I	Response effect: C	Implementation considerations
Domestic adaptation - Brazil	Soy farmer insurance	X [orange]			*High costs for farmers; historical issues with payouts.*
	Move soy production to new area	X [orange]			*Environmental risks, farmers take on risk – depends on suitability of new area.*
	Loans for soy farmers	[orange]			*Redistributes risk over time period of loan. Government action.*
	Technology & management practices	X [green]		[green]	*Requires investment; limited effectiveness during severe events.*
	Irrigation	X [green]		[green]	*High costs for farmers.*
	Export ban	[red]		[red]	*Would increase soy prices for importers, reduce soy prices for soy farmers. Government action.*
System-wide adaptation	Storage	X [green]	X [green]	X [green]	*High costs; time-limited.*
	Diversifying transport modes	[green]	[green]	[green]	*Implemented by the transport sector and governments.*
	Futures contracts	X [orange]	X [orange]	X [orange]	*Relative impact depends on what happens to future prices.*
	Monitoring yields/ supply chain	X [green]	X [green]	X [green]	
	Free trade agreements	[green]	[green]	[green]	*Could exacerbate local impacts. Implemented by governments.*
	Climate mitigation	X [green]	X [green]	X [green]	*Efficacy depends on the time horizon adopted.*
Substitution	Using flexibility of supply		X [green]	X [green]	*Can be limited by policy, prices, availability, etc.*
	Diversifying protein sources	[red]		X [green]	*Would reduce soy demand.*
	(Temporarily) relax trade regulations	[green]	[green]	[green]	*E.g. pesticide, genetically modified organism (GMO) and deforestation regulations. Environmental risks. Implemented by governments.*
Domestic adaptation - Europe	Plant more domestic soy acreage	[red]		[green]	*Land use limits. Would reduce soy demand.*
	Gov. financial support			[green]	*For sectors affected by shock. Government action.*
	Banning soy for biofuels	[red]		[green]	*Would reduce soy demand. Implemented by governments.*

China, the US and the UK (B-Pol3). Planting more soy acreage domestically was also mentioned, though participants warned that lack of available land and biodiversity in concerns in Europe could limit this (B–C8, B–C9, B–I6).

'System-wide adaptation' describes responses which target the entire risk transmission system, aiming to build system-wide resilience (Talebian et al., 2023). Several responses mentioned by participants fit within this category, which can be implemented at government level or at multiple points along the supply chain, such as increasing and improving storage and transport infrastructure (B–I1, B–I4, B–I5, B-Pro5). Market and contract-related responses were also mentioned by participants, such as the use of futures contracts along the supply chain (protecting against future price fluctuations), the role of the Single Market in the EU (B–C7), and free trade agreements (B–C5). Many participants also mentioned the importance of monitoring the supply chain, as well as climate change mitigation and other sustainability measures (6 participants).

Participants described several potential 'substitution' responses which can be implemented by stakeholders towards the consumer end of the supply chain: substituting the origin of soy, substituting soy with other protein sources for food and feed, and substituting the type of soy (e.g. relaxing pesticide and genetically modified organism, GMO, regulations). For example, during the Russia-Ukraine war, there was a temporary acceptance of certain previously banned pesticides and discussions over whether to relax GMO-free rules in the EU (B-Pol3, B–C3). Substitution responses were frequently described by interviewees, with 20 participants stating their organisation would draw on flexibility of supply origins, 10 mentioning diversifying protein sources, and two mentioning substituting the type of soy. This response type relies on trade flexibility (described above) and the availability of other sources, which is a concern for current protein alternatives, as B–C7 summarised: *"soya today is irreplaceable, it's ubiquitous, it's everywhere […] it will take decades before these new or these novel raw materials are able to replace soya in a significant way."*

Table 3 highlights how responses in one part of the soy supply chain could lead to positive or negative repercussions on other stakeholders. In particular, some approaches by consumer stakeholder groups could lead to a reduction in demand for soy, which could exacerbate risk for soy farmers, whereas some soy farmer responses to increase soy yields would have positive effects on consumer stakeholders. We also found several responses redistributed risk within stakeholder groups, rather than reducing risk overall. We discuss the implications of these response effects in section 4.2.

