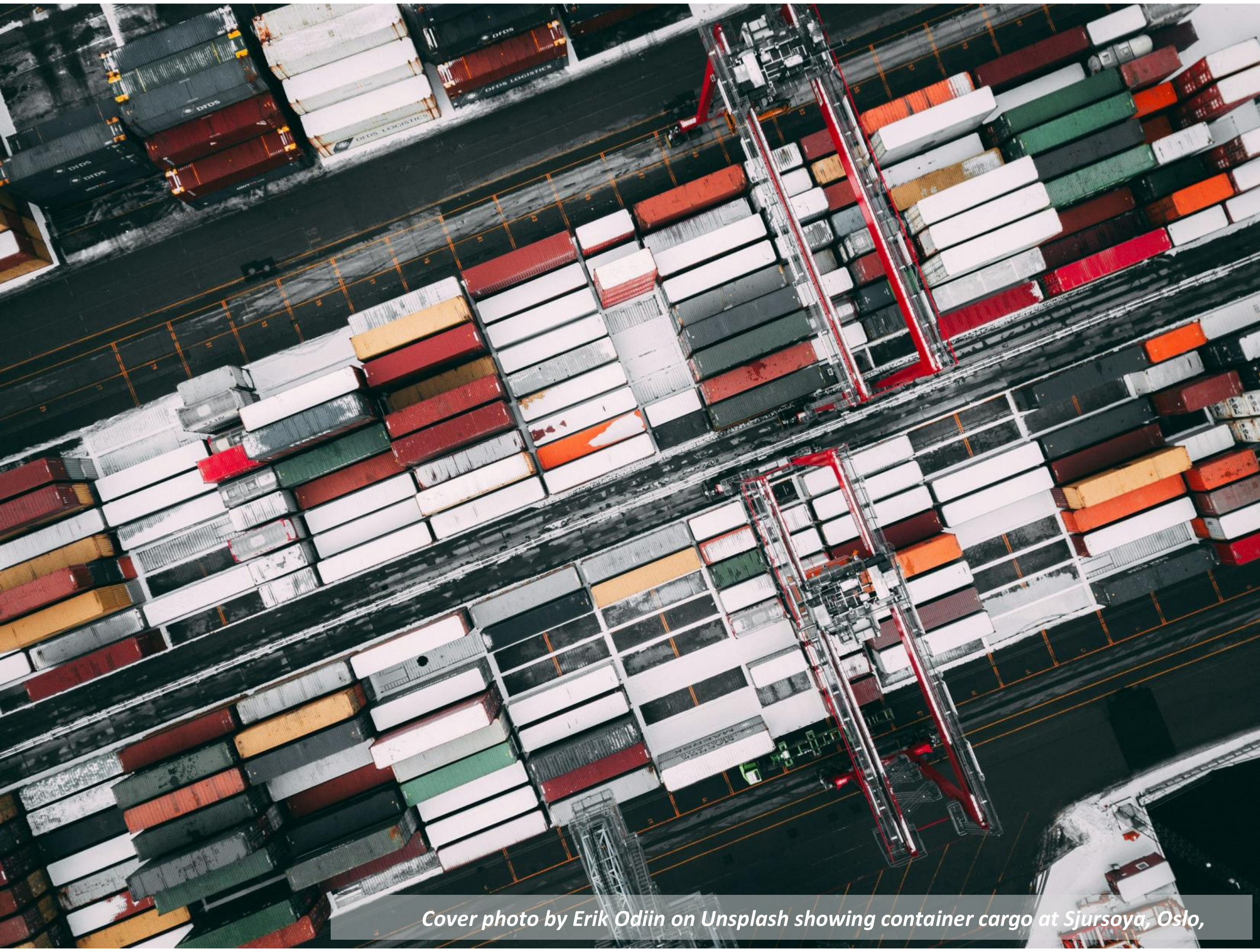
Cover photo by Erik Odiin on Unsplash showing container cargo at Sjursoya, Oslo,

Cross-border and cascading climate risk in Norwegian food systems: a data summary report

Author: Frida Lager, Stockholm Environment Institute (SEI). April 2025.

