New risk horizons: Sweden’s exposure to climate risk via international trade

SEI report
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Executive summary

This SEI Working Paper is an output of the Mistra Geopolitics programme, which looks into the evolving dynamics between environmental change, shifting geopolitics and sustainable development globally.

Our study focuses on Sweden and its place in the global trade system. The objective was to develop innovative multi-method approaches to identify and assess transboundary climate risks facing Sweden via its international trade links.

Sweden is projected to experience direct impacts from climate change as a result of changing temperature, precipitation and weather patterns within its borders. However, due to its relatively high levels of wealth, social cohesion, institutional stability and other factors, Sweden is generally thought to be well-placed to adapt to these direct impacts and therefore ranks among the least vulnerable countries globally (ND-GAIN, 2020).

Transboundary climate risks, on the other hand, pose an altogether different, more complex challenge. Due to the openness of its economy and society, its position “high up” in the global value chain and its reliance on imports and exports to support consumption and jobs, Sweden is likely to be highly exposed to climate risks that originate in other countries, especially via trade. This “external” dimension of Sweden’s climate vulnerability has been largely ignored until relatively recently (Nationella expertrådet för klimatanpassning, 2022), due partly to the lack of established tools for identifying and assessing such risks. That is why we set out to develop and test multi-method approaches for assessing national-level exposure to climate risk via trade.

This study introduces and provides results for two such approaches. The first analyses Sweden’s trade interactions with the rest of the world using three distinct sets of trade data. Each type of data emphasizes different levels or tiers of Swedish trade; each has strengths, but also limitations, for the purpose of assessing transboundary climate risk. National toll logs – traditional trade statistics – give accurate and timely information about the first tier only (i.e. direct imports from “the last port of call”); so-called “input-output” tables can be used to trace the “value added” to consumption at stages in the supply chain, but with an emphasis on the higher tiers; and resource footprints provide insights on the initial material input to supply chains in the lowest tiers (e.g. land or water inputs). We develop a method for combining data on climate risk in other countries with these three classes of trade data to compare the insights generated by each.

Our study finds that traditional approaches provide a relatively reassuring picture, highlighting the dominant role played by geographically close trading partners (Germany, Nordic countries) whose climate vulnerability is among the lowest globally. Beyond this first tier, Sweden largely trades with EU countries and other relatively low-vulnerability markets.

However, more nuanced trade data reveal Sweden’s previously hidden links to much more vulnerable countries that play a critical role in Swedish supply chains, particularly emerging economies in Asia and Africa. These revelations add up to a new risk horizon for Sweden; global climate change threatens the stability and availability of inputs to Swedish consumption that first enter our supply chains thousands of miles away in higher-risk countries. Key trading partners in lower tiers of our supply chains play an important role in the Swedish economy and yet they have existed in a statistical shadow, meaning their influence on our own climate vulnerability has not been appreciated, until now.

Our second approach focuses on a particular Swedish supply chain: soy from Brazil. Soy has rapidly become a key commodity for Swedish consumption because of the role it plays as animal feed and an oil crop in various forms of meat and dairy and processed food production. And it is not only Sweden that has developed a love for soy. Countries at various levels of development now depend on imported soy in ways that few people realize. If climate change affects the

availability and price of soy, consumers around the world will feel the effects on the cost of their weekly food shop; food and drink businesses will suffer and traders and governments will enter a costly and uncertain struggle to secure access to soy imports.

We therefore pioneered an approach to assess supply chain climate risk using the best available data at the highest level of granularity possible. This resulted in a mapping of climate risks to soy production at the municipality level throughout Brazil, which is then traced all the way through international supply chains to identify embedded soy in Swedish consumption. In addition, we developed a method to assess the risks that climate change poses to the transport of this soy from farm to port in Brazil, recognizing the importance of climate change "choke points" on supply chain logistics (Bailey & Wellesley, 2017) – a dimension that is rarely included in climate risk assessments of trade.

These two approaches constitute a significant innovation in multi-method assessments of transboundary climate risk. They combine to raise important new insights and questions for adaptation policy and global governance more generally. They reveal a category of climate risk that, today, is not governed by anyone.

We have therefore sought to introduce insights from this analysis to ongoing policy processes in Sweden throughout the research phase. Results have been presented at various workshops and conferences, as well as specifically to the process led by Sweden's National Expert Council on Adaptation to Climate Change and their advice to the Swedish government on priorities for the next iteration of Sweden's National Adaptation Strategy.

The purpose of this Working Paper is therefore to address the research and practitioner community and to describe the two approaches taken in some detail, record the results of our analysis and introduce some points of discussion for policymaking and planning on adaptation. Our intention is to be fully transparent and facilitate replication of the study, providing insight into the various methods at a level of detail rarely afforded in peer-reviewed journal articles, for example.

The report is structured as follows:

- Section 1 introduces the background to the research and offers a short justification for the focus on national-level exposure.
- Section 2 reviews the state of the art and describes the data that are used in the study. It then introduces the multi-method approaches in detail.
- Section 3 provides results for both approaches; detailed descriptions of methodological steps and choices are offered in Appendices 1–6.
- Section 4 offers a discussion of the success and limits of the multi-method approaches, and offers a few reflections for future research.

  Sections 2, 3, 4 and Appendices 1–6 are therefore likely to be of most interest to researchers and practitioners with an eye for detail and perhaps a desire or interest in repeating or advancing the approaches we have taken in this study.

- Section 5 summarizes our reflections on the policy implications of our study, and offers four recommendations for actors based in Sweden. Appendix 7 provides a longer form version of these reflections.

  Section 5 and Appendix 7 are therefore likely to be of most interest to policymakers and planners who are considering the appropriate way forward for adaptation and climate risk management in light of transboundary climate risk.

- Lastly, Section 6 provides conclusions for the report as a whole.

The contribution of this SEI Working Paper hopefully goes beyond a purely technical level. It makes the case for a new generation of adaptation research and planning. We highlight the limits of traditional approaches to risk management, like substitution and trade diversification, in a world facing cascading, systemic risk in the trade system as a result of accelerating climate change. Likewise, traditional trade statistics and climate risk assessment methods are not fit for purpose in this world of systemic climate risk.

Above all, the report invites Sweden-based actors to think and work across borders to build systemic resilience to climate change and raise global ambition on adaptation.

Interested readers should engage with the Adaptation Without Borders global partnership[1] to find out more about opportunities for collaboration.

The Mistra Geopolitics programme[2] is in its second phase (2021–2024) and will continue to look at transboundary climate risk with a focus on national responses.

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[1] https://adaptationwithoutborders.org/

[2] https://www.mistra-geopolitics.se/

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1. Introduction

1.1. Background

This study was designed to test new methods for climate risk assessment using trade and supply chain data in order to explore the implications of climate change for Sweden's engagement with the rest of the world. It complements the emerging evidence base on Sweden's trade and other forms of exposure to transboundary climate risk (IVL Svenska Miljöinstitutet (IVL), 2020; Mobjörk, 2011; PwC, 2019; Tillväxtanalys, 2020). This study was undertaken between 2018 and 2021 as part of the Mistra Geopolitics programme, which investigates the relationship between environmental change, such as climate change, sustainable development and changing geopolitical dynamics. Specifically, it is the output under Work Package 2 of the first phase of this programme, which looked at "Impact pathways in a changing environmental and geopolitical context". It builds on and benefits enormously from the Master's thesis undertaken by Frida Lager during this period (Ain't our business? A study of transnational climate change impacts on Swedish consumption through the lens of Brazilian soy, Stockholm Resilience Centre, 2019). Frida Lager is now a Research Associate at Stockholm Environment Institute (SEI).

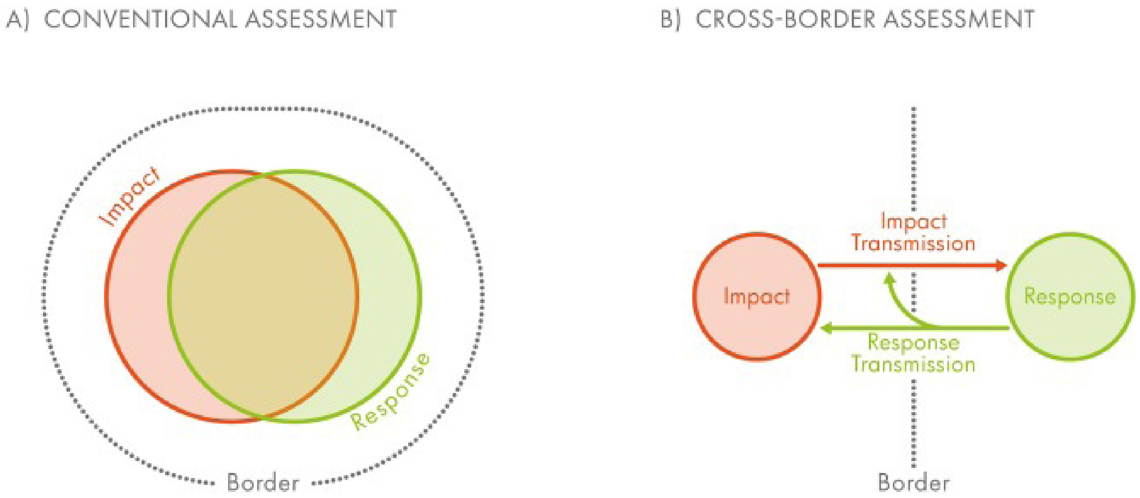
The study is an output of a research programme and not a piece of analysis requested directly by a government or policymaker. In some ways, the analysis pre-empts – and even aims to spark – demand from decision-makers for information about transboundary climate risk. We return to this theme in our Discussion. Nevertheless, the authors have engaged with relevant policy stakeholders and experts in Sweden to test and disseminate messages from the analysis. Insights gleaned from this exercise have been used to inform the first report by the Swedish Expert Council on Climate Change Adaptation (Nationella expertrådet för klimatanpassning, 2022) and as such will contribute to the revision of Sweden's National Adaptation Strategy. We also hope that the report will help to inform efforts by other Nordic and European countries, as well as the European Union itself, as they grapple with the challenge of understanding and adapting to transboundary climate risk via trade.

The report is addressed primarily to a research and practitioner audience. Its main contribution is to describe the development of new multi-method approaches for assessing transboundary climate risk via trade and to present results and reflections from an initial application of this method to the case of Sweden. Insights and results from the analysis described here have been packaged into formal and informal submissions to policy processes and presented at various conferences and workshops on adaptation to transboundary climate risk. The working paper therefore seeks to achieve a high level of transparency and detail so that other researchers and practitioners can learn from and even adopt the method we have developed and applied when undertaking their own assessments.

1.2. Why national level exposure to transboundary risk via trade?

Climate change risks have traditionally been identified and assessed using "territorial" assessment techniques (Benzie & Persson, 2019). The underlying assumption in these assessments is that climate change impacts, the resulting risks and adaptation responses will all manifest within the same territory (see **Figure 1**, where the "impact system" and "response system" overlap). However, attention is increasingly being paid in both research and policy circles to the potential for transboundary climate risk (e.g. Benzie, 2014; Carter et al., 2021; Challinor & Benton, 2021; European Commission, 2021; Moser & Hart, 2015; Persson, 2019). Transboundary climate risk refers to the potential for physical climate change impacts to cross borders, as well as the potential for adaptation interventions to have positive or negative transboundary effects (see Benzie et al., 2019).

Figure 1. The relationship between climate change impacts and responses in conventional (a) and cross-border (or transboundary) (b) assessments.



Source: Carter et al. (2021).

A key dimension of risk in these emerging scientific and policy discussions is the propagation of climate risk across borders via international trade (e.g. Adams et al., 2020; Ercin et al., 2021). Trade is one of several pathways by which climate risk may cross borders, but it may be the most significant, according to early assessments that have been undertaken at the national scale (see Peter et al., 2020). In a globalizing world, countries are tightly linked to one another via international supply chains that deliver materials, goods and food for consumption. This means that events in potentially faraway countries – including those caused by climate change – can ripple or cascade across borders via trade links, creating a need for new kinds of adaptation.

Adaptation is the process of adjusting to actual or expected changes in the climate in order to avoid or reduce harm, or to seize opportunities. Adaptation can be planned or autonomous; planned adaptation occurs at various scales, but is most commonly undertaken by local and national governments, who produce adaptation plans or strategies. The global process of planning, coordinating, supporting and monitoring progress on adaptation is based on these National Adaptation Plans. National plans and strategies play an important role in prioritizing and coordinating action between sectors and scales of government within countries. These plans are therefore very important because they provide a road map for building resilience to climate change on the ground and they are the most concrete component for international coordination on adaptation (Benzie et al., 2019).

Given the growing awareness of transboundary climate risk, it is important for National Adaptation Plans and strategies to account for this dimension of risk. However, few currently do (Benzie et al., 2019). In fact, expertise, evidence and stakeholders from the trade domain are conspicuous by their absence from the climate change adaptation process in most if not all countries. It is therefore essential to identify and assess trade-related climate risks in order to fill this evidence gap and to provide a basis on which to engage stakeholders to take action to reduce risks in an effective and equitable manner.

For these reasons, we chose to undertake this study on national-level exposure to transboundary climate risk via trade in Sweden.

2. Trade data and transboundary climate risk

2.1. State of the art of transboundary climate risks via trade: Achievements and gaps

Assessing transboundary climate change risk via trade from a country perspective is a relatively new area of research and there is as yet no consensus on how to approach such an assessment (Benzie et al., 2019). Typically, national toll-based import and export data are used to understand trade flows on a national level (e.g. PwC, 2019). While using physical flows of commodities might seem an intuitively apt approach, it is misleading for linking production to consumption for many traded products (Croft et al., 2018; Steen-Olsen et al., 2016). This is because most exported goods are logged at first port of entry or from the country of last processing, overlooking the product inputs' origin (this is known as the "Rotterdam effect"[3]). The more tiers of processing a product goes through before consumption (i.e. the higher the complexity of the supply chain), and the more embedded a product is through processing steps, the more difficult it is to derive the origin of the product and the more misleading national trade statistics are as a depiction of origin. The soy supply chain is an example of a semi-complex system, indicating that national trade statistics are not sufficient for a robust assessment of supply chain risks. According to UN Comtrade (the world's most comprehensive trade data compilation on national statistics) 60% of all Swedish soy is sourced from Norway, a country with no commercial production of soy (Observatory of Economic Complexity, 2021). This is because the majority of soy that is imported by Sweden travels through Norwegian ports (Swedwatch, 2012).

A range of different methods have been employed for assessing transboundary effects of climate change on trade, including quantitative and qualitative methods ranging from economic modelling to systematic research review, country profile-based assessments and expert opinions (Adams et al., 2020; Benzie et al., 2019; Challinor et al., 2018a). The scope varies from country-wide assessments to targeting specific sectors. Much of the methodological development to date has been focused on transboundary climate risk transmitted via trade, such as the recent German impact assessments (Peter et al., 2019, 2020). That study applies a global computable general equilibrium model, a macro-economic model based on input-output tables, consumer data and government budget, to assess sectors' exposure to climate change under two different climate change and socio-economic scenarios. Other approaches, such as the recent Swedish and Norwegian assessment of transboundary effects on a country level and a European assessment of agricultural supply chain risks, all analyse climate change risk via trade by comparing national-level toll data with climate vulnerability in relation to a global climate vulnerability index, ND-GAIN (European Environment Agency, 2021; EY, 2018; PwC, 2019).

In addition to national- and regional-level case studies there have also been studies carried out on a global scale. The work of Schenker and colleagues (Schenker, 2013; Schenker & Stephan, 2014) is a prominent example, focusing on the economic consequences of climate impacts on trade based on general equilibrium models, and arguing for an increased efficiency in engaging in adaptation measures for more vulnerable regions. A specific focus has also been put on understanding transboundary climate risk via trade in global agricultural supply chains. For example, Bren d'Amour and colleagues (2016) investigated vulnerability to teleconnected food supply shocks based on agricultural trade data from the UN Food and Agriculture Organization, taking into account crop climate vulnerability, poverty and nutrition and calculating food market fluctuations. Lastly, Costinot and colleagues (2012) have quantified the economic macro-level consequences of projected crop yield changes due to climate impacts. Getting a comprehensive overview of available and appropriate methods is, however, difficult due to limited transparency of

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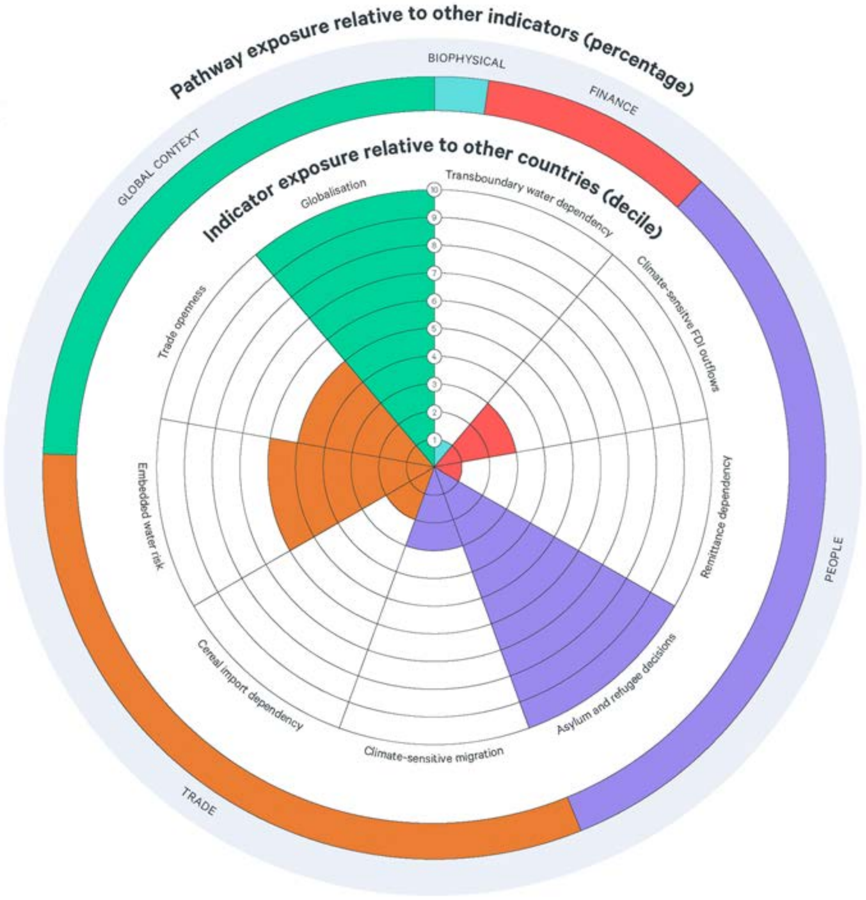
[3] Named because such data give the impression that traded goods are "from" the last port they went through before arriving in the country in which they are consumed, despite the fact that most commodities and products are re-exported several times for processing or simply on their supply chain journey. For many European countries such data might identify one of the major trade hubs, such as the port of Rotterdam, suggesting, for example, that Sweden's bananas "come from" Rotterdam.

approaches, language barriers (country-level assessments are often produced in the language of origin) and divergence in use of terminology, as well as large variations in data availability for low-, middle- and high-income economies.

Sweden as a case study

Sweden was chosen as an example to evaluate a single country's exposure to trade-related climate risk as it is a small country, deeply embedded in the global economy. Imports and exports combined account for 86% of Swedish gross domestic product, half of the food is directly imported (exempting the inputs needed for domestic agricultural produce), and recent assessment estimated that at least one-third of all jobs in Sweden rely on exports (Jordbruksverket, 2015; Ketels, 2017; National Board of Trade, 2015, 2018). **Figure 2** illustrates Sweden's exposure to transboundary climate risks according to the transnational climate impact index (Hedlund et al., 2018), showing a high exposure to transboundary effects via the "trade" and "people" pathways. Attempts have been made to scope Sweden's exposure to transboundary climate risk, including from a security perspective (Myndigheten för samhällsskydd och beredskap, 2012), qualitative analysis focusing on food and energy (Mobjörk, 2011), an overall country profiling (PwC, 2019), empirical research in the manufacturing sector (Tenggren et al., 2020), quantitative analysis from a Swedish trade and industry perspective (Tillväxtanalys, 2020) and expert workshops (IVL, 2020). The latest analysis identifies trade and food security as prioritized areas of interest for Sweden's exposure (IVL, 2020). This paper sets out to understand Sweden's exposure to trade-related climate risks, looking at different data and approaches, to put into context the findings of earlier studies and explore Sweden's exposure in more depth.

Figure 2. Sweden's exposure to transboundary climate risk according to the transnational climate impacts index.



Source: Benzie and Bessonova (2018).

2.2. Risk assessment methodology

At the outset, two approaches for analysis were chosen:

A. Using data and statistics on Sweden's imports to explore and compare different analytical methods.

B. An in-depth case study to investigate how current best-in-class data can be utilized to undertake a detailed trade-related climate risk assessment for a single supply chain.

Our first approach (A) is a broad one. The intention was to assess and compare sets of available statistical trade data for Sweden. The aims of the analysis are to provide a comprehensible illustration of possible applications of different datasets for distinct purposes in assessing transboundary risk for any specific country, and to provide an overview of limitations and common pitfalls in engaging with the datasets.

In addition to the country-wide trade profile, a narrower, but more in-depth case study was conducted (B), assessing transboundary climate risk in one bilateral trade flow and one commodity: the case of Brazilian soy for Swedish consumption. The aims of this exercise are: (a) method innovation – to see what is possible using best-in-class-data; (b) stakeholder challenge – to see how stakeholders might respond to detailed information on trade-related climate risk; and (c) to raise questions that may be pertinent to a geopolitical inquiry into the implications of transboundary climate risk for a bilateral relationship.

The two approaches are explained in depth in the sections below and key challenges are discussed before presenting the results of the analysis. To facilitate transparency the input data and results are assembled and presented in an interactive tool. Researchers and stakeholders can use the tool to explore the trade datasets used for the analysis, hosted at https://public.flourish.studio/story/656845/ for Sweden's trade profile and https://public.flourish.studio/story/25055/ for the case study of Brazilian soy for Swedish consumption.

Approach A: Using national-level trade data to understand transboundary climate risk

At the national level, three types of datasets were analysed and compared in order to understand transboundary climate risk via trade for Sweden. These comprise the most common types of international trade data: (a) national toll logs, which we have taken from Statistika centralbyrån, or Statistics Sweden, a government agency (herein: SCB); (b) global input-output models, which we have taken from the World Input Output Database (WIOD); and (c) footprint analysis, which we have taken from the Policy-Relevant Indicators for National Consumption and Environment project (PRINCE). The datasets were chosen with the following parameters in mind: replicability (being often accessible in official statistics for repetition of this analysis in other country contexts), accessibility (freely available) and data accuracy and granularity (cover a high number of world countries and regions and are accessible over a number of consecutive years). The characteristics of each type of trade data and their relevance for assessing climate risk are expanded on in Box 1.

The three datasets were analysed with a focus on the importance of bilateral trade relations to Sweden (share of imports), climate vulnerability embedded in those relations (climate weighting), trends over time and geographical distance from Sweden; see **Table 1**.

Trade datasets, such as the accounts and models used in this study, either report physical flows of commodities leaving and entering the country (national toll data such as SCB, Eurostat, UN Comtrade), or are based on financial flows between countries' economic sectors (input-output tables, such as the WIOD and Global Trade Analysis Project (GTAP)). The input-output tables can subsequently be "environmentally extended" with environmental impact data, for example covering land and water use, CO_2 emissions and so on, in order to produce "footprint" analyses (e.g. PRINCE). These methods all have their advantages and limitations.

- National toll data have advantages in accounting for actual physical flows of commodities rather than modelled estimates. They offer comprehensive geographical coverage, but fall short in accounting for imports beyond the last country of entry or processing.
- Input-output table-based models estimate flows of inputs between economic sectors all the way down to the estimated origin. However, they often struggle with geographical coverage (aggregating smaller economies into “rest of the region” or “rest of the world” groups). A further challenge is acquiring accurate estimates, especially for developing economies, as the financial models are based on “typical” world sector performance. Environmental extensions can be applied to these models, so-called, supplying footprint.
- Footprint data are environmentally extended multi-regional input-output tables (EE-MRIOs) and provide a resource-focused account of inputs to a country’s consumption for different economic sectors. Such approaches inherit much of the modelling limitations of the input-output models.

The datasets are described and compared in detail in **Table 2** and the method is described in detail and mathematically expressed in **Appendix 1**.

Table 1. Data analysis: Steps 1–4.

Step 1: Which are the most important trade partners for Swedish imports?

To investigate the relative importance of trading partners across datasets the following steps were taken:

- **Ranking in order of importance:** Countries were ranked by order of importance across the three datasets by share of imports (SCB data), share of inputs to sectors (WIOD) and resource use in Swedish consumption (PRINCE land and footprint analysis).
- **Top 30:** The top 30 trading partners – in terms of Swedish imports and inputs – were then extracted for each dataset; a total of 44 countries and regions featured in the top 30 across the three data types.
- **Dependency of inputs:** “Input dependency” was then calculated as the share of total input use for Swedish sectors for the WIOD and PRINCE data (no total inputs available for the SCB data).

To perform a comparative analysis across datasets only imports were analysed (technically it is possible to also analyse exports using national toll logs and input-output data, but footprint analyses do not cover exports and the focus of this analysis is on climate risks “imported” into Sweden). The latest year for which data are available (2014) was used for comparison across datasets. A detailed description of the data analysis is provided in **Appendix 1**.

Step 2: How can those trade partners be impacted by climate change?

A “climate weighting” was carried out by multiplying the relative importance of the trading partner by a measure of that country’s climate vulnerability. Total trade value was converted to percentage of total traded value and “weighted” using the Notre Dame Global Adaptation (ND-GAIN) vulnerability score for 2014 (both values on a range from 0 to 1). The ND-GAIN is also used as a visual aid for the representation of climate risk in Swedish trade relations, using a colour scale from green (low climate vulnerability) to red (high climate vulnerability).

ND-GAIN is a country index that assesses countries’ vulnerability to climate change taking into consideration aspects of water, agriculture, health, infrastructure, food and ecosystems (Chen et al., 2015).

Step 3: How do these trade relationships change over time?

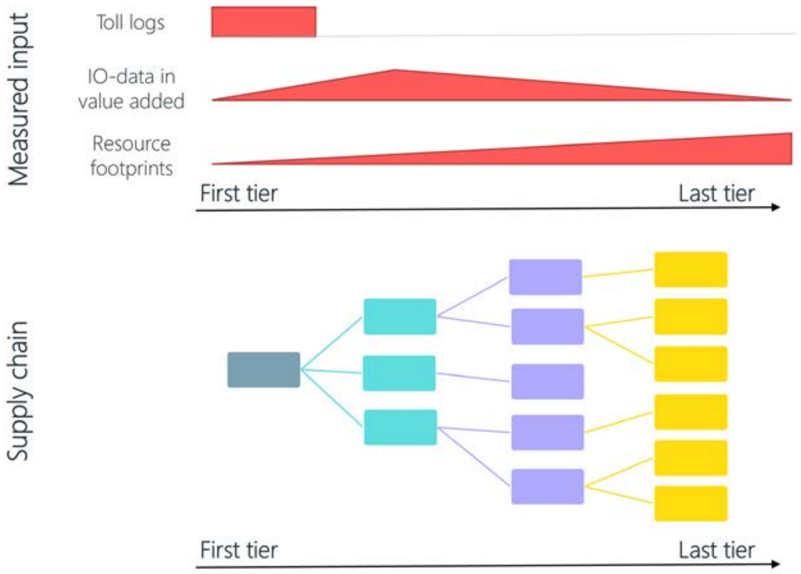
- To investigate changes over time, a trend analysis was carried out using available time series for each dataset (shortest time period available: 2008–2014).
- Trend analysis was carried out by country, and by groups of Organisation for Economic Co-operation and Development (OECD) countries and non-OECD countries.

Step 4: How far away do inputs come from?

To understand geographical spread of input patterns across datasets, the distance of trade partners from Sweden was acquired, utilizing the GeoDist database, specifically designed to be used for trade flow analysis (Mayer & Zignago, 2011). Countries’ distances from Sweden were then put in relation to the climate vulnerability and share of input.

Box 1: What counts? Understanding trade data and origin of inputs.

In this paper we attempt to reveal the main differences in the properties of commonly used trade datasets and the implications of these for the study of climate change risk in trade. There is not much literature to date describing the differences and implications for communication and decision-making of using these different datasets for risk analysis related to trade. The figure in this box is an attempt to schematically illustrate which part of the supply chain the studied datasets best capture.



Schematic illustration of which part of the supply chain different datasets capture

Toll logs measure only the first tier of the supply chain without accounting for any embedded inputs or earlier stages of production or trade beyond the last logged port. For **input-output (IO) data in value added** the emphasis is on the higher tiers of the supply chain (i.e. closer to the consumer), which is typically where most value is added to imports (e.g. during the latter stages of manufacturing and assembly). Costs in labour input, especially in developed economies, are often significant, so later stages of production will generally heavily outweigh the value of the physical inputs themselves. For example, the value of the physical components in the Apple iPod is just a fraction of the total value of the final product (Dedrick et al., 2010). Lastly, **resource footprints** data have the opposite emphasis to value added: resource inputs are highest at the early stages of the supply chain (last tier).

Table 2. Comparison of dataset properties: bilateral trade statistics.

	National statistics	OECD’s input-output model (WIOD)	PRINCE footprint data (land and water use)
Full name (source)	Imports of goods from countries of consignment (SCB, 2019)	OECD’s World Input-Output Tables (OECD, 2019)	Policy-Relevant Indicators for National Consumption and Environment (PRINCE, 2019)
Unit	Thousand SEK (total value)	Value added, US$ millions	km^2 (land) and mm^3 (blue water[4])
Geographical coverage	262 countries and groups of countries	43 countries and 1 aggregate Rest of the World region	44 countries and 5 aggregate “rest of” regions
Trade inputs	Goods	Goods and services	Goods and services
Latest available year	2021 (2017 at the time of analysis)	2014	2014
Available time series	1998–2021	2000–2014	2008–2014
Sectors	No sector division. Divided into commodity groups according to the Standard International Trade Classification (SITC) in 265 categories	56 sectors (International Standard Industrial Classification of All Economic Activities: ISIC Rev. 4)	59 “product groups”
Embedded inputs	No	Yes (in value added)	Yes
Technical description	Toll logs for imported goods. Also available (SCB): Export data on goods, imports and export of services – datasets not compatible for merging http://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__HA__HA0201__HA0201A/OImpExpLandTotAr/?rxid=f45f90b6-7345-4877-ba25-9b43e6c6e299	Global input-output model based on supply-and-use-tables from national accounts. https://www.rug.nl/ggdc/valuechain/wiod/	Consumption and environmentally extended IO-model based on Exiobase (MRIO table). Countries: supply-and-use-tables from national accounts. Rest of the World regions: UN national accounts official country data https://www.prince-project.se/footprinting-results/
Similar datasets	Eurostat (Europe), UN Comtrade (global)	GTAP, OECD’s Trade in Value Added	Several alternative footprint analyses (environmentally extended MRIOs, GTAP-MRIO, Exiobase, Eora), but not as detailed in regard to domestic consumption for Sweden
Cost	Free	Free	Free
+	Physical flows. Largest geographical coverage. Updated yearly	Accounts for inputs along the entire supply chain. Latest update of free global input-output data. Free and available for immediate use	Accounts for resource use tightly connected to climate change exposure, along the entire supply chain. Swedish specific consumption-based footprint data
–	Does not account for imports beyond port of entry or location of last processing. Does not include services. Data for goods and services cannot be combined	Based on global economic models of financial flows. Lags in yearly update as the modelling is time-consuming	Resource- and time-consuming updates

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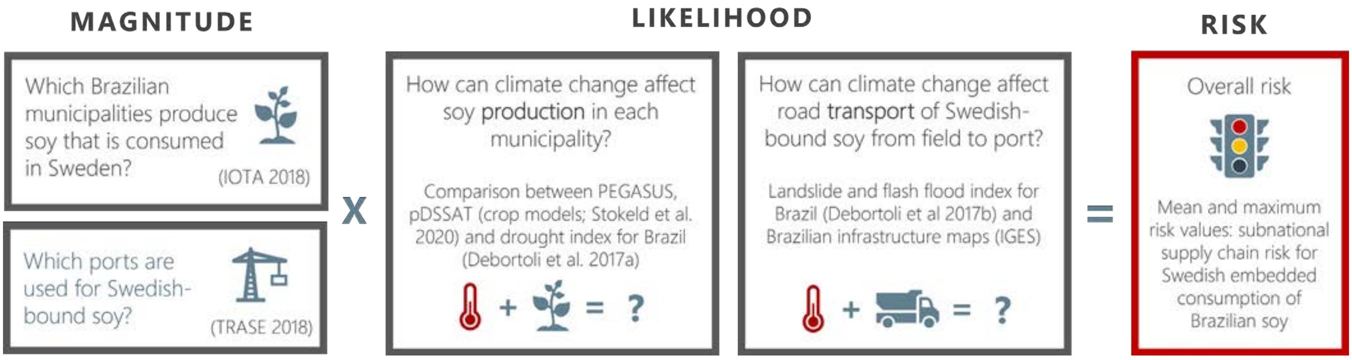
[4] Fresh water, surface or groundwater (including from lakes, rivers and aquifers).

Approach B: A bilateral case study: Climate risk in Brazilian soy to Sweden

There are multiple reasons why Brazilian soy to Sweden has been chosen as the focus of the in-depth case study. Due to its high content of fat and protein, soy is the world's largest traded protein source in animal feed (Brack et al., 2016). Soy is an excellent example of a highly embedded commodity, used as input to multiple complex manufacturing and production processes. It is most commonly used as a feedstock for animals and as a direct input to food manufacturing as vegetable oil (Ceres, 2017). Over the past two decades global demand for meat and dairy products is estimated to have doubled (Chemnitz & Becheva, 2021), which has in turn increased global demand for feedstock and, proportionately, global production of soy has also doubled during the time period (Trase, 2018a). Sweden alone imported 236 000 tonnes of soy from Brazil in 2014 (Croft et al., 2018) amounting to 46% of total consumption of soy in Sweden for that year, ranking it the 13th top importer of Brazilian soy in the EU. A more in-depth story about Sweden–Brazil relations and soy trade is provided in **Box 2**.

To determine climate risks posed to the supply of Brazilian soy to Sweden, the case study uses a quantitative multi-factor risk assessment approach (Jaeger et al., 2013) where three types of input data have been assessed and combined, estimating mean and maximum risk values. Risk is defined simply as the combined likelihood and magnitude of an undesired impact on the system studied (Aven & Renn, 2009) (see **Figure 3**). While more elaborate risk frameworks are sometimes used in climate change assessments, for example Lavell et al. (2012), this definition is chosen because it provides a simple and transparent framework with which to explore a novel, relatively complex methodology.[5]

Figure 3. Visual representation of data sources and definition of risk as magnitude x likelihood of adverse impact.



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[5] The output of mean and maximum risk values should be considered a simplified representation of risk. The mean risk value assumes a linear interaction of input components, with no weights applied. Although, theoretically, this relationship is not likely to be linear and equally weighted, the purpose of this arrangement is to identify areas where high potential importance for Swedish sourcing (magnitude of impact) and high exposure to climate change (likelihood of impact) coexist, as these locations are likely to represent the highest climate change risks to Swedish supply chains in future.

As few case studies of climate risks in bilateral trade flows on multiple impact points in specific commodities exist to date, the study is an exercise of innovating methods. The specific innovations of this method are:

- It utilizes new, state-of-the-art, high-resolution trade data – specific to municipality scale in Brazil and economic sectors in Sweden (Trase, Input-Output Trade Analysis (IOTA)).
- It assesses multiple impact points along the supply chain (production and transport).
- It compares and combines different data on climate impacts to better account for uncertainty in the "risk signal" (slow onset changes via more than one globally gridded crop model, plus extreme event risk – drought for production, and landslides and flooding for transport).