4. Discussion

4.1. Stakeholder differences and power in the supply chain

During the interviews, participants identified a range of different weather-related shocks which have affected the soy supply chain in the past, and which could affect it in the future under climate change. Participants reported the various ways in which these weather shocks could interact with soy production, transport and infrastructure to affect supply chain performance, including soy quantity and quality, delivery time, and price. We have found that different stakeholder groups experience different consequences from weather shocks, are vulnerable to different types of weather shocks and have different capacities to respond, with risks from climate change interacting with those from other sources.

Impacts to producers depend on the relationship with, and response of, traders, and the contracts set up in advance. Previous research has also highlighted the financial risks that Brazilian soy producers can face as a result of a globalised soy market which ties them to a cycle of investment and debt (Bicudo Da Silva et al., 2020), with increased farmer indebtedness identified as a consequence of drought (Silva et al., 2023). Whilst our results show that producer debt is one outcome of harvest losses, we also find that farmer experiences can be highly variable and depend on their adaptive capacity. Some weather variability is accepted as 'normal', and farmers have good capacity to adapt up to a point, by changing planting dates, selecting cultivars, implementing soil management techniques, irrigation and storage (some of which requiring investment). These all depend on the severity and frequency of the weather shocks; historical observations in Brazil have shown agricultural technologies do not provide adaptation to extreme heat for soy yields, for example, creating a dependence on irrigation (Silva et al., 2023).

Traders and retailers see less financial losses from negative impacts to yield than other supply chain stakeholders. Previous work has also found traders to be less exposed as they can more easily pass costs on to their customers (West, 2021) and are able to easily switch suppliers due to their expansive connectivity (Österblom et al., 2015). However, our results show that traders are more vulnerable to shocks to transport. This underlines the importance of considering a range of different weather-related shocks, as research so far has been focused on climate risks to crop production (FAO, 2017). Whilst traders and retailers have a high capacity to adapt to localised weather shocks, as they are able to switch sourcing patterns easily, larger or concurrent weather shocks (Kornhuber et al., 2020; Lunt et al., 2016) may limit this adaptation capacity.

Our findings suggest the feed sector and livestock farmers are at risk of absorbing the costs of larger scale shocks since they can find it difficult to pass costs down the supply chain. Recent events in Europe have illustrated this finding, where droughts were expected to impact the livestock sector in particular (Bukhta, 2022), and in Ireland where pig farmers faced higher feed prices due to drought in South America (Walsh, 2021). Impacts depend on the local context, the industry, the availability of alternatives, and the price setting mechanisms. Previous work focused on the UK has also found the livestock industry to be most affected by soy supply shocks and, in particular, the poultry sector due to a lack of available substitutes (West, 2021). Our findings echo this point: whilst there are lots of alternatives being researched, there are few alternatives available at sufficient scale, availability and price levels, meaning these stakeholders have limited options to adapt.

However, the ultimate impact to end-consumers is unclear. Retailer power may prevent the full transmission of higher soy prices to consumers, keeping consumer prices stable during volatile periods (Assefa et al., 2017; Davis et al., 2021), but at the same time causing livestock producers to absorb higher feed costs. Previous work has shown that changes in consumer food prices are much smaller than changes in producer prices, due to a combination of mark-ups for transport, processing, marketing and consumer-level subsidies (IFAD, WFP, FAO, 2013). As highlighted by Assefa et al. (2017), both the transmission and non-transmission of prices can be undesirable: full transmission would mean consumers bear the cost of any price shock. Participant B–C10 advocated for all stakeholders to collaborate so that farmers receive a fair price, and to improve sustainability: *"we need everyone in the whole value-chain to collaborate and, including the consumers, paying for the products."* However, not all consumers are equal: participants highlighted that the EU may be comparatively less at risk since food is not a large proportion of consumer spending, in contrast to low-income, food-importing countries where consumers allocate a higher proportion of their spending on food (IFAD, WFP, FAO, 2013).

During the interviews, the ability or inability to pass costs along the supply chain was highlighted as a key driver of stakeholder vulnerability. This finding supports previous research which asserts that a company's climate risk exposure depends on interfirm relationships and dependencies (Canevari-Luzardo et al., 2020), and underlines the importance of a supply chain perspective, and stakeholder theory approach, in assessing climate risk. Some participants explained this in terms of power: power in price or contract negotiations determines where the costs of soy supply chain shocks are absorbed. We found that soy traders and retailers emerged as key nodes of power, with both being examples of stakeholder groups with a small number of large actors. Market consolidation and globalisation have led to the concentration of market power in the global food system (Davis et al., 2021). In contrast, individual soy producers have little power, though sectoral and collective actions (such as associations) can help producers increase their bargaining power (Bicudo Da Silva et al., 2020). This work underlines that an awareness of power and stakeholder relationships in the supply chain is critical to understanding how the impacts of future cross-border climate shocks might be distributed and could help to identify where additional support might be needed for particular stakeholder groups.