Abstract

Norway's food security is increasingly exposed to cross-border climate risks due to its reliance on imports from climate-vulnerable regions. This study quantifies Norway's embedded dependencies in global food systems by analyzing trade-linked water use, land use, and biodiversity risks under climate change. Using spatially explicit data on production origins the report identifies key vulnerabilities in countries like India, Brazil, and Russia, which taken together supply over 66% of food consumed in Norway. Results highlight disproportionate exposure to water scarcity in Pakistan, deforestation-linked soy from Brazil, and biodiversity risks in species-rich regions. By framing these dependencies through a climate-risk lens, this work provides actionable insights for policymakers to build resilience in interconnected food-trade systems. The methodology combines descriptive trade statistics, geospatial risk mapping, and consumption-based accounting, advancing approaches from Adams et al. (2021) and Lager & Benzie (2022).

Key messages

- **High Import Dependency:** Over 60% of Norway's food consumption is reliant on foreign production, exposing the country to climate risks in exporting regions.
- **Water and Land Use Risks:** Norwegian food consumption is linked to significant water stress and land use change in major supplier countries such as Brazil, India, and China.
- **Deforestation and Biodiversity Impacts:** Key commodities, including soy, coffee, and beef, contribute to deforestation risks and biodiversity loss in tropical and semi-arid regions.
- **Cascading Climate Risks:** Climate-related disruptions in food-producing regions can propagate through trade networks, affecting Norwegian food security.

Introduction

In an era of increasing climate disruptions and geopolitical tension food security is no longer a national concern, but a deeply interconnected global issue (FAO 2022; IPCC, 2023). The effects of climate change – ranging from extreme weather events, to shifts in water availability and land degradation – have profound implications for food production and trade (Ibid). Recent global events, including Covid-19 and Russia's full-scale invasion of Ukraine, have further underscored the interplay between trade dynamics, climate change, and food security (Jia et al. 2024; Laborde et al., 2020). Norway, a country with a high reliance on imported food, is particularly exposed to these transboundary risks.

Climate risks do not exist in isolation; they interact with socioeconomic and environmental factors to create cascading effects that extend across borders. Cascading climate risks refer to situations where climate-related shocks in one region trigger disruptions in food production, trade flows, and economic stability in another (Pescaroli and Alexander, 2018; Challinor et al., 2018). These risks can manifest through multiple channels, including reductions in crop yields due to droughts or extreme temperatures, supply chain disruptions from infrastructure disturbance and damage, and shifts in global commodity prices impacting food affordability and accessibility (Moseley and Battersby, 2020). Given Norway's dependence on food imports, particularly from climate-vulnerable regions, it serves as a case study to understand how these risks can impact at the national level and what adaptation strategies can be utilized to mitigate them.

Water scarcity poses a significant challenge globally already today and will be exacerbated by climate change and agricultural expansion alongside competing demands for water resources driven by population growth and urbanisation, energy production, minerals extraction and processing, and unsustainable water management practices. According to the latest IPCC assessment already today approximately half of the world's population experiences extreme water scarcity for parts of the year, exacerbated by hotter temperatures and extreme events with severe impacts observed across Africa, Asia, Central and South America, Least Developed Countries (LDCs), Small Islands and the Arctic (IPCC, 2022).

Aside from water use, the interplay between land use, climate change, biodiversity, deforestation, and ecological resilience profoundly shape the dynamics of global food production systems. Land use change, including through agricultural expansion, exert significant pressure on ecosystems, leading to deforestation and habitat destruction (IPCC 2022, Richardson et al. 2023). This, in turn, has adverse effects on biodiversity, as numerous species lose their habitats and face extinction threats. Biodiversity and habitat loss weakens the ecological resilience, diminishing ecosystems' capacity to withstand stress and function in providing ecosystem services including food production (ibid.).

Climate change further exacerbates these challenges, altering precipitation patterns, increasing the frequency and intensity of extreme weather events, and disrupting temperature regimes crucial for agricultural productivity (IPCC, 2022). Such changes have far-reaching implications for global food security, as they directly impact crop yields, water availability, and the spread of pests and diseases. In turn, deforestation exacerbates climate change by releasing carbon stored in forested areas and reducing the capacity of ecosystems to sequester carbon dioxide from the atmosphere (Li et al. 2022).

Maintaining and reinforcing ecosystem resilience will be crucial to mitigate the adverse effects of these interconnected challenges on food production systems globally. Understanding the use and impact on land for Norwegian food systems and dependencies can help inform policy and actors of key considerations that are needed to be taken into account for adaptation action in interconnected systems to contribute to resilience on a broader scale.