Given the novel nature of this kind of analysis, as well as the relevance of trade-related climate risks for all countries, including many import-dependent developing countries (Hedlund et al., 2018), we have striven for transparency and clarity in the way that data choices and the methodology are described, as well as full, open access to all results and outputs from this analysis. The working paper is therefore intended to spur innovation in methods for assessing trade-related climate risk and at the same time make accessible the method pioneered here for replication in other country contexts.

Box 2: In context: Making the case for Brazilian soy to Sweden.

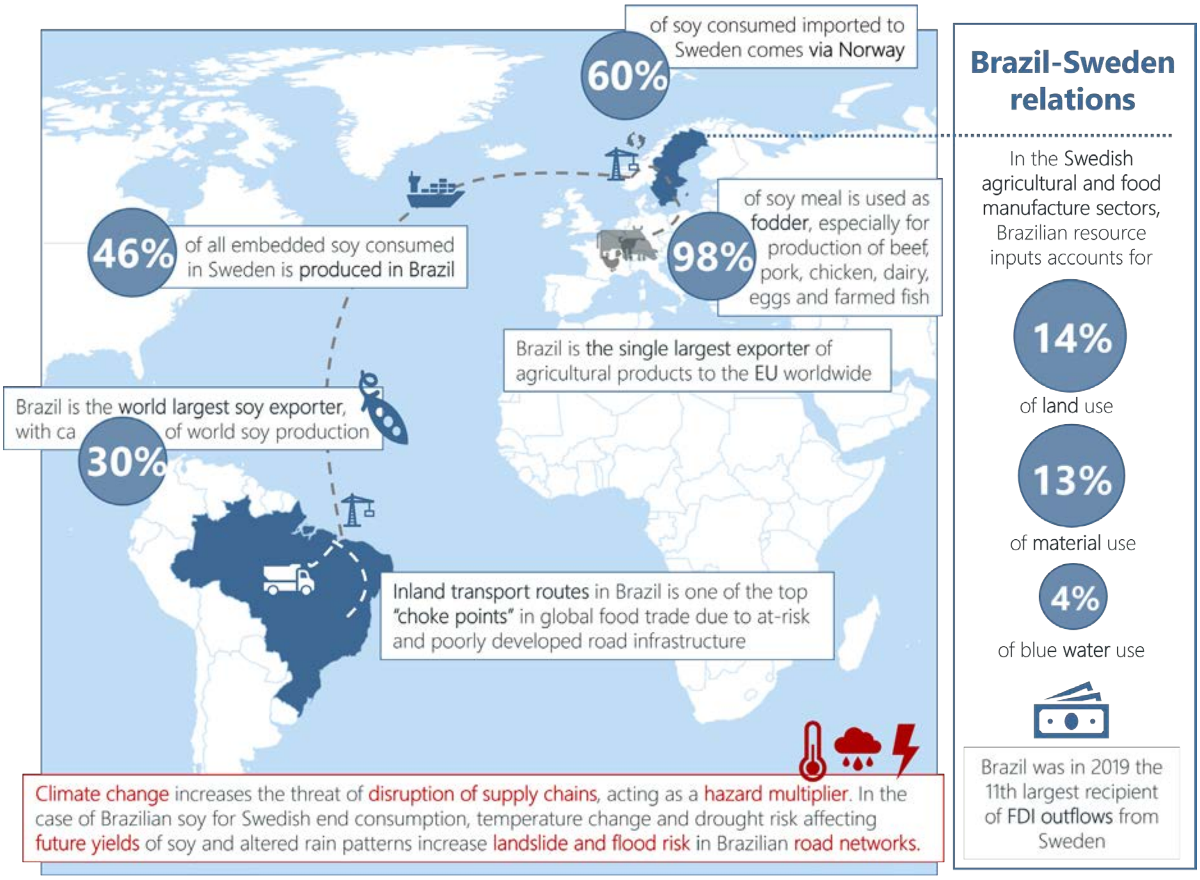
Exports of major food commodities are concentrated in just a few countries, making the global supply of input to domestic and regional food manufacturing potentially vulnerable to food supply shocks in distant regions (Bren d'Amour et al., 2016). Argentina, Brazil and the US together accounted for 80% of all traded soy in 2013. In 2018, Brazil became the world's largest soy exporter (Trase, 2018a). The past decades have seen a spatial decoupling of production and consumption facilitated by trends of increased global trade and fragmentation of supply chains (Goldin & Mariathasan, 2015). This means food production systems such as meat and dairy, as well as other food production that uses soy as an ingredient, are increasingly dependent on agricultural production systems thousands of miles away.

Sweden is a small country, deeply embedded in the global economy. Over half of the food consumed in Sweden is directly imported. The share of imports in Swedish food consumption would be even higher if all *embedded inputs into Swedish food consumption* were considered, including commodities that are embedded at all stages of the entire supply chain as well as embedded land and water use. In other words, Sweden depends on inputs from abroad for much more than half of its total food consumption – and these inputs are likely to be affected by climate change. As such, in order to understand the threats to Swedish food security from climate change it is necessary to look in detail at the key strategic inputs to Swedish consumption. Given its increasingly important role as an input to dairy, poultry and meat products, as well as a ubiquitous ingredient in many manufactured food and drink items, soy is an example of a commodity that should be considered strategic for Swedish food security. In this study we ask the question, where does the food really come from? And how can those supply chains be affected by climate change? Brazil is the largest soy exporter to Europe, and Sweden ranked the 13th top importer of Brazilian soy in the EU in 2014, consuming 236 000 tonnes of embedded soy from Brazil (Croft et al., 2018).

As the world's number one soy exporter, and as shown in the diagram below, Brazil is a strategic trade partner for other major soy-importing countries such as China and the rest of the EU. Brazil is also an increasingly strategic trade partner for Sweden, particularly given its role as the source of the water, materials and land embedded in other forms of Swedish consumption, and as an increasingly important economic partner for Sweden and recipient of Swedish investment. All of these factors suggest that the trade relationship – in general, but specifically for soy – between Brazil and Sweden is likely to remain of high importance during the coming years when climate change impacts are projected to intensify. Due to the high level of scrutiny regarding deforestation in Brazil to clear land for agricultural production, most of which is then exported, there have been significant investments in supply chain data transparency in recent years (see, e.g., https://trase.earth/). The main use for these data is to trace consumption (e.g. by specific companies or sectors in Europe) to specific locations in Brazil in order to identify where supply chains link consumers with areas of high deforestation risk, for example to assist efforts to make supply chains "deforestation free". However, these data can also be utilized to look in the opposite direction, that is, to identify climate risks at the point of production (i.e. at the municipal scale in Brazil) and to trace how these impacts may drive risk for commodity importers (e.g. in Europe or China). The existence of this high granularity of supply chain data, as well as the high quality of municipality scale data on other factors, such as extreme event risk indices, add to the attractiveness of Brazil as a case study.

For these reasons, the production and transport of soy in Brazil that is eventually consumed in Sweden presents an important, strategic and workable in-depth case study for analysing trade-related climate risks.

Box 2: *Continued…*



Multi-factor risk assessment

The magnitude of impact for Sweden is quantified in this study by a combined IOTA/Trase modelling approach, allowing sub-national production data (for more than 1700 Brazilian municipalities) to be interrogated from the perspective of embedded consumption (for 43 Swedish sectors) (Croft et al., 2018; Green et al., 2019; see Trase website: https://trase.earth/).

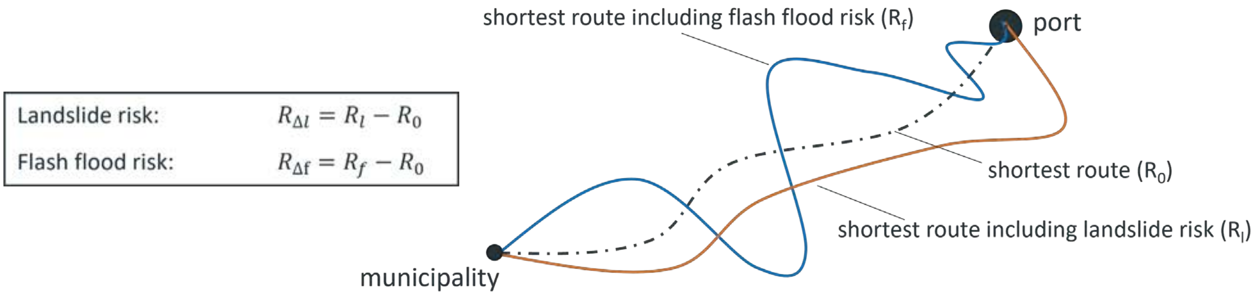
The likelihood of impact is quantified by combining production risks (future crop yield projections and vulnerability to drought based on the work by Stokeld et al. (2020) and Debortoli et al. (2017a)) and transport risk (detailed transport data combined with landslide and flash flood predictions based on work by Trase (https://trase.earth/) and Debortoli et al. 2017b)). A method for assessing climate change risk for inland transport routes in Brazil was specifically produced for the case study using geographic information system (GIS) analysis. This method enables us to assess the climate risks to the transport of soy in Brazil that is destined for import into the EU/Sweden, described in **Box 3**. It computes the specific route from farm to port and the specific climate risk profile of that route. A comprehensive description of data model components and technical details are provided in **Appendices 2, 3** and **4**.

The Intergovernmental Panel on Climate Change (IPCC) representative concentration pathway (RCP) RCP 4.5 is used in all datasets for this study. RCP 4.5 can be considered a conservative climate change scenario in which average global temperatures are expected to increase by 1.0–1.6°C above pre-industrial levels by 2050 and are likely to exceed 2°C by 2100 (van Vuuren et al., 2011; IPCC, 2019). The climate model used in all climate simulations in this study is the Hadley Centre Global Environment Model version 2 (HadGEM2-ES), a widely accepted and implemented model in the climate modelling community (Martin et al., 2011). The time frame is mid- to end of century depending on the availability of input components.

Box 3: Calculating transportation risk.

Assessing climate change risks to inland transport routes in supply chains is a novel field without a toolkit of established methodologies from which to draw. The study therefore has developed a new method for this purpose, assessing climate change impacts on the road transport system from producing municipality to exporting port in Brazil. The method combines sub-regional information on landslide and flash flood risk with transport data for soy supply to the European Economic Area (EEA; the EU including the UK, plus Iceland, Lichtenstein and Norway) (https://trase.earth/). Flooding and landslides are the most frequent weather-related events in Brazil causing transport disruptions (Bailey & Wellesley, 2017; Challinor et al., 2016). Landslide and flash flood risk indices for Brazil used for the assessment have been developed by Debortoli and colleagues (Debortoli et al., 2017b).

For the analysis, an origin-destination model was developed based on geographical data analysis of routes from producing region to port using geographic information system (GIS) software. An origin-destination (OD) matrix is a multiple network function, computing shortest or fastest routes from multiple points of origin to multiple points of destination. The landslide and flash flood risk were attributed to the OD-matrix calculation as cost, in this case “speed limits”. The analysis rendered shortest routes for routes with no risk (R_0), landslide risk (R_l) and flash flood risk (R_f), schematically illustrated in the figure in this box. The method thus considers alternative routes and is described in its entirety in **Appendix 3**.


Landslide risk: $R_{\Delta l} = R_l - R_0$
Flash flood risk: $R_{\Delta f} = R_f - R_0$

2.3. Key methodological challenges

Overcoming trade data constraints: physical or financial flows and granularity

As discussed in Approach A, and as exhibited using three types of data sources to understand and reflect on the different results stemming from the three methods, using physical, financial or environmentally extended flow data has advantages and limitations when trying to assess climate risk in trade systems. In addition, all of the data sources included in Approach A use national accounts (physical or financial) as the basis of analysis; none has a geographical granularity finer than the national level. See **Table 3** for a comparison of dataset properties.

To overcome these limitations Approach B of Brazilian soy to Sweden uses a combination of the IOTA and Trase models. IOTA was specifically developed by Croft and colleagues (Croft et al., 2018) to account for embedded flows of commodities at a sub-national scale. It is a hybridized physical-monetary multi-regional input-output (MRIO) model (SEI, 2019a). Embedded commodity flows throughout the supply chain are estimated based on sector-level monetary transaction data *and* physical commodity flows. Combined with Trase, an interactive supply-chain transparency platform (https://trase.earth/), flows from a sub-regional production level, via exporting ports and traders to importing countries, are accessed. A detailed overview of the data and analysis is provided in **Appendix 2**. The combined IOTA/Trase modelling approach allows sub-national production data to be interrogated from the perspective of embedded consumption.

Other commonly used approaches to study climate change impacts on trade are computable general equilibrium models and integrated assessment models; these macro-economic models perform cost–benefit analysis based on single or aggregated “damage functions” (e.g. temperature rise or yield losses). Labelled a “bottom-up” approach, computable general equilibrium models allow for a more detailed sector breakdown, and their “top-down” counterparts, integrated assessment models, allow for integrating complex socio-economic scenarios. With a potential to provide rich economic model results, both methodologies offer limited transparency regarding the interaction of components in the model and its algorithms. Performing both of these approaches is also extremely resource-intensive (Steininger et al., 2016).

Goods and services

One of the major challenges in comparing datasets in Approach A (Sweden and the rest of the world) is the difference in inputs accounted for. Both WIOD and PRINCE account for both goods and services together (data cannot be analysed separately), whereas the national toll data report on imports of goods and services separately (datasets cannot be combined methodologically). Combining the approaches (as is done in this study), while challenging from a compatibility viewpoint, also provides opportunities to better understand trade dynamics and trends and climate change risk.

Trade in services is growing faster than trade in goods globally, and for Sweden the increase is faster than the world average (World Trade Organization, 2020). The possible impacts of climate change on physical assets and the flow of goods, for example as a result of disruptions to production or transport, are better known, but there is also evidence that suggests climate change will have negative effects on services, too, for example on labour productivity due to heat stress (Kjellstrom et al., 2016; Wenz & Levermann, 2016), as well as the physical risk posed to service facilities. Nevertheless, assessing the impacts of climate change on the service sector remains challenging given current data and knowledge.

Time trends

As trade relationships change over time, it is important to take trends into account, rather than to simply focus on static data that provide information about moments in time, or mean values. Approach A (Sweden and the rest of the world) uses a series of data to understand trends related to climate vulnerability in trade, whereas Approach B (Brazilian soy) only displays soy imports from a snapshot in time due to data availability. Time trend analysis enables us to ask questions such as: Is Sweden becoming more or less exposed to climate impacts via trade? Does the relative difference between sectors change over time?

3. Sweden’s exposure to trade-related transboundary climate risk

3.1. Results

Trade data analysis: Sweden and the rest of the world

This section presents the results of trade data analysis for Sweden (**Figures 4** to **8**). Examples of data visualization are presented, but the full range of visualizations is available on an interactive web tool at https://public.flourish.studio/story/656845/. Where possible, we would encourage the reader to visit the web tool while reading through this analysis in order to access a more in-depth presentation of the results and to explore the factors that are of most interest and relevance. A summary of highlights for each dataset is provided in **Table 3.**

Figure 4. Doughnut charts showing total share of inputs for each dataset by country. Colour according to ND-GAIN climate index from green (low climate vulnerability) to red (high climate vulnerability). A detailed, interactive presentation of these results is available at https://public.flourish.studio/story/656845/.

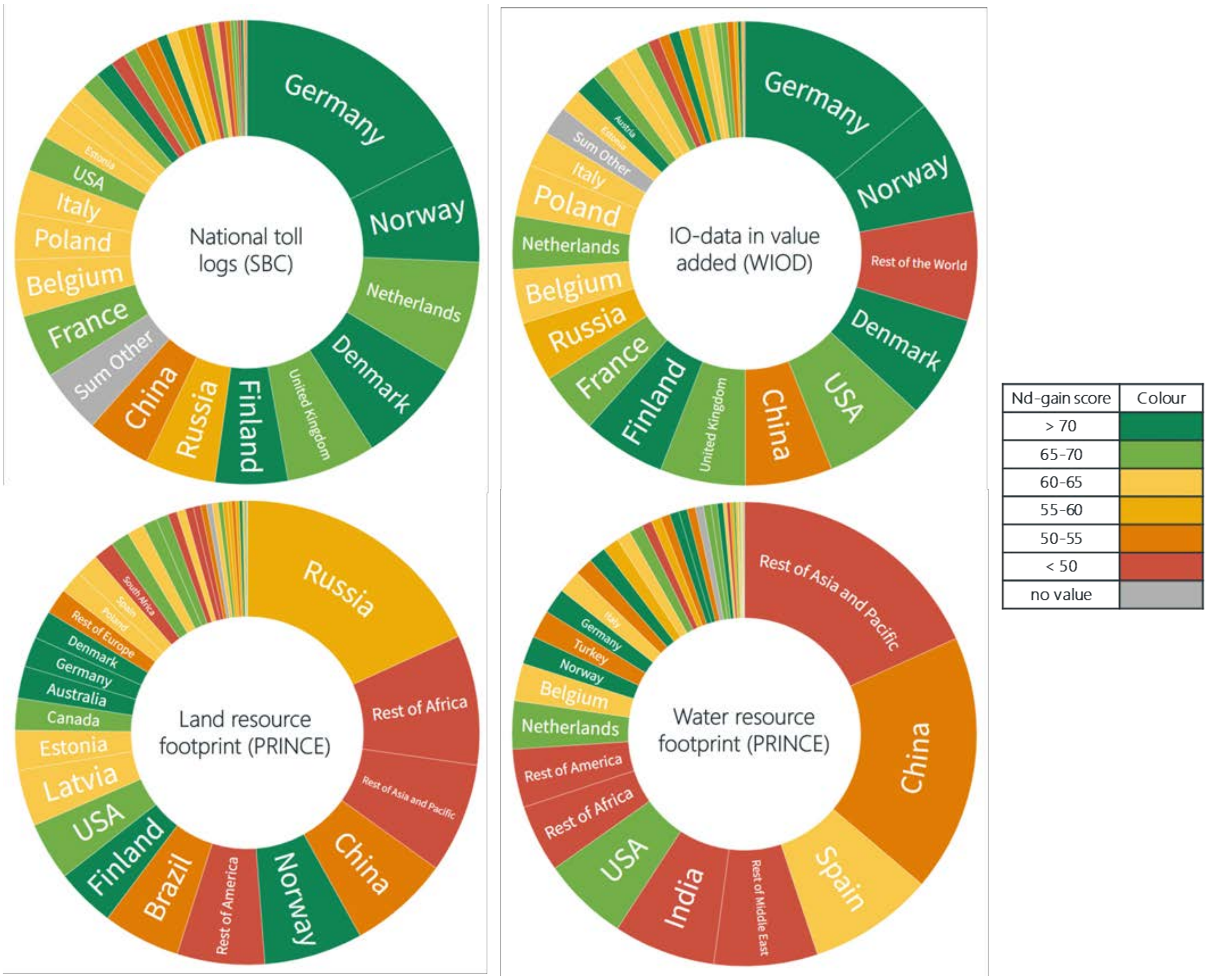
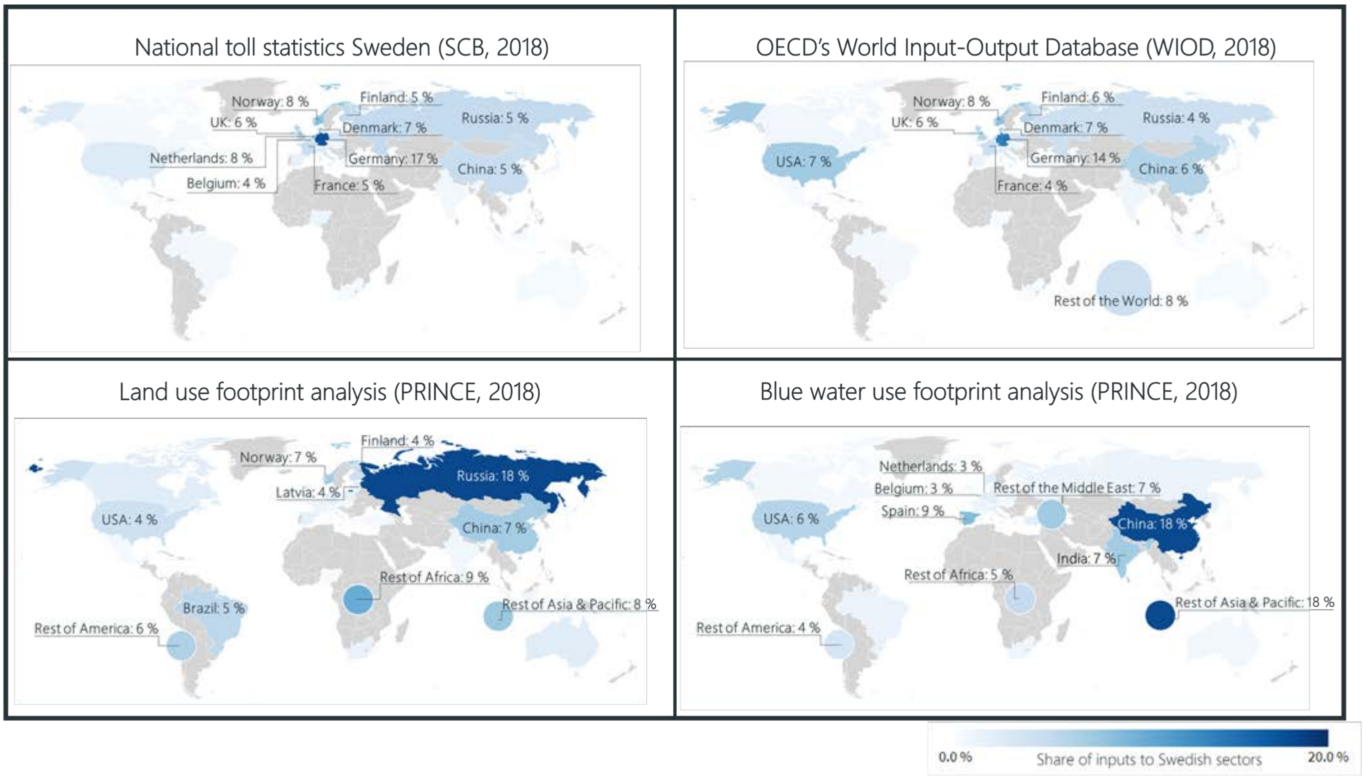


Figure 5. Geographical representation of share of imports/input by country for the Swedish top 43 trading partners across all datasets. Input shares outlined for top 10 trading partners or regions for respective dataset.



Sweden is connected to the global economy via trade. As noted above, how those connections are articulated depends on the type of trade data that is being analysed and how. **Figure 4** shows Sweden's top 30 trade connections according to the logic of each of the three datasets, as well as the level of vulnerability to climate change for each of these top trade partners. This provides a high-level overview of Sweden's exposure to climate risk via trade, compared across all four types of data. **Figure 5** shows the geographical representation of the same linkages.

According to national toll statistics (SCB) Sweden gets most of its imports from other European countries with a low climate vulnerability, similar to Sweden itself. Looking at world input-output data (WIOD), the trade links are slightly more geographically dispersed, with China, the US and "Rest of the World" region increasing in importance, implying a higher reliance on regions whose vulnerability to climate change is higher than Sweden's (i.e. riskier). The land and water footprint analysis gives a quite different impression. Embedded land use for Swedish consumption is mostly linked to regions with a higher climate vulnerability than Sweden, such as China, Russia, "Rest of Africa" and "Rest of Asia and Pacific". For embedded blue water use, the most significant trading partners are China, Spain and "Rest of Asia and Pacific", all predicted to be hit harder by climate change than Sweden in the future. This is also illustrated in **Figure 8** where countries' climate vulnerability and share of inputs are displayed as a function of the geographical distance from Sweden.

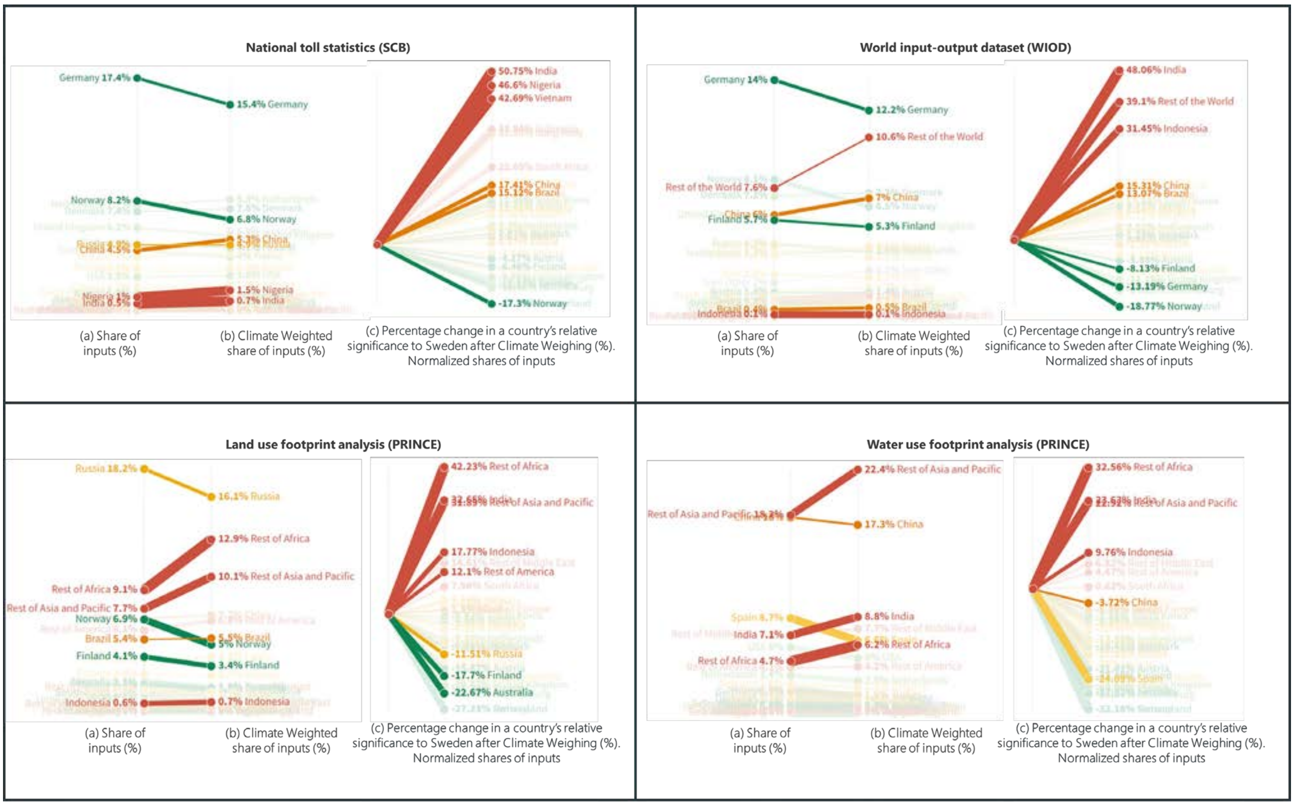
To understand important transmission pathways for transboundary climate risk via trade, it is important to look not only at the largest flows, but also at those which might be most at risk and how these are changing over time. **Figure 6** shows an overview of the changes in the relative importance of a country to Sweden when climate vulnerability is taken into account (here referred to as “climate weighting”). The figure also highlights a selection of countries of particular interest: those showing a large increase or decrease in relative importance when climate vulnerability is incorporated (the graphs on the right side).

Although in the lower region of the top 30 trading partners – according to national toll and input-output statistics – India, Indonesia, Nigeria and Viet Nam, as well as the “Rest of the World” region, stand out as potential climate risk hotspots for Swedish trade. China should also be of high interest in terms of climate risks to trade, given the combined effects of the nation’s climate vulnerability and the size of its trade flow to Sweden. Neighbouring Finland, Germany and Norway, on the other hand, decrease in relative importance due to the projected low climate vulnerability for these countries.

While the footprint data show a different geographical pattern, the world regions of high importance – Asia and Pacific, Africa and the Americas, as well as India – continue to stand out in relevance when climate change effects are considered. Contrary to the SCB and WIOD data, the footprint data show a decrease in relative importance of countries with moderate aggregate climate vulnerability, such as China and Russia; this is because countries with even higher vulnerability scores provide significant inputs to Swedish consumption. Taken together, the results in **Figure 6** highlight a key message: that small, seemingly insignificant or mid-level trade partners for Sweden may in fact represent a higher level of risk than we currently appreciate, given their susceptibility to climate change.

The time trends also show large disparities between datasets (see **Figure 7**). Both the national toll and IO-data in value added show an increasing trend in trade for virtually all trading partners. Embedded use of land shows an overall decreasing trend, indicating a domestication rather than overall decline of land resource use (Palm et al., 2019). Exceptions are embedded land use from China, Finland, Latvia and Norway, which are increasing. Overall, the trends would suggest that land use reliance is shifting from faraway regions with high climate vulnerability, closer to home with a lower climate risk. The trend for embedded water use shows slightly more complex dynamics, with regions close to Sweden such as Spain and Belgium increasing in importance, and regions located in Asia and Africa decreasing. This would suggest that for embedded water use the trend also reveals a tendency towards decreasing climate risk exposure in Sweden, albeit one that remains at a high level.

Figure 6. Results of “climate weighting” across the datasets, depicting the relative importance of a country to Sweden in share of inputs (a) without climate weighting, (b) the climate weighted share of inputs and (c) the countries showing the largest change in relative significance for Sweden after climate weighting (negative and positive change) – combining the input shares with countries’ vulnerability to climate change. Comparison across datasets. Selected countries are highlighted.



National toll statistics (SCB)

(a) Share of inputs (%)

(b) Climate Weighted share of inputs (%)

(c) Percentage change in a country’s relative significance to Sweden after Climate Weighing (%). Normalized shares of inputs

World input-output dataset (WIOD)

(a) Share of inputs (%)

(b) Climate Weighted share of inputs (%)

(c) Percentage change in a country’s relative significance to Sweden after Climate Weighing (%). Normalized shares of inputs

Land use footprint analysis (PRINCE)

(a) Share of inputs (%)

(b) Climate Weighted share of inputs (%)

(c) Percentage change in a country’s relative significance to Sweden after Climate Weighing (%). Normalized shares of inputs

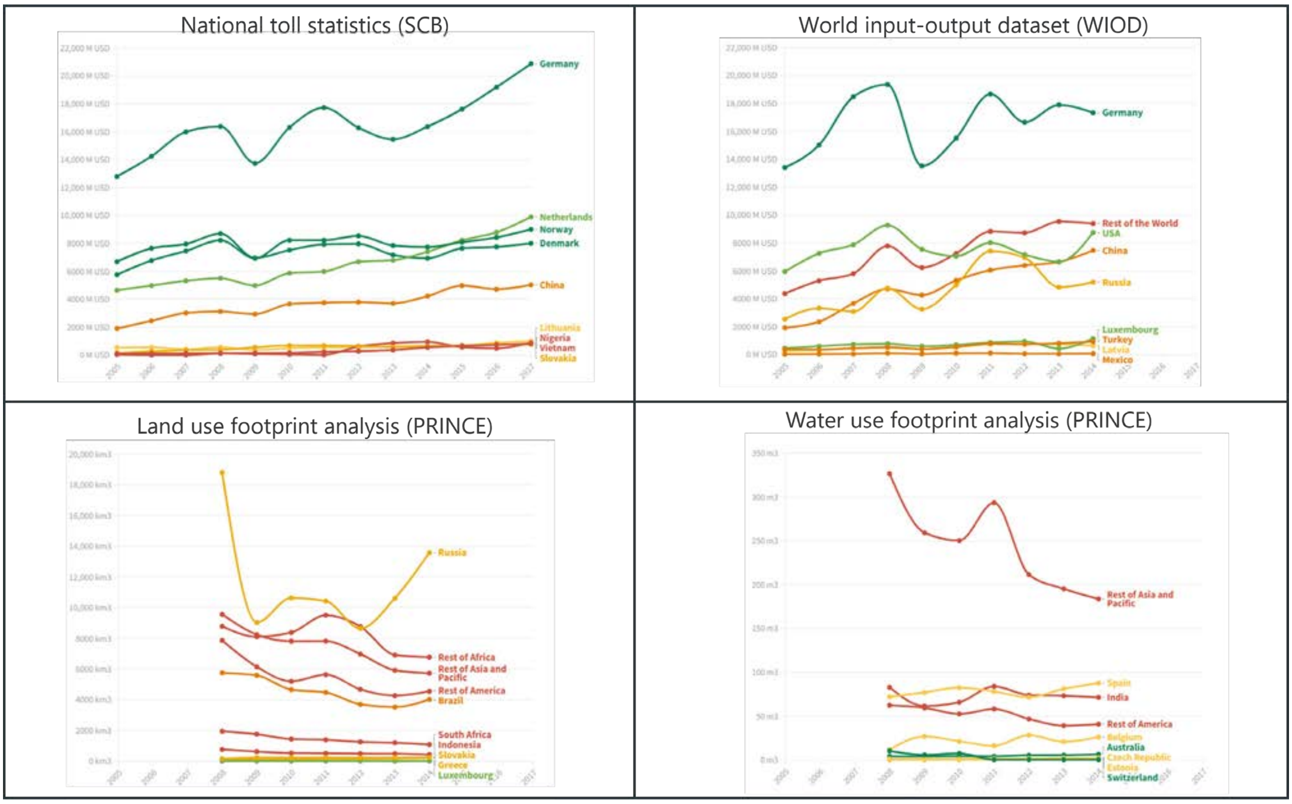
Water use footprint analysis (PRINCE)

(a) Share of inputs (%)

(b) Climate Weighted share of inputs (%)

(c) Percentage change in a country’s relative significance to Sweden after Climate Weighing (%). Normalized shares of inputs

Figure 7. Time trend analysis across all datasets. Figure shows a selection of the top five “movers” in time, both by volume/value and change in share of inputs over time (absolute value/change rate counted, accounting for both increase and decrease). Time series varies depending on availability of data.