4.2. Response effects and maladaptation

In contrast to previous research on Australian seafood supply chains, which found that most potential responses were at the producer end of the supply chain (Lim-Camacho et al., 2015), we found that all stakeholders across the Brazil-Europe soy supply chain described response options they could implement. This could be due to recent examples of global supply chain disruption causing intermediate and consumer-end stakeholders to pay more attention to cross-border risk. However, identifying potential trade-offs and synergies in responses is *"crucial to their success"* (Rosenzweig et al., 2020).

Our findings (see section 3.3) suggest that some responses benefit multiple stakeholders in the supply chain, such as diversifying transport modes, climate change mitigation and monitoring supply chain risks. However, our results also highlight examples of trade-offs and imbalances between stakeholders, and responses which might have negative impacts outside of the supply chain, confirming concerns in the literature of maladaptation or an unjust redistribution of risk (Barnett and O'Neill, 2010; Lager et al., 2021). For example, many soy producer level responses would benefit consumer stakeholders (e.g. irrigation, technologies for soy production), whereas several consumer responses could exacerbate risk at the producer end of the supply chain (e.g. diversifying protein sources, planting domestic soy acreage). Weather shocks could lead to riskier sourcing of soy from regions where other supply chain risks may occur (as demonstrated in a Nordic context; Berninger et al., 2022), and it may encourage expansion of soy into new areas, potentially increasing deforestation risk. Some responses identified in section 3.3 can redistribute risk, which can be beneficial if risk had previously been unevenly concentrated (for example, farmer insurance helps spread the cost of harvest losses over time), but close attention must be paid to the particular context.

Seen through the strategic lens of stakeholder theory, our case study demonstrates that stakeholders could be affected by other stakeholders' responses to shocks, and awareness of other stakeholders' risk exposure and responses could be of benefit to companies along the supply chain. Since the emergence of stakeholder theory, stakeholders have increasingly taken a more central position in organisational activities (Wagner Mainardes et al., 2011), and our study supports a close attention to stakeholders in the context of cross-border climate risk management. Previous work has highlighted the need for network-level approaches for climate risk management systems (Er Kara et al., 2021), and our findings support this point by highlighting the potential for mutually beneficial adaptation actions, whilst also revealing the tensions and imbalances between stakeholders which could inhibit cooperation.

Our results also provide broader guidance on adaptation to cross-border climate risks. Participants highlighted that the appropriateness of a response depends on the frequency of the shock over the long-term. A long-term increase in the frequency of drought, for example, might require structural changes in the supply chain, whereas temporary measures would be more appropriate for a one-off occurrence of drought. Our study confirms previous findings that whilst proactive adaptation in food supply chains is seen as beneficial, this has not yet been implemented (Birchall et al., 2021; Ghadge et al., 2019). Only a few of the responses identified in section 3.3 could be implemented immediately when a shock occurs, and many would take a year or more to implement. Finally, as our participants identified a range of different and overlapping supply chain risks (see Section 3.1), responses to climate-related risks must be designed in combination with responses to other risks (Miller, 2020). This may reveal actions which address multiple risks at once, and previous research has found that it is easier to encourage the implementation of adaptation practices that are relevant for both climate and market risks (Silva et al., 2023).

4.3. Supply chain cooperation, governance and justice

The possibility of maladaptation points to a need to improve supply chain cooperation (Talebian et al., 2023; United Nations Global Compact, 2022), and our results show a lack of coordinated responses in the soy supply chain, despite examples of responses which would benefit multiple stakeholder groups. This absence of coordinated responses could in part be due to our chosen system boundaries; we might expect to find these types of responses in international trade and development government departments, or global frameworks such as the United Nations Framework Convention on Climate Change, rather than sector-specific stakeholders. However, previous work also identified a lack of coordinated business action for climate adaptation, such as in the orange and sugarcane supply chains in Brazil, where existing adaptation strategies tend to be at a firm-level rather than supply chain-level (Sá et al., 2019), and underlined the need for consumer-end businesses to take responsibility for helping small-scale producers adapt to climate change as an ethical issue (Thorpe and Fennell, 2012). One way of improving supply chain coordination on climate adaptation may be to bring discussion of cross-border risk into existing whole-sector discussions on other risks, such as deforestation.