This report examines the environmental and climate risks embedded in Norway's food system by providing a data analysis of key trade dependencies, water and land use footprints, and projected climate vulnerabilities in major food-producing regions critical for Norwegian food consumption and imports. While climate change is a central focus, this report also considers broader environmental pressures, including deforestation, biodiversity loss, and water resource depletion, critical for understanding the full scope of food system vulnerabilities in a future facing multiple ecological crises (Springmann et al., 2018; Richardson et al. 2023; Steffen et al., 2015). By integrating these dimensions, the report aims to fill a gap in national climate adaptation strategies by linking global risks to domestic food security planning.

Using high-resolution trade data, climate modelling, and geospatial assessments, we identify core vulnerabilities in Norway's import-dependent food system that can inform pathways for adaptation and resilience-building. Key questions addressed in this report are:

- What are the main environmental risks associated with Norwegian food imports and consumption?
- How do climate change and resource constraints in supplier countries affect Norwegian food security?

Report purpose and structure
This report serves as background material for workshop dialogues and provides context for policy analysis within the TransAdapt project (2021-2025), funded by Noradapt. It consolidates publicly available and previously published data resources and methodologies. The primary objective of this report is to present these readily accessible data and methods in a streamlined format, offering a basis for analysis critical to generating insights through further research, analysis, and dialogue with policymakers, researchers in related fields, and industry stakeholders seeking to enhance Norway's food system resilience in a rapidly changing global climate. In addition, Norway's situation offers valuable lessons for other countries with similar food import dependence, particularly in Europe and beyond, as they navigate the complex interplay of climate risk, trade, and food security.

Structure
This report consists of two distinct parts, first it begins with a macro-level analysis of Norway's food import dependencies, water use, and land use and biodiversity risks, providing a foundation for understanding cross-border climate exposures. In the second section, two deep dives are hereafter included—focused on wheat/soy and key globally traded crops—offering granular insights into commodity-specific vulnerabilities. The two sections utilize entirely separate methodologies and after giving a general overview of the data and analytical frameworks utilised, to facilitate for the reader each section methodology is described separately in each sub-section chapter.

These two sections are designed to support TransAdapt project workshops by enabling stakeholders to prioritize adaptation actions (e.g., supplier diversification, due diligence). The deep dives illustrate how climate risks manifest in critical supply chains, such as heatwave-driven yield losses in Russian wheat or deforestation-linked soy from Brazil. By contextualizing these examples within broader trends, the report bridges issues of systemic risk awareness and ownership discussions, with actionable, commodity-level information.

Methodology

This report utilizes previously published quantitative methodologies and publicly available datasets to assess climate change and associated environmental risk to food consumption in Norway, trade flows, and climate change and environmental risks. Together these datasets provide a geospatial overview of Norway's core dependencies within the food sector and associated environmental risk, of use to further research including in stakeholder dialogues and risk assessments. This section outlines the methodological framework and data sources used to examine Norway's food import dependencies and associated environmental vulnerabilities under climate change.

Data sources

The study relies on multiple best-in-class databases and scientific assessments, all publicly available and previously published, listed below:

Trade flows and dependencies:

- **CommodityFootprints (2024):** Providing high-resolution data on embedded food trade, including total tonnage, water use, scarcity weighted water use, land use, land use with species richness, and deforestation risk per commodity. Using methodology developed in **Lager and Benzie (2022).**
- Adams et al. **(2021):** Global assessment of Previous assessments of transboundary climate risks in food trade. Later adjusted for the Nordic countries (including Norway) in **Beringer, Lager et al. (2022)**
- **In-dept anaylsis of cliamte risk for Norwegian embedded wheat and soy consumption following methodologies developed in Lager and Benzie (2022).**

Data sources: Climate risk

- **ND-GAIN Climate Vulnerability Index:** Used to assess climate exposure, sensitivity, and adaptive capacity in Norway's key food-producing regions. https://gain.nd.edu/our-work/country-index/
- **Hasegawa et al. (2022):** Systematic review of crop model projections, used to estimate climate-induced yield changes for key agricultural commodities.

The methodologies utilised in this report have been developed in earlier assessments of climate risk in global food trade (Adams et al. 2021), assessment of Nordic dependencies and risk in the food system (Beringer, Lager et al. 2022) and an analysis of climate risk to Swedish international trade (Lager and Benzie, 2022). Strengths and weaknesses of the data use cases are briefly presented and discussed for each analytical part (1-3) where relevant to understand the results, and a methodology note is provided for each section separately.