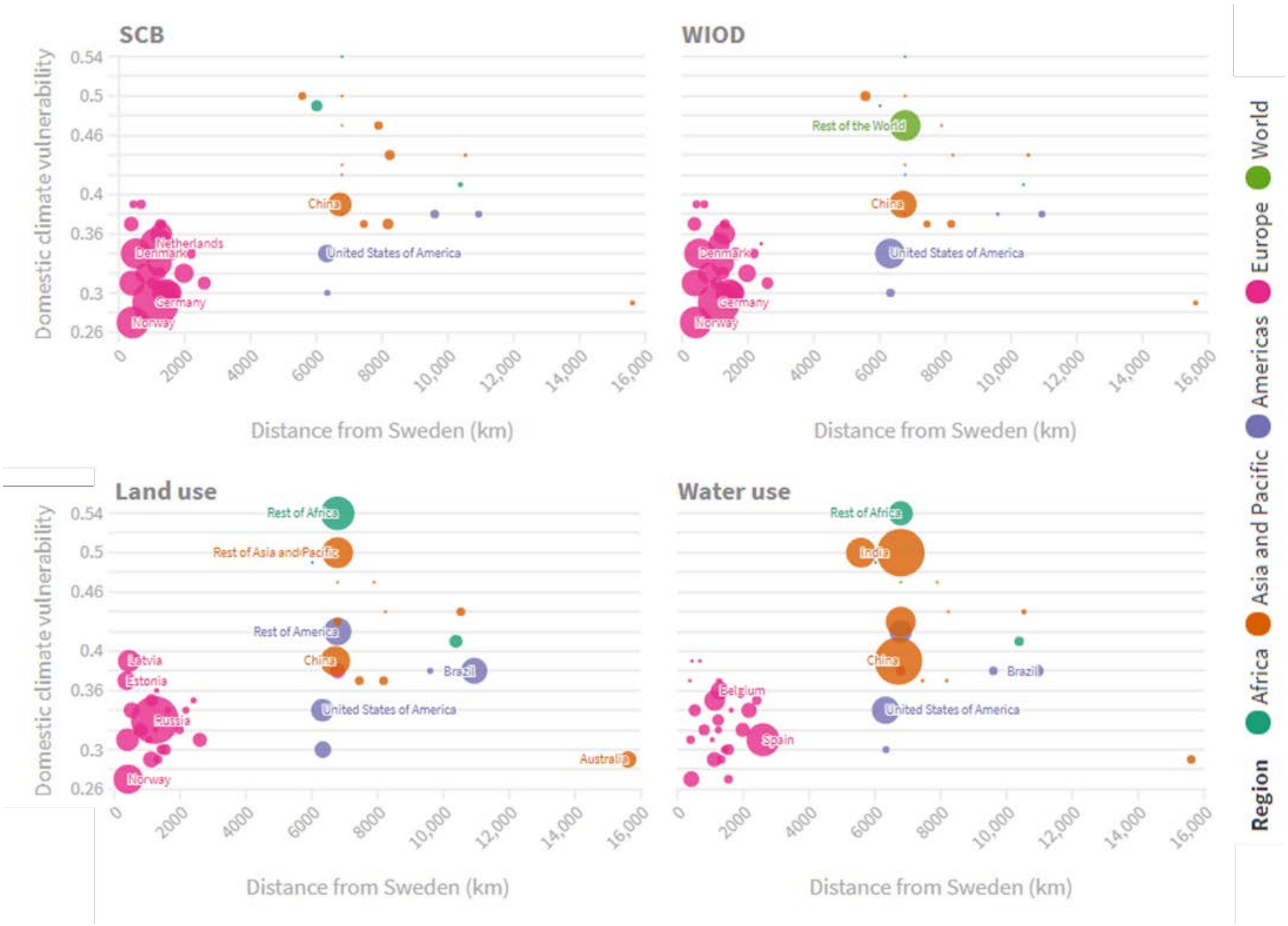
National toll statistics (SCB)

World input-output dataset (WIOD)

Land use footprint analysis (PRINCE)

Water use footprint analysis (PRINCE)

Figure 8. Relation between countries' domestic climate vulnerability (y-axis; ND-GAIN vulnerability index), their geographical distance from Sweden (x-axis) and their share of input/imports to the Swedish economy (dot sizes) for each available dataset. Countries are grouped by colour into their geographical region.



It is also revealing to look at what the different datasets tell us about the physical distances between Sweden and its most significant trade partners. As shown in **Figure 8** (see also **Figure 5**), the geographical distance of traded inputs to Sweden differs significantly depending on the trade data used. Trade data that focus on material inputs into Swedish consumption (i.e. footprint data), reveal the importance of countries that are further away from Sweden. Trade data that emphasize high tiers of the supply chain (e.g. WIOD) or the top tier, or last port of call (e.g. SCB) indicate that countries closer to home are most important. See **Box 1** for a reflection on why this is.

This has important implications when studying climate risk in trade. Sweden has low climate vulnerability and is located in a region with a similarly low level of exposure to direct climate change impacts. Climate vulnerability tends to increase as one travels away from the Nordic region, meaning the further away inputs derive from, the more vulnerable to climate change they are likely to be. Thus, the further our assessment reaches towards the "origin of inputs", by using more sophisticated and nuanced trade data, the more important transboundary climate risk is revealed to be for Sweden.

Results summary

Table 3. Results highlights and summary for each dataset.

Dataset	Summary
National toll logs (SCB)	Analysis of the **SCB national statistics** shows that Sweden is highly dependent on imports from other OECD countries and countries in close geographical proximity to Sweden. The most important trading partners have a low climate vulnerability. Between 1998 and 2017 the data show a general increase of imports over time. However, non-OECD growth is higher than OECD trade growth. Non-OECD countries are on average more vulnerable to climate change than OECD countries, according to the ND-GAIN index. This means that Sweden is becoming subtly and gradually more dependent on more climate-vulnerable countries.
Input-output data in value added (WIOD)	The **input-output model WIOD** shows a high input share from other OECD countries, but with an increased importance of geographically distant regions compared to SCB data, such as China and the USA (and the slightly decreasing importance of EU neighbours such as Germany and the Netherlands). Using WIOD data weighted for climate vulnerability, the most important trading partners have a low climate vulnerability, although the share of inputs from the more vulnerable "Rest of the World" region is slightly higher according to this data than when using SCB data. Time trend analysis between 2005 and 2014 shows a general increase of overseas input to Swedish sectors. The non-OECD share of inputs is increasing overall. There is a mix of increasing inputs from low and middle climate-vulnerable regions (i.e. China, Russia, Rest of the World) as well as increases from countries with low climate vulnerability (i.e. Germany, the USA). Time trend analysis points towards an overall but subtle increase in Sweden's dependence on climate-vulnerable countries.
Embedded land use (PRINCE land footprint)	According to the **land footprint (PRINCE)** data, inputs to Swedish consumption are highly dependent on climate-vulnerable regions such as Brazil, China, the "Rest of Africa", "Rest of Asia and the Pacific" and "Rest of America". Russia (mid-vulnerability to climate change according to the ND-GAIN vulnerability score) is the single most important trading partner to Sweden according to the land footprint analysis. Time trend analysis between 2008 and 2014 shows a general decrease of embedded land use in Swedish consumption and an overall, but subtle increase in the dependence on OECD countries. The largest decrease of inputs is within the current top trading partners, with the exceptions of China, Finland, Latvia and Norway. This would imply that Sweden is domesticating the embedded land use, and moving dependency from more climate-vulnerable countries to less vulnerable countries.
Embedded water use (PRINCE water footprint)	Analysis of the **water footprint (PRINCE)** data shows that Sweden is highly dependent on embedded water in consumed products, mainly from climate-vulnerable and geographically distant regions such as China, India, the "Rest of Asia and Pacific" and "Rest of Middle East", as well as countries of closer proximity such as Spain and the "Rest of Europe". Time trend analysis between 2008 and 2014 shows that total water dependency is quite stable, and the OECD share of embedded water use is increasing slightly. Sweden is moving embedded blue water dependency from more climate-vulnerable countries (India, Rest of Asia and Pacific, and Rest of America) to less vulnerable countries (Belgium, Spain), mostly as a result of shifting import patterns; that is, away from textiles towards more fruit and vegetables, as examples of products with high levels of embedded blue water.

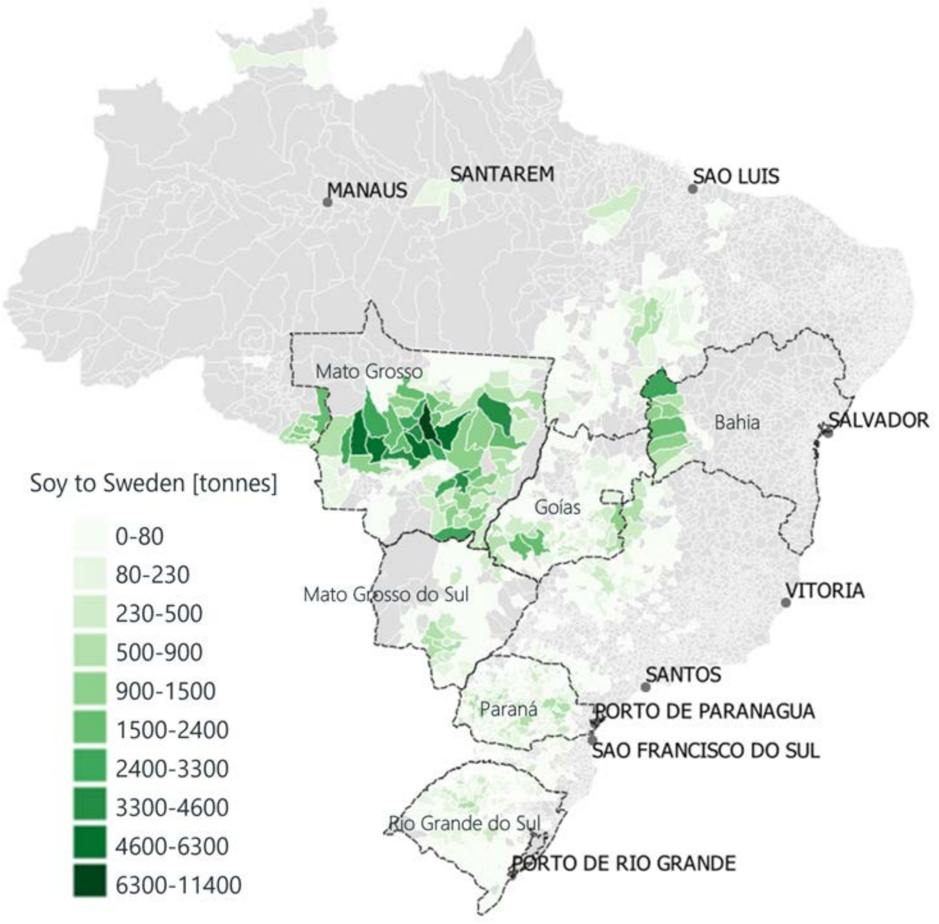
The case of Brazilian soy for Swedish consumption

The aggregate results and sub-index inputs of the case study of Brazilian soy for Swedish consumption are presented in their entirety as an interactive web tool at https://public.flourish.studio/story/25055/.

In 2011 the largest single source of Sweden's Brazilian soy derived from the state of Mato Grosso (see **Figure 9**). The region comprised a total of 48% of Swedish embedded soy consumption in 2011 (in relation to a 28% overall production share in Brazil). The state of Paraná comes second, comprising 18% of embedded soy for Sweden. Another interesting geographical hotspot for Swedish soy sourcing is the western part of Bahia state. Other areas of relative interest to Sweden are Goiás/Central region, Mato Grosso do Sul and Rio Grande do Sul, each of which represents around 5% of total Swedish embedded soy consumption.

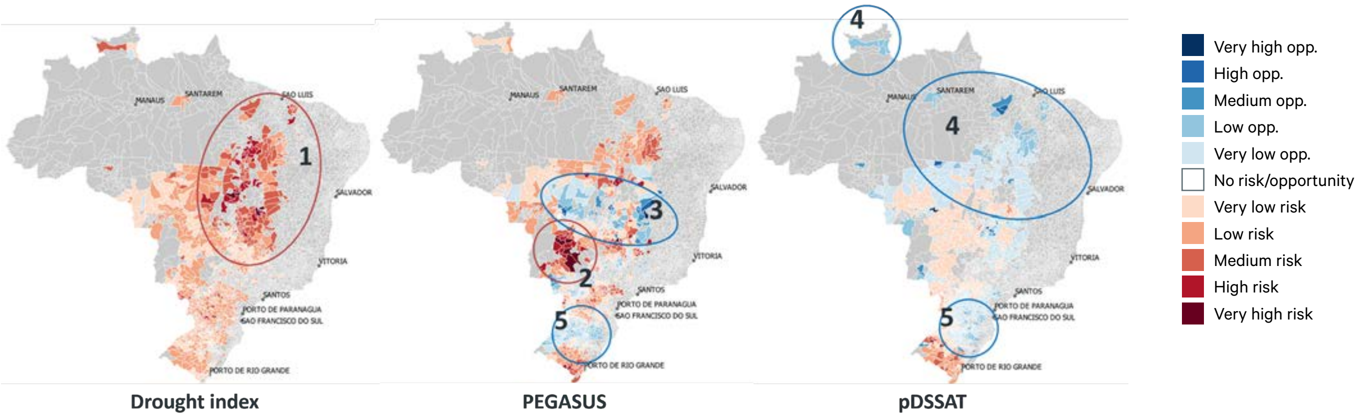
The production risks were analysed through a comparison of two different globally gridded crop models (GGCMs) and a drought vulnerability index (to capture extreme weather event risk; drought is the most important type of extreme weather to impact soy production). A combination of these three input parameters rendered five key typological areas for production risks/opportunities across the models, emphasized in **Figure 10**.

Figure 9. Origin of embedded Brazilian soy for Swedish consumption in 2011. Dotted lines show areas of particular interest.



Source: Based on IOTA/Trase data (Croft et al., 2018).

Figure 10. Impacts on production: from left to right, drought vulnerability index and the two crop models PEGASUS and pDSSAT. Numbered circles show areas of particular interest.



1. The north-eastern parts of Brazil are dominated by areas of medium to very high drought risk. The rest of the country is dominated by very low to low drought risk.

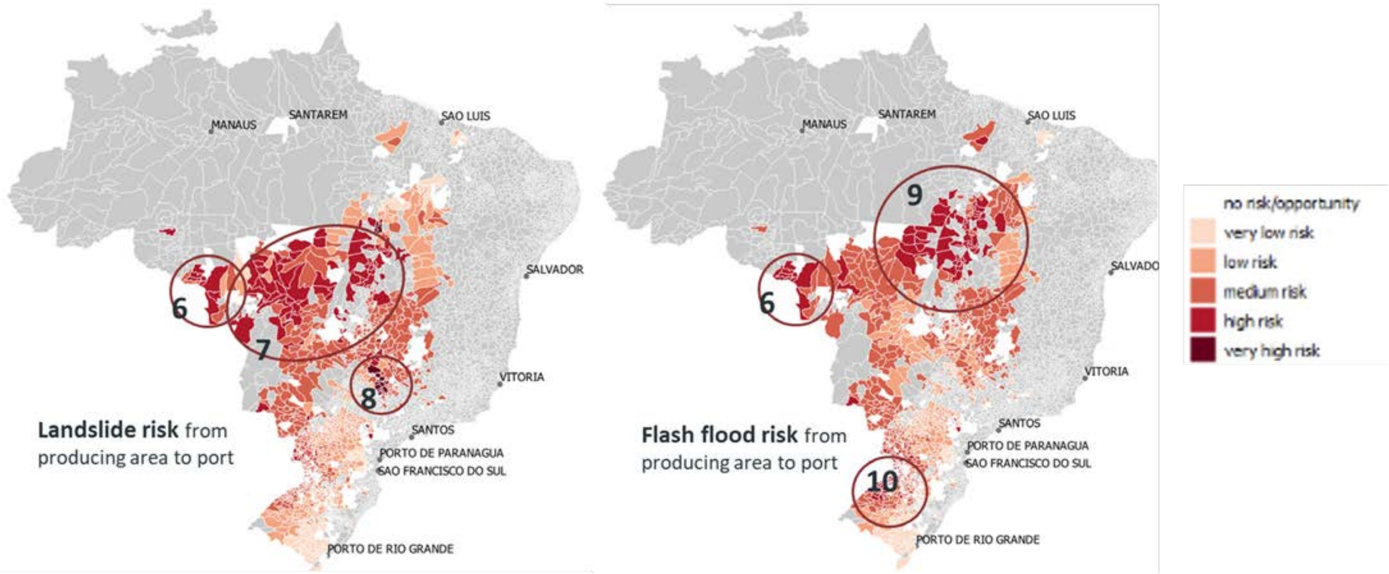
The two crop yield models return quite opposing yield predictions:

2. The PEGASUS model predicts high to very high yield losses in Mato Grosso do Sul; and
3. Low to high opportunities of increased yield in the central region of Brazil.
4. The pDSSAT model, however, shows a more positive yield prediction overall, predicting low to high opportunity in the north-east where the PEGASUS instead shows low to medium losses.
5. Both GGCMs, however, agree on moderate increases in yield in the area of northern Rio Grande do Sul/Santa Catarina.

Finally, transport risks to the supply of Brazilian soy to Sweden were determined through a GIS analysis of the landslide and flash flood risks along the road from producing municipality to exporting port, taking into consideration alternative routes (see **Box 3** and **Appendix 3** for a full description of the transport risk methodology). **Figure 11** provides a geographical overview of the road network and the exporting ports to the EU. Overall, the transport impacts return higher risk values than the production risks. Transport risk typological areas and "hotspots" are illustrated and numbered in **Figure 12**.

Figure 11. Road and port network of Brazil. Size of port circles represents share of soy exports to the EU/EEA in 2011.

Figure 12. Predicted impacts on road transport from producing municipality to port of export. To the left, landslide risk, and flash flood risk to the right. Numbered circles show areas of particular interest.



6. From Rodônia state to port, risks of both landslides and flash floods are high as a result of having the longest roads to port.

7. Transport from the State of Mato Grosso involves long roads to port, passing areas of medium/high landslide risks, with few alternative roads. Municipalities in these areas are characterized by the usage of several ports.

8. High to very high landslide risk values are also retained from southern Goiás, where municipalities ship their soy from Porto de Rio Grande, accessed via a long coastal road with high landslide risks and few alternative routes.

9. Hotspots for flash flood risks are located in the north-western so-called Matopiba region, and the very southern part of the country (9 and 10), where although the roads to port are short, they have high or very high flash flood risk.

Based on the above results, 11 typological areas (A–K) were identified and rated, based on the geographical patterns in the sourcing, production and transport sub-indices. The results show that Swedish sourcing patterns of Brazilian soy are connected to areas of relatively low risk of impacts of climate change along the supply chain (see **Figure 13** for combined risk values and **Figure 14** for detailed breakdown of results). The majority of Swedish sourced soy from Brazil derives from the vicinity of the state of Mato Grosso (area C), an area predicted to be at very low to low risk of drought and crop yield losses in the future. The high likelihood of adverse impact in this area is related to transport risk. Road transport from the area entails long and underdeveloped roads with medium to high risk of landslide and flash floods along the way and few alternative routes to port. The area is, however, a hotspot for ongoing developments in alternative infrastructure, such as waterways in the Amazon, which the method does not take into account (see Reed & Fontana, 2019). Thus, the significance of the future transport risk to this area should be carefully interpreted, based on future infrastructure development.

Figure 13. Characteristic areas showing the combined magnitude and likelihood of risks of climate change for Swedish sourcing of Brazilian soy.

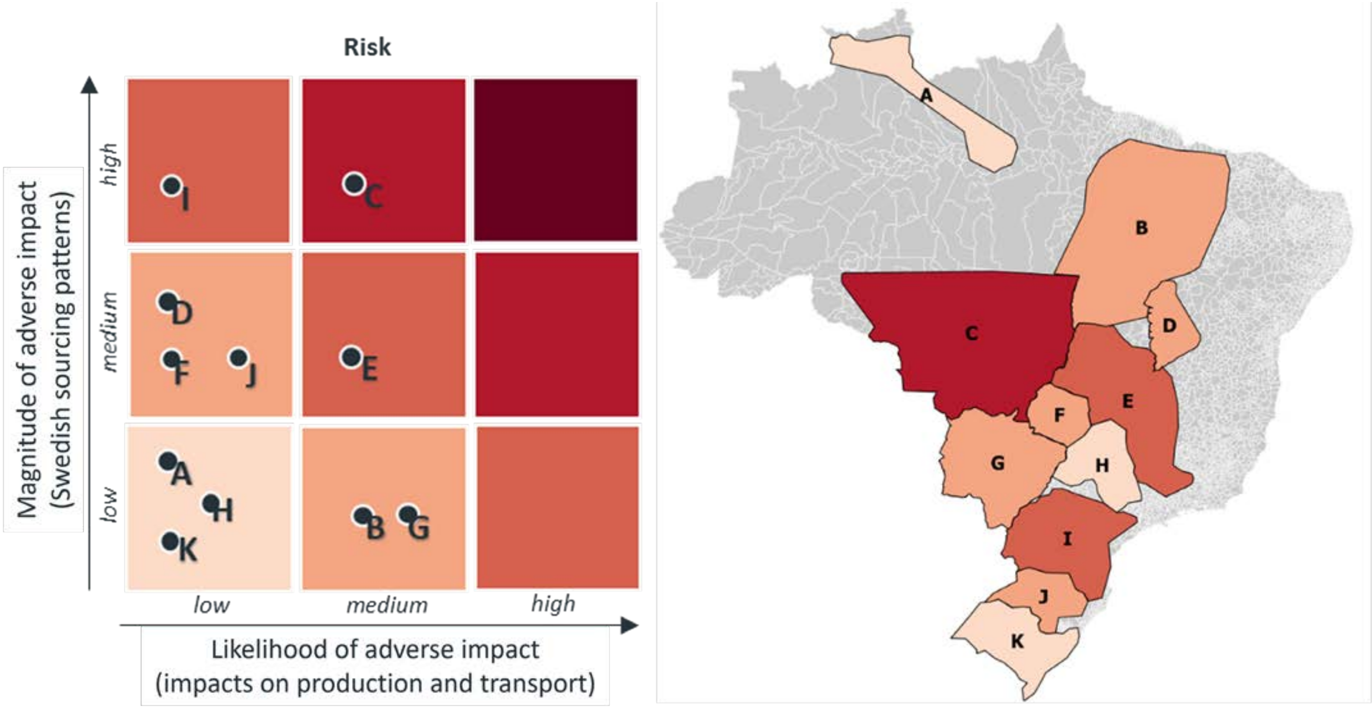
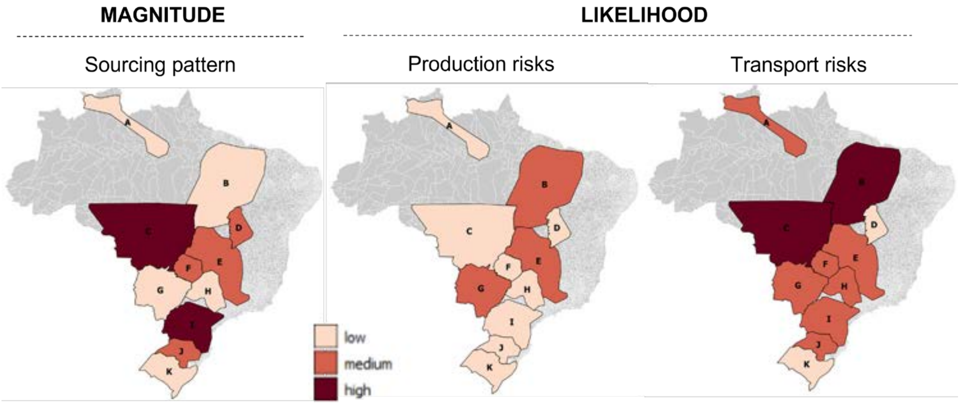
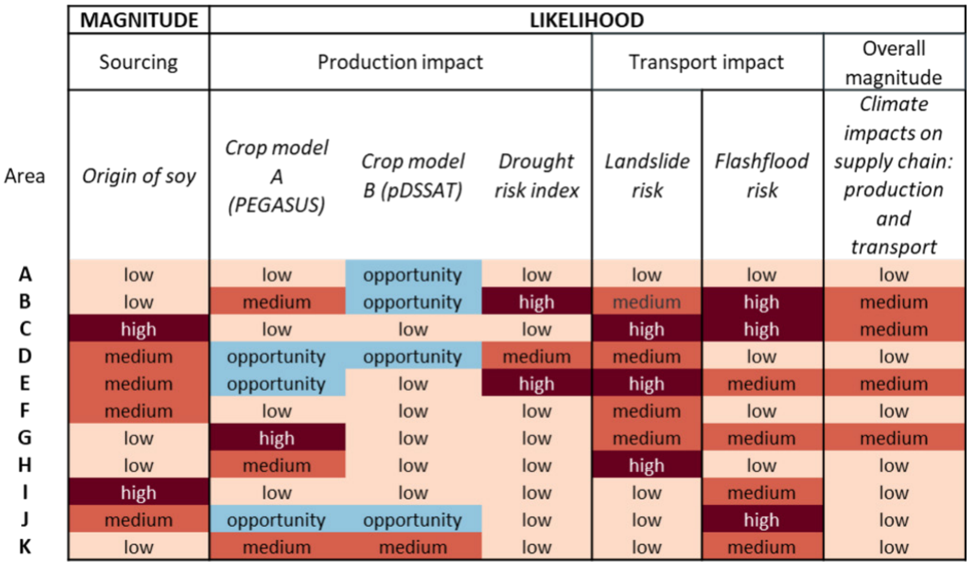


Figure 14. Result breakdown into sub-components. Top: the magnitude and likelihood of impacts from the typological areas (A–K) on Swedish consumption are illustrated from low to high. Below: the matrix describes scores for each characteristic area and the input indices individually.





	MAGNITUDE	LIKELIHOOD					
	Sourcing	Production impact			Transport impact		Overall magnitude
Area	*Origin of soy*	*Crop model A (PEGASUS)*	*Crop model B (pDSSAT)*	*Drought risk index*	*Landslide risk*	*Flashflood risk*	*Climate impacts on supply chain: production and transport*
A	low	low	opportunity	low	low	low	low
B	low	medium	opportunity	high	medium	high	medium
C	high	low	low	low	high	high	medium
D	medium	opportunity	opportunity	medium	medium	low	low
E	medium	opportunity	low	high	high	medium	medium
F	medium	low	low	low	medium	low	low
G	low	high	low	low	medium	medium	medium
H	low	medium	low	low	high	low	low
I	high	low	low	low	low	medium	low
J	medium	opportunity	opportunity	low	low	high	low
K	low	medium	medium	low	low	medium	low

4. Method discussion and recommendations

Diving into the task of understanding trade-related climate risk for a country like Sweden reveals some apparent constraints in available and applied methods. Understanding the implications of these for the transboundary risk assessments and working towards bridging and overcoming these constraints proves a substantial task for future research. This section presents a reflection and discussion on the key methodological challenges and considerations for trade data analysis and climate models and provides recommendations for future research in the field, as well as pointing towards key future innovations identified in this study.

Available trade data and how it can inform us about climate risk

The first identified methodological constraint is that the trade data used for analysing trade dependencies and links are often insufficient for understanding the nature of climate risks that can be transmitted via this pathway. National toll logs, that are often used for this task, do not by their nature reveal the intricate connections in the trading system, and as a result hide important risk pathways, as a country like Sweden looks mostly connected to other similar countries, at a close geographical distance. Because national toll logs are familiar, often accessible and in that sense easy to use, they can provide a good starting point to understand trade relations and implications for climate risk, but results need to be understood in the light of their limitations. Input-output tables, on the other hand, tell us more about how countries such as Sweden are connected to the rest of the world, beyond the first tier, but these data face similar constraints as they are based on "value added", a concept that emphasizes the accumulation of value in the latter stages of the supply chain, giving us a limited understanding of the importance of climate vulnerability in the producing and processing stages. Resource footprints, such as land and water use, offer a partial solution because they focus on the material inputs to supply chains in the initial stages. While this overcomes some of the constraints of the first two approaches, it does not give us a comprehensive understanding of the nature of land and water use linked to the resource use in production. The aggregation of smaller and many developing economies into "rest of the world" regions further obscures the much-needed details of global trade relations for risk analysis. In summary, while readily available national and sector-wide trade data generally serve the purposes of supporting economic and environmental impact analysis, they are less reliable for informing us about climate risk, where it is vital to understand links to climate-vulnerable regions in the lower tiers of supply chains.

With that said, the analysis carried out in the first part of this report (Approach A) has focused on transboundary climate risk at a country scale. For all datasets used in this method, the trade data can be broken down into specific commodity groups and sectors. This provides opportunities for detailed understanding of trade-related climate risks, especially in relation to the use of input-output and resource use data (footprints). The breakdown of trade data by sector invites the use of sector-specific climate vulnerability data. To name a few prominent examples, in the textile industry and for fruit and vegetable production, both highly dependent on blue water resources, water stress data could be matched with sector-specific data. The same approach goes for forestry, paper and printing, as well as the food and agriculture sector, which are both highly dependent on land use. Of further specific interest for an in-depth sector analysis of transboundary climate risk via trade from a Swedish perspective are sectors such as the manufacturing and vehicle industries that, for Sweden, represent a large share of value added, and are important for Swedish jobs and for Swedish exports. Using sector-specific data to provide sector-specific climate risk analysis would be extremely helpful for engaging supply chain actors as stakeholders; this would be a welcome next step in understanding Sweden's trade-related climate risks in more depth.

Moving beyond climate-driven production risk in supply chains

None of the three types of national-scale data gives us any insights for understanding the processing locations and transport patterns that are embedded in supply chains. Our analysis of this data therefore leaves us uninformed about the supply chain climate risks beyond the production stage. Trade data would need to be combined with processing location data and transport patterns (for example AIS (automatic identification system) logs of shipping routes and vulnerable ports combined with data on sea level rise or storm frequency, and most trafficked inland networks). Such data would enable future assessments to include the supply chain logistics risk in trade analyses. This task might also be more appropriate to address on a sector-specific scale and possibly in combination with stakeholder dialogues (e.g. to verify and correct available data) and in specific critical supply chain analysis.

The case study (Approach B) attempts to address this shortcoming by combining data on the most climate-vulnerable transport networks specific to the supply chain of soy from farms in Brazil to Sweden (inland road transport in Brazil and EU transport logs), with climate risks (flash flood and landslide risk). This type of analysis could possibly be expanded to include climate vulnerability to Brazilian river and sea ports. The methodologies presented in this study have not addressed risks other than production and road transport risk to supply chains. It would be a welcome addition if research on transboundary climate risk via trade addressed specific processing risks and risks pertaining to major trading ports such as extreme weather events and sea level rise. Some work has already begun to chart out attempts in this direction (Bailey & Wellesley, 2017; Hanson et al., 2011; Hanson & Nicholls, 2020; Knittel et al., n.d.).

Climate change models and indicators

For Sweden and the rest of the world (Approach A), climate-weighted relative share of inputs are produced by joining input shares with the Notre Dame Global Adaptation vulnerability index (Chen et al., 2015; ND-GAIN, 2020). Climate risk exposure is also visualized by colour-coding country results in accordance with the ND-GAIN country score. The use of ND-GAIN is a convenient but crude way to represent the climate risk to Sweden's trade with partner countries. If data were more easily available, it would be preferable to use sector-specific climate risk or vulnerability data to "weight" the effect of climate impacts on Sweden's trade partners. There are a few recent examples where a more detailed attempt has been made to reflect climate vulnerability in supply chains; Taherzadeh and colleagues (2020) combined footprint analysis with a related climate risk (such as water matched with water scarcity index footprint). In a Swedish setting, Tillväxtanalys (2020) qualitatively estimates a sector's main risk type of climate exposure (e.g. water, personnel, localization of industry). There are numerous methodological challenges with combining sector and risk level while correctly interpreting the climate signal. As an example, negative effects of high temperatures and extreme flooding have been shown to have stronger effects for geographically concentrated suppliers, mining, construction and agriculture, with less evidence on the negative effects in other sectors or geographically dispersed supply chains (Pankratz & Schiller, 2019). We have in this study (Approach A) chosen to use the cruder measurement of country vulnerability score to be able to interpret the overall vulnerability in trade flows. Addressing the issue of matching the trade data presented here with more detailed climate vulnerability models for specific sectors or type of exposure in a methodologically sound way would be a welcome next step for research on this topic.

In agricultural production, as for the case study in Approach B, assessment of climate change impacts or risk is often represented by climate model projections of globally gridded crop models (GGCMs). Using GGCMs to assess climate risk at a sub-national level is a telling example of the crude and dissatisfactory way in which the risk signal (i.e. climate change) is often represented by available data (i.e. from GGCMs) (for a further comparison and discussion of limitations, see Stokeld et al. (2020)). In reality, the risk may be quite different from that implied by available data due to many modelling assumptions and constraints (Rosenzweig et al., 2013, 2016). The most telling of these limitations is that GGCMs are not able to consider extreme event occurrence, which is the biggest factor in triggering supply chain shocks that would affect Swedish consumption of embedded soy (see, for example, droughts and floods in Argentina and Brazil and the effects on world soy and grain exports: Bailey & Wellesley, 2017; Batista, 2020; Polansek et al., 2018). The uncertainties in GGCM outputs are considered especially high in the case of global production of soy, with concentrated production areas, rendering the models more sensitive to regional differences (Rosenzweig et al., 2013). In the case study of Brazilian soy to Sweden (Approach B) we dealt with this by including an index that also captures extreme events (the drought index) to supplement the slow onset changes that are captured by the GGCMs for risk to production. We also included and compared the results of two crop models to be able to show the range of projected yield change.

In the particular case of Brazilian soy for Swedish consumption, the combined final result of the risk assessment shows little disparity between the two GGCMs, as the regions of most importance for Swedish sourcing coincide with the regions of least deviations of the two crop models (full data comparison in **Appendices 2** and **6**). The GGCM prevents the user from backtracking the cause of the models' major output disparities, such as the PEGASUS model prediction of high losses in the region of Mato Grosso do Sul (**Figure 14**, area G). This makes the implications of the results difficult to interpret. In contrast, the drought, landslide and flash flood indices are all specifically developed for Brazil and controlled against a baseline period of past events. For future research, this study indicates that the feasibility of the use of GGCMs for regional analysis is debatable, especially in the case of soy.

Non-climate drivers

Climate change is but one of several risk drivers from a supply chain perspective, and separating climate change from other risk drivers is in many cases not possible. Social disruption is one such example (such as strikes in harbours causing delays, see, e.g., Bailey & Wellesley, 2017), where climate change may play a role in driving these kinds of disruptions, interacting with non-climate factors. These impacts and second and third order effects of climate change on societies and trade are highly uncertain and assessing the role of climate change in other kinds of disruption, rather than direct physical impacts from the effects of climate change, would require significant methodological innovation and the potential benefits are unclear. The line of reasoning does, however, lead to a question of a more general kind: how do you integrate climate into generic supply chain risk assessments?

Uncertainty and modelling assumptions

In quantifying the risk of future exposure to climate change, results are limited by the predictive ability of the models as well as the accuracy of the representation of risk chosen by a study. In this study we have chosen to deal with the reality of uncertainty in assessing climate risk in international trade by comparing datasets and using simple and transparent methods for assembling the input datasets. The comparison between trade datasets (for Approach A) and straightforward risk definition and calculation (Approach B) facilitates and encourages the reader to interact with the input data.

Specifically, for the case study of Brazilian soy to Sweden, climate change modelling uncertainties also exist in relation to the input data, concerning the accuracy of the representative scenario (RCP 4.5), the time frame (mid-to-end-century), the climate model used (HadGEM2-ES) and the assumptions made in the modelling for each sub-index. Furthermore, the risk quantification assumes an unweighted relation for the scope of impact of production and transport on the supply chain. It is possible that a more explicit approach to weighting the various components of risk can be justified. For example, the production risk may well be more significant to Swedish consumers than transport risk, because it may have a higher influence over the soy price. Such a weighting could be carried out consulting actors involved in this specific supply chain. The straightforward risk definition and calculation chosen as the method facilitates and encourages the reader to interact with the input data as well as the combined risk value, and both outputs have been treated as results in this study. The results of this initial assessment could be used in such a stakeholder process. This is a contribution of this study for future research.

Dynamic effects and responses

Risks related to climate change and global trade are systemic in nature, with high complexity, uncertainty and ambiguity (Renn et al., 2011). As such, the effects of events and measures are difficult to foresee and might be valued differently by different stakeholders or outcomes may differ depending on the focus of the system components. There are several important factors related to system response and behaviour omitted from this study, such as market responses and price effects, social amplification of risk and adaptive measures (Challinor et al., 2018). This means that the assessment represents a somewhat static view of Sweden's exposure to transboundary climate risk via trade.

For example, the risks accounted for in Approach B (Brazilian soy) are likely to primarily lead to price effects from yield losses, delivery delays and an increased market competition among buyers. The method presented here to study risk in a supply chain is not able to account for the potential dynamic system level of effects that might result from major adjustments in the global soy market in response to major climate-related disruptions. For example, if Brazilian production of soy was severely impacted, how might Swedish sourcing patterns shift temporarily or permanently to other markets?