The competing and contrasting aims and vulnerabilities of different soy supply chain stakeholders suggests that cooperation may not be straightforward. Dzebo and Adams (2022) find an absence of established roles and norms in transboundary (cross-border) climate risk management, creating *"a space for political contestation with legitimacy at its center"*. They describe five different governance pathways: transnational governance, development cooperation, international diplomacy, global markets and domestic policy. The main governance pathways discussed by stakeholders in the interviews are transnational governance (power of international grain traders), global markets (belief that lack of intervention is the best approach), and domestic policy (what can Brazil and Europe do domestically to address climate risks). However, these governance pathways can lead to policy contradictions: the global markets governance pathway and the domestic policy pathway are not always compatible (for example free trade agreements contradict export bans).

Dzebo and Adams (2022) argue for greater attention to the concept of 'fairness', currently rarely used as an argument for governance pathway legitimacy in cross-border risk management. This relates to the concept of justice in adaptation (or 'just resilience'; Lager et al., 2021; Miller, 2020). Lager et al. (2021) conceptualise this with two key components: procedural justice (who can participate in decision-making) and distributive justice (how benefits and harms of adaptation are allocated). In order to achieve globally just resilience, the authors recommend strengthened multilateral cooperation (as discussed above), the development of shared principles for adaptation, incentivising just adaptation via policies, and advancing research to support decision-making. By including a wide range of stakeholder groups (procedural justice) and considering how consequences of cross-border impacts differ between groups (distributive justice), our study contributes to a move towards just resilience.

Whilst carefully considered adaptation will be crucial to reduce the harms of climate change, effective adaptation relies on urgent and increased climate change mitigation. Many potential adaptive responses mentioned by participants will be less effective under more severe climate change scenarios, such as adapting soy cultivars and relying on flexibility of supply. The trade-offs between climate mitigation and adaptation is also an area of concern for climate justice (IPCC et al., 2022), and future soy supply chain collaboration could integrate adaptation and mitigation.

4.4. Further work and limitations

Further work could expand the scope of our analysis to additional supply chain stakeholders, including consumer stakeholders in Brazil, and end-consumers. In particular, attention to the unequal distribution of impacts across (end) consumer populations is important (Davis et al., 2021). A different group of participants may lead to different results. For example, it is likely that stakeholders who agreed to be interviewed were more aware of, and interested in, climate shocks than average. There may be high levels of heterogeneity within stakeholder groups which our sampled participants did not capture, such as differences within farmer groups, as highlighted in previous work (Stringer et al., 2020). The timing of the study (some interviews followed the COVID-19 pandemic and occurred during a war between key food exporters) is also likely to have influenced the results, and our findings should be understood within this context.

Our findings suggest current awareness of cross-border risks is low: other supply chain risks dominate industry discussions. In part, this may be due to uncertainties in projected impacts of climate change on soy yields in Brazil and on the supply chain (Stokeld et al., 2020; Thorpe and Fennell, 2012). Further research could provide improved projections of weather-related shocks affecting the soy supply chain, taking into account both shocks to the production and transport of soy, and raise awareness of cross-border climate risks with relevant sectors and stakeholders (Thorpe and Fennell, 2012). Alongside climate change projections, a corresponding improvement in supply chain transparency and traceability (Tenggren et al., 2020), and information-sharing across the supply chain (Er Kara et al., 2021), would improve supply chain risk managers' ability to identify their stakeholders and assess cross-border risk exposure.

5. Conclusions

Stakeholders in the soy supply chain are already used to managing a certain level of disruption (harvest losses, fluctuating transport costs, wider geopolitical and economic stresses), yet climate change is projected to bring new disruptions. Despite increasing attention to cross-border climate risk in the literature, few studies have analysed these impacts at a stakeholder level along an international supply chain, and guidance on how to adapt is lacking. Our study contributes to the literature on cross-border climate risks by exploring stakeholder vulnerability, exposure and potential responses to climate shocks, in a detailed case study of the Brazil to Europe soy supply chain.