Justification of data sources: embeddedness and geographical granularity

Embedded Trade Data vs. Toll Statistics: Addressing Supply Chain Complexity
Classical toll statistics, which log direct imports from the "last port of call," fail to account for multi-tiered supply chains and obscure the true geographic origin of commodities (Lager and Benzie, 2022). For example, Norwegian soy imports may be logged as originating from Rotterdam (a transport hub) rather than Brazil (the actual production region). This "Rotterdam effect" distorts dependency mapping and undermines climate risk assessments (ibid.). The benefit of using embedded trade flows (rather than e.g. toll import data) to understand dependencies is that it gives a more accurate depiction of origin of production of the commodities consumed. Typically, when toll-reported national trade statistics is used for this type of analysis, key regions for Norwegian imports get distorted, depicting in majority key transporting hubs in the Nordics and Europe, or processing regions for food industries

related to Norway and those representing the most value added in the food supply chain, often centring around facilities in Europe.[1]

Advantages of embedded trade data:

- **Multi-regional input-output (MRIO) models** trace commodities to their source regions, even when processed through multiple countries (e.g., Brazilian soy processed in Germany before export to Norway).
- **Resource footprints** quantify indirect dependencies, such as water and land use embedded in animal feed, which constitute 90% of Norway's aquaculture inputs.
- **Spatial granularity**: Platforms like CommodityFootprints (2024) map subnational production hotspots, enabling targeted risk analysis (e.g., drought-prone Brazilian states supplying soy).

Limitations of toll statistics:

- Overrepresent intermediate hubs (e.g., EU processing centers) and undervalue climate-vulnerable source regions.
- Ignore embedded resource flows critical for systemic risk analysis (e.g., water stress in source regions affecting Norwegian food security).

Analytical Approach

To provide a comprehensive understanding of Norwegian food system risks, a combination of the following methodologies was applied:

1. **Embedded trade flows: Descriptive Statistics & Spatial Analysis:**
   - Food trade dependencies were mapped using geospatial representation techniques to visualize production regions and trade linkages.

Embedded consumption data Commodity footprint data was aggregated to determine total consumption-based water and land use impacts.

2. **Water Risk Assessment:**
   - Green water use (rainfall) and blue water stress (groundwater extraction and scarcity-weighted use) were quantified using a combination of embedded water consumption datasets and global water stress indicators.
   - Country-specific water scarcity indices from Liu et al. (2022) were incorporated to assess regional vulnerability to climate change-driven water stress.
3. **Land Use, Deforestation, and Biodiversity Risk Analysis:**

[1] For an in-dept discussion on trade data types and relevance for climate risk assessments, strengths and weaknesses we refer to Lager and Benzie (2022).

- Land use impacts were measured in hectares of harvested area embedded in Norwegian food consumption.
- Deforestation risk was evaluated by overlaying trade data with known deforestation frontiers (Li et al., 2022).
- Biodiversity risk was estimated using species-richness-weighted habitat loss assessments in key producing countries.

4. **Climate Risk to Key Crops:**

Yield projections for maize, rice, wheat, soy, sugarcane, and coffee were extracted from multi-model ensemble projections (Hasegawa et al., 2022) under an RCP4.5 scenario. Risk was assessed based on the expected percentage decline in yield, the importance of each trade partner for Norwegian imports, and the feasibility of alternative sourcing options.

5. **Longitudinal Trade and Climate Risk Analysis:**
    - Historical consumption and sourcing trends (2005–2018) were examined for wheat and soy to understand long-term dependencies.
    - Climate risks to these supply chains were further analyzed using sub-national drought and transport risk data for Brazil, derived from Trase (2022) and Debortoli et al. (2018).

Table 1. Blue and green water use

Green water use *refers to the consumption of rainfall by vegetation and soil during the process of evapotranspiration.*	***Blue water use*** *refers to the extraction and utilization of groundwater from aquifers for various purposes such as irrigation, industrial processes and human and animal consumption.*

Assessing climate risk using the ND-GAIN index

The Notre Dame Global Adaptation Initiative (ND-GAIN) Index is a composite index that evaluates countries' climate vulnerability and adaptation readiness using 45 indicators across six sectors: food, water, health, ecosystem services, human habitat, and infrastructure (REF). Its climate vulnerability index utilised to asses overall climate risk combines the three components i) exposure: biophysical risks from projected climate hazards e.g., changes in runoff, temperature extremes, ii) sensitivity: dependence on climate-sensitive sectors (e.g., agriculture, water resources) and population susceptibility (e.g., rural demographics, poverty rates), and iii) Adaptive Capacity: availability of sector-specific resources (e.g., disaster preparedness, infrastructure quality) to mitigate climate impacts.