One commonly discussed response to supply or price fluctuation is changing import/input markets. One problem with this approach is that if the total global stock of agricultural commodities diminishes due to climate change, diversification cannot be a successful risk management strategy for all players in the market. Another relevant aspect to account for is “stickiness” in trade relations. Due to factors such as long-standing trade relationships, conglomeration of markets, policy, culture and tradition, built-in infrastructure and geographical proximity, markets are not “perfect”, but trade relationships often exhibit “sticky” qualities, persisting under changing conditions, or show slow or passive responses to price fluctuation or other market shocks (dos Reis et al., 2020). In the example of the Brazilian soy export market, supply of soy to Sweden carries traits of “stickiness” in a trade relationship involving few actors with long-standing actor-place relationships (Godar & Gardner, 2019). On a global scale, the substitutability of soy to other protein crops is unlikely at the scale of the demand for feedstock, due to the high production and quality of the crop as feed (Trase, 2018a).

A changing world

Current trends in risk awareness and management are highly relevant to future available response mechanisms, and how the global dynamics of markets will play out. Recent decades have seen an increased globalization, including trends such as fragmentation of supply chains, offshoring and lengthening supply chains and an increased complexity in traded commodities (Baldwin & Lopez-Gonzalez, 2015; Goldin & Mariathasan, 2015). For analysis of trade data, this means that intermediate products cross borders more often than before, making supply chains and climate chain risk analysis more complex. Worth noting, however, is that several recent developments point to a reversed trend, where a re-shoring, diversification and regionalization of value chains has been noticeable since 2012; these are predicted as trends in the global trade system in the forthcoming years, driven and accentuated by an increased awareness of global supply chain risk due to recent crises, the latest example being the COVID-19 pandemic (Javorcik, 2020; Miroudot, 2020; Miroudot & Nordström, 2019).

4.1. Recommendations

Data availability, future opportunities and potential synergies

Each of the datasets analysed in Approach A entails detailed breakdown of data into economic sectors (WIOD and PRINCE) or goods (national toll data). Sector- and commodity-specific breakdown of trade data coupled with sector-relevant climate risk analysis could be combined to provide an in-depth analysis of trade-related climate risk for specific sectors or supply chains. Such analysis could be used by, for example, an industry organization or a government trying to understand the implications of transboundary climate risk. Furthermore, looking into sector-specific results can enable a deeper understanding of trends and exposure to climate risk via international trade.

As a last point, we want to highlight the opportunities presented by the increased data availability from recent decades to meaningfully map supply chains. The data used for this analysis (beyond national accounting and economic trade relations) come from efforts in understanding distant environmental impacts, such as footprint analysis. Another telling example is the Trase data used for the case study of climate risks in Brazilian soy for Swedish consumption. The Trase platform was developed to understand and tackle the geography, structure and actor relationships of deforestation embedded in the supply chain. As the data origins are the drivers and feedback mechanisms of climate risk, they should not be approached entirely separately from one another, both in regards to understanding impacts and risk, and how they are governed. At present, there is a need for a deeper understanding of the structures, underlying mechanisms, systems, actors and governance mechanisms involved in the drivers, feedback and effects of climate change on trade systems. There are clear opportunities in addressing these issues, and the need for better access and transparency of data in the trade systems on climate change and other environmental drivers such as resource use and deforestation, in tandem. Current governance initiatives and roundtables for deforestation risk in soy production, for example, could potentially be explored as an avenue to introduce the aspect of climate risk to supply chains and support climate-resilient practices.

5. Policy discussion and recommendations

Our analysis of trade dependencies reveals that Sweden's deepest, most stable trade links tend to be with countries that are both close to Sweden and relatively resilient to climate change.

Germany and Nordic countries form the top tier of Sweden's "direct" trade profile. These partners are assessed as having the lowest level of vulnerability according to the ND-GAIN index, which we utilized in our study. After this, there is a second tier made up largely of other EU countries, with slightly higher vulnerability relative to Sweden, but still among the least vulnerable countries globally.

Sweden's top trade tiers are well "hedged" across relatively resilient economies, providing a reassuring view of climate risk exposure. Sweden should continue to work within the European Union, as well as other forums for cooperation, to ensure resilience through stable trade. Sweden should continue to invest in key bilateral relationships, especially with Germany and Nordic partners, to ensure that trade relationships will continue to offer a resilient, as well as efficient, source of exchange as the climate changes.

Our analysis has also revealed the trade links between Sweden and countries that are more vulnerable to climate change – links that are often hidden or obscured by conventional trade statistics. When we look at data on the material inputs to Swedish consumption, we see that countries like Brazil, Russia and many in Africa (for land inputs) and China, India and many others in Asia (for water inputs) are much more significant from a Swedish perspective. These countries are much more vulnerable to climate change than Nordic or most European countries, revealing a layer of high climate risk in the third tier of Sweden's trade profile – one that is usually hidden in a statistical shadow.

By revealing this layer of climate risk, we highlight how emerging economies – which face significant adaptation challenges – become much more important to Sweden. For example, Brazil, China, India, Indonesia, Nigeria and Viet Nam emerge across various datasets as "big movers" when we add a climate weighting to measures of "importance" to Sweden via trade (see **Figure 15**). Generally, the Asia and Pacific and Africa regions become much more important to Sweden when we build in measures of climate vulnerability to Sweden's trade profile.

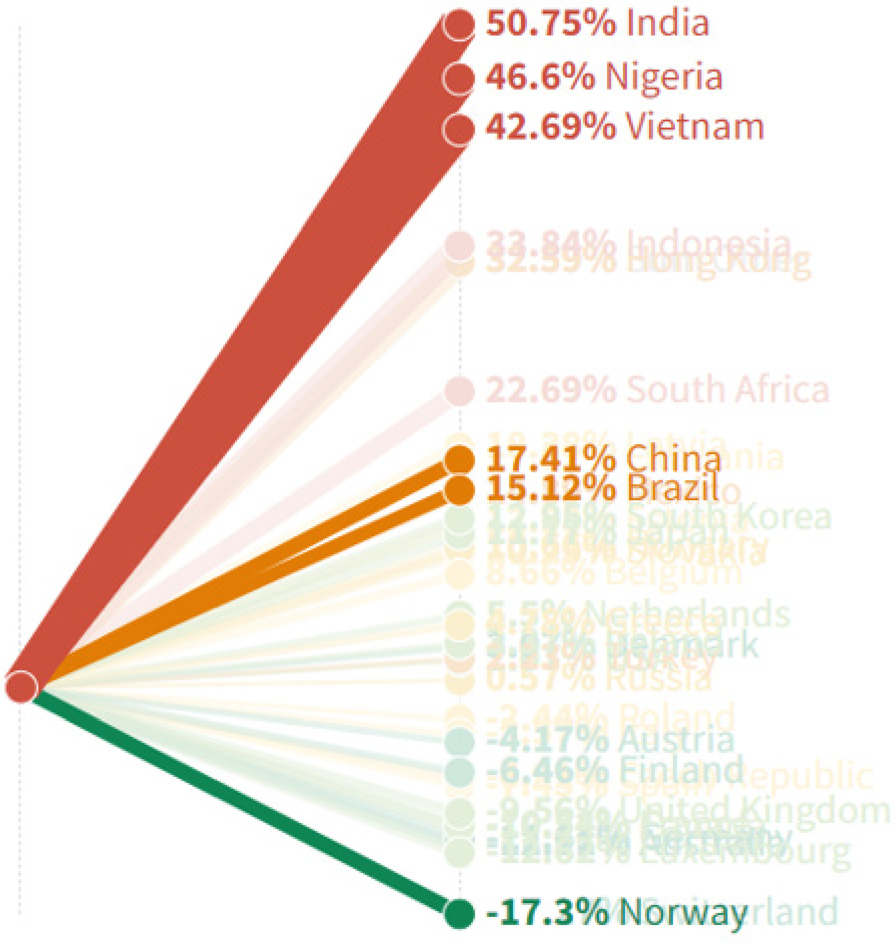
Despite their low levels of direct inputs into Swedish consumption, the important roles these trade partners play in Swedish supply chains mean that this constitutes a new horizon of risk for Sweden.

The governance implications of this are far-reaching. Sweden cannot pursue resilience-building via bilateral relationships with so many countries at once, and these countries lie beyond the reach of regional cooperation afforded by the EU. Instead, Sweden can only rely on a robust multilateral process to build resilience to climate change throughout its trade network.

Mechanisms under the Paris Agreement on climate change could be utilized for this end. The Paris Agreement framed adaptation as a "global challenge faced by all" with "international dimensions". Sweden should encourage all countries to adopt a transboundary and systemic framing of climate risk in their National Adaptation Plans and provide financial and other support for adaptation efforts worldwide in order to build systemic resilience to climate risk.

Moreover, the results of this study demonstrate why it is in Sweden's interests to establish and possibly co-lead a new coalition to advance an ambitious global adaptation agenda. As high-income consumers, positioned at the top of global value chains, small, globalized, open, industrialized countries like Sweden have the most to lose from the increase in systemic risks to global trade networks that is likely to result from climate change. Sweden is well positioned to do this given its membership of the EU, the relatively high levels of trust Sweden enjoys on the world stage and its active participation and proven commitment to multilateralism.

Figure 15. Percentage change in countries' "importance" to Sweden after considering the role of climate risk via trade.



Source: SCB data, selected countries highlighted, visualization by Lager, available at https://public.flourish.studio/story/656845/

In light of the transboundary risks identified in this study, we offer the following recommendations to Sweden-based actors.

1. **Initiate dialogues on adaptation to transboundary climate risk with economic sectors in Sweden**

The role of private actors in adaptation to transboundary climate risk – particularly in the case of trade-related risks – has been noted several times in this study. The challenges faced and opportunities available for adaptation will be specific to each sector, based, among other things, on the structure, complexity and globalization of their supply chains, as well as the sensitivity of their inputs, processes and export markets to climate change impacts. It will therefore be necessary to initiate dialogues with sector-based organizations (e.g. trade associations) to begin raising awareness of climate risk in supply chains and to exchange views on the division of responsibility between state and private actors in the risk management, disclosure and adaptation process.

Sector-specific data on trade-related climate risks have been collected as part of this study and could be used as the basis for these dialogues. These data identify the dependence of sectors on imports from different countries and the climate risk associated with those imports. Visualizations of these data are available via a tool created as part of this analysis.[6]

2. Focus on transboundary climate risk in the next iteration of the National Adaptation Strategy

Sweden’s forthcoming revised National Adaptation Strategy should include a dedicated chapter on transboundary climate risk. This should identify, at a minimum:

- A summary of the climate risks that Sweden is exposed to throughout the transboundary climate risk pathways, including trade.
- An initial identification of adaptation options for managing or reducing these transboundary climate risks.
- Clear assignment of ownership for managing each risk to a relevant ministry and/or government agency.
- Direct response to the recommendations of the *Nationella expertrådet för klimatanpassning’s* report, where “expanding the understanding and policy-uptake of climate-related security risks and transboundary dependencies” has been highlighted as a priority measure (Nationella expertrådet för klimatanpassning, 2022, p. 653; author’s translation). The report highlights the necessity of assessing transboundary climate risk as part of civic defence and in particular food security, for the business sector (näringslivet), as well as for future energy systems. The section in the report on justice in climate adaptation also draws attention to the risk of negative unintended transboundary consequences of an isolated and purely territorial approach to climate adaptation in Sweden (i.e. transboundary maladaptation).

Ideally, the new adaptation strategy should also:

- Establish a new cross-government working group on managing transboundary climate risk. Adaptation to transboundary climate risk requires the engagement of departments that have hitherto not been deeply engaged in adaptation, due to the external nature of the risk, for example Ministries of Trade, Foreign Affairs, Economy, and Finance. It is likely to be more effective if this working group was *additional* to existing cross-government or stakeholder groups for adaptation, given the particular character of transboundary as opposed to direct, domestic climate risk.
- Identify an individual desk officer who is given responsibility for coordinating adaptation efforts to transboundary climate risk, including throughout government. This individual would be given a remit to develop a monitoring and evaluation framework to track exposure to transboundary climate risk over time within Sweden.
- Initiate a dialogue on the role of central versus local government in climate change adaptation in Sweden. Whereas a highly devolved approach to adaptation, as adopted in Sweden, is appropriate for direct impacts that originate and manifest locally, the prospect of transboundary climate risk raises strategic governance questions that may be more appropriately addressed by central government. This sensitive topic would require careful dialogue involving all relevant stakeholder groups.

It is important to note that, whereas it is commonly an objective of climate change adaptation governance in all countries, there are potentially downsides to rushing the process of “mainstreaming” responsibility for climate risks. As an emerging topic that is still poorly understood in both the scientific and policy realms, prematurely mainstreaming adaptation to

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[6] Interested readers should contact the authors of this report for advice on how to interpret and use these visualizations, for example in order to facilitate dialogues on risk ownership and management; see this link for data visualizations: https://public.flourish.studio/story/921947/

transboundary climate risk may bring with it the very real danger that these issues disappear and drop out of adaptation planning before they have been properly explored and analysed.

Despite the commissioning of several national assessments of transboundary climate risk, no country has yet institutionalized an effective adaptation response or clear "risk ownership" for these risks. Doing so will likely be a slow learning process, which suggests that there are merits to treating it as a stand-alone topic in the National Adaptation Strategy, at least for an initial iteration.

Very little analytical work has been undertaken to identify adaptation options for transboundary climate risk via trade (Bednar-Friedl et al., 2022). Conceptually, Sweden might consider a range of responses, such as those summarized in **Table 4**.

Table 4. Conceptual examples of adaptation options to address trade-related transboundary climate risk for a country like Sweden.

Response type	Examples	Challenges
Internal policy	Reduce dependence on imports	• Uncertain effectiveness or legitimacy of government regulation to disincentivize import-based diets
	Increase self-sufficiency	• Limited agricultural capacity in Sweden • Less efficient: price increases
Nordic cooperation	Agreement on standards, joint investment and joint diplomatic efforts	• Relatively weak voice in competitive geopolitical space
EU cooperation	Diversify agricultural production to reduce extra-EU imports	• Limited flexibility within Common Agricultural Policy framework • Climate risks to agriculture also within EU
External policy	Diversify trade	• Supply chain "stickiness" • Climate risk is systemic, affecting production and trade everywhere
	Substitute high-risk imports	• Limits to substitution if global markets squeezed • May increase prices
	Reduce volatility of markets through global governance	• Depends on cooperation with international partners
At source	Burden sharing for adaptation costs, e.g. in food production and supply chain logistics	• Unclear division of responsibility between private actors and the state (both in Sweden and in source countries, like Brazil) • Questions over legitimacy of government intervention: autonomy of "source" countries • Unclear and indirect benefits to consumer countries (e.g. Sweden) from investments in production and supply chains abroad • May imply diversion of public funds away from "most vulnerable" countries (UN Framework Convention on Climate Change principle) to strategic trade partners
	Private investment in supply chain resilience	• Private decisions may conflict with public or international principles like "just resilience" • Disincentive for private investment in high-risk regions or markets (cf. current challenges with mobilizing private adaptation finance)
Laissez-faire	Just do nothing/ autonomous adaptation	• Prices passed on to customers, risking food affordability problems among low-income households and volatility for small and medium enterprises in Sweden, threatening unemployment and disruption • Private adaptation strategies creating incoherence with Swedish development and diplomatic priorities (e.g. abandoning or selling assets in high-risk markets, undermining climate-resilient development there)

3. Expand the remit of the Swedish National Knowledge Centre for Climate Change Adaptation to address transboundary climate risk

Sweden has enjoyed the benefits of a knowledge management, capacity building and information hub supporting climate change adaptation since 2012. The prospect of adapting to transboundary climate risk raises new challenges.

- The Knowledge Centre should be provided with a new remit to gather data, build capacity and develop tools and guidance to support adaptation by Sweden-based actors to transboundary climate risk. This will require the collection and organization of altogether new kinds of information, for example on the links and flows between Sweden and other countries, paired with information about climate impacts and risks in those countries.
- In order to support the work of the Knowledge Centre to this end, new research is needed to assess Sweden's full exposure to transboundary climate risk, including at local and sector levels.
- Progress should also be made to collect and organize data that are relevant to the assessment of transboundary climate risk, for example trade-related data beyond national accounting of toll statistics, as well as other data of a systemic nature (i.e. non-territorial, or un-bordered), such as those relating to financial flows, migration and transboundary ecosystems and infrastructure. As the data and technological options expand for understanding complex linkages in global systems, the culture and guidance for national policy decision-making, as well as planning processes by non-government actors in the public and private spheres, should keep pace and benefit from the new insights that better data open up.

4. Engage in climate diplomacy to build systemic resilience to transboundary and systemic climate risk

Sweden already contributes to global ambition on adaptation through its diplomacy, development cooperation, climate finance provision and support for multilateralism. However, to achieve resilience to transboundary climate risk, as noted in this study, Sweden needs to ensure that global ambition on adaptation is raised to new heights. Sweden also needs international partners to specifically address transboundary climate risks in order to avoid the redistribution and exacerbation of climate risk via maladaptation. Sweden's Ministry of Foreign Affairs, via its network of diplomats, embassies and partners, should aim to:

- Increase coordination and cooperation on adaptation regionally (in the Nordic region and within the EU) and internationally.
- Champion adaptation to transboundary climate risk within the United Nations Framework Convention on Climate Change (UNFCCC), particularly by supporting a more ambitious implementation of the global goal on adaptation under Article 7 of the Paris Agreement. In doing so, Sweden should ensure that transboundary climate risk is framed as a reason for global action on adaptation, particularly via the *Glasgow to Sharm el-Sheikh Work Programme on the global goal on adaptation* and that these risks are incorporated in the first global stocktake in 2023.
- Overcome the "us versus them" divide in international adaptation negotiations between developing and industrialized countries by establishing and jointly leading a new coalition of Parties to the UNFCCC under the umbrella of "shared resilience through adaptation".
- Work within the EU to champion adaptation to transboundary climate risk, taking advantage of the updated framing of adaptation in the new EU Adaptation Strategy, which explicitly recognizes the importance of transboundary climate risk for adaptation within Europe, and globally. This requires articulation of the importance of solidarity within the EU to achieve climate resilience, shaping and advancing the narrative on "just resilience" – both internally and globally by the EU. It also entails contributing to the design and implementation of new partnerships and initiatives within the EU and globally to support knowledge and capacity building for adaptation to transboundary climate risk.

Adopting some or all of these recommendations is likely to contribute to Sweden's resilience to systemic risk, not only to transboundary climate risk. Increasing engagement and dialogue between government and business on risk management, clarifying the role of central government in strategic risk management and increasing the capacity to monitor global risks are measures that represent fairly low-regret options for responding to the heightened state of systemic risk observed globally (World Economic Forum, 2020, 2021).

6. Conclusions

As the world emerges from the COVID-19 pandemic, during an era in which the lure of nationalism and isolationism is on the rise, leadership and facilitation is needed to renew a multilateral approach to protecting global public goods and reducing systemic risk. Building resilience in the global trade system to future shocks is a clear and unifying priority. While the role of climate change as a magnifier of systemic risk in global systems is still under-appreciated in most policy forums, Sweden has an opportunity and perhaps an obligation to spearhead political processes to build climate resilience internationally.

This study has explored the nature of trade-related climate risks facing Sweden. It developed two multi-method approaches: one assessed Sweden's climate risk exposure via trade with the rest of the world, looking across a suite of different trade datasets, each of which revealed different insights pertaining to different tiers of Sweden's supply chains; the second attempted to push supply chain climate risk assessment to the current boundaries of what is possible, given data constraints, with an in-depth study of one critical supply chain (Brazilian soy). In doing so the study has arrived at a set of insights that currently outstrip the demand for such information among decision-makers, who are perhaps only beginning to realize the relevance of transboundary climate risk to the stability of their operations, organizations and communities.

The results of the study can be used to motivate a new generation of adaptation planning – one that engages with the challenging reality of risk in a globalized world. Two overarching conclusions stand out:

- There are limits to substitutability in volatile systems because climate change is a risk driver that will be occurring everywhere at once; the number of vulnerable lower tier trade partners and the "stickiness" of certain trade links imply that substitution in practice may not be as feasible an adaptation response as is often assumed.
- Systemic risk is subtle and hard to measure, especially when relying on traditional statistics and methods. While seemingly well-insulated from climate risk via resilient "top tier" trade partners, Sweden is exposed to cascading systemic risk because of its deeply embedded position high in the value chain. In a world experiencing extreme climate change, this level of climate risk may reach toxic proportions.

Together this constitutes a new risk horizon for Sweden. But Sweden is well placed to push forward as a pioneer in this new adaptation landscape.

References

Adams, K., Harris, K., Klein, R. J. T., Lager, F., & Benzie, M. (2020). *Climate resilient trade and production.* Policy Brief, 1/2020. Adaptation Without Borders. https://adaptationwithoutborders.org/knowledge-base/transnational-climate-impacts/climate-resilient-trade-and-production

Aven, T., & Renn, O. (2009). On risk defined as an event where the outcome is uncertain. *Journal of Risk Research, 12*(1), 1–11. https://doi.org/10.1080/13669870802488883

Bailey, R., & Wellesley, L. (2017). *Chokepoints and vulnerabilities in global food trade.* Chatham House Report. https://www.chathamhouse.org/2017/06/chokepoints-and-vulnerabilities-global-food-trade

Baldwin, R., & Lopez-Gonzalez, J. (2015). Supply-chain trade: A portrait of global patterns and several testable hypotheses. *The World Economy, 38*(11), 1682–1721. https://doi.org/10.1111/twec.12189

Batista, F. (2020, October 23). *Floods, drought are destroying crops and sparking food inflation.* Claims Journal. https://www.claimsjournal.com/news/international/2020/10/23/300118.htm

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. *Wiley Interdisciplinary Reviews: Climate Change, 13*(2), Article e758. https://doi.org/10.1002/wcc.758

Benzie, M. (2014). National Adaptation Plans and the indirect impacts of climate change. SEI policy brief. https://www.sei.org/publications/national-adaptation-plans-and-the-indirect-impacts-of-climate-change/

Benzie, M., & Bessonova, E. (2018). Inescapably intertwined: the reality of globalization and borderless climate risks. https://www.sei.org/featured/inescapably-intertwined/

Benzie, M., Carter, T. R., Carlsen, H., & Taylor, R. (2019). Cross-border climate change impacts: implications for the European Union. *Regional Environmental Change, 19*(3), 763–776. https://doi.org/10.1007/s10113-018-1436-1

Benzie, M., & Persson, Å. (2019). Governing borderless climate risks: moving beyond the territorial framing of adaptation. *International Environmental Agreements: Politics, Law and Economics, 19*(4–5), 369–393. https://doi.org/10.1007/s10784-019-09441-y

Brack, D., Glover, A., & Wellesley, L. (2016). *Agricultural commodity supply chains.* Chatham House Report. https://www.chathamhouse.org/sites/default/files/publications/research/2016-01-28-agricultural-commodities-brack-glover-wellesley.pdf

Bren d'Amour, C., Wenz, L., Kalkuhl, M., Christoph Steckel, J., & Creutzig, F. (2016). Teleconnected food supply shocks. *Environmental Research Letters, 11*(3), Article 035007. https://doi.org/10.1088/1748-9326/11/3/035007

Carter, T. R., Benzie, M., Campiglio, E., Carlsen, H., Fronzek, S., Hildén, M., Reyer, C. P., & West, C. (2021). A conceptual framework for cross-border impacts of climate change. *Global Environmental Change, 69,* Article 102307. https://doi.org/10.1016/j.gloenvcha.2021.102307

Ceres (2017). *An investor brief on impacts that drive business risks: Soybeans.* Engage the Chain. https://engagethechain.org/drivers-financial-risk

Challinor, A., & Benton, T. G. (2021). International dimensions. In R. A. Betts, A. B. Haward, & K. V. Pearson (Eds.), *The third UK climate change risk assessment technical report.* Prepared for the Climate Change Committee, London. https://www.ukclimaterisk.org/wp-content/uploads/2021/06/CCRA3-Chapter-7-FINAL.pdf

Challinor, A., Adger, W. N., Di Mauro, M., Baylis, M., Benton, T., Conway, D., Depledge, D., Geddes, A., McCorriston, S., Stringer, L., & Wellesley, L. (2016). *UK climate change risk assessment evidence report: Chapter 7, International dimensions*. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.

Challinor, A. J., Adger, W. N., Benton, T. G., Conway, D., Joshi, M., & Frame, D. (2018). Transmission of climate risks across sectors and borders. *Philosophical Transactions of the Royal Society A, 376*, Article 20170301.

Chemnitz, C., & Becheva, S. (2021). *Meat atlas: Facts and figures about the animals we eat*. Heinrich Böll Foundation. https://eu.boell.org/en/MeatAtlas

Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., & Chawla, N. (2015). *University of Notre Dame global adaptation index: Country index technical report*. ND-GAIN. https://gain.nd.edu/assets/254377/nd_gain_technical_document_2015.pdf

Costinot, A., Donaldson, D., & Smith, C. (2012). Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world. *Journal of Political Economy, 124*(1), 205–248.

Croft, S. A., West, C. D., & Green, J. M. H. (2018). Capturing the heterogeneity of sub-national production in global trade flows. *Journal of Cleaner Production, 203*, 1106–1118. https://doi.org/10.1016/j.jclepro.2018.08.267

de Smith, M. J., Goodchild, M., & Longley, P. A. (2018). *Geospatial analysis. A comprehensive guide to principles, techniques and software tools* (6th ed.). https://www.spatialanalysisonline.com/extractv6.pdf

Debortoli, N., Camarimba, P. I., & Hirota, M. (2017a). *Índice de vulnerabilidade aos desastres naturais relacionados às secas*. Ministério Do Meio Ambiente, Ministério Da Integração. Nacional, WWF-Brasil. https://www.wwf.org.br/natureza_brasileira/reducao_de_impactos2/clima/copy_of_mudancas_climaticas2_20062017_1938/

Debortoli, N. S., Camarinha, P. I. M., Marengo, J. A., & Rodrigues, R. R. (2017b). An index of Brazil's vulnerability to expected increases in natural flash flooding and landslide disasters in the context of climate change. *Natural Hazards, 86*(2), 557–582. https://doi.org/10.1007/s11069-016-2705-2

Dedrick, J., Kraemer, K .L., & Linden, G. (2010). Who profits from innovation in global value chains? A study of the iPod and notebook PCs. *Industrial and corporate change, 19*(1), 81–116. https://doi.org/10.2139/ssrn.1125024

dos Reis, T. N. P., Meyfroidt, P., zu Ermgassen, E. K. H. J., West, C., Gardner, T., Bager, S., Croft, S., Lathuillière, M. J., & Godar, J. (2020). Understanding the stickiness of commodity supply chains is key to improving their sustainability. *One Earth, 3*(1), 100–115. https://doi.org/10.1016/j.oneear.2020.06.012

Dzebo, A., & Adams, K. M. (2022). *The coffee supply chain illustrates transboundary climate risks: Insights on governance pathways*. Policy brief. Stockholm Environment Institute, Stockholm. https://doi.org/10.51414/sei2022.002

Ercin, E., Veldkamp, T. I. E., & Hunink, J. (2021). Cross-border climate vulnerabilities of the European Union to drought. *Nat Commun 12*, 3322. https://doi.org/10.1038/s41467-021-23584-0

European Commission. (2018). *Evaluation of the EU Strategy on adaptation to climate change (SWD (2018) 461 Final)*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018SC0461

European Commission. (2021). *Forging a climate-resilient Europe: The new EU Strategy on adaptation to climate change*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0082&from=EN

European Environment Agency. (2021). *Global climate change impacts and the supply of agricultural commodities to Europe*. https://www.eea.europa.eu/themes/climate-change-adaptation/global-climate-change-impacts-and/global-climate-change-impacts-and

EY. (2018). *Utredning om konsekvenser for Norge av klimaendringer i andre land*. Miljødirektoratet Norway. https://www.miljodirektoratet.no/publikasjoner/2018/februar-2018/utredning-om-konsekvenser-for-norge-av-klimaendringer-i-andre-land/

Food and Agriculture Organization of the United Nations. (2015). *Climate change and food systems: Global assessments and implications for food security and trade.* https://www.fao.org/3/a-i4332e.pdf

Freitas, T. (2016). *Brazil's soybean output, exports to decline on stubborn drought*. Bloomberg. https://www.bloomberg.com/news/articles/2016-06-09/brazil-s-soybean-output-exports-to-decline-on-stubborn-drought

GIMP Team. (2019). GNU Image Manipulation Program (GIMP). Version 2.10.8, 2019. https://www.gimp.org/

Global Trade Analysis Project. (2019). *GTAP 9 data base sectors*. https://www.gtap.agecon.purdue.edu/databases/v9/v9_sectors.asp

Godar, J. (2018). *Supply chain mapping in Trase: Summary of data and methods*. http://resources.trase.earth/documents/Trase_supply_chain_mapping_manual.pdf

Godar, J., & Gardner, T. (2019). Trade and land-use telecouplings. In *Telecoupling* (pp. 149–175). Springer. Palgrave Studies in Natural Resource Management book series.

Godar, J., Persson, U. M., Tizado, E. J., & Meyfroidt, P. (2015). Towards more accurate and policy relevant footprint analyses: Tracing fine-scale socio-environmental impacts of production to consumption. *Ecological Economics, 112*, 25–35. https://doi.org/10.1016/j.ecolecon.2015.02.003

Godar, J., Suavet, C., Gardner, T. A., Dawkins, E., & Meyfroidt, P. (2016). Balancing detail and scale in assessing transparency to improve the governance of agricultural commodity supply chains. *Environmental Research Letters, 11*(3). https://doi.org/10.1088/1748-9326/11/3/035015

Goldin, I., & Mariathasan, M. (2015). *The butterfly defect: How globalization creates systemic risks, and what to do about it*. Princeton University Press.

Green, J. M., Croft, S. A., Durán, A. P., Balmford, A. P., Burgess, N. D., Fick, S., Gardner, T. A., Godar, J., Suavet, C., Virah-Sawmy, M., Young, L. E., & West, C. D. (2019). Linking global drivers of agricultural trade to on-the-ground impacts on biodiversity. *Proceedings of the National Academy of Sciences, 116*(46), 23202–23208.

Hanson, S. E., & Nicholls, R. J. (2020). Demand for ports to 2050: Climate policy, growing trade and the impacts of sea-level rise. *Earth's Future, 8*(8), Article e2020EF001543.

Hanson, S., Nicholls, R., Ranger, N., Hallegatte, S., Corfee-Morlot, J., Herweijer, C., & Chateau, J. (2011). A global ranking of port cities with high exposure to climate extremes. *Climatic Change, 104*(1), 89–111.

Hedlund, J., Fick, S., Carlsen, H., & Benzie, M. (2018). Quantifying transnational climate impact exposure: New perspectives on the global distribution of climate risk. *Global Environmental Change, 52*, 75–85. https://doi.org/10.1016/j.gloenvcha.2018.04.006

Intergovernmental Panel on Climate Change (2019). *AR5 Synthesis report. Topic 2. Future climate changes, risks and impacts*. https://ar5-syr.ipcc.ch/topic_futurechanges.php

IVL Svenska Miljöinstitutet. (2020). *Konsekvenser för Sverige av klimatförändringar i andra länder*. https://www.ivl.se/publikationer/publikationer/konsekvenser-for-sverige-av-klimatforandringar-i-andra-lander.html

Jaeger, C. C., Webler, T., Rosa, E. A., & Renn, O. (2013). *Risk, uncertainty and rational action*. Routledge.

Javorcik, B. (2020). Global supply chains will not be the same in the post-COVID-19 world. In E. Baldwin, & S. Everett (Eds.), *COVID-19 and trade policy: Why turning inward won't work* (p. 111). Centre for Economic Policy Research.

Jordbruksverket. (2015). *Livsmedelskonsumtionen i siffror – hur har konsumptionen utvecklats de senaste 50 åren och varför?* Jordbruksverket.

Ketels, C. (2017). *The Swedish competitiveness scorecard*. https://www.hbs.edu/ris/Publication%20Files/SEFR2017_kap2_Ketels_169db4b6-29b5-4f33-8613-0b0122736d34.pdf

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., & Hyatt, O. (2016). Heat, human performance, and occupational health: a key issue for the assessment of global climate change impacts. *Annual Review of Public Health, 37*, 97–112.

Knittel, N., Bachner, G., Bednar-Friedl, B., Jury, M. W., Lincke, D. & Hinkel, J. (n.d.). The effects of global climate change on foreign trade patterns – Insights from a cross-sectoral impact assessment for Austria. https://ethz.ch/content/dam/ethz/special-interest/mtec/cer-eth/resource-econ-dam/documents/research/sured/sured-2020/The%20effects%20of%20global%20climate%20change%20on%20foreign%20trade%20patterns_%20Insights%20from%20a%20cross- sectoral%20impact%20assessment%20for%20Austria.pdf

Lager, F. (2019). Ain't our business? A study of transnational climate change impacts on Swedish consumption through the lens of Brazilian soy. [Master's thesis, Stockholm Resilience Centre, Stockholm University]. https://su.diva-portal.org/smash/get/diva2:1330371/FULLTEXT01.pdf

Lager, F., Adams, K., 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* (Policy brief No. 2). Adaptation Without Borders, Stockholm Environment Institute. https://adaptationwithoutborders.org/sites/weadapt.org/files/pb2_rev4_web.pdf

Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., Muir-Wood, R., & Myeong, S. (2012). Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In *Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the Intergovernmental Panel on Climate Change* (pp. 25–64). Cambridge University Press.

Malczewski, J., & Rinner, C. (2015). *Multicriteria decision analysis in geographic information science*. Springer.

Martin, G. M., Bellouin, N., Collins, W. J., Culverwell, I. D., Halloran, P. R., Hardiman, S. C., Hinton, T. J., Jones, C. D., McDonald, R. E., McLaren, A. J., O'Connor, F. M., Roberts, M. J., Rodriguez, J. M., Woodward, S., Best, M. J., Brooks, M. E., Brown, A. R., Butchart, N., Dearden, C., Derbyshire, S. H., et al. (2011). The HadGEM2 family of Met Office Unified Model climate configurations. *Geoscientific Model Development*, *4*(3), 723–757. https://doi.org/10.5194/gmd-4-723-2011

Mayer, T., & Zignago, S. (2011). Notes on CEPII's distances measures: the GeoDist Database, CEPII Working Paper 2011-25. *Data retrieved from* http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=6

Miroudot, S. (2020). Reshaping the policy debate on the implications of COVID-19 for global supply chains. *Journal of International Business Policy, 3*(4), 430–442. https://doi.org/10.1057/s42214-020-00074-6

Miroudot, S., & Nordström, H. S. (2019). *Made in the world revisited*. EUI RSCAS, 2019/84, Global Governance Programme-373, [Global Economics]. http://hdl.handle.net/1814/64724

Mobjörk, M. (2011). *Svensk krisberedskap och klimatförändringarnas indirekta effekter*. FOI-R--3270--SE. https://rib.msb.se/Filer/pdf%5C26062.pdf

Moser, S. C., & Hart, J. A. F. (2015). The long arm of climate change: societal teleconnections and the future of climate change impacts studies. *Climatic Change, 129*(1), 13–26.

Myndigheten för samhällsskydd och beredskap. (2012). *Klimatförändringarnas konsekvenser för samhällsskydd och beredskap: En översikt*. https://www.msb.se/RibData/Filer/pdf/26173.pdf

National Board of Trade. (2015). *Trade is essential for jobs – A value chain perspective for Sweden*. Kommerskollegium.

National Board of Trade. (2018). *Sveriges utrikeshandels koppling till sysselsättning – region- och sektorsfördelad statistik*. Kommerskollegium.