We found that the consequences of climate shocks for stakeholders along the supply chain are highly influenced by their relationships to other stakeholders, and their relative power in determining prices. This points to the importance of a supply chain approach in climate risk assessment and management, and the value of companies considering their surrounding stakeholders' climate risks. Applying Talebian et al.'s (2023) typologies of responses and response effects at a stakeholder scale, we found that stakeholders have a range of different potential responses which could reduce this cross-border climate risk, but which in some cases could redistribute or exacerbate risk for other stakeholders. Coordination of responses across stakeholders has the potential to improve overall supply chain adaptation. However, the differing aims and vulnerabilities among stakeholders is a potential barrier to supply chain cooperation. Framed within stakeholder theory, our findings have implications from strategic and moral perspectives: from a strategic perspective, companies may benefit from better understanding their surrounding stakeholders' exposure, vulnerability and potential responses to climate risks; and from a moral perspective, the distribution of risk across stakeholders and repercussions of their responses are important to consider as part of efforts towards just resilience.

Through this study, we highlight the need to define the 'who' when discussing cross-border climate impacts. Recognising the different levels of stakeholder power and response capacity could help policymakers target adaptation support more effectively, and provide a foundation on which discussions of fairness and just adaptation can be built. It is also important to acknowledge that several adaptation strategies require significant investment, and may be limited in the face of escalating climate change impacts. As our world experiences increasing climate shocks, an attention to cross-border risks and the heterogeneity of stakeholders affected will be critical in order to help avoid maladaptation and offer opportunities for more collaborative adaptation.

CRediT authorship contribution statement

Emilie Stokeld: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Simon Croft:** Conceptualization, Methodology, Writing – review & editing. **Tiago N.P. dos Reis:** Conceptualization, Methodology, Writing – review & editing, Investigation. **Lindsay C. Stringer:** Conceptualization, Methodology, Writing – review & editing. **Chris West:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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References

Adams, W., 2015. Conducting semi-structured interviews. In: Handbook of Practical Program Evaluation. https://doi.org/10.1002/9781119171386.ch19.

Arvis, B., Simonet, C., Dubois, G., Ceron, J.-P., Bourkane, I., 2020. Consequences of Global Climate Change and Their Impacts on Europe – A View on Agricultural Commodities. European Environment Agency, Ramboll.

Assefa, T.T., Meuwissen, M.P.M., Gardebroek, C., Oude Lansink, A.G.J.M., 2017. Price and volatility transmission and market power in the German fresh pork supply chain. J. Agric. Econ. 68, 861–880. https://doi.org/10.1111/1477-9552.12220.

Barnett, J., O'Neill, S., 2010. Maladaptation. Glob. Environ. Chang. 20, 211–213. https://doi.org/10.1016/j.gloenvcha.2009.11.004.

Bednar-Friedl, B., Knittel, N., Raich, J., Adams, K.M., 2022. Adaptation to transboundary climate risks in trade: investigating actors and strategies for an emerging challenge. WIREs Clim. Chang. e758. https://doi.org/10.1002/wcc.758.

Benzie, M., Hedlund, J., Carlsen, H., 2016. Introducing the Transnational Climate Impacts Index: Indicators of Country-Level Exposure – Methodology Report 48.

Berninger, K., Lager, F., Botnen Holm, T., Tynkkynen, O., Klein, R.J.T., Aall, C., Dristig, A., Määttä, H., Perrels, A., 2022. Nordic Perspectives on Transboundary Climate Risk: Current Knowledge and Pathways for Action. Nordic Council of Ministers.

Bicudo Da Silva, R.F., Batistella, M., Moran, E., Celidonio, O.L.D.M., Millington, J.D.A., 2020. The soybean trap: challenges and risks for Brazilian producers. Front. Sustain. Food Syst. 4 https://doi.org/10.3389/fsufs.2020.00012.

Birchall, S.J., MacDonald, S., Slater, T., 2021. Anticipatory planning: finding balance in climate change adaptation governance. Urban Clim. 37, 100859 https://doi.org/10.1016/j.uclim.2021.100859.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 77–101. https://doi.org/10.1191/1478088706qp063oa.