Application to Transboundary Climate Risk

The vulnerability sub-index helps identify risks transmitted across borders through trade and supply chains forming the basis of this analysis. For example, high vulnerability in agricultural exporters like Brazil or Southeast Asia signals potential disruptions to food imports. The data analysis follows the 2023 Nordic study, conducted by the author, where integrated ND-GAIN's vulnerability scores with trade-flow data to quantify dependencies on climate-exposed partners (Beringer, Lager et al. 2023).

Findings

Norwegian food import dependency and key vulnerabilities

A first assessment of trade flows for Norwegian food systems can be made by simply identifying key producing regions of food for Norway. **Figure 1** provides a geographical representation of the origin (in tonnes) of total *embedded* consumption of food for Norway in 2021, and **Table 1** a numerical description of the same figure, describing top 12 producing countries for Norwegian consumption (making up a total 2/3 of Norwegian food consumption) for the same time period. Based on the aggregated weight of agricultural and food commodities consumed in Norway, only 24 % is produced in the country itself. Another 14 % comes from the closest neighbour, Sweden (Commodityfootprints 2024). Thereafter the largest producers of foods for Norwegian consumption are India, China, Russia, Denmark and Brazil, all countries with a higher climate vulnerability than Norway itself.

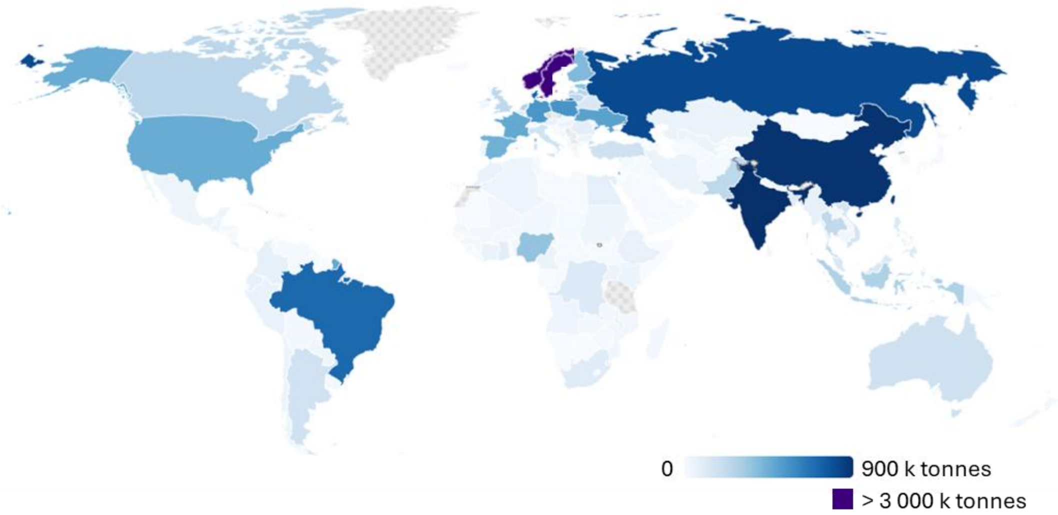

Figure 1. World map showing total origin of production of agricultural and food commodities consumed in Norway in 2021, in tonnes (based on data from commodityfootprint.earth).

Table 2. Top 12 producing countries for Norwegian food consumption in 2021 (including Norway). In total the top 12 producing countries represent 2/3 of all food consumption in Norway. Climate risk score in this table is represented by ND-GAIN vulnerability score for 2021, taking into account climate exposure, sensitivity and adaptative capacity. The higher the number (red), the higher the climate vulnerability and low numbers (blue) indicate low climate vulnerability.

Producing country	Total consumption in Norway (tonnes)	Share of total	Rank	Climate risk (ND-GAIN) *
Norway	5 577 853	24%		0.26
Sweden	3 273 476	14%	*top 2*	0.29
India	864 948			0.50
China	848 472			0.39
Russia	778 937	total 17 %		0.33
Denmark	703 795			0.34
Brazil	675 040		*top 7*	0.37
Poland	526 391			0.31
Germany	520 499			0.29
Ukraine	475 650	total 11 %		0.36
France	449 770			0.30
USA	440 423		*top 12*	0.31

To understand cross-border dependencies, total tonnage, however, is still a crude measurement, especially as the aim is to understand risk under climate change related to producing landscapes. The following two sections therefore also presents a set of data describing land and water use and impacts on ecosystems directly related to Norwegian food consumption globally.