Nationella expertrådet för klimatanpassning. (2022). *Första rapporten från Nationella expertrådet för klimatanpassning 2022*. https://klimatanpassningsradet.se/polopoly_fs/1.180289!/Rapport%20fr%C3%A5n%20Nationella%20expertr%C3%A5det%20f%C3%B6r%20klimatanpassning%202022.pdf

ND-GAIN. (2020). *Notre Dame Global Adaptation Initiative: Country index*. https://gain.nd.edu/our-work/country-index/

Observatory of Economic Complexity. (2021). *Sweden (SWE) exports, imports, and trade partners*. https://oec.world/en/profile/country/swe/

Palm, V., Wood, R., Berglund, M., Dawkins, E., Finnveden, G., Schmidt, S., & Steinbach, N. (2019). Environmental pressures from Swedish consumption – A hybrid multi-regional input-output approach. *Journal of Cleaner Production, 228*, 634–644. https://doi.org/10.1016/j.jclepro.2019.04.181

Pankratz, N. M., & Schiller, C. M. (2019). *Climate change and adaptation in global supply-chain networks*. European Corporate Governance Institute Global working papers. https://ecgi.global/sites/default/files/working_papers/documents/pankratzschillerfinal.pdf

Peri, M. (2017). Climate variability and the volatility of global maize and soybean prices. *Food Security, 9*(4), 673–683. https://doi.org/10.1007/s12571-017-0702-2

Persson, Å. (2019). Global adaptation governance: An emerging but contested domain. *Wiley Interdisciplinary Reviews: Climate Change, 10*(6), Article e618.

Peter, M., Guyer, M., & Füssler, J. (2019). *Folgen des globalen Klimawandels für Deutschland Erster Teilbericht: Die Wirkungsketten in der Übersicht*. Climate Change 20/2019. https://www.umweltbundesamt.de/publikationen/folgen-des-globalen-klimawandels-fuer-deutschland

Peter, M., Guyer, M., Füssler, J., Bednar-Friedl, B., Knittel, N., Bachner, G., Schwarze, R., & von Unger, M. (2020). *Folgen des globalen Klimawandels für Deutschland – Abschlussbericht: Analysen und Politikempfehlungen*. Climate Change 15/2020. Umweltbundesamt. https://www.umweltbundesamt.de/publikationen/folgen-des-globalen-klimawandels-fuer-deutschland-0

Polansek, T., Hirtzer, M., & Rizzi, M. (2018, March 5). *Argentina drought bakes crops, sparks grain price rally.* Reuters. https://www.reuters.com/article/argentina-grains-drought/argentina-drought-bakes-crops-sparks-grain-price-rally-idUSL2N1QK1TT

Prytz, N. (2018). *Consequences for Norway of transnational climate impacts.* English summary of final report *"Utredning om konsekvenser for Norge av klimaendringer i andre land"*. https://www.miljodirektoratet.no/globalassets/publikasjoner/M968/M968.pdf

PwC. (2019). *Konsekvenser för Sverige av klimatförändringar i andra länder.* https://www.pwc.se/sv/pdf-reports/hallbar-affarsutveckling/konsekvenser-for-sverige-av-klimatforandringar-i-andra-lander-ny.pdf

QGIS Development Team. (2019). QGIS Geographic Information System. Open Source Geospatial Foundation. 3.2.2, 2019. https://www.qgis.org/en/site/

Raffler, C. (2018). QNEAT3. OD-matrix algorithm., 2018. https://root676.github.io/

Reed, S., & Fontana, V. (2019, February 18). *Soy demand pushes agribusiness to the banks of the Amazon.* Diálogo Chino. https://dialogochino.net/en/infrastructure/23265-soy-demand-pushes-agribusiness-to-the-banks-of-the-amazon/

Renn, O., Klinke, A., & Van Asselt, M. (2011). Coping with complexity, uncertainty and ambiguity in risk governance: A synthesis. *Ambio, 40*(2), 231–246. https://doi.org/10.1007/s13280-010-0134-0

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T., Schmid, E., Stehfest, E., Yang, H., & Jones, W. J. (2016). Supplementary material. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison [Supplementary Appendix. 1–18]. https://www.pnas.org/doi/10.1073/pnas.1222463110#supplementary-materials

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., & Arneth, A. (2013). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences, 111*(9), https://doi.org/10.1073/pnas.1222463110

Schenker, O. (2013). Exchanging goods and damages: The role of trade on the distribution of climate change costs. *Environmental and Resource Economics, 54*(2), 261–282. https://doi.org/10.1007/s10640-012-9593-z

Schenker, O., & Stephan, G. (2014). Give and take: How the funding of adaptation to climate change can improve the donor's terms-of-trade. *Ecological Economics, 106*, 44–55. https://doi.org/10.1016/j.ecolecon.2014.07.006

Steen-Olsen, K., Owen, A., Barrett, J., Guan, D., Hertwich, E. G., Lenzen, M., & Wiedmann, T. (2016). Accounting for value added embodied in trade and consumption: An intercomparison of global multiregional input–output databases. *Economic Systems Research, 28*(1), 78–94.

Steininger, K. W., Bednar-Friedl, B., Formayer, H., & König, M. (2016). Consistent economic cross-sectoral climate change impact scenario analysis: Method and application to Austria. *Climate Services, 1*, 39–52.

Stockholm Environment Institute. (2019a). *IOTA*. https://www.sei.org/projects-and-tools/tools/iota/

Stockholm Environment Institute. (2019b). *Trase methodology.* https://www.sei.org/projects-and-tools/tools/trase/#how-does-trase-work

Stokeld, E., Croft, S. A., Green, J. M. H., & West, C. D. (2020). Climate change, crops and commodity traders: Subnational trade analysis highlights differentiated risk exposure. *Climatic Change. 162*(2), 175–192. https://doi.org/10.1007/s10584-020-02857-5

Swedwatch. (2012). *Mera Soja Mindre Mångfald. En Granskning Av Sojaimporten Från Brazilien*. Swedwatch uppföljningsrapport #48. https://www.swedwatch.org/wp-content/uploads/2016/12/swedwatch_-_mera_soja_mindre_mangfald.pdf

Taherzadeh, O., Bithell, M., & Richards, K. (2020). Water, energy and land insecurity in global supply chains. *Global Environmental Change, 67*, Article 102158. https://doi.org/10.1016/j.gloenvcha.2020.102158

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. *Journal of Environmental Planning and Management, 63*(7), 1266–1282. https://doi.org/10.1080/09640568.2019.1660626

Tillväxtanalys. (2020). *Klimatrelaterade fysiska risker i leverantörskedjan - en analys av svenska branschers exponering* (PM 2020:10, Dnr 2020/71). https://www.tillvaxtanalys.se/publikationer/pm/pm/2020-04-27-klimatrelaterade-fysiska-risker-i--leverantorskedjan---en-analys-av-svenska-branschers-exponering.html

Trase. (2018a). *Trase Yearbook 2018: Sustainability in forest-risk supply chains: Spotlight on Brazilian soy.* Transparency for Sustainable Economies, Stockholm Environment Institute & Global Canopy. ISBN: 978-91-86125-48-6. http://resources.trase.earth/documents/TraseYearbook2018.pdf

Trase. (2018b). *Trase Data Sources: SEI-PCS Brazil Soy (v.2.3) and Paraguay Soy (v1.0). December 2018*. http://resources.trase.earth/documents/Trase-data-sources_release_may_2019.pdf

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., & Rose, S. (2011). The representative concentration pathways: an overview. *Climatic Change, 109*(1–2), 5–31. https://doi.org/10.1007/s10584-011-0148-z

Wenz, L., & Levermann, A. (2016). Enhanced economic connectivity to foster heat stress-related losses. *Science Advances, 2*(6), Article e1501026.

World Economic Forum. (2020). *The global risks report 2020*. https://www3.weforum.org/docs/WEF_Global_Risk_Report_2020.pdf

World Economic Forum. (2021). *The global risks report 2021*. https://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2021.pdf

World Trade Organization (2020). *Services trade*. https://www.wto.org/english/tratop_e/serv_e/serv_e.htm

Appendix 1: Detailed method of national-level trade data analysis (Approach A)

Three datasets were used for cross-analysis: Statistics Sweden (1), OECD's IO-table WIOD (2) and the PRINCE project footprint analysis (3) of embedded land and water use. Since the most recent OECD and footprint data are from 2014, 2014 was chosen as a reference year for all input datasets as well as the ND-GAIN vulnerability and country index score.

For the Statistics Sweden dataset (SCB), values of trade in goods were chosen and counted in total product value (available also in tonnes). Services were excluded for this dataset as the method of procuring the data for goods and services does not allow for integration at a country level.

Data were converted to percentage of total traded value for that year (all-country aggregated). Countries/regions representing the top 30 importers/inputs to Sweden in any of the datasets SCB, WIOD or PRINCE land and water footprint data were singled out. All other countries/regions were combined in the category "other". Across all datasets, the share of total imports and inputs did not exceed 1% total. A total of 44 countries/regions have held a significant share of the market (over 1% of total trade) in any given year.

Step 1: Share of inputs

Country C's share of inputs (C_I) is expressed in **Equation 1**:

$$\text{Equation 1:} \qquad C_I = \frac{C_{tot}}{I_{tot}}$$

Where C_{tot} represents the total value of the country's inputs to the Swedish economy: Swe_{tot}. The top 30 countries/regions in order of importance were then singled out for each dataset.

Thereafter, the dependency (D) of Sweden on inputs from abroad was calculated for the WIOD and PRINCE datasets according to **Equation 2**:

$$\text{Equation 2:} \qquad D_{dataset} = \frac{I_{tot}}{Swe_{tot}}$$

Where Swe_{tot} represents all inputs to Swedish sectors, domestic and foreign.

Analysis of OECD and non-OECD members was carried out based on OECD affiliation collected from https://www.oecd.org/about/members-and-partners/.

Step 2: Climate weighting

A calculation of “climate-weighted” share of inputs for each country (C_{cw}) was carried out by multiplying the country’s share of inputs (C_I) with the ND-GAIN vulnerability score for each country (C_{vuln}) (both values ranging from 0 to 1) and normalized through division of the sum of the climate-weighted shares ($\sum c=all$) (amounting to 100% of share of inputs) according to **Equation 3**. The vulnerability score as well as the full country index and description is available for download at https://gain.nd.edu/our-work/country-index/download-data/.

$$\text{Equation 3:} \quad C_{CW} = \frac{C_I \times C_{vuln}}{\Sigma_{C=all} \left(C_I \times C_{vuln}\right)}$$

The difference between climate and non-climate-weighted share of importance to Swedish imports/inputs ($C_{\Delta CW}$) was then calculated for each country, as expressed in **Equation 4**.

$$\text{Equation 4:} \quad C_{\Delta CW} = C_{CW} - C_I$$

Step 3: Time series

Time trend analysis (T_c) for each country and dataset was carried out using the earliest (y1) to latest (y2) time series for each dataset for the top 44 countries/regions according to **Equation 5**.

$$\text{Equation 5:} \quad T_C = C_I^{y2} - C_I^{y1}$$

Step 4: Distance calculator

Countries’ and regions’ distance from Sweden was estimated based on the GeoDist database, where two countries’ simple bilateral distances (“dist” in GeoDist database) were used for analysis, measuring the bilateral distance between two countries’ most populated cities. The database is most commonly used for trade analysis as the geographical centre point or closest border to a country is regarded as a less appropriate means of measurement. Goods and services are thus assumed to be traded largely to where people reside. The distance was compared to a country’s climate vulnerability and share of input.

ND-GAIN: Colour coding and proxies for Rest of the World and missing regions

To display climate risk in trade the country-level results were colour-coded in relation to the ND-GAIN country index score, according to **Table 5**.

Table 5. ND-GAIN country index colour scheme.

ND-GAIN country index	Colour code
>70	#0f8554 🟩
65–70	#73af48 🟩
60–65	#f9c94a 🟨
55–60	#edad09 🟨
50–55	#e17c05 🟧
<50	#cc503e 🟥
no value	#B0B0B0 ⬜

For countries/regions with no ND-GAIN score the following proxies were used:

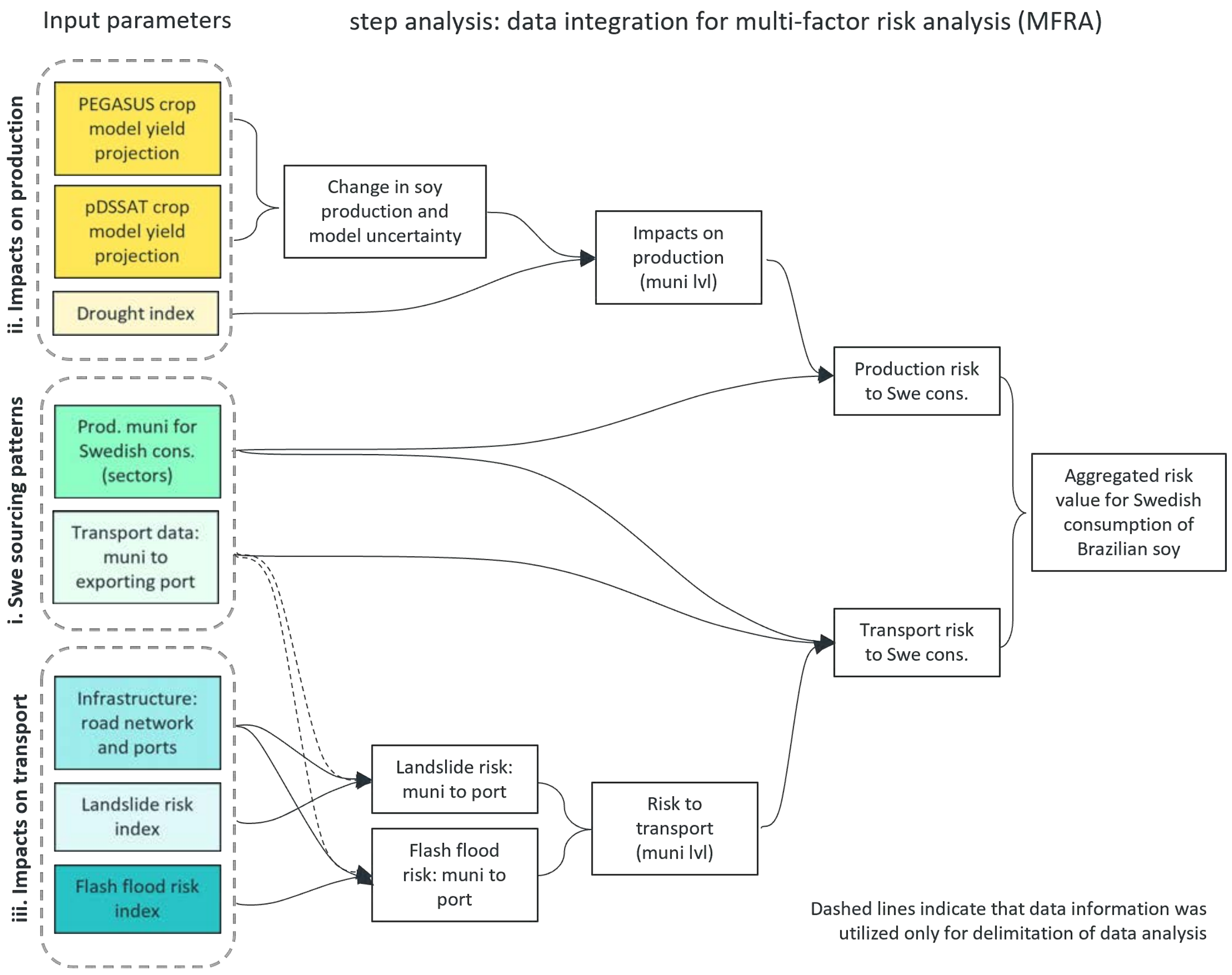
- ND-GAIN scores for Hong Kong are missing; values for China are used as proxy.
- ND-GAIN scores for Taiwan are missing; values for Rest of the World Asia and Pacific are used as proxy.
- For all other countries with no ND-GAIN vulnerability score an average of all countries' vulnerability score was used for climate weighting.
- ND-GAIN for "Rest of" regions was calculated as an average ND-GAIN vulnerability score excluding the countries accounted for in each data table. For the region "Rest of the World" in the OECD data this means excluding the 43 economies included in the dataset, OECD countries and large economies. Similarly for the PRINCE data: Rest of the World Africa, America, Asia Pacific, Europe and Middle East were calculated by dividing each country into its specific geographical region, and then extracting countries with existing trade data in PRINCE from the vulnerability index, by region. This resulted in slightly shifting vulnerability scores for each RoW region.

Appendix 2: Detailed method of case study: Climate risk in Brazilian soy to Sweden (Approach B)

Data analysis

This study uses a combination of the IOTA and Trase models, developed by Croft and colleagues (Croft et al., 2018). IOTA is a hybridized physical-monetary multi-regional input-output (MRIO) model (SEI, 2019a). Using MRIOs, embedded commodity flows throughout the supply chain can be estimated based on sector-level monetary transaction data and physical commodity flows. Combined with Trase, an interactive supply-chain transparency platform (https://trase.earth/), flows from a sub-regional production level via exporting ports and traders to importing countries are accessed. The combined IOTA/Trase modelling approach allows sub-national production data to be interrogated from the perspective of embedded consumption, which is a key innovation and original component of this study.

Figure 16. Visual representation and flow diagram of all data sources and intermediate steps in the risk analysis of sub-national Brazilian soy production for Swedish end consumption (Approach B). The final output (to the far right) is the combined risk to Swedish consumption of soy, via projected impacts of climate change on transport and production in Brazil.



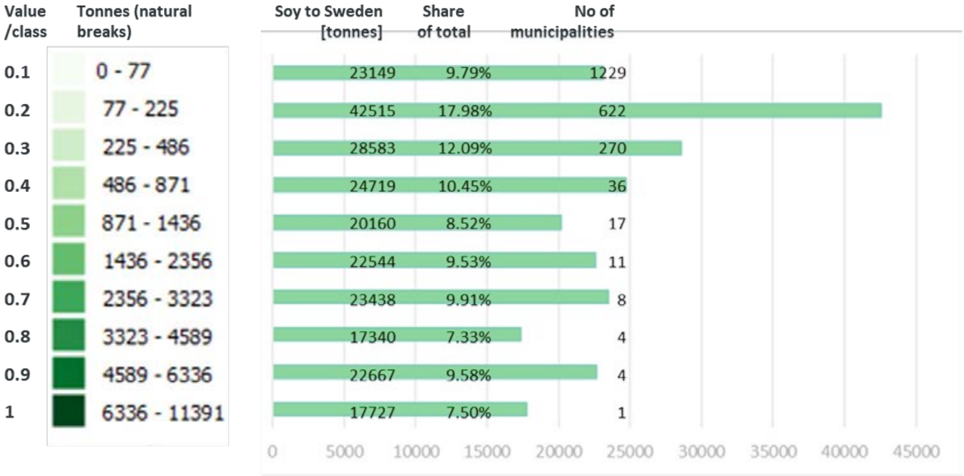
Dashed lines indicate that data information was utilized only for delimitation of data analysis

Data analysis was carried out using spatial analysis and the QGIS open source software (QGIS Development Team, 2019). For image manipulation, the open source image software GIMP was used (GIMP Team, 2019). All maps and input data are projected in coordinate system EPSG 4674: SIRGAS2000. **Appendices 3** and **4** explain in detail the data analysis method used for each data component within the study. To minimize noise in the data, the analysis is delimited to soy-producing municipalities in Brazil with a production exceeding 1000 tonnes of soy per annum, and with documented production linked to Swedish end consumption.

Classification of importance of producing regions to Swedish consumption

The importance of a soy-producing municipality in Brazil to Swedish end consumption is classified on a scale of 0–1 (low to high importance) using natural breaks (Jenks method, QGIS). **Figure 17** illustrates the breaks and the value assigned to each category, as well as the total volume of soy represented by each category. The natural breaks method is utilized for classification of data into groups for the purpose of reducing variance within classes, and maximizing the difference between them (de Smith et al., 2018). It proved the most apt classification method to provide division into 10 sub-classes representing relatively equal shares of the total contribution to soy production for Swedish consumption. A value from 0 to 1 (low to high) was then attributed to each class, weighing municipalities' relative importance to Swedish consumption, as illustrated in **Figure 17**.

Figure 17. Soy production for Swedish consumption. Municipalities divided into 10 "classes".



Normalization of GGCM output data

There is no uniform way of comparing loss of yield to increase of yield on a farm level. Decreases in crop production can be expected to have a greater negative impact on a farm level than a proportionate increase of the same size (Food and Agriculture Organization of the United Nations, 2015). In agricultural economics, price changes in complex market models are often assessed in relation to crop yield changes and market effects (Peri, 2017). The adaptive capacity, such as crop diversity and access to other assets, will also influence the severity of impact. For the sake of simplicity and transparency, in this study we assume a standardized relation, where loss in yield on a farm level is assumed to have impacts twice as high as an increase in yield. Output values were standardized according to Table 6. The values are based on the moderate range of value outputs (PEGASUS −50% to 100% change).

Table 6: Normalization of GGCM output data.

Value	Change in yield	Risk / Opportunity	
−1	−45 to 50% and above	Very high risk	🟥
−0.9	−40 to −45%	Very high risk	🟥
−0.8	−35 to −40%	High risk	🟥
−0.7	−30 to −35%	High risk	🟥
−0.6	−25 to−30%	Medium risk	🟥
−0.5	−20 to −25%	Medium risk	🟥
−0.4	−15 to −20%	Low risk	🟥
−0.3	−10 to −15%	Low risk	🟥
−0.2	−5 to −10%	Very low risk	🟥
−0.1	−0.01 to −5%	Very low risk	🟥
0	0%	No risk/opportunity	⬜
0.1	0.01 to 10%	Very low opportunity	🟦
0.2	10 to 20%	Very low opportunity	🟦
0.3	20 to 30%	Low opportunity	🟦
0.4	30 to 40%	Low opportunity	🟦
0.5	40 to 50%	Medium opportunity	🟦
0.6	50 to 60%	Medium opportunity	🟦
0.7	60 to 70%	High opportunity	🟦
0.8	70 to 80%	High opportunity	🟦
0.9	80 to 90%	Very high opportunity	🟦
1	90 to 100% and above	Very high opportunity	🟦

Change in yield (R_y) is calculated by subtracting the reported actual yield in 2011 for municipality m (P_a) from the projected yield in 2050 (P_{proj}), divided by actual yield for each municipality, according to **Equation 6**.

$$\text{Equation 6:} \quad R_y = \frac{(P_a - P_{proj})}{P_a} = 1 - \frac{P_{proj}}{P_a}$$

In order to inform the discussion on uncertainty, the difference in yield model projection (Y_Δ) was also calculated for the normalized values of the PEGASUS (PE) and pDSSAT (PD) models; see **Equation 7**:

$$\text{Equation 7:} \quad Y_\Delta = \left| R_{y(PD)} - R_{y(PE)} \right|$$

The risk quantification assumes an unweighted relation for the scope of impact of production and transport on the supply chain. It is possible that a more explicit approach to weighting the various components of risk can be justified. For example, production risk may well be more significant to Swedish consumers than transport risk, because it may have a higher influence over the soy price. Such a weighting could be carried out consulting actors involved in this specific supply chain. The results of this initial assessment could be used in such a stakeholder process. This is a contribution of this study for future research.

Characteristic areas

Table 7 provides the criteria for the ranking of opportunity from low to high for the characteristic areas.

Table 7. Criteria for evaluation of aggregated risk profile for the characteristic areas.

	Production		Transport	
Rank	**Crop models: PEGASUS and pDSSAT**	**Drought vulnerability**	**Landslide risk**	**Flash flood risk**
Opportunity	Majority of area opportunity, low to high	n.a.	n.a.	n.a.
Low	Majority of area with very low to low risk or low risk mixed with opportunity	Majority of area with very low to low risk	Majority of area with very low to low risk	Majority of area with very low to low risk
Medium	Majority of area with medium risk or majority low risk with areas of high/very high risk	Majority medium risk	Majority medium risk	Majority medium risk
High	Majority of area with medium risk, regions with high risk	Majority medium risk, regions with high risk	Majority medium risk, regions with high/very high risk	Majority medium risk, regions with high/very high risk

Appendix 3: Transport risk methodology

A new method to assess climate change impacts on the road transport system from producing municipality to exporting port in Brazil, for the Swedish supply of Brazilian soy, has been developed using GIS. The method combines sub-regional information on landslide and flash flood risk with transport data for soy supply to the European Economic Area (the EU including the UK, plus Iceland, Lichtenstein and Norway) (https://trase.earth/). Flooding and landslides are the most frequent weather-related events in Brazil causing transport disruptions (Bailey & Wellesley, 2017; Challinor et al., 2016). This appendix gives a detailed account of the transport risk assessment method.

Attributing flash flood and landslide risk to transport data

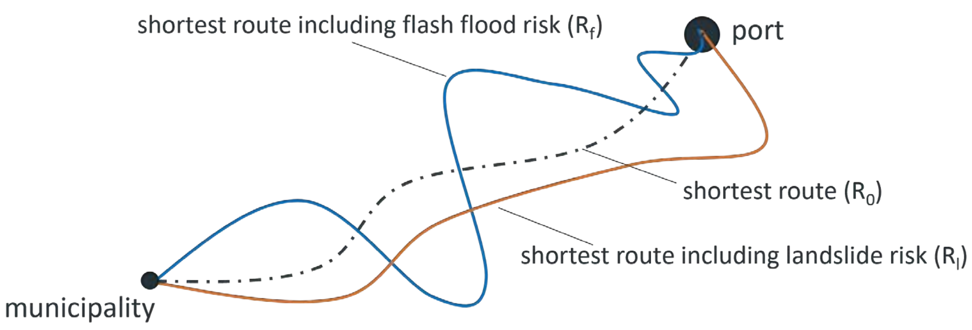
An origin-destination (OD) matrix is a network function, computing the shortest or fastest routes from multiple points of origin to multiple points of destination. The QGIS network tool QNEAT3 was applied for the transport risk calculation (Raffler, 2018). The landslide and flash flood risk were attributed to the OD-matrix calculation as cost, in this case "speed limits", in accordance with **Table 8**. Default speed was set to 5 (no risk) ([km/hour], default speed for QNEAT3 OD-matrix calculation).

Table 8. Risk values and categories for calculation of landslide and flash flood risk to the transport network.

Risk category	Risk range (mean values)	Speed limit [km/h]
Very low	0–0.2	5 (no limit)
Low	0.2–0.4	4
Medium	0.4–0.6	3
High	0.6–0.8	2
Very high	0.8–1	1

The analysis rendered shortest routes for routes with no risk (R_0), landslide risk (R_l) and flash flood risk (R_f), schematically illustrated in **Figure 18**.

Figure 18. Schematic illustration of shortest route values.



Total risk value for landslide risk ($R_{\Delta l}$) and flash flood risk ($R_{\Delta f}$), as well as mean combined risk (R_{FL}) were calculated, respectively, according to **Equation 8**.

$$\textit{Equation 8:} \quad \begin{aligned} &\textit{Landslide risk:} \quad R_{\Delta l} = R_l - R_0 \\ &\textit{Flash flood risk:} \quad R_{\Delta f} = R_f - R_0 \end{aligned}$$

The output data were normalized on a scale of 0–1 for each of the transport risk values (R_t), using the "value function", as described by Malczewski and Rinner (2015) and illustrated in **Equation 9**. It is a common standardization method in multi-factor risk assessments and uses the natural range of data to assess high to low value range on a scale of 0–1.

$$\textit{Equation 9:} \quad R_t = 1 - \left(\frac{max(R) - R_t}{max(R) - min(R)} \right)$$

Calculation of landslide and flash flood risk values

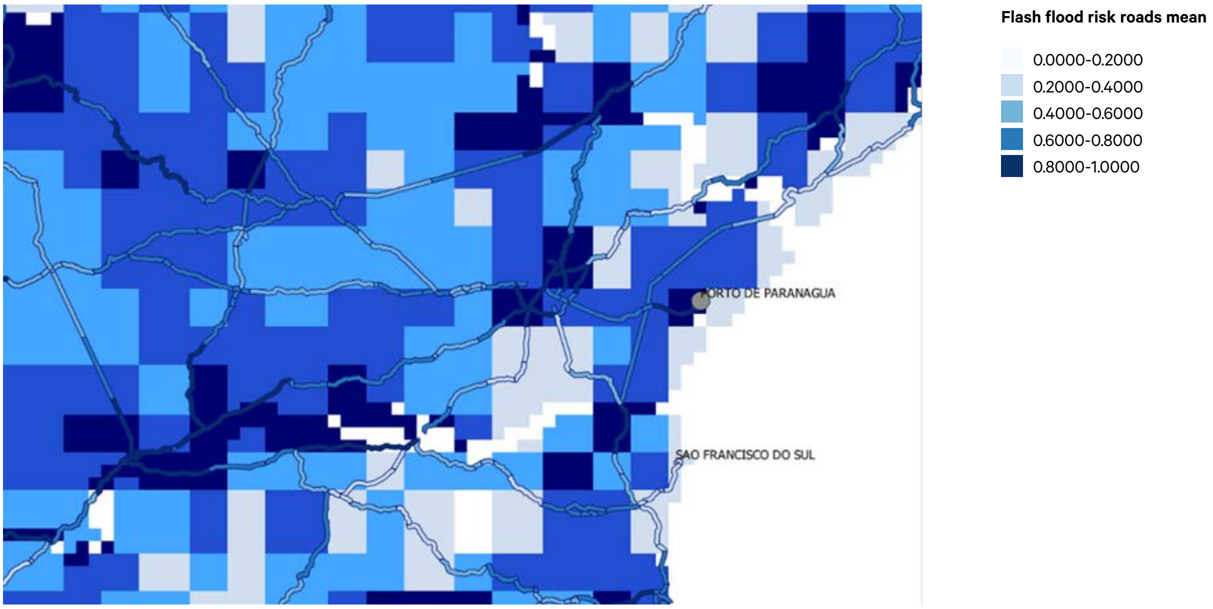
Risk values for the landslide and flooding indices were retrieved from JPEG images. The raster was given a "risk value" ranging from 0 (very low) to 1 (very high) according to **Table 9** and corresponding to the risk categories of each index. The values were stored as raster values in geocoded .tiff format.

Table 9. Risk values and categories based on landslide and flash flood indicies. Conversion from raster data.

Risk category	Risk value	Risk range (mean values)
Very low	0	0–0.2
Low	0.25	0.2–0.4
Medium	0.5	0.4–0.6
High	0.75	0.6–0.8
Very high	1	0.8–1

For the purpose of attributing landslide and flash flood risks to the transport between producing municipality and exporting port, a mean risk value for each of the indices was calculated. This was done for each road segment (range 0.1 km to 104 km), based on the statistical mean values of a 1 km buffer zone (QGIS vector geometry tool > buffer) around each segment (flat edges). See the image representation of a road buffer zone for flash flood index in **Figure 19**.

Figure 19. Example of road buffer zone transport mean representation of risk: flash flood index.



Logistics

Table 10 lists the input parameters (assumptions made) for the selected data from the custom download function of the Trase data platform for this study (https://supplychains.trase.earth/data) The year 2011 was chosen to match the production data available for the analysis. The importing countries of the EU and EEA were chosen as representative of flows of soy to Sweden for 2011 leaving the Brazilian ports. The selection was made to best reflect transport patterns for embedded soy to Sweden, assuming that transport patterns for Swedish end consumption of soy are similar to European transportation patterns. Specific data for transport of embedded Swedish soy consumption are currently being developed. It will be possible to update the assessment with more detailed commodity transport data for Sweden specifically as soon as the data are developed and released.

Table 10. Trase data download.

Delimitation of transport data from Trase platform custom download	
Category	**Input parameters**
Production country	Brazil
Commodity	Soy
Year	2011
Companies	All
Consumption countries	EU and EEA countries (Albania, Belgium, Bulgaria, Croatia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom)
Indicators	Volumes (tonnes)

Road to port calculation

The importing countries of the EU and EEA were chosen as representative of flows of soy to Sweden leaving the Brazilian ports as explained in the logistics section above. The data show the exporting ports utilized by each municipality, for exports to the EU/EEA. The numbers were converted to a percentage share, showing the relative share of soy reaching each port for each municipality. A risk value for each municipality to each port (R_n) was calculated (explained above in section “Attributing flash flood and landslide risk to transport data”) for each of the indices landslide and flash flood risk. This risk value was then multiplied by the percentage share of the port used (P_n), and summarized, for all nine ports (n = P1–9), as expressed in **Equation 10**.

$$\text{Equation 10:} \quad T_m = \sum \left(R_{p1} \times P_{p1} + R_{p2} \times P_{p2} + \cdots + R_{p9} \times P_{p9}\right)$$

Appendix 4: Input models for case study (Approach B)

Climate models and scenarios

The climate model used throughout the climate simulations in this study is the Hadley Centre Global Environment Model version 2 (HadGEM2-ES), a widely accepted and implemented model in the climate modelling community (Martin et al., 2011). It was chosen for the study as it is the only climate model available for all datasets used. This is because the HadGEM2-ES is the only available climate model for all six globally gridded crop model (yield predictions) simulations (Stokeld et al., 2020). The drought, landslide and flash flood index are all additionally available in MIROC simulations (an alternative climate simulation model).

The time frame differs between mid- and end-century, based on availability of the input data, specified in **Table 11**.

The representative concentration pathway (RCP) 4.5 was chosen based on available data for the crop yield simulations. The scenario depicts a stabilization scenario without overshoot to a total radiative forcing of 4.5 W/m^2 after 2100 (IPCC, 2019). The pathway is considered a relatively optimistic climate scenario. Under the RCP 4.5 global average temperatures are expected to have increased by 1.0–1.6°C above pre-industrial levels by 2050, and likely to exceed 2°C by 2100 (IPCC, 2019; van Vuuren et al., 2011).

In three of the indices, the drought, landslide and flash flood data, socio-economic factors representing vulnerability and adaptive capacity are factored in, in addition to the physical and environmental exposure. These factors are described for each index in Tables 16–18 below. For the socio-economic factors considered, no future projection, such as the Shared Socio-economic Pathways, is used. Thus, the indices compare the projected climate change exposure to a socio-economic sensitivity and adaptive capacity of today.

Table 11. Model input parameters for future scenarios.

Dataset	Climate scenario	Climate model	Time frame
Globally gridded crop models (GGCMs): PEGASUS and pDSSAT	RCP 4.5	HadGEM2-ES	2011–2050
Drought index Brazil	RCP 4.5 (available for RCP 8.5)	HadGEM2-ES (also available for MIROC)	2011–2040 (available for 2041–2070 and 2071–2100)
Landslide and flash flood risk index Brazil	RCP 4.5 (available for RCP 8.5)	HadGEM2-ES (also available for MIROC)	2070–2100
Flash flood index Brazil	RCP 4.5 (available for RCP 8.5)	HadGEM2-ES (also available for MIROC)	2070–2100 (available for 2011–2040 and 2041–2070)

Brazilian soy for Swedish consumption: Sourcing data

The sub-national production data for embedded soy for Swedish consumption are based on data from the hybridized multi-regional input-output (MRIO) model IOTA, developed by Croft and colleagues at SEI York (SEI, 2019a). The production data used for this study and the methodology for the Sweden–Brazil soy data are explained in their entirety in the paper "Capturing the heterogeneity of sub-national production in global trade flows" (Croft et al., 2018). It is based on the producing year of 2011. The IOTA model uses data reported in physical units (on production, exports and domestic supply), supplemented with calculations (such as a re-export algorithm based on domestic demand) and monetary data (GTAP input-output tables) covering intermediate demand. It is then combined with detailed transport data from the Trase project (https://trase.earth/), providing municipality-level information on the supply sources in Brazil (SEI, 2019b). The methods allow for supply chain tracing from sub-national production to sector-divided embedded end consumption of soy. For an in-depth account of the Trase methodology, see the following section on logistics.