Bukhta, Y., 2022. Livestock hit hardest by EU harvest drop caused by drought [WWW Document]. www.euractiv.com. https://www.euractiv.com/section/agriculture-food/news/livestock-hit-hardest-by-eu-harvest-drop-caused-by-drought/, 3.1.23.

Cadez, S., Czerny, A., Letmathe, P., 2019. Stakeholder pressures and corporate climate change mitigation strategies. Bus. Strat. Environ. 28, 1–14. https://doi.org/10.1002/bse.2070.

Canevari-Luzardo, L.M., Berkhout, F., Pelling, M., 2020. A relational view of climate adaptation in the private sector: how do value chain interactions shape business perceptions of climate risk and adaptive behaviours? Bus. Strat. Environ. 29, 432–444. https://doi.org/10.1002/bse.2375.

Carter, T.R., Benzie, M., Campiglio, E., Carlsen, H., Fronzek, S., Hildén, M., Reyer, C.P.O., West, C.D., 2021. A conceptual framework for cross-border impacts of climate change. Glob. Environ. Chang. 69, 102307 https://doi.org/10.1016/j.gloenvcha.2021.102307.

Chatham House, 2021. 'resourcetrade.earth'. https://resourcetrade.earth/.

Czaplicki Cabezas, S., Bellfield, H., Lafortune, G., Streck, C., Hermann, B., 2019. Towards more sustainability in the soy supply chain: how can EU actors support zero-deforestation and SDG efforts? Global Canopy. Clim. Focus.

Davis, K.F., Downs, S., Gephart, J.A., 2021. Towards food supply chain resilience to environmental shocks. Nat. Food 2, 54–65. https://doi.org/10.1038/s43016-020-00196-3.

De Maria, M., Robinson, E., Kangile, J.R., Kadigi, R.M., Dreoni, I., Couto, M., Howai, Niko, Peci, J., Fiennes, Sicily, 2020. Global Soybean Trade – the Geopolitics of a Bean. UN Environment Programme World Conservation Monitoring Centre. UNEP-WCMC). https://doi.org/10.34892/7YN1-K494.

Dzebo, A., Adams, K.M., 2022. Contesting Legitimacy in Global Environmental Governance – an Exploration of Transboundary Climate Risk Management in the Brazilian-German Coffee Supply Chain. https://doi.org/10.2139/ssrn.4060870.

Elliott, V., 2018. Thinking about the coding process in qualitative data analysis. Qual. Rep. 23, 2850–2861.

Er Kara, M., Ghadge, A., Bititci, U.S., 2021. Modelling the impact of climate change risk on supply chain performance. Int. J. Prod. Res. 59, 7317–7335. https://doi.org/10.1080/00207543.2020.1849844.

FAO, 2017. The Future of Food and Agriculture – Trends and Challenges. Rome.

FAO, 2023a. FAOSTAT. License: CC BY-NC-SA 3.0 IGO. Extracted from: https://www.fao.org/faostat/en/#data, 01-03-2023.

FAO, 2023b. Food Price Monitoring and Analysis (FPMA) Tool. License: CC BY-NC-SA 3.0 IGO. Extracted from: https://fpma.fao.org/giews/fpmat4/#/dashboard/tool/international. (Accessed 1 March 2023).

Fleming, A., Hobday, A.J., Farmery, A., van Putten, E.I., Pecl, G.T., Green, B.S., Lim-Camacho, L., 2014. Climate change risks and adaptation options across Australian seafood supply chains – A preliminary assessment. Climate Risk Manage. 1, 39–50. https://doi.org/10.1016/j.crm.2013.12.003.

Freeman, R., 1984. Strategic Management: A Stakeholder's Approach. Pitman, Boston, MA.

Ghadge, A., Wurtmann, H., Seuring, S., 2019. Managing climate change risks in global supply chains: a review and research agenda. Int. J. Prod. Res. 58, 44–64. https://doi.org/10.1080/00207543.2019.1629670.

Glauber, J., Hernández, M., Laborde, D., Martin, W., Rice, B., Vos, R., 2022. No end in sight yet for the global food price crisis. IFPRI Int. Food Pol. Res. Inst. [WWW Document] https://www.ifpri.org/blog/no-end-sight-yet-global-food-price-crisis 2.28.23.

Godde, C.M., Mason-D'Croz, D., Mayberry, D.E., Thornton, P.K., Herrero, M., 2021. Impacts of climate change on the livestock food supply chain; a review of the evidence. Glob. Food Secur. 28, 100488 https://doi.org/10.1016/j.gfs.2020.100488.