Consumption-based water use and water scarcity under climate change

To understand the consequences of increased global water scarcity on Norwegian food systems we look at two specific indicators to understand implications for water stress and water scarcity for Norwegian food consumption: Green water use (rainfall) and blue water stress (ground and surface water paired with use).

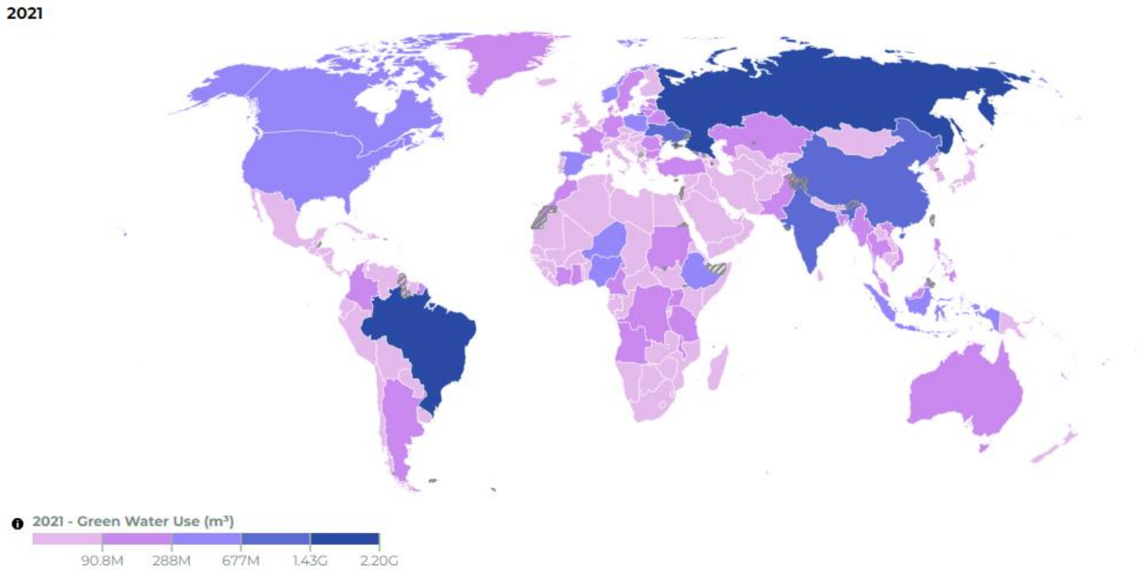

Figure 2. Green water use (rainfall) embedded in Norwegian food consumption. Data depicts trade in 2021, based on commodityfootprint.earth.

Green Water Use: Rain-Fed Commodities

- **Top sourcing partners for Norway:** Russia, Brazil, Ukraine, India and China
- **Key commodities:** Wheat, soybeans, maize, sunflower seeds, rapeseeds

Water scarcity context:

- These regions largely rely on green water for crop production, which is inherently linked to precipitation patterns. While green water use is generally more sustainable than blue water, its availability is highly climate-sensitive.
- Russia and Ukraine: Major wheat exporters with vast rain-fed croplands. However, climate models project increased drought frequency in these regions, threatening crop yields.
- Brazil: Soybean production in the Cerrado savanna relies on seasonal rains. Deforestation and shifting rainfall patterns under climate change could reduce green water reliability.
- India and China: Despite significant irrigation, rain-fed agriculture remains critical. Monsoon variability and rising temperatures are already stressing green water availability, risking crop failures.

Climate change implications:

- Increased rainfall variability and extreme weather (droughts/floods) will disrupt green water supplies, reducing crop productivity in rain-fed systems.
- Norway's dependence on these regions exposes its food supply to climate-driven yield fluctuations.