Data on Swedish end consumption are based on GTAP's IO-data, divided into 57 GTAP sectors (GTAP, 2019). The data used in this study are total Swedish consumption as well as the top 10 Swedish soy-consuming sectors, based on the data provided by the IOTA model (see **Table 12**). The sub-national production scale in Brazil is municipality level (5570 municipalities in 27 states).

Logistics data

The transportation data for the analysis (municipality to consuming country via ports) are based on data from the Trase platform (https://trase.earth/). Trase is an interactive supply-chain transparency tool that allows the user to track agricultural commodity flows from a sub-regional production level (municipalities in Brazil), via exporting ports to importing countries. The physical road and port networks are based on shapefiles produced by the Brazilian Institute of Geography and Statistics (https://www.ibge.gov.br/). The physical network considered for the study is delimited to paved highways, *rodovias*, and exporting ports.

Trase utilizes a specific material flow analysis called SEI-PCS (Spatially Explicit Information on Production to Consumption Systems), initially developed by Godar et al. (2015, 2016). The method is based on publicly available data (free or via purchase) and can be replicated for any commodity and trade flow, given the availability of data. Three core features differentiate the SEI-PCS method from other supply chain mapping methods: it links individual supply chain actors to sub-national production regions; it identifies companies of export, import and shipping; and it covers all exports of a given commodity from a given country of production (https://trase.earth/).

For Brazilian soy the "gold standard" version 2 of the SEI-PCS method is used, utilizing sub-regional production data, customs records, maritime shipping contracts, tax registration, logistics data and commodity movement controls to track sub-national (municipality scale) Brazilian production of soy to consuming countries (Trase, 2018a). The methodology of SEI-PCS is explained in its entirety in *Supply chain mapping in Trase: Summary of data and methods* (Godar, 2018). The data sources used for the tracing of the Brazilian soy supply chain are listed in the Trase fact sheet (Trase, 2018b).

Table 12. Swedish sectors' end consumption of Brazilian soy, sum total and top 10 sectors. Sectors ordered by size.

Description	Embedded soy consumption Sweden [tonnes]	Share of total Swedish consumption [%]	GTAP code	Detailed description
Total (all sectors)	**236 494**	**100.00%**		
Top 10 GTAP sectors				
Meat products nec* (1)	51 375	21.72%	OMT	Other meat: pig meat and offal, preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal, greaves.
Dairy products (1)	36 323	15.36%	MIL	Milk: dairy products.
Food products nec*	30 122	12.74%	OFD	Other food: prepared and preserved fish or vegetables, fruit juices and vegetable juices, prepared and preserved fruit and nuts, all cereal flours, groats, meal and pellets of wheat, cereal groats, meal and pellets nec, other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers' wares, starches and starch products; sugars and sugar syrups nec, preparations used in animal feeding, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, food products nec.
Bovine meat products (1)	28 138	11.90%	CMT	Cattle meat: fresh or chilled meat and edible offal of cattle, sheep, goats, horses, asses, mules, and hinnies. Raw fats or grease from any animal or bird.
Trade	19 144	8.09%	TRD	Trade: all retail sales; wholesale trade and commission trade; hotels and restaurants; repairs of motor vehicles and personal and household goods; retail sale of automotive fuel.
Public Administration, Defense, Education, Health	14 854	6.28%	OSG	Other services (government): public administration and defense; compulsory social security, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organizations nec, extra-territorial organizations and bodies.
Animal products nec* (1)	6 770	2.86%	OAP	Other animal products: swine, poultry and other live animals; eggs, in shell (fresh or cooked), natural honey, snails (fresh or preserved) except sea snails; frogs' legs, edible products of animal origin nec, hides, skins and furskins, raw, insect waxes and spermaceti, whether or not refined or coloured.
Beverages and tobacco products	5 343	2.26%	B_T	Beverages and tobacco products.
Business services nec*	4 821	2.04%	OBS	Other business services: real estate, renting and business activities.
Leather products	4 692	1.98%	LEA	Leather: tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear.
Sum of top 10 sectors	**201 581**	**85.24%**		
(1) Sum of meat and dairy sectors	**122 605**	**51.84%**		

Source: GTAP codes and descriptions according to GTAP (2019).

*nec: "not elsewhere classified"

Data on climate change impacts on production: Globally gridded crop models

The data presenting projected changes in crop yield under climate change scenarios are based on work by Stokeld and colleagues (2020). They incorporate globally gridded crop models (GGCMs) for Brazilian soy production within the framework of the Inter-Sectoral Impact Model Intercomparison Project. The original study by Stokeld et al. is a comparison of six crop models, resulting in diverging results based on differences in crop model characteristics (see **Table 13**). The diversity in outputs of the model comparison is due to differences in crop model "type" (original model purpose), which stressors are included, the nature of the output and sensitivity to CO_2 (Rosenzweig et al., 2013, 2016). **Table 13** provides an overview of the model parameters.

For this study, we have selected the PEGASUS and the pDSSAT model results based on input parameters and yield projection results. The PEGASUS and pDSSAT model results represent one negative and one moderately positive yield prediction; see **Table 13** for a comparison between producing states and **Figure 20** for a spatial illustration of the model differences. Both models utilize a diversity of stressors, five and six out of a maximum eight, including water, temperature, CO_2 and heat stress, all important to soy crop yield (see **Table 14** and **15**). Lastly, both models' outputs are in potential yield (making comparison between models feasible). The selection is motivated by comparison purposes. Model output divergence is most likely in response to differences in modelling of CO_2 fertilization, as well as general differences in model designs (Rosenzweig et al. 2013).

Figure 20. Deviation of normalized input values for the GGCM models PEGASUS and pDSSAT.

Production impacts data: Drought vulnerability index

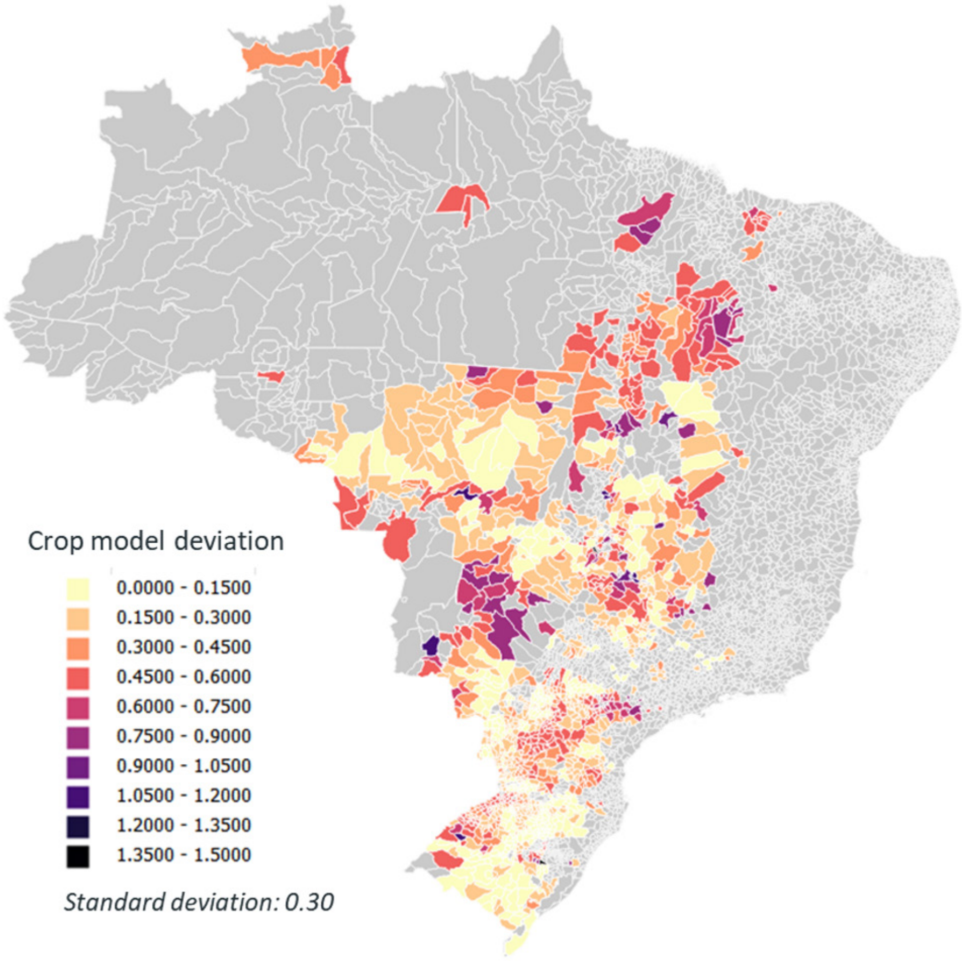


Table 13. Model output comparison for the 18 soy-producing states (out of 27 states), ordered by size of production. Green shows the highest values and red lowest values.

	GGCM	**PEGASUS**		**LPJmL**	**LPJ-GUESS**	**IMAGE**	**GEPIC**	**Δ PEGASUS, pDSSAT**
	No of stressors included	**6**		**2**	**2**	**2**	**8**	
State	**2011 actual prod.**							
Mato Grosso	20 800 544	0.96%	−0.15%	0.40%	18.32%	−1.22%	−3.33%	1.11%
Paraná	15 457 911	−7.88%	0.80%	0.93%	9.64%	0.13%	−7.29%	8.67%
Rio Grande do Sul	11 717 548	9.54%	−2.87%	2.74%	10.63%	1.16%	3.08%	12.42%
Goiás	7 703 982	−6.97%	1.13%	3.70%	14.96%	−0.84%	−6.19%	8.09%
Mato Grosso do Sul	5 079 581	−1.56%	−0.90%	13.48%	20.26%	−0.17%	−8.08%	0.66%
Bahia	3 512 568	0.48%	4.79%	−0.93%	17.73%	−1.18%	1.11%	4.31%
Minas Gerais	2 940 857	−6.86%	0.95%	2.57%	15.17%	−0.81%	−3.21%	7.81%
Maranhão	1 571 418	−15.87%	10.56%	7.02%	19.39%	−2.81%	−5.57%	26.43%
Santa Catarina	1 490 551	3.23%	7.13%	0.32%	3.24%	0.18%	6.98%	3.91%
São Paulo	1 271 437	−4.07%	−2.55%	0.88%	18.28%	−0.27%	−4.03%	1.52%
Tocantins	1 193 453	−15.70%	9.18%	2.15%	17.60%	−2.74%	−7.24%	24.88%
Piauí	1 144 033	−22.65%	10.28%	6.46%	20.09%	−2.75%	−6.60%	32.93%
Rondônia	419 522	−1.58%	8.99%	1.80%	21.79%	−0.33%	−2.18%	10.57%
Pará	317 093	−14.92%	29.32%	4.33%	19.97%	−1.30%	−8.61%	44.24%
Distrito Federal	184 047	15.22%	1.61%	0.34%	11.65%	−0.05%	−0.30%	13.61%
Roraima	10 080	−9.30%	15.04%	0.47%	22.06%	−0.38%	−8.14%	24.34%
Amazonas	540	−11.15%	9.54%	7.69%	24.46%	−0.16%	−4.36%	20.69%
Acre	282	−5.57%	7.52%	10.16%	26.96%	1.13%	0.94%	13.09%

Source: Based on data from Stokeld et al. (2020).

Table 14. Comparison of GGCMs. Models chosen for this study are highlighted in green.

Crop model	Full name	Type	Stressors included (#)	CO_2 effects	Output
PEGASUS	Predicting Ecosystem Goods And Services Using Scenarios model	Agro-ecosystem	Water, temperature, specific heat stress, oxygen, nitrogen, potassium (6)	Radiation use efficiency, transpiration efficiency	Actual yield
pDSSAT	Parallel Decision Support System for Agro-technology Transfer	Site-based	Water, temperature, specific heat stress, oxygen, nitrogen (5)	Leaf-level photosynthesis	Actual yield
EPIC	Environmental Policy Integrated Climate Model	Site-based	Water, temperature, specific heat stress, oxygen, nitrogen, phosphorus, bulk density, aluminium (8)	Radiation use efficiency, transpiration efficiency	Actual yield and yield gap
GEPIC	Geographic Information System (GIS)-based Environmental Policy Integrated Climate Model	Site-based	Water, temperature, specific heat stress, oxygen, nitrogen, phosphorus, bulk density, aluminium (8)	Radiation use efficiency, transpiration efficiency	Actual yield
IMAGE	Global Agro-Ecological Zone Model in the Integrated Model to Assess the Global Environment	Agro-ecological zone	Water, temperature (2)	Radiation use efficiency	Potential yield
LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator with Managed Land	Agro-ecosystem	Water, temperature (2)	Leaf-level photosynthesis, stomatal conductance	Potential yield
LPJmL	Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model	Agro-ecosystem	Water, temperature (2)	Leaf-level photosynthesis, stomatal conductance	Actual yield

Source: Adapted from Rosenzweig et al. (2013).

Table 15. Climate change stressors affecting soy yield.

Factor	Relationship with soy yield	Importance	Expected change in factor under climate change
Mean temperature	Development can occur at 7–45°C, but reproductive capacity will start to decline from 30°C.	Temperature is the dominant variable in determining crop yield according to some sources. Soy production in South America is mostly sensitive to temperature.	Warming projected for the whole of Brazil.
Precipitation	Increasing water deficit reduces soybean yield.	In-season water deficit is described as the main factor reducing soy yield in Brazil.	Reduction in south- and central-east Brazil. Mixed changes in north-east Brazil.
CO_2 concentration	Increasing atmospheric CO_2 concentration increases soy yield.	Soy is particularly sensitive to CO_2, and one study found an overall yield enhancement of 29±8%, the highest among the 10 crops in the study.	Atmospheric CO_2 concentration is expected to reach almost 685 ppm by 2050 (currently 405 ppm).
Heat stress	Heat stress "drastically" reduces agricultural crop productivity.	The Fourth IPCC Assessment report acknowledged heat stress as an important threat to global food supply.	More extreme high temperatures expected in South America towards end of century.
Surface ozone	An increase in surface ozone causes damaging effects to soy.	Estimates suggest current yield loss due to surface ozone is ~5%, and could rise to 30% in 2050.	A 20% increase in global surface ozone is expected by 2050.

Source: Adapted from Stokeld et al. (2020).

The IVDNS: Index of Vulnerability to Drought-Related Natural Disasters in the context of climate change (hereafter drought index) was launched by WWF-Brazil, the Ministry of the Environment and the Ministry of Integration in Brazil in 2015 and developed by Debortoli and colleagues (Debortoli et al., 2017a); a thumbnail version is shown in **Figure 21**. Components and methodology are explained in their entirety in Debortoli et al. (2017a). The index is divided into three sub-indices: exposure, sensitivity and adaptive capacity. **Table 16** lists the variables used to produce each index and **Equation 11** shows how the indices are combined. **Table 17** provides technical details, climate scenarios used and time frame.

Figure 21. Drought vulnerability sub-index developed by Debortoli and colleagues (2017a).

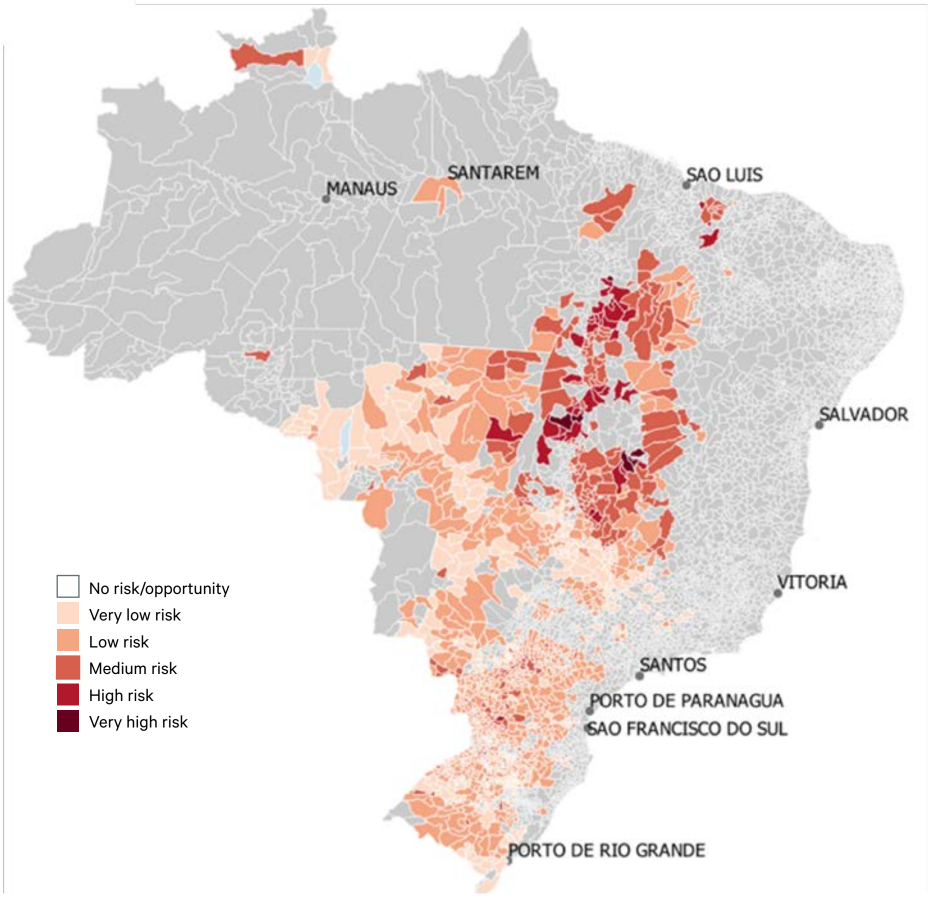


Table 16. Variables included in drought index.

Sub-indices	Variables
Exposure (EXP)	• Increase in average annual precipitation (−) • Increase of altered precipitation patterns (+) • Increased drought probability – from Standardized Evaporation Precipitation Index (+)
Sensitivity (SENS)	• Land use (weighted) • % of the population with income less than ¼ of the minimum wage (+) • Infant mortality (cases/1000 inhabitants) (+) • Demographic density (+)? • Water Demand and Supply Index (from the Brazilian National Water Agency, ANA) (+)
Adaptive capacity (CA)	• Municipal human development index (IDHm, United Nations Development Programme) (+) • Social inequality – Gini index (−) • Illiteracy (DATASUS) (−)

$$Equation\ 11: \quad IVDNS = \frac{EXP + SENS}{2} \times \left(0.5 + \frac{1 - CA}{2}\right)$$

Table 17. Technical details for the drought index. Input parameters used for this study are in bold.

Technical details	Drought index
Resolution	Projection: 20 km resolution. **Municipality scale index used**
Climate models	IPCC AR5 models: **HadGEM2-ES** and MIROC 5 (no future scenarios used for socio-economic parameters of sensitivity and adaptive capacity)
Baseline period	1961–1990
Climate scenarios	**RCP 4.5** and RCP 8.5
Projection (years)	**2011–2040**, 2041–2070 and 2071–2100

Impacts on transport: Landslide and flash flood vulnerability indices

The flash flood and landslide risk indices developed by Debortoli and colleagues (2017b) are illustrated in **Figure 22**; for further methodological details see Debortoli et al. (2017b). The indices were developed to assess how vulnerability to extreme climate events such as flash floods and landslides may be altered in the face of climate change in Brazil. Three types of datasets are included in the indices: climatic, physical/environmental and socio-economic. **Table 18** lists the variables used to produce each index. Technical details are provided in **Table 19**.

Table 18. Landslide and flash flood index components.

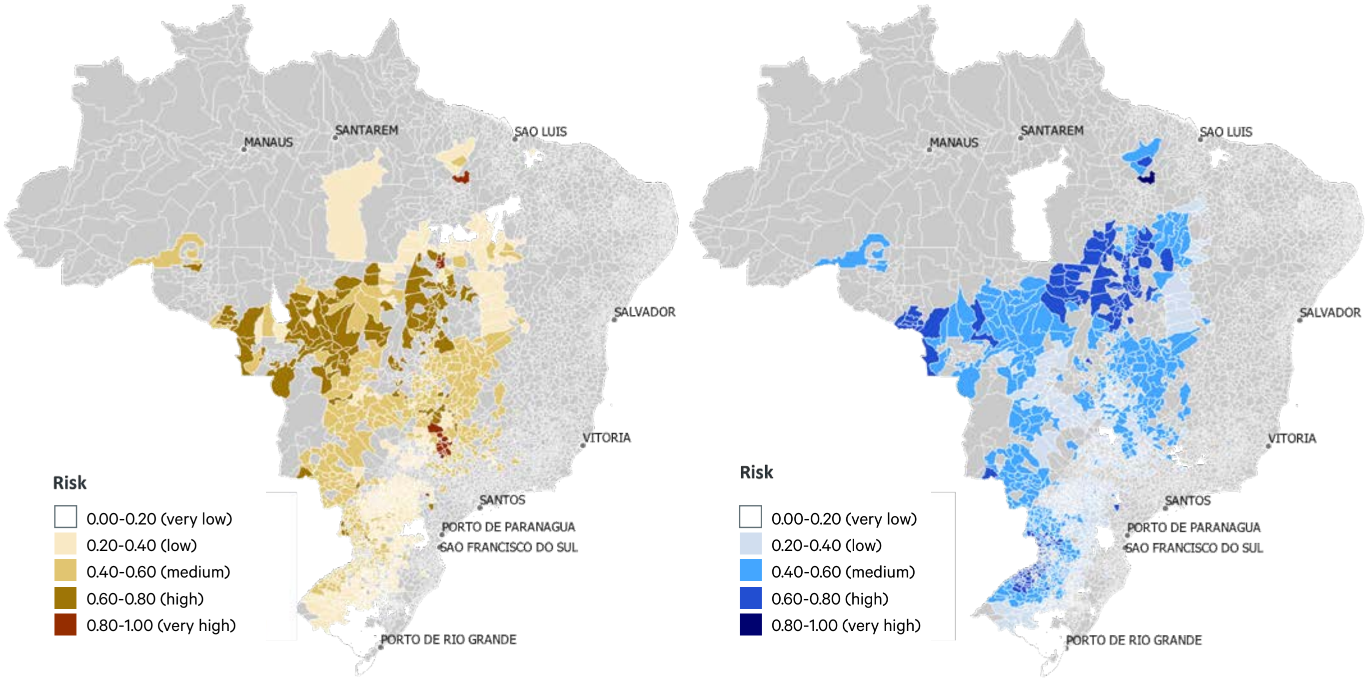
Sub-indices	Variables
Climatic	**Flash floods and landslides*** Geographical distribution of climatic extremes in precipitation rates: Rx1day and Rx5day (monthly maximum consecutive 1- and 5-day precipitation), R95p (very wet days, values exceeding the 95-percentile) and CWD (maximum number of consecutive wet days)
Physical/ environmental	**Flash floods** Road density, land use (least to most vulnerable based on runoff sensitivity and economic activity), hydrography (stream density) and flooding vulnerability (flood frequency and impacts on waterways) **Landslides** Slope and landform (susceptibility for landslides)
Socio-economic	**Flash floods and landslides** Municipal human development index (IDHm), Gini index (social inequality) and percentage share of people: in poverty, vulnerable to entering the poverty class, extremely poor, without access to water and sewage services, and living in households with poorly constructed walls, as well as people without access to electricity.

* The same components were used for the flash flood and landslide indices, with different relative weights, as both disasters are caused by precipitation. Flash floods are mostly related to extreme precipitation whereas the occurrence of landslides is mostly related to consecutive days of rainfall.

Table 19. Technical details for the drought index. Input parameters used for this study are in bold.

Technical details	Landslide and flash flood indices
Resolution	Projection: 20-km resolution
Climate models	IPCC AR5 models: **HadGEM2-ES** and MIROC 5 (no future scenarios used for socio-economic parameters of sensitivity and adaptive capacity)
Baseline period	1961–1990
Climate scenarios	**RCP 4.5** and RCP 8.5
Projection (years)	**2071–2100** (flash flood available also for 2011–2040, 2041–2070)

Figure 22. To the left: Landslide risk index, municipal mean risk values. To the right: Flash flood risk index, municipal mean risk values.



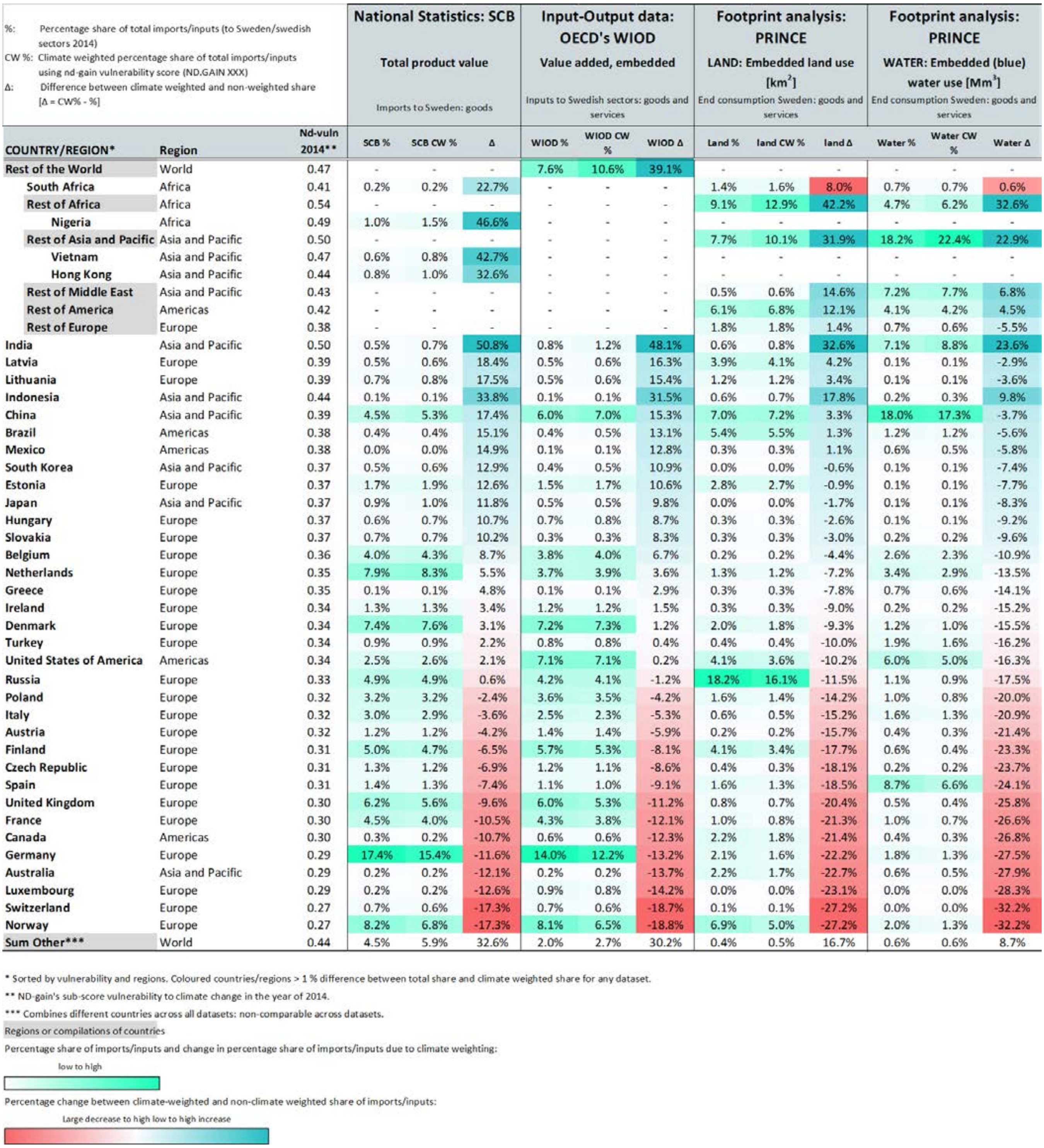
Landslide risk sub-index

Flash flood risk sub-index

Appendix 5: Detailed results of national-level analysis (Approach A): trade statistics

All data for Approach A, Sweden and trade, are publicly available at https://public.flourish.studio/story/656845/. **Table 20** shows the results for the top 30+ countries and regions in this study, the climate-weighted share of inputs.

Table 20. Trade data results comparison table: national statistics (SCB), IO-data (WIOD), and land and water footprints. Inputs to Swedish sectors/Swedish end consumption.



%: Percentage share of total imports/inputs (to Sweden/swedish sectors 2014)
CW %: Climate weighted percentage share of total imports/inputs using nd-gain vulnerability score (ND.GAIN XXX)
Δ: Difference between climate weighted and non-weighted share [Δ = CW% - %]

			National Statistics: SCB			Input-Output data: OECD's WIOD			Footprint analysis: PRINCE			Footprint analysis: PRINCE		
			Total product value			Value added, embedded			LAND: Embedded land use [km^2]			WATER: Embedded (blue) water use [Mm^3]		
			Imports to Sweden: goods			Inputs to Swedish sectors: goods and services			End consumption Sweden: goods and services			End consumption Sweden: goods and services		
COUNTRY/REGION*	Region	Nd-vuln 2014**	SCB %	SCB CW %	Δ	WIOD %	WIOD CW %	WIOD Δ	Land %	land CW %	land Δ	Water %	Water CW %	Water Δ
Rest of the World	World	0.47	-	-	-	7.6%	10.6%	39.1%	-	-	-	-	-	-
South Africa	Africa	0.41	0.2%	0.2%	22.7%	-	-	-	1.4%	1.6%	8.0%	0.7%	0.7%	0.6%
Rest of Africa	Africa	0.54	-	-	-	-	-	-	9.1%	12.9%	42.2%	4.7%	6.2%	32.6%
Nigeria	Africa	0.49	1.0%	1.5%	46.6%	-	-	-	-	-	-	-	-	-
Rest of Asia and Pacific	Asia and Pacific	0.50	-	-	-	-	-	-	7.7%	10.1%	31.9%	18.2%	22.4%	22.9%
Vietnam	Asia and Pacific	0.47	0.6%	0.8%	42.7%	-	-	-	-	-	-	-	-	-
Hong Kong	Asia and Pacific	0.44	0.8%	1.0%	32.6%	-	-	-	-	-	-	-	-	-
Rest of Middle East	Asia and Pacific	0.43	-	-	-	-	-	-	0.5%	0.6%	14.6%	7.2%	7.7%	6.8%
Rest of America	Americas	0.42	-	-	-	-	-	-	6.1%	6.8%	12.1%	4.1%	4.2%	4.5%
Rest of Europe	Europe	0.38	-	-	-	-	-	-	1.8%	1.8%	1.4%	0.7%	0.6%	-5.5%
India	Asia and Pacific	0.50	0.5%	0.7%	50.8%	0.8%	1.2%	48.1%	0.6%	0.8%	32.6%	7.1%	8.8%	23.6%
Latvia	Europe	0.39	0.5%	0.6%	18.4%	0.5%	0.6%	16.3%	3.9%	4.1%	4.2%	0.1%	0.1%	-2.9%
Lithuania	Europe	0.39	0.7%	0.8%	17.5%	0.5%	0.6%	15.4%	1.2%	1.2%	3.4%	0.1%	0.1%	-3.6%
Indonesia	Asia and Pacific	0.44	0.1%	0.1%	33.8%	0.1%	0.1%	31.5%	0.6%	0.7%	17.8%	0.2%	0.3%	9.8%
China	Asia and Pacific	0.39	4.5%	5.3%	17.4%	6.0%	7.0%	15.3%	7.0%	7.2%	3.3%	18.0%	17.3%	-3.7%
Brazil	Americas	0.38	0.4%	0.4%	15.1%	0.4%	0.5%	13.1%	5.4%	5.5%	1.3%	1.2%	1.2%	-5.6%
Mexico	Americas	0.38	0.0%	0.0%	14.9%	0.1%	0.1%	12.8%	0.3%	0.3%	1.1%	0.6%	0.5%	-5.8%
South Korea	Asia and Pacific	0.37	0.5%	0.6%	12.9%	0.4%	0.5%	10.9%	0.0%	0.0%	-0.6%	0.1%	0.1%	-7.4%
Estonia	Europe	0.37	1.7%	1.9%	12.6%	1.5%	1.7%	10.6%	2.8%	2.7%	-0.9%	0.1%	0.1%	-7.7%
Japan	Asia and Pacific	0.37	0.9%	1.0%	11.8%	0.5%	0.5%	9.8%	0.0%	0.0%	-1.7%	0.1%	0.1%	-8.3%
Hungary	Europe	0.37	0.6%	0.7%	10.7%	0.7%	0.8%	8.7%	0.3%	0.3%	-2.6%	0.1%	0.1%	-9.2%
Slovakia	Europe	0.37	0.7%	0.7%	10.2%	0.3%	0.3%	8.3%	0.3%	0.3%	-3.0%	0.2%	0.2%	-9.6%
Belgium	Europe	0.36	4.0%	4.3%	8.7%	3.8%	4.0%	6.7%	0.2%	0.2%	-4.4%	2.6%	2.3%	-10.9%
Netherlands	Europe	0.35	7.9%	8.3%	5.5%	3.7%	3.9%	3.6%	1.3%	1.2%	-7.2%	3.4%	2.9%	-13.5%
Greece	Europe	0.35	0.1%	0.1%	4.8%	0.1%	0.1%	2.9%	0.3%	0.3%	-7.8%	0.7%	0.6%	-14.1%
Ireland	Europe	0.34	1.3%	1.3%	3.4%	1.2%	1.2%	1.5%	0.3%	0.3%	-9.0%	0.2%	0.2%	-15.2%
Denmark	Europe	0.34	7.4%	7.6%	3.1%	7.2%	7.3%	1.2%	2.0%	1.8%	-9.3%	1.2%	1.0%	-15.5%
Turkey	Europe	0.34	0.9%	0.9%	2.2%	0.8%	0.8%	0.4%	0.4%	0.4%	-10.0%	1.9%	1.6%	-16.2%
United States of America	Americas	0.34	2.5%	2.6%	2.1%	7.1%	7.1%	0.2%	4.1%	3.6%	-10.2%	6.0%	5.0%	-16.3%
Russia	Europe	0.33	4.9%	4.9%	0.6%	4.2%	4.1%	-1.2%	18.2%	16.1%	-11.5%	1.1%	0.9%	-17.5%
Poland	Europe	0.32	3.2%	3.2%	-2.4%	3.6%	3.5%	-4.2%	1.6%	1.4%	-14.2%	1.0%	0.8%	-20.0%
Italy	Europe	0.32	3.0%	2.9%	-3.6%	2.5%	2.3%	-5.3%	0.6%	0.5%	-15.2%	1.6%	1.3%	-20.9%
Austria	Europe	0.32	1.2%	1.2%	-4.2%	1.4%	1.4%	-5.9%	0.2%	0.2%	-15.7%	0.4%	0.3%	-21.4%
Finland	Europe	0.31	5.0%	4.7%	-6.5%	5.7%	5.3%	-8.1%	4.1%	3.4%	-17.7%	0.6%	0.4%	-23.3%
Czech Republic	Europe	0.31	1.3%	1.2%	-6.9%	1.2%	1.1%	-8.6%	0.4%	0.3%	-18.1%	0.2%	0.2%	-23.7%
Spain	Europe	0.31	1.4%	1.3%	-7.4%	1.1%	1.0%	-9.1%	1.6%	1.3%	-18.5%	8.7%	6.6%	-24.1%
United Kingdom	Europe	0.30	6.2%	5.6%	-9.6%	6.0%	5.3%	-11.2%	0.8%	0.7%	-20.4%	0.5%	0.4%	-25.8%
France	Europe	0.30	4.5%	4.0%	-10.5%	4.3%	3.8%	-12.1%	1.0%	0.8%	-21.3%	1.0%	0.7%	-26.6%
Canada	Americas	0.30	0.3%	0.2%	-10.7%	0.6%	0.6%	-12.3%	2.2%	1.8%	-21.4%	0.4%	0.3%	-26.8%
Germany	Europe	0.29	17.4%	15.4%	-11.6%	14.0%	12.2%	-13.2%	2.1%	1.6%	-22.2%	1.8%	1.3%	-27.5%
Australia	Asia and Pacific	0.29	0.2%	0.2%	-12.1%	0.2%	0.2%	-13.7%	2.2%	1.7%	-22.7%	0.6%	0.5%	-27.9%
Luxembourg	Europe	0.29	0.2%	0.2%	-12.6%	0.9%	0.8%	-14.2%	0.0%	0.0%	-23.1%	0.0%	0.0%	-28.3%
Switzerland	Europe	0.27	0.7%	0.6%	-17.3%	0.7%	0.6%	-18.7%	0.1%	0.1%	-27.2%	0.0%	0.0%	-32.2%
Norway	Europe	0.27	8.2%	6.8%	-17.3%	8.1%	6.5%	-18.8%	6.9%	5.0%	-27.2%	2.0%	1.3%	-32.2%
Sum Other***	World	0.44	4.5%	5.9%	32.6%	2.0%	2.7%	30.2%	0.4%	0.5%	16.7%	0.6%	0.6%	8.7%

* Sorted by vulnerability and regions. Coloured countries/regions > 1 % difference between total share and climate weighted share for any dataset.