IFAD, WFP, FAO, 2013. The State of Food Insecurity in the World 2013: the Multiple Dimensions of Food Security. Food and Agriculture Organization of the United Nations, Rome.

IPCC, 2022. In: Pörtner, H.-O., Roberts, D.C., Poloczanska, E.S., Mintenbeck, K., Tignor, M., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A. (Eds.), Summary for Policymakers, Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33 [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (Eds.)].

Jägermeyr, J., Müller, C., Ruane, A.C., Elliott, J., Balkovic, J., Castillo, O., Faye, B., Foster, I., Folberth, C., Franke, J.A., Fuchs, K., Guarin, J.R., Heinke, J., Hoogenboom, G., Iizumi, T., Jain, A.K., Kelly, D., Khabarov, N., Lange, S., Lin, T.-S., Liu, W., Mialyk, O., Minoli, S., Moyer, E.J., Okada, M., Phillips, M., Porter, C., Rabin, S.S., Scheer, C., Schneider, J.M., Schyns, J.F., Skalsky, R., Smerald, A., Stella, T., Stephens, H., Webber, H., Zabel, F., Rosenzweig, C., 2021. Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. Nat. Food 2, 873–885. https://doi.org/10.1038/s43016-021-00400-y.

Kornhuber, K., Coumou, D., Vogel, E., Lesk, C., Donges, J.F., Lehmann, J., Horton, R.M., 2020. Amplified Rossby waves enhance risk of concurrent heatwaves in major breadbasket regions. Nat. Clim. Change 10, 48–53. https://doi.org/10.1038/s41558-019-0637-z.

Kuepper, B., Stravens, M., 2022. Mapping the European Soy Supply Chain. Embedded Soy in Animal Products Consumed in the EU27+UK. Profundo.

Lager, F., Adams, K.M., Dzebo, A., Eriksson, M., Klein, R.J.T., Klimes, M., 2021. A Just Transition for Climate Change Adaptation: towards Just Resilience and Security in a Globalising World.

Lim-Camacho, L., Hobday, A.J., Bustamante, R.H., Farmery, A., Fleming, A., Frusher, S., Green, B.S., Norman-López, A., Pecl, G.T., Plagányi, É.E., Schrobback, P., Thebaud, O., Thomas, L., van Putten, I., 2015. Facing the wave of change: stakeholder perspectives on climate adaptation for Australian seafood supply chains. Reg. Environ. Change 15, 595–606. https://doi.org/10.1007/s10113-014-0670-4.

Lunt, T., Jones, A.W., Mulhern, W.S., Lezaks, D.P.M., Jahn, M.M., 2016. Vulnerabilities to agricultural production shocks: an extreme, plausible scenario for assessment of risk for the insurance sector. Clim. Risk Manag. 13, 1–9. https://doi.org/10.1016/j.crm.2016.05.001.

Miller, F., 2020. Exploring the consequences of climate-related displacement for just resilience in Vietnam. Urban Stud. 57, 1570–1587. https://doi.org/10.1177/0042098019830239.

Mirzabaev, A., Bezner Kerr, R., Hasegawa, T., Pradhan, P., Wreford, A., Cristina Tirado von der Pahlen, M., Gurney-Smith, H., 2023. Severe climate change risks to food security and nutrition. Clim. Risk Manag. 39, 100473 https://doi.org/10.1016/j.crm.2022.100473.

Österblom, H., Jouffray, J.-B., Folke, C., Crona, B., Troell, M., Merrie, A., Rockström, J., 2015. Transnational corporations as 'keystone actors' in marine ecosystems. PLoS One 10, e0127533. https://doi.org/10.1371/journal.pone.0127533.

Pankratz, N.M.C., Schiller, C., 2021. Climate Change and Adaptation in Global Supply-Chain Networks. https://doi.org/10.2139/ssrn.3475416.

Patton, M.Q., 2002. Qualitative Research & Evaluation Methods. Sage, 3rd Edition.

Pörtner, H.-O., Roberts, D.C., Tignor, M.M.B., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., Rama, B. (Eds.), 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Reis, T.N.P. dos, Ribeiro, V., Garrett, R.D., Kuemmerle, T., Rufin, P., Guidotti, V., Amaral, P.C., Meyfroidt, P., 2023. Explaining the stickiness of supply chain relations in the Brazilian soybean trade. Glob. Environ. Chang. 78, 102633 https://doi.org/10.1016/j.gloenvcha.2022.102633.