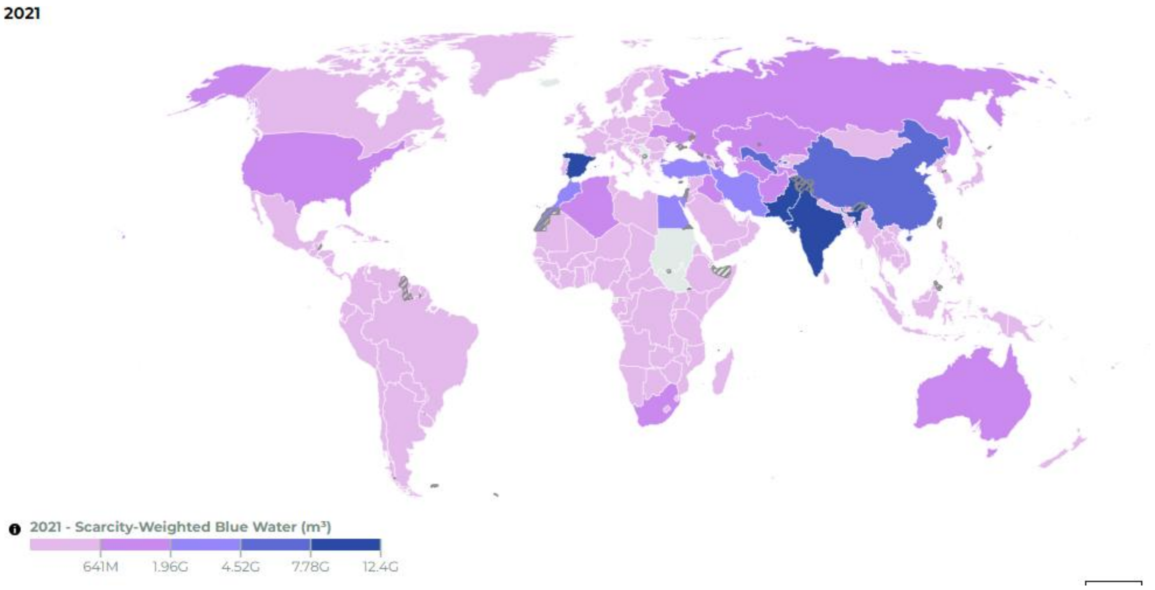

Figure 3. Blue water use weighted by water stress embedded in Norwegian food consumption. Data depicts trade in 2021, based on commodityfootprint.earth.

Scarcity-Weighted Blue Water Use: Irrigated Commodities

- **Top partners:** Pakistan, India, Spain, Uzbekistan, China
- **Key commodities:** Wheat, rice, maize, sugarcane

Water scarcity context:

- These countries face extreme blue water stress, where irrigation demand exceeds sustainable limits:
    - Pakistan and India: Over 65% of their blue water use infringes environmental flow requirements (EFRs), with rice and wheat production being major drivers.
    - Spain: Chronic overexploitation of aquifers for irrigated agriculture, exacerbated by drought frequency.
    - Uzbekistan: Relies on transboundary rivers (e.g., Amu Darya) depleted by upstream glacier melt and cotton monocultures.
    - China: Northern plains face groundwater depletion, with 25% of cropland already water-scarce.

Climate change implications:

- **Reduced river flows**: Glacier melt in Central Asia (critical for Uzbekistan) and declining snowpack in regions like Spain will shrink irrigation supplies.
- **Competing demands**: Urbanization and industrial growth in India and China will intensify competition for scarce blue water, prioritizing non-agricultural uses.
- **Salinization and pollution**: Over-extraction in stressed basins (e.g., Indus, Ganges) degrades water quality, further limiting agricultural usability.

Synthesis: Risks to Norway's Food Security

- Green water vulnerability:
  - Norway's rain-fed imports depend on stable precipitation in exporting regions. Climate-driven shifts in rainfall patterns (e.g., weaker monsoons, prolonged droughts) could disrupt production.
  - Example: A 20% decline in Russian wheat yields due to drought could directly impact Norway's food supply chains.
- Blue water scarcity amplification:
  - Irrigation-dependent partners like Pakistan and Spain are among the world's most water-stressed countries. Climate change will exacerbate scarcity, raising production costs and trade volatility.
  - Example: Groundwater depletion in Punjab (India) could reduce rice exports by 15–30% by 2050.
- Cascading trade disruptions:
  - **Over 43% of global blue water trade flows already infringe EFRs2. Stricter sustainability policies (e.g., EU regulations) may restrict exports from high-stress regions, forcing Norway to diversify sources.**

Consumption-based land use, deforestation risk and biodiversity loss under climate change