** ND-gain's sub-score vulnerability to climate change in the year of 2014.

*** Combines different countries across all datasets: non-comparable across datasets.

Regions or compilations of countries

Percentage share of imports/inputs and change in percentage share of imports/inputs due to climate weighting:

low to high

Percentage change between climate-weighted and non-climate weighted share of imports/inputs:

Large decrease to high low to high increase

Appendix 6: Detailed results of Approach B

The table and maps presented in this appendix give a detailed account of the typological areas (**Figure 23** and **Table 21**), sub-index results (**Figure 24** to **Figure 27**) and combined results (**Figure 28** to **Figure 31**), and a sensitivity analysis (**Figure 32**).

Figure 23. Typological areas and level of magnitude and likelihood of risk for sourcing, production and transport of Brazilian soy to Sweden.

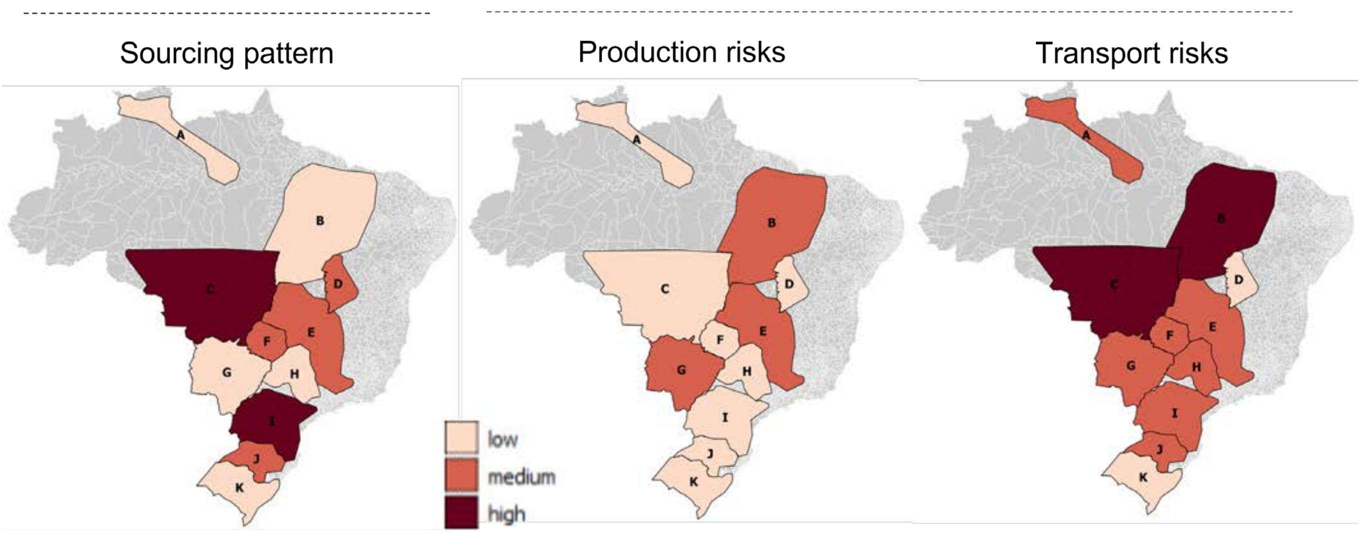


Table 21. Overview and description of the characteristic areas for each input parameter of the risk assessment.

Area code	Area description	Sourcing	Production risk (dominating patterns per area)			Transport risk	Risk/opportunity summary
	Supply chain origin to Swedish end consumption	**Importance of area (% of total Swedish consumption of Brazilian soy)**	**Crop model A (PEGASUS)**	**Crop model B (pDSSAT)**	**Drought risk index**	**Transport risk (for the route to port(s) from this producing area)**	**Dominating trends for the area**
A	The north	Low (0.3%)	Low yield losses	Low increase in yield	Low to medium drought risk	No transport risk	Of very little importance to Swedish sourcing to date. One yield model predicts a substantial increase in yield. Risk profile low to medium across parameters.
B	North Matopiba	Low (2.9%)	Expected yield losses range from low to very high in the south, medium risk	Low to medium increase in yield	Medium to high drought risk	Short distance to port with high/ very high flash flood risks along the way. High risk of landslides in the south	Low importance for Swedish sourcing. Drought-prone area. Roads to port at risk of floods. Landslide risks related to transport from the southern part.

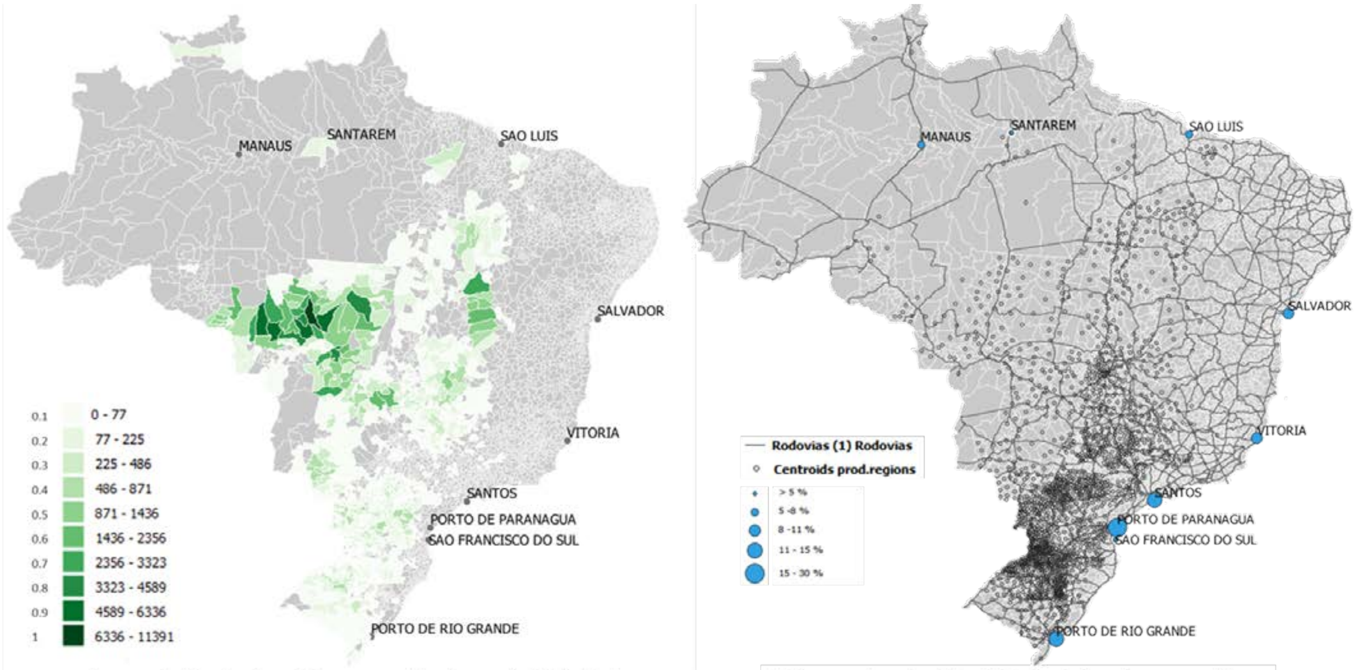
Table 21. Continued...

Area code	Area description	Sourcing	Production risk (dominating patterns per area)			Transport risk	Risk/opportunity summary
C	Mato Grosso and east Rodônia	High. Most important production area for Swedish sourcing (50.8%)	Mixed prediction, area dominated by low opportunity to low risk	Mixed prediction, area dominated by low opportunity to low risk	Very low to low drought risk, few areas with medium/ high risk in the north-east	Long roads to port with high risk of landslide and flash floods	Dominating sourcing region. Low drought risk and expected low increase or decrease of yield. Long roads to port with high risk of landslide and flash floods; however, alternative waterways exist for transport in the west.
D	Western Bahia	Medium (4.5%)	Low to high predicted increase in yield	Very low increase in yield	Dominated by medium drought risk	Medium landslide, low flash flood risk	Of medium importance for Swedish sourcing. Drought prone area. Medium landslide risks to ports.
E	Central region	Medium (4.5%)	Mixed prediction, area dominated by low opportunity to low risk. Very high opportunity and very high risk in a few smaller municipalities.	Mixed prediction, area dominated by low opportunity to low risk	Medium to high drought risk, few areas with very high risk	Medium risk of both landslides and flash floods	Of medium importance for Swedish sourcing. Drought prone area. Medium risk of both landslides and flash floods.
F	Southern Goiás	Medium (4.3%)	Low to very low yield losses	Low to very low yield losses	Very low to low drought risk	High landslide risks in the north. Overall medium risks of landslides and flash floods	Medium production for Swedish sourcing, low production risks. Areas of high landslide risk to port in the south.
H	Mato Grosso do Sul	Low (2.6%)	Medium yield losses	No change	Very low to low drought risk	High to very high landslide risk due to usage of long coastal road with few alternative routes	High to very high landslide risk due to usage of long coastal road with few alternative routes. Otherwise low importance and risk profile.
I	Paraná and São Paolo	Second most important production area for Sweden (19.1%)	Low to very low yield losses	Area dominated by very low to low yield increases	Low drought risk, few municipalities with medium risk	High flash flood risk in the south-west	Important sourcing region for Sweden. Low production risks. High flash flood risk from areas in the south-west.

Table 21. Continued...

Area code	Area description	Sourcing	Production risk (dominating patterns per area)			Transport risk	Risk/opportunity summary
J	North Rio Grande do Sul	Medium (5.9%)	Low to medium predicted increase in yield	Area dominated by very low to low yield increases	Low drought risk, few municipalities with medium risk	Short distance to port with high/ very high flash flood risks along the way. High risks of landslides in the south.	Medium production for Swedish sourcing, low production risks. Short distance to port with high/very high flash flood risks along the way. High risks of landslides in the south.
K	South Rio Grande do Sul	Low (3.3%)	Low to high yield losses	Low to medium yield losses with very high predicted losses in smaller municipalities	Low drought risk	High flash flood risk in the north-west	Low importance for Swedish sourcing. Low production risks. High flash flood risk related to transport from the north-west.

Figure 24. To the left: Brazilian production of soy for Swedish consumption. To the right: Brazilian inland transport routes via roads, and exporting ports.



Soy production for Swedish consumption (tonnes), divided into 10 "classes" 1-10 (low-high importance/magnitude of impact)

Highway network of Brazil (Rodovias) and soy exporting ports, classified by percentage share of exports to the EU.

Figure 25. Globally gridded crop models (GGCMs). To the left: PEGASUS; to the right: pDSSAT.

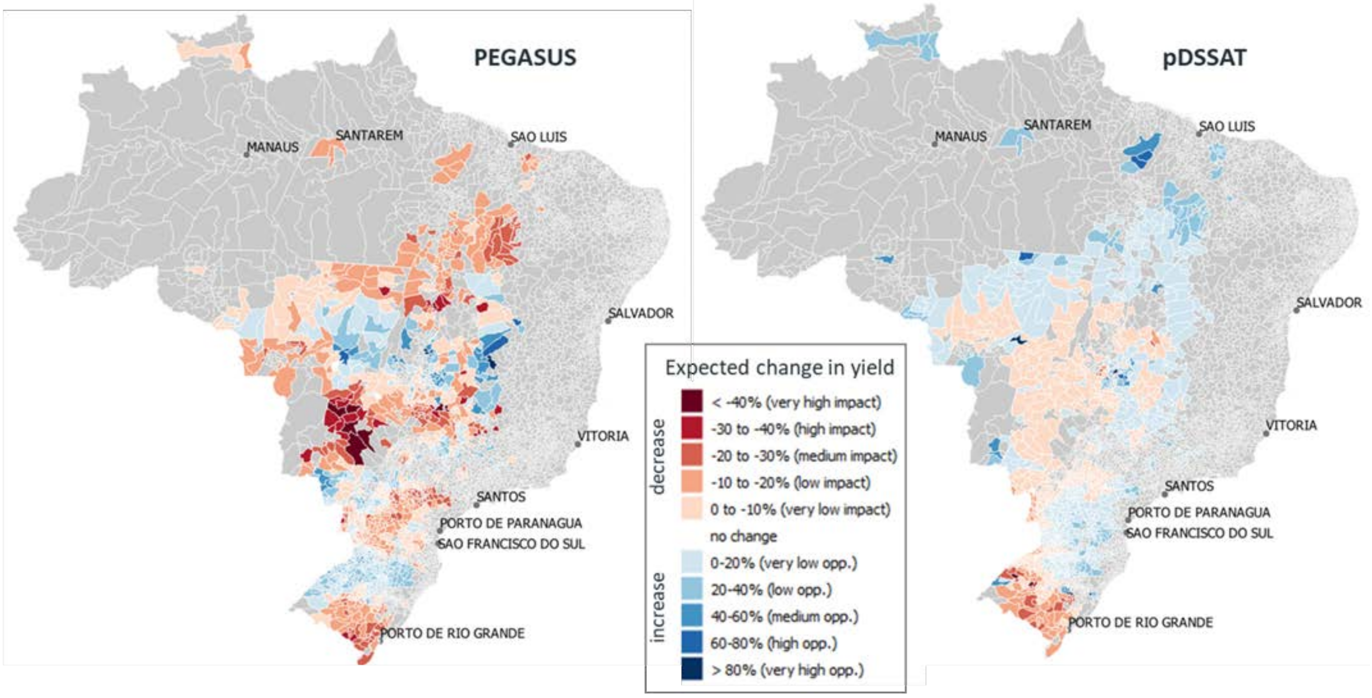


Figure 26. Drought vulnerability index.

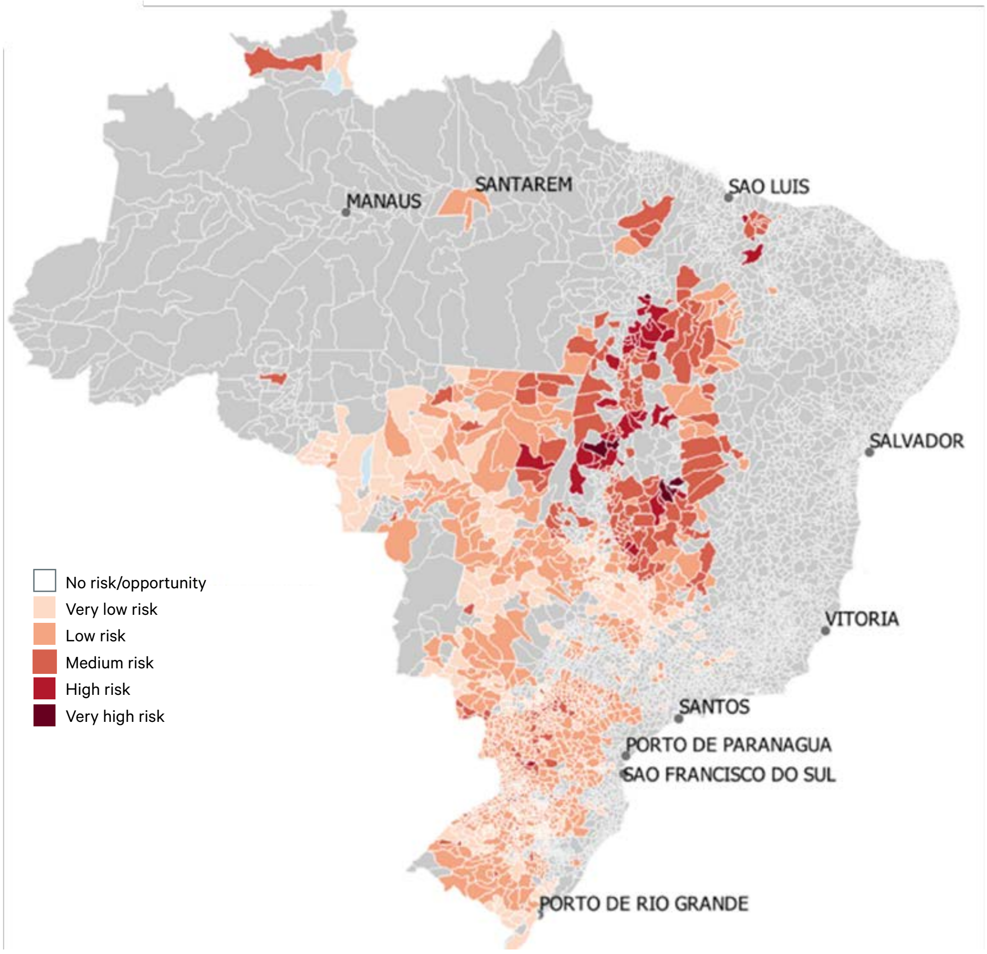
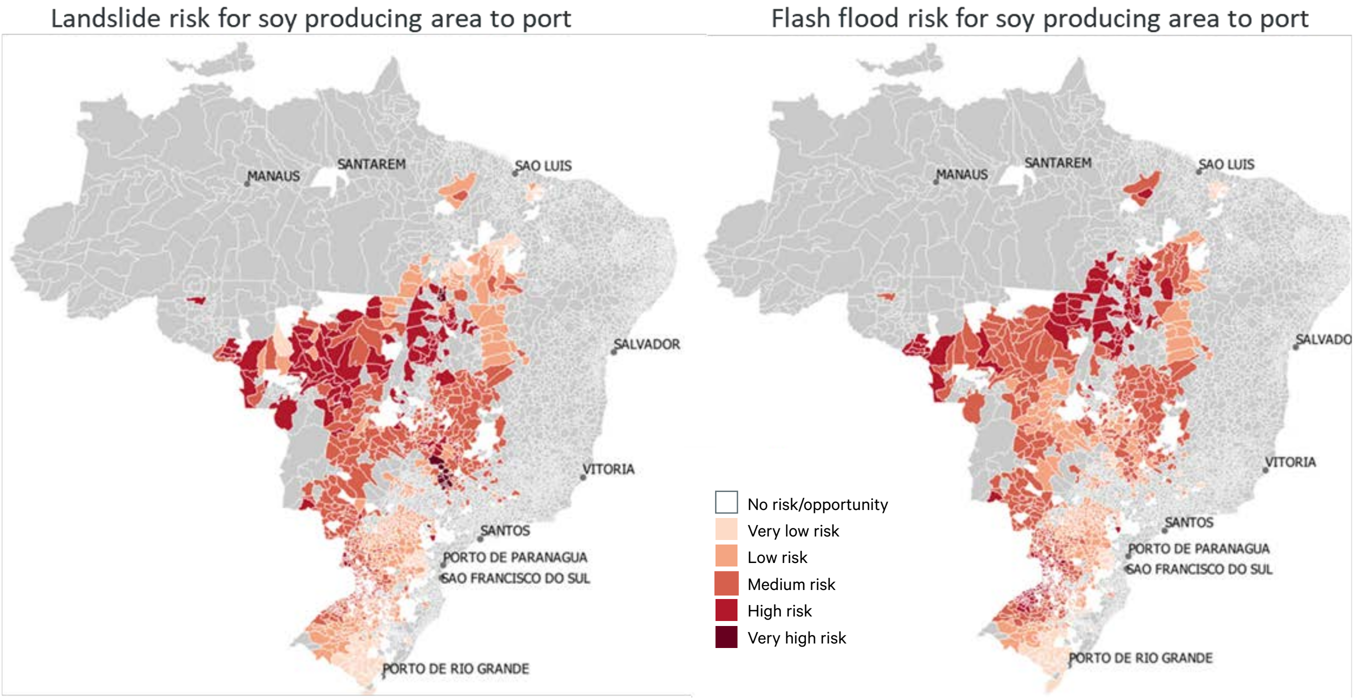


Figure 27. Transport risk from producing farm to exporting port. To the left: landslide risk to the transport network; to the right: flash flood risk.



Landslide risk for soy producing area to port

Flash flood risk for soy producing area to port

Figure 28. Combined risk values for flash flood and landslide index, from producing municipality to exporting port. To the left: combined transport risk; to the right: transport risk weighted by importance of producing municipalities for Swedish soy consumption. The top maps show mean risk values, the bottom maps show maximum risk values.

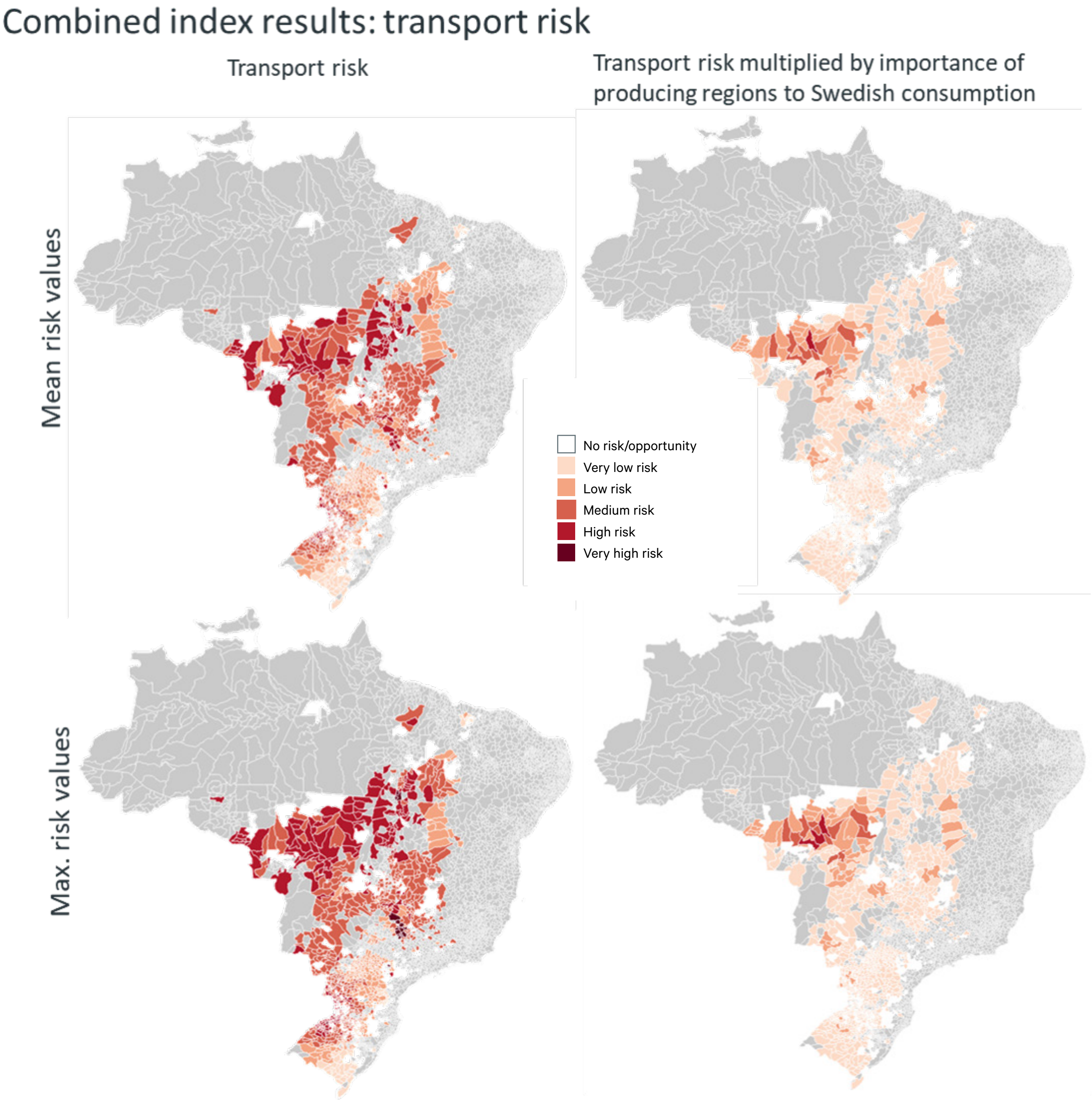


Figure 29. Combined risk values for production risk, crop predictions and drought index. To the left: combined risk values using the GGCM PEGASUS; to the right: the GGCM pDSSAT. The top maps show mean risk values; the bottom maps show maximum risk values.

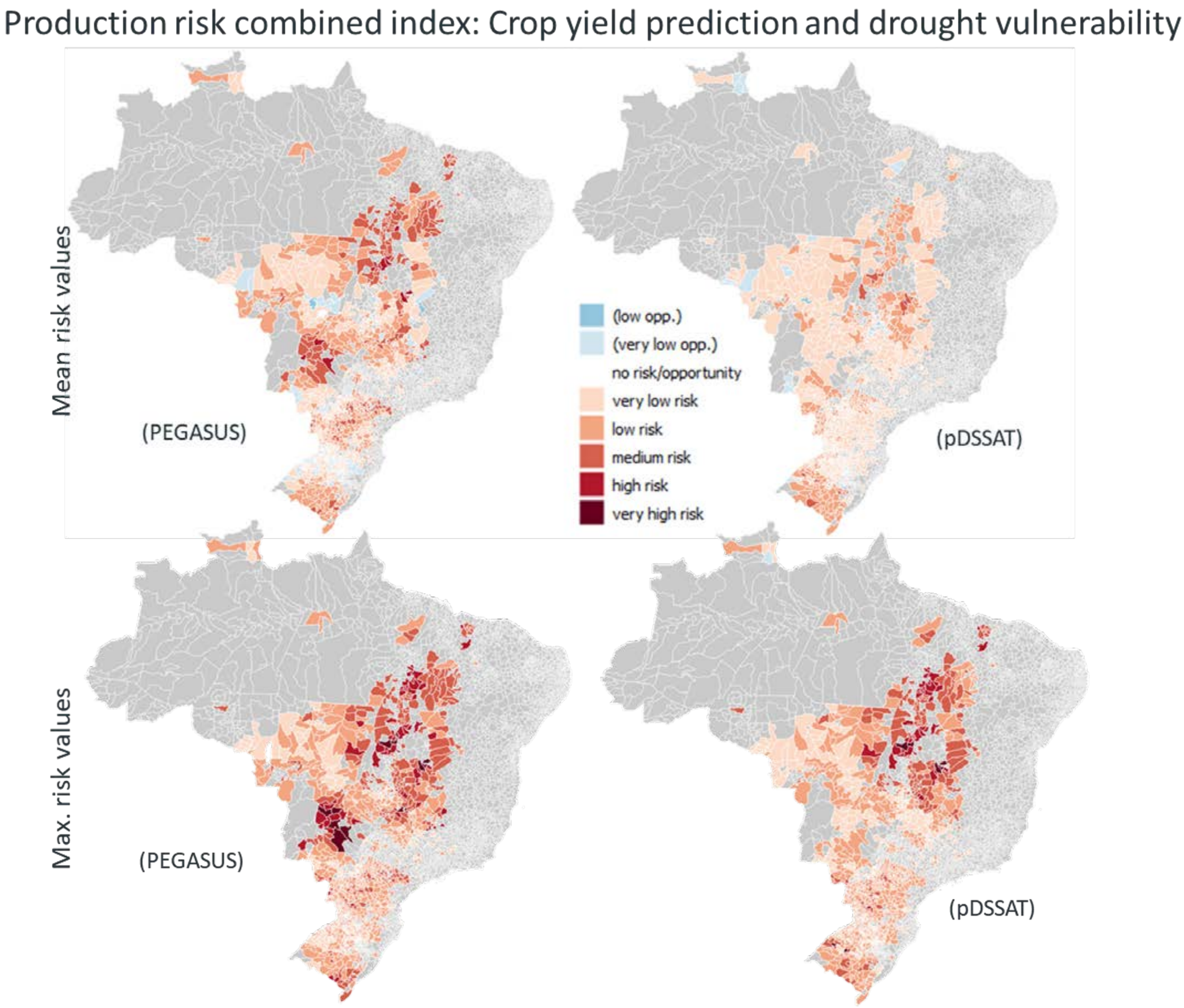


Figure 30. Combined risk values for production and transport risk. To the left: combined risk values using the GGCM PEGASUS; to the right: the GGCM pDSSAT. The top maps show mean risk values; the bottom maps show maximum risk values.

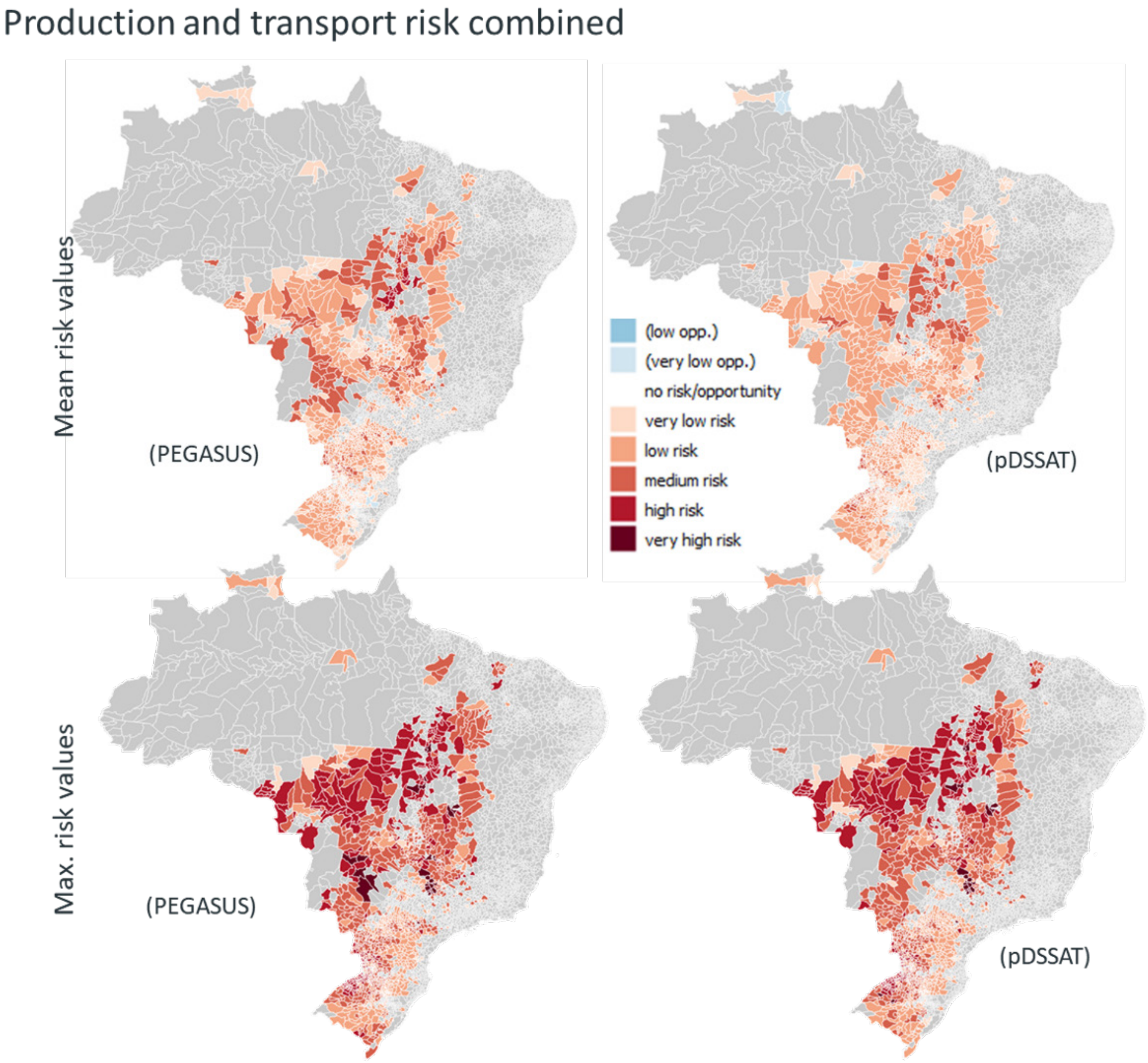


Figure 31. Total combined production and transport risk weighted by importance of Swedish producing sectors, for the two GGCMs, PEGASUS (left) and pDSSAT (right). The top maps show mean risk values; the bottom maps show maximum risk values.