Reisinger, A., Howden, M., Vera, C., Garschagen, M., Mintenbeck, K., O'Neill, B., Pathak, M., Pedace, R., Pörtner, H.-O., Poloczanska, E., Rojas Corradi, M., Sillmann, J., van Aalst, M., Viner, D., Jones, R., Ruane, A.C., Ranasinghe, R., 2020. Guidance note – the concept of risk in the IPCC Sixth Assessment Report: a summary of cross Working Group discussions. Guidance for IPCC authors. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Rosenzweig, C., Mbow, C., Barioni, L., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M., Sapkota, T., Tubiello, F., Xu, Y., Contreras, E., Portugal Pereira, J., 2020. Climate change responses benefit from a global food system approach. Nat. Food 1, 94–97. https://doi.org/10.1038/s43016-020-0031-z.

Sá, M.M. de, Miguel, P.L. de S., Brito, R.P. de, Pereira, S.C.F., 2019. Supply chain resilience: the whole is not the sum of the parts. Int. J. Oper. Prod. Manag. 40, 92–115. https://doi.org/10.1108/IJOPM-09-2017-0510.

Silva, D.S., Arima, E.Y., dos Reis, T.N.P., Rattis, L., 2023. Temperature effect on Brazilian soybean yields, and farmers' responses. Int. J. Agric. Sustain. 21, 2173370 https://doi.org/10.1080/14735903.2023.2173370.

Silverman, D., 2010. Doing Qualitative Research: a Practical Handbook, third ed. Sage.

Stokeld, E., Croft, S., Green, J.M.H., West, C.D., 2020. Climate change, crops and commodity traders: subnational trade analysis highlights differentiated risk exposure. Clim. Change 162, 175–192. https://doi.org/10.1007/s10584-020-02857-5.

Stringer, L.C., Fraser, E.D.G., Harris, D., Lyon, C., Pereira, L., Ward, C.F.M., Simelton, E., 2020. Adaptation and development pathways for different types of farmers. Environ. Sci. Pol. 104, 174–189. https://doi.org/10.1016/j.envsci.2019.10.007.

Talebian, S., Benzie, M., Harris, K., Jarząbek, Ł., Magnuszewski, P., Carter, T.R., Obermeister, N., 2023. A conceptual framework for responding to cross-border climate change impacts (Version 01). Zenodo. Preprint. https://doi.org/10.5281/zenodo.7817615.

Tenggren, S., Olsson, O., Vulturius, G., Carlsen, H., Benzie, M., 2020. Climate risk in a globalized world: empirical findings from supply chains in the Swedish manufacturing sector. J. Environ. Plann. Manag. 63, 1266–1282. https://doi.org/10.1080/09640568.2019.1660626.

Thorpe, J., Fennell, S., 2012. Climate Change Risks and Supply Chain Responsibility. How Should Companies Respond when Extreme Weather Affects Small-Scale Producers in Their Supply Chain? Oxfam Discussion Papers.

United Nations Global Compact, 2022. Just Transition for Climate Adaptation. A Business Brief.

Wagner Mainardes, E., Alves, H., Raposo, M., 2011. Stakeholder theory: issues to resolve. Manage. Decis. 49, 226–252. https://doi.org/10.1108/00251741111109133.

Walsh, S., 2021. Shortage of soya and citrus pulp as drought hits crops [WWW Document]. Ir. Farmers J. URL. https://www.farmersjournal.ie/shortage-of-soya-and-citrus-pulp-as-drought-hits-crops-658313, 7.26.22.

West, C.D., 2021. Resilience of the UK Food System Regarding Demand for Soy (Policy Brief). SEI, Oxford.

West, C.D., Stokeld, E., Campiglio, E., Croft, S., Detges, A., Duranovic, A., von Jagow, A., Jarząbek, Ł., König, C., Knaepen, H., Magnuszewski, P., Monasterolo, I., Reyer, C.P. O., 2021. Europe's cross-border trade, human security and financial connections: a climate risk perspective. Clim. Risk Manag. 34, 100382 https://doi.org/10.1016/j.crm.2021.100382.