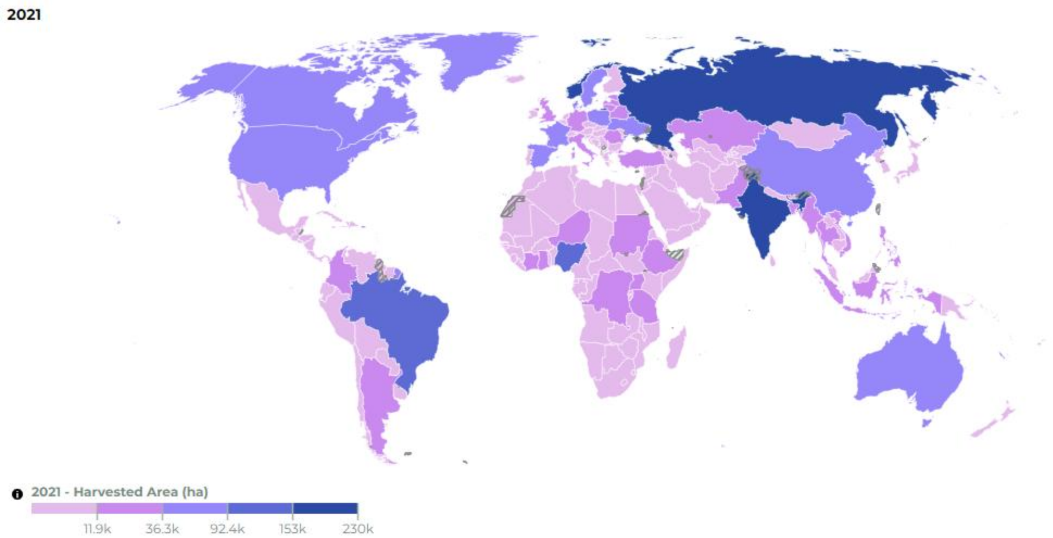

Figure 4. Land use (hectares) of harvested areas embedded in Norwegian food consumption. Data depicts trade in 2021, based on commodityfootprint.earth.

Figure 3 depicts total land use in foreign productions systems for Norwegian food consumption. Norway's food consumption relies on ecosystems as far away and apart as Russia, India and Brazil (top countries outside of Norway by land use) and the largest land use areas for Norwegian consumption in 2021 are for the consumption of wheat (401 000 ha), soybeans (222 000 ha) and barley (200 000 ha). These dependencies expose Norway to risks associated with climate change, land use change, and biodiversity loss.

According to the same analysis, the countries associated with deforestation risk driven by production of food commodities consumed in Norway are Brazil, Russia and Democratic Republic of the Congo (DRC), driven in particular by the consumption of cattle meat, soy and cooking oil (sunflower and oil palm). The countries most exposed to biodiversity risk (species-richness weighed areas at risk due to food production) in conjunction with Norway's food consumption are Brazil, India, Russia, Nigeria and China, driven mainly by the consumption of wheat, soy, maize, rice, and coffee.

Embedded food for Norwegian end consumption: Summary of results
Norway is dependent on both neighbouring and far-away production systems for its food consumption as well as for inputs to its domestic food production system. Looking at embedded consumption of food in Norway the most significant regions of dependencies outside of the country's own borders in total weight, water and land use are neighbouring Sweden and Denmark, but also far away productions regions like India, China and Brazil as well as both large food producers to the global markets of Russia and Ukraine. Far away production regions associated with Norwegian embedded consumption typically are more vulnerable to climate change impacts, including being less equipped to adapt to a changing climate than Norway.

Looking deeper into climate change risk to these production systems, already today water scarcity weighted data pinpoints countries including Pakistan, India, Spain, Uzbekistan and China as particularly at risk in relation to Norwegian food consumption, water use and water scarcity. In Norway, the commodities associated with water scarcity risk for these countries are Wheat, Rice, Maize and Sugarcane, but also fresh fruits and vegetables (olives and oranges from Spain, grapes and apples form Uzbekistan). Land use and the associated risks of deforestation and biodiversity loss are significant in relation to Norwegian consumption in Russia, India and Brazil with additional deforestation risk connected to activities on DRC, and for biodiversity risk in particular Nigeria and China. A broad set of globally traded commodities are associated with this land use and accompanying risk, including wheat, soy, maize, rice, and coffee.

Deep dive 1: Norway and Globally Traded Climate Risk: Analysis of 6 globally traded crops

Introduction

In this part of the assessment, we deep dive into the climate risk associated with the Norwegian consumption of six key global agricultural commodities: maize, rice, wheat, soy, sugarcane and coffee. These crops are targeted for this analysis