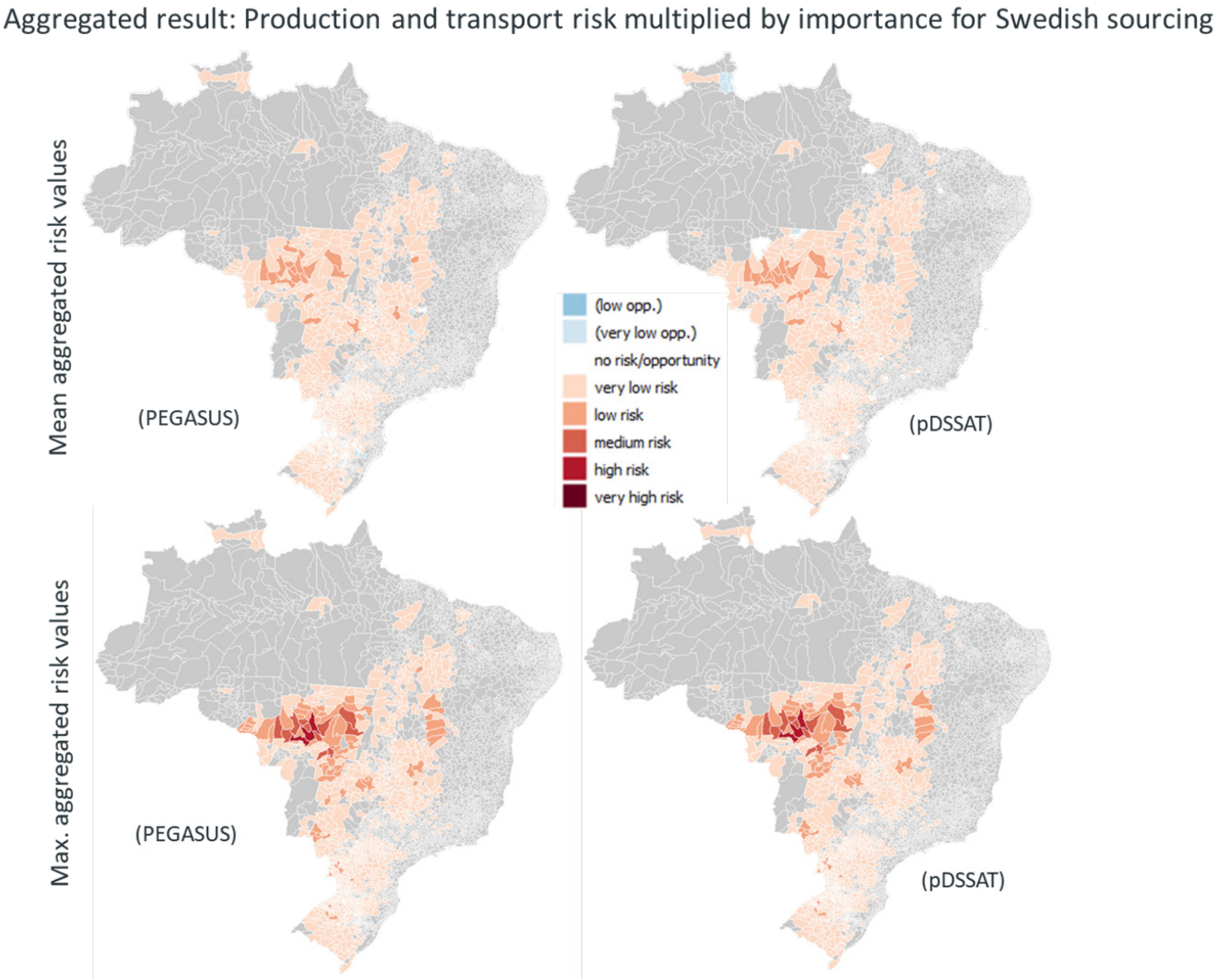
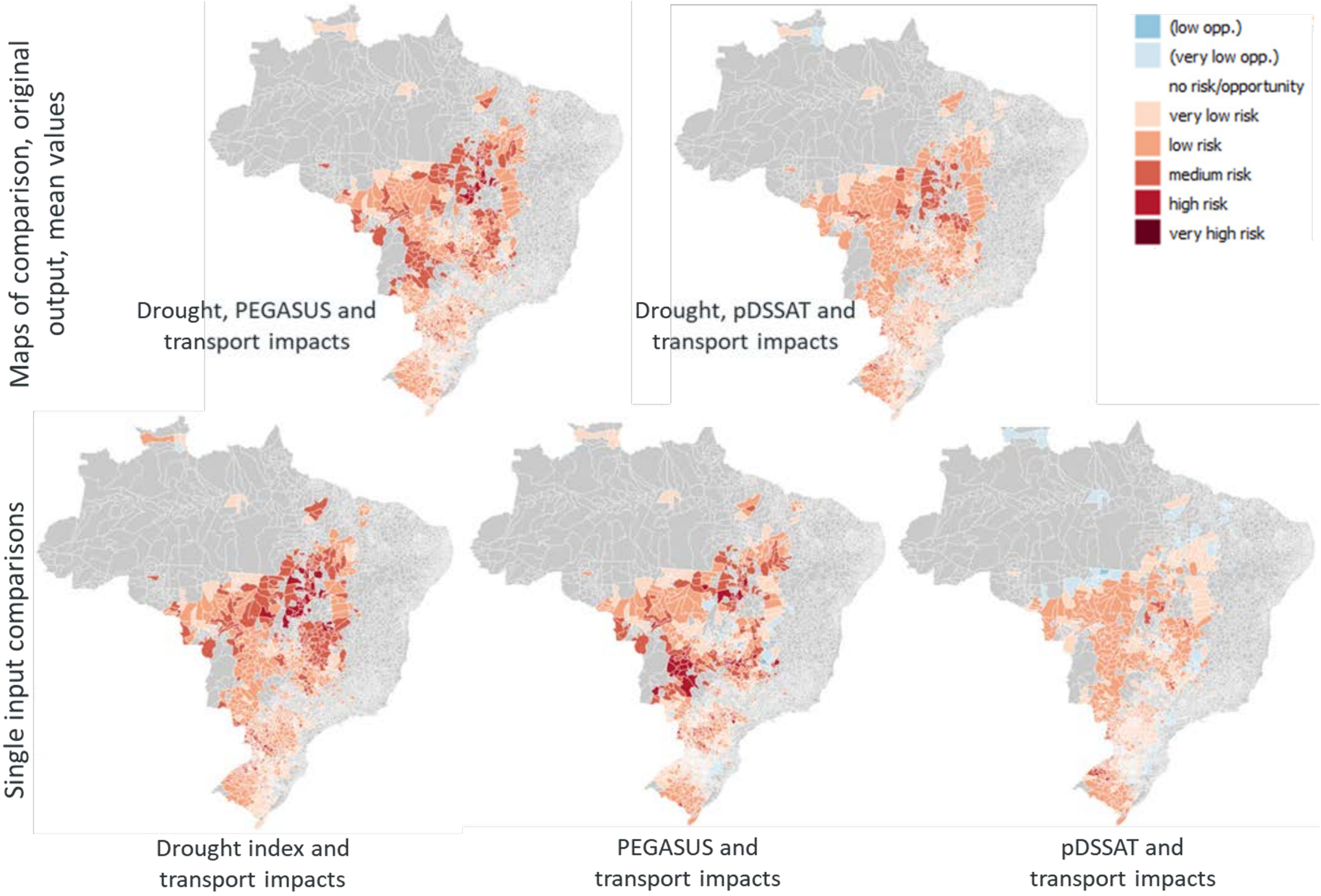


Figure 32. Sensitivity analysis for the globally gridded crop models (GGCMs) PEGASUS and pDSSAT. Comparison between datasets. Likelihood of adverse impacts (risk to production and transport “unweighted” by Swedish sourcing patterns for Brazilian soy).



Appendix 7: Policy reflections

This SEI Working Paper describes a new multi-method approach that the authors developed to provide insights on national-level exposure to transboundary climate risk via trade. During this process of method innovation and results analysis, we have made several reflections about the nature and extent of transboundary climate risk and the implications for risk governance and adaptation, particularly from a Swedish or Nordic perspective. We therefore record here a list of these personal reflections, in case they are of relevance to other researchers or practitioners in the field who may be embarking on similar processes. These reflections elaborate the points made in the Policy discussion (Section 5) and Conclusions (Section 6) of the Working Paper.

1. The near-sighted view from Sweden is reassuring

Our analysis of Sweden's trade dependencies reveals that the deepest, most stable trade links tend to be with countries that are both close to Sweden and relatively resilient to climate change. Germany and Nordic countries form the top tier of Sweden's "direct" trade profile. These partners are assessed as having the lowest level of vulnerability according to the ND-GAIN index, which we utilized in our study. After this, there is a second tier made up largely of other EU countries, with slightly higher vulnerability relative to Sweden, but still among the least vulnerable countries globally. This suggests that any marginal increases in Sweden's climate exposure that are brought about via trade (by creating dependencies on countries whose climate vulnerability is higher than Sweden's domestic vulnerability) are likely to be less significant than the advantages that are enabled through trade itself (i.e. diversification, specialization). Sweden's access to the EU single market creates close ties with stable economies that are also geographically close to Sweden. Sweden's top trade tiers are well "hedged" across relatively resilient economies, providing a reassuring view of climate risk exposure.

The governance implications of this are that Sweden should continue to work within the EU, as well as other forums for cooperation, and with its primary, most valuable bilateral trading partners such as the Organisation for Economic Co-operation and Development (OECD). The EU provides Sweden with a means for regular communication, joint action (where necessary) and mutual oversight of factors relevant to climate risk management and adaptation. Another implication is that Sweden should continue to invest in key bilateral relationships, especially with Germany and Nordic partners, to ensure that trade relationships will continue to offer a resilient, as well as efficient, source of exchange for Sweden as the climate changes.

The prospects for this are encouraging. Both the EU and key bilateral trade partners of Sweden are taking an interest in the trade-related dimension of cross-border climate risk. In the evaluation of the EU Adaptation Strategy conducted in 2018 (European Commission, 2018) the failure to address trade-related "spillover effects" from climate change was acknowledged and the recently revised EU Adaptation Strategy (European Commission, 2021) puts a greater emphasis on transboundary climate risk and the need for intra-EU cooperation on adaptation. The EU is also conducting research into the nature and scope of climate change risks for Europe via trade.[7] Meanwhile, Sweden's key trade partner, Germany, has conducted analysis of its own exposure to trade-related climate risk (Peter et al., 2020), including analysis of the effects of climate change on exports. Other "top tier" trade partners have begun this process, for example Norway (see Prytz, 2018), but without conducting detailed analysis of specific trade-related risks. Globally, it is mostly European countries, and especially Nordic ones, that have begun investigating this topic (see summary in Benzie et al., 2019) and the Nordic Council of Ministers are currently undertaking an assessment of key Nordic risks and the prospects for Nordic cooperation on adaptation to transboundary climate risk.

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[7] See for example the RECEIPT (climatestorylines.eu) and CASCADES (www.cascades.eu/) Horizon 2020 projects.

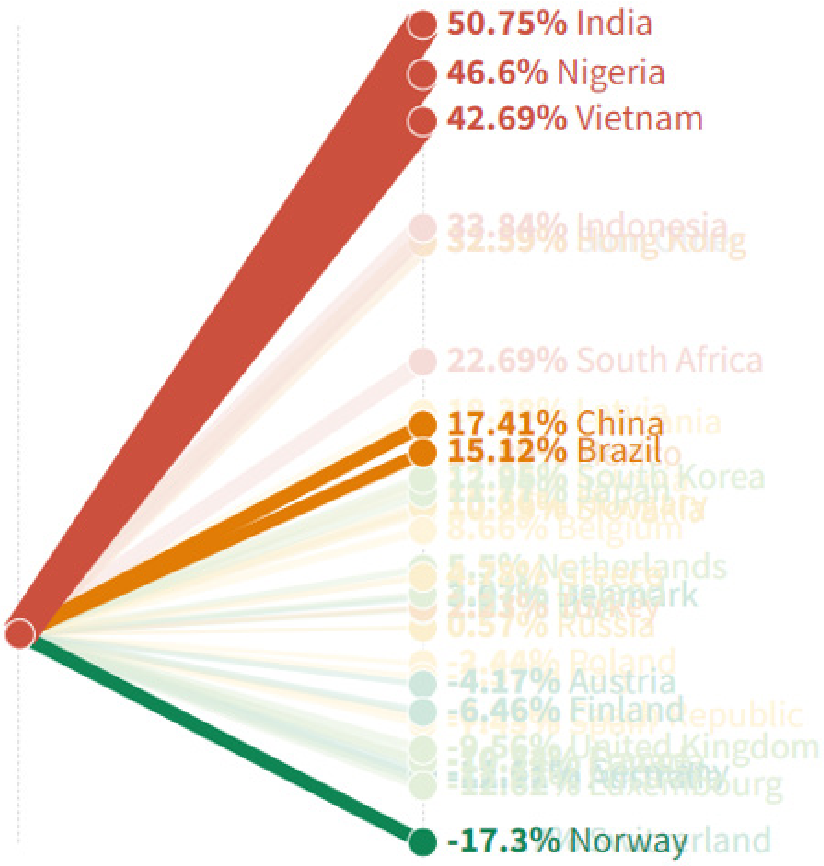
Provided that this emerging evidence base is used to inform responses that build resilience to climate risk, then Sweden's exposure via trade partners in the EU, and especially Germany, will be reduced.

2. The long-sighted view is more concerning

Our analysis has also revealed the trade links between Sweden and countries that are more vulnerable to climate change – links that are often hidden or obscured by conventional trade statistics. When we look at data on the material inputs to Swedish consumption, we see that countries like Brazil, Russia and many in Africa (for land inputs) and China, India and many others in Asia (for water inputs) are much more significant from a Swedish perspective. These countries are much more vulnerable to climate change than Nordic or most European countries are, revealing a layer of high climate risk in the third tier of Sweden's trade profile – one that is usually hidden in a statistical shadow.

When we look into the climate risk that is embedded in Sweden's trade relationships (Section 3) we see how emerging economies, which face significant adaptation challenges, become much more important to Sweden. For example, Brazil, China, India, Indonesia, Nigeria and Viet Nam emerge across various datasets as "big movers" when we add a climate weighting to measures of "importance" to Sweden via trade (see **Figure 33**). Generally, the Asia and Pacific and Africa regions become much more important to Sweden when we build in measures of climate vulnerability to Sweden's trade profile.

Figure 33. Percentage change in countries' "importance" to Sweden after considering the role of climate risk via trade.



Source: SCB data, selected countries highlighted, visualization by Lager, available at https://public.flourish.studio/story/656845/.

This amounts to a new horizon of risk for Sweden: the previously unseen risk from climate change impacts in vulnerable countries that Sweden is linked to via lower tiers of its trade network.

The governance implications of this are far-reaching. Sweden cannot pursue resilience-building via bilateral relationships with so many countries at once, and these countries lie beyond the reach of regional cooperation afforded by the EU. Instead, Sweden can only rely on a robust multilateral process to build resilience to climate change throughout its trade network.

Very few countries have yet conducted detailed assessments of trade-related climate risk. The first step, therefore, is to encourage and facilitate such assessments in other countries, mirroring what has happened in Germany, for example: to assess and communicate national-level exposure to transboundary climate risks via trade.

Mechanisms under the Paris Agreement on climate change could be utilized to this end. The Paris Agreement framed adaptation as a “global challenge faced by all” with “international dimensions”. It also introduced adaptation communications, which each Party should submit and update periodically. Adaptation Communications will be synthesized as part of the global stocktake, which will measure progress towards meeting the global goal on adaptation. Sweden should encourage other countries to adopt a transboundary and systemic framing of climate risk in their Adaptation Communications. The information disclosed in these and other adaptation documents (such as National Adaptation Plans and Nationally Determined Contributions) can be used by Parties to assess potential risks resulting from cross-border climate change impacts and the cross-border effects of national adaptation measures. Sweden should also offer both financial and technical support to other countries to embed this dimension of risk in their Adaptation Communications, via capacity building initiatives and via political dialogues to raise the issue of transboundary climate risk in climate diplomacy.

Moreover, the results of this study demonstrate why it is in Sweden’s interests to establish and possibly co-lead a new coalition to advance an ambitious global adaptation agenda. As high-income consumers, positioned at the top of global value chains, small, globalized, open, industrialized countries like Sweden have the most to lose from the increase in systemic risks to global trade networks that is likely to result from climate change. Countries like Sweden therefore have an important role to play in bringing like-minded and similarly affected countries together to address these issues more proactively in multilateral forums like the UNFCCC. Sweden is well positioned to do this given its membership of the EU, the relatively high levels of trust Sweden enjoys on the world stage and its active participation and proven commitment to multilateralism.

3. Zooming in to specific supply chains raises new questions

This study looked in detail at the climate risks to Swedish consumption of agricultural exports from Brazil. Brazil emerged from our global analysis as a significant and increasingly strategic trade partner for Sweden, due to the important role it plays in providing material inputs to Swedish consumption – not least via its crucial role in the production of several agricultural commodities, but also as an increasingly significant recipient of Swedish foreign direct investment. Zooming in on the soy trade link between Brazil and Sweden revealed multiple points of risk and therefore multiple potential points of intervention to improve climate risk management in the supply chain. This raises new questions for adaptation by Swedish actors. In particular, who can do what, where, to improve climate risk management?

Within Sweden, “imported climate risks” could be reduced if import-dependent consumption were reduced. For example, if Swedish diets changed to become less dependent on soy (i.e. lower meat and dairy consumption, or reduced consumption of products that contain soy as an ingredient), then the overall magnitude of climate risks in the soy supply chain would be lower. This might be brought about, in theory, through regulation that disincentivizes food and drink products with “high climate risk” supply chains. Alternatively, Sweden could, again in theory, produce soy or alternative high-protein feed and oil crops domestically, thus reducing demand for import, and thereby reducing the magnitude of the risk.

However, both of these risk management options are problematic. It is unclear to what extent state regulators could legitimately seek to influence private decisions about food consumption on the grounds of managing climate risk (as opposed to health risks, for example). However, there may be synergies with seemingly more legitimate objectives for regulation, for example to incentivize more nutritional, more sustainable consumption, which may, coincidentally in many cases, overlap with more localized, less “climate risky” diets. The post-war status quo in Sweden, like much of Europe, in which the consumption preferences of autonomous consumers are largely established and met through liberalized international markets, is unlikely to be challenged because of real or perceived increases in the level of risk present in supply chains, at least in the short to medium term.

A more pragmatic barrier is the suitability of the Swedish climate and agriculture sector to efficiently produce feed and oil crops. A policy to reduce import dependence for animal feed and oil crops, for example, would likely lead to significant price increases and stiff political opposition.

Swedish food and drink companies and commodity traders supplying the Swedish market could seek to substitute high-risk supply chains, for example Brazilian soy, with alternatives. Two options present themselves, in theory: first, reform of the European Common Agricultural Policy (CAP) to incentivize increased production within the EU of commodities that are deemed critical to Swedish consumption; and second, diversification of trade partners to hedge the risk of climate impacts affecting the price and availability of imports.

The diversity of growing climates within the EU, coupled with the institutional capacity of the CAP, offers a valuable resource for the resilience of European food security in a changing climate. However, there are limits to the production capacity of European agriculture and cost implications of importing EU-grown commodities over those grown outside the EU. There are also climate risks associated with agricultural trade within the EU (particularly for crops that require tropical growing conditions, such as soy, which would need to be produced in parts of the EU that face severe water stress as a result of future climate change), notwithstanding the political challenges associated with CAP reform.

A strategy of substitution assumes that existing supply chains can be quickly, easily or cheaply initiated or abandoned. The truth is, however, that many commodity supply chains are “sticky”; institutional factors, such as commercial relationships, contracts and even infrastructure dependencies inhibit the agility of importers and prevent tactical and low-cost substitution decisions as a way to manage supply chain risk (see dos Reis et al., 2020). This is the case for Swedish imports of soy, which are dominated by the AMAGGI Group via imports to Norway, linking Swedish consumers to particular areas of Brazil where AMAGGI operates (particularly in the state of Mato Grosso). It is not accurate to assume that Swedish food and drink companies could easily and cheaply substitute Brazilian soy with soy imports from another producing country, or even other “less risky” parts of Brazil, in response to changes in climate risks at the farm level in states like Mato Grosso.

How, then, can Swedish actors manage climate risk through measures taken outside Sweden? Perhaps Sweden-based actors can take steps to reduce the overall volatility of soy prices by “managing the market”. As extreme weather events in producer countries can have an impact on export volumes, which historically has led to export restrictions (Freitas, 2016; Polansek et al., 2018), perhaps Sweden could work with other affected countries to better enforce existing World Trade Organization rules to prevent export bans. Or to better regulate the role of financial products and futures markets on commodity price volatility. Perhaps Sweden-based actors could cooperate with others to increase critical commodity storage (stockpiles), either in Brazil or within Europe, to dampen the effect of production shocks on international prices.

These measures hold some promise, though they require recognition by a number of other actors that climate risks to trade are significant and strategic enough to warrant enhanced cooperation and transnational or global governance. This again raises the incentive for Sweden to champion the issue of transboundary climate risk among its global partners, in order to encourage greater multilateral engagement on climate change adaptation.

The challenge is significant, though. Many influential global actors currently assume that supply chain risk is and can be adequately managed by commercial actors who operate supply chains daily. Proactive, strategic management of supply chain risk via intergovernmental governance is assumed to be unnecessary in a liberal market-oriented trade system. The current political deadlock within the World Trade Organization suggests that agile climate risk management involving governments within the trade regime remains a distant objective.

Can Sweden-based actors engage on the ground in countries like Brazil to manage climate risks affecting Swedish consumption? At a conceptual level, in a sticky supply chain within a complex global trade regime, perhaps the simplest way to avoid exposure to climate risks in importing countries is to implement adaptation measures directly at vulnerable points in the supply chain. For example, adaptation measures to increase the resilience of soy farming to drought and heat stress will help to avoid production shocks. Enhancing the resilience of the inland road network in Brazil to landslides and floods will reduce the risk of disruption between farm and port. Can Swedish consumers help Brazilian farmers to cover the costs of adaptation and thereby secure their soy lattes and s*mörstekta raggmunkar med fläsk*?

Certainly, awareness of the interdependence between Swedish consumers and Brazilian farmers could raise the incentives for cooperation and burden sharing in the pursuit of climate resilience. But on what basis, via what mechanisms and with what implications for justice and legitimacy might this co-adaptation occur?

As this report has revealed, modern supply chains are often complex and the true links between producers, inputs, processors, traders and consumers are often hidden from decision-makers in statistical shadows. One way in which soy consumers are linked to producers, though, is via existing certification schemes, whose primary objective is to increase accountability for deforestation in the Amazon and Cerrado by certifying commodities that are “deforestation free”, while also considering various other social and environmental dimensions, such as labour rights and biodiversity protection. Where they exist, such schemes may evolve to facilitate and perhaps share the burdens of adaptation between consumers and producers.

The nature of the “risk” targeted by existing certification schemes differs in important ways from the risk of climate change to production. Deforestation, habitat destruction, labour and indigenous rights infringements are driven by consumer demand for cheap commodities, as well as the regulatory risk that lenders and retailers might be exposed to as a result of infringements of workers’ rights or the environment throughout their supply chain. They occur primarily at the point of production (and processing, transport, etc.), but responsibility is assigned at the consumption end of the chain, via the companies that process commodities into products, as well as investors and traders. Climate risks to production are driven by pollution of the atmosphere globally (a much more diffuse driver); the risks also occur at the point of production (and processing, transport, etc.), but responsibility is assigned to producers and lower tier suppliers in whose interest it is to adapt (e.g. in order to make profit, or to adhere to the terms of supply contracts). Thus, certification schemes have evolved as instruments to trace responsibility from consumers *down the supply chain*, whereas climate risk manifests at the production end, and is transmitted *up to consumers*. Certification schemes have not traditionally been used to manage risks “up” the supply chain, though innovative new applications of these “governance instruments” could help to incentivize and facilitate adaptation too. Deforestation, however, will remain the primary driver of sustainability governance in commodity supply chains in the Brazilian context: climate risk management is likely to remain an afterthought.

Other options for Sweden-based actors to invest in the resilience of Sweden's supply chains include: private investment from Sweden to build the climate resilience of trade-related infrastructure, and public investments via bilateral and multilateral channels to support adaptation in Brazil.

There is an active discussion on the role of private adaptation finance in vulnerable and emerging countries. Key issues include the missing incentives, oversight and tracking of private adaptation funds that would be needed to leverage the full potential for private finance for adaptation. Nevertheless, increasing commercial ties between Brazil and Sweden suggest that there may be investments from Sweden-based actors in sectors of the Brazilian economy that might contribute to the resilience of agricultural commodity supply chains. For example, Swedish banks could fund large infrastructure improvement projects, such as road, rail and inland waterways, which indirectly reduce transport risks from soy farm to port.

Sweden contributes significantly to bilateral and multilateral adaptation funds, financing adaptation projects on the ground in a number of priority countries, though Brazil is not one of these. This raises a difficult question: will import-dependent countries (like Sweden) divert a share of their adaptation finance to reduce *their own* risk exposure as they become aware of the extent and scale of transboundary climate risks?

The provision of adaptation finance is motivated by several factors. Chief among these is the historical responsibility of large emitters and the principle of equity. Industrialized countries played a disproportionate role in creating the climate risks that particularly vulnerable countries now face. These countries are both least responsible for causing climate change and least able to adapt to its impacts. This implies that a country's vulnerability should determine its eligibility for adaptation finance. Ratification of the Kyoto Protocol and the Paris Agreement under the UNFCCC also provides political reasons for contributing to international adaptation finance. But self-interest has not been a stated objective of adaptation finance provision. Therefore, with what legitimacy might an import-dependent country seek to support adaptation in a country because of mutual trade links? And what might be the effects on other, potentially more vulnerable countries, if a limited (and insufficient) supply of adaptation finance was used strategically in this way to protect donors' self-interest (see Dzebo & Adams, 2022).

This is one reason why the dispersal of adaptation finance should be administered via multilateral funds, which should reduce the scope for strategic allocation by individual states based on self-interest. Sweden must remain committed to fair, equitable and legitimate mechanisms for providing adaptation finance to vulnerable countries. But at the same time, it may also pursue *new and additional* ways to support adaptation in other countries that also face severe climate risk, even if they are not the most vulnerable globally. This can be achieved both by directing and orchestrating private finance flows for adaptation, and through the provision of public investments to meet the demand for adaptation at the local level in countries like Brazil. Adaptation support should always reflect locally determined objectives, rather than self-interest, and must also adhere to the principles of legitimacy, equity and fairness in its design and implementation.

Specifically, countries like Sweden should aim to facilitate "just resilience" by ensuring that they support adaptation to transboundary climate risk in ways that leave no one behind, building resilience to climate change throughout global supply chains and refraining from adaptation measures that "abandon" risky suppliers (see Lager et al., 2021).

What other options might Sweden-based actors have at their disposal?

Given the dependence of Sweden on Norway for the majority of its soy imports, and the similar trade profiles and challenges faced by neighbours in the region, a coordinated Nordic approach to managing supply risks may hold promise. For example, Sweden is already de facto embedded in Norwegian governance of deforestation risk in the supply chain via its dependence on Norway's standards on non-genetically modified (GM) soy imports (Sweden imports most of its soy via Norway). Cooperation with Nordic partners, who have a similar willingness and ability to pay for premium soy (e.g. non-GM soy, non-deforestation risk soy and, potentially in future, more "climate-resilient" soy), for example, might enable direct funding to soy producers to build resilience in the soy supply chain. Cooperation to set new standards for soy that incorporate climate resilience may also be possible. Working together may increase the influence that Nordic countries are able to wield in negotiating new supply contracts from regions that are likely to be more resilient to (or less affected by) drought and other climate impacts. Sweden's Nordic neighbours are also among the most advanced countries in recognizing their high exposure to transboundary climate change risk; Finland and Norway were among the first countries globally to commission studies of this dimension of climate risk (see Benzie et al., 2019), which indicates that their awareness and capacity to engage in cooperative measures to manage such risks will be higher than in other countries.

The space for Swedish or even Nordic engagement in climate risk management via trade is likely to remain constrained, however. The global trade system is a theatre of geopolitics. Larger forces than supply chain management are at play and efforts to improve the climate resilience of supply chains may be overshadowed by (and therefore need to work within the context of) geopolitical rivalries and tensions, which themselves might be stoked or challenged by climate change impacts. For example, soy trade became a pawn in the recent "trade war" between the US and China. Such events can have disruptive effects on global markets and severely restrict or altogether reverse the efficacy of adaptation measures, if they alter the overall structure of international markets.

Similarly, Sweden will not be the only importer seeking to adapt to heightened climate risk in supply chains. Competitors will be utilizing their capacities to adapt, including potentially in ways that directly interfere with Sweden's preferred responses. For example, soy import-dependent countries may seek to exert diplomatic or commercial influences to secure access to the most resilient sources of Brazilian soy, or sources of soy production in other countries. The relatively low vulnerability of current Swedish sourcing of Brazilian soy cannot therefore be taken as a constant. For example, China currently sources Brazilian soy from locations that are more exposed to higher drought risk than the areas supplying Sweden. Entire supply chains will change as multiple actors adapt simultaneously to the same triggers of risk.

The future for agricultural commodity importers is therefore uncertain. Climate change is one of many key drivers that threaten the stability of international supply chains. Depending on the extent of future climate change impacts and the success of international cooperation to facilitate adaptation, the viability of some supply chains – and the business models of food retailers and consumption patterns of society that have evolved in the post-war period – may be threatened.

Finally, an alternative approach would be to just do nothing. A *laissez-faire* approach to adaptation in market-driven trade networks would be to allow private actors to adjust their decisions and strategies in response to price and other information signals (including those sent by their investors and insurers) about the changing nature of risk in supply chains. Private companies manage the vast majority of Sweden's imports and exports daily. They are literate in risk and naturally think beyond borders. In this way they tend to differ from governments and other public sector agencies and actors whose focus and remit is territorial. Both companies and consumers will adapt autonomously; those exposed to high risk will adapt or fail and consumers will change consumption patterns if prices rise. This approach may require the tweaking of regulatory guidelines, for example to include climate risk in non-financial risk disclosure regulations. But it would not require any proactive management by the government.

Such an approach is feasible, and perhaps foreseeable, but it would also come with some expense. From an international perspective, effective risk management in one place (i.e. the successful reduction of risk exposure in Sweden), such as the sale of high-risk assets or the reconfiguration of a supply chain away from high-risk producers, may redistribute risk to other places (e.g. to other trade partners or consumers who remain within the "risky" network). Or it may even exacerbate vulnerability to climate change (e.g. if traders abandon high-risk soy producers, who then struggle to generate income from sales and therefore lose adaptive capacity to face the impacts of climate change on their livelihoods). As such, "effective" adaptation by private actors (e.g. in Sweden) may in fact exacerbate the vulnerability of communities in other countries. This undermines Sweden's development cooperation objectives and the attainment of the Sustainable Development Goals. It might also create feedbacks that harm Sweden's interests, for example by exacerbating risk in financial markets, disrupting other supply chains or driving conflict, international migration or geopolitical instability. The concept of a "just transition" for climate change adaptation is therefore key for researchers, planners and diplomats to consider (see Lager et al., 2021).

A strategy of autonomous adaptation may also have negative side effects closer to home. Relying on price signals to dictate adaptation may, in extreme cases, mean that private consumers have to absorb massive price spikes, for example supermarket shoppers in the event of major price crises on staple commodities like wheat or sugar (affecting the price of all products in which these commodities are embedded), or sensitive imports such as fruit and vegetables. This can threaten the food and nutritional security of Swedes, especially those on low incomes, worsening domestic inequality. Transboundary climate-driven impacts on food security have already been observed among low-income groups in high-income countries such as the UK (Challinor et al., 2018). Blanket exposure to price signals may also lead to bankruptcy among many small- and medium-sized companies in Sweden that might be unaware of their exposure to supply chain climate risks. Such companies are, therefore, unable to adapt, leading to unemployment, with resulting stress on social stability and well-being in affected households. This might even affect major companies, leading to economy-wide impacts at the local and regional scale where affected sectors are concentrated.

Beyond "adaptation"

The measures that have been briefly summarized above as offering potential solutions to this set of risks go beyond what we currently classify as "climate change adaptation". No such measures are currently identified in Sweden's National Adaptation Strategy, for example. In light of new trade-related climate risks, countries like Sweden need to re-think what adaptation is, how adaptation decisions should be informed by analysis and who should be involved in planning and implementing adaptation.

This is a potentially daunting new challenge, given the complexity inherent in modern trade networks and supply chains, and given the limited remit of the nation state to manage these processes. Nevertheless, these new questions arrive at an opportune moment for Sweden, which is currently revising its National Adaptation Strategy.

A national adaptation strategy should identify all of the climate change impacts that will affect a country's well-being and it should identify and assess potential adaptation measures to reduce negative effects and seize opportunities. For a globalized, open country like Sweden, this clearly includes climate change impacts that originate beyond national borders, including, crucially, those transmitted via international trade.

This study has explored the nature of Sweden's links and flows via trade with countries around the world. It has shown that Sweden is linked to countries that are much more vulnerable to climate change impacts than Sweden itself, suggesting that Sweden's total climate risk exposure is increased as a result of its trade connections. The new adaptation strategy must recognize this dimension of exposure and identify adaptation options – and the specific actors who hold responsibility for adapting to these risks.

But Sweden enjoys a diverse set of trade partners, many of which are relatively resilient to climate change, and will therefore be able to hedge and distribute its exposure across a number of countries, bringing flexibility and resilience through its participation in trade networks. But the resilience of those networks will be a key factor in Sweden's overall risk exposure, so Sweden has a clear interest in cooperating and investing in adaptation globally. Building climate resilience in international trade networks is too great a task for any individual country, and so Sweden's National Adaptation Strategy should also articulate the importance of international cooperation and multilateralism to Swedish adaptation.

As the world emerges from the COVID-19 pandemic, during an era in which the lure of nationalism and isolationism is on the rise, leadership and facilitation is needed to renew a multilateral approach to protecting global public goods and reducing systemic risk. Building resilience in the global trade system to future shocks is a clear and unifying priority. While the role of climate change as a magnifier of systemic risk in global systems is still under-appreciated in most policy forums, Sweden has an opportunity and perhaps an obligation to spearhead political processes to build climate resilience internationally.

This study has explored the nature of trade-related climate risks facing Sweden. It has attempted to push supply chain climate risk assessment to the current boundaries of what is possible, given data constraints, with an in-depth study of one critical supply chain (Brazilian soy). In doing so it has arrived at a set of insights that currently outstrip the demand for such information among decision-makers, who are perhaps only beginning to realize the relevance of transboundary climate risk to the stability of their operations and organizations.

The results can be used to motivate a new generation of adaptation planning – one that engages with the challenging reality of risk in a globalized world. Two overarching conclusions stand out:

- There are limits to substitutability in volatile systems.
- Systemic risk is subtle and hard to measure or even conceive when using traditional methods.

Together this constitutes a new risk horizon for Sweden. But Sweden is well placed to push forward as a pioneer in this new adaptation landscape.

The limits of substitutability in a volatile and risky system

It is likely that some level of climate change impact can be absorbed and adapted to in many countries, but that the residual effects will lead to the reconfiguration of certain markets and supply chains as a result of autonomous adaptation.

In order to capitalize on these autonomous changes, import-dependent countries simply need to respond to market signals and stay open to new trade relationships. Avoiding over-dependence on a small number of trade partners would likely reduce disruption. In this sense, Sweden is well placed to benefit from its openness and its current diverse set of trade partners inside and beyond the EU.

However, climate change is a risk driver that will be occurring everywhere at once. There will be spatial differences in the impacts and damage caused by climate change due to variations in exposure and adaptive capacity. But the phenomenon of climate change is truly global and this constrains the space in which countries high in the value chain will be able to substitute highly vulnerable trade partners with more resilient ones.

The further we see into Sweden's trade profile, using innovative, alternative data to reveal new insights on trade dependence beyond the first tier, the more trade links are revealed, with a greater number of countries. Our investigation into Sweden's consumption of Brazilian soy also suggests the "stickiness" of certain trade relationships and the high transaction costs of substituting risky suppliers in the hope of finding more resilient ones. Both this expansion in the number of vulnerable lower tier trade partners and stickiness of certain trade links imply that substitution in practice may not be as feasible an adaptation response as is often assumed.

The nature of systemic climate risk

One way to interpret the results of this study is that Sweden is likely to be relatively well insulated against *low magnitude, high likelihood* risks in the global trade system that result from climate change. This is on account of its diverse trade portfolio and the relative resilience of its primary trade partners. But Sweden might be much more exposed to *high magnitude, low likelihood* risks because of its deeply embedded position high in the value chain.

There is a cumulative nature to risk in complex hierarchical systems, much like in a food web. In polluted water, small amounts of heavy metals concentrate in plankton and aquatic invertebrates, but higher concentrations build up in the predatory species that consume these organisms, potentially reaching toxic levels when humans consume top predators, like tuna. Similarly, economies like Sweden that are high in the global value chain may *accumulate climate risk*. The Swedish economy is characterized by an import-dependent, export-oriented manufacturing sector and as final consumers of highly processed food and manufactured consumables. Climate risk is concentrated at each stage of the supply chain, from the climate-sensitive material inputs of land, water and commodities, along value-adding manufacturing processes to the point of consumption in Swedish households and hi-tech assembly facilities. In a world experiencing extreme climate change, this level of climate risk may reach toxic proportions.

This cumulative, systemic climate risk is hard to identify and assess in detail. It is implied by the climate-weighted analysis of Swedish trade links conducted in this study, which shows the increasing relevance of more distant and climate-vulnerable countries at lower tiers of Sweden's trade portfolio. This raises the prospect of climate change contagion in the Swedish economy because of the systemic nature of climate risk in international trade.

The governance implications are challenging at both the internal and external levels for Sweden. They suggest the importance of an adaptation pathway characterized by flexibility and innovation domestically and cooperation internationally.

Equipped with insights from studies such as this, Sweden should be able to navigate these new risk horizons and contribute to building climate resilience globally to the benefit of all.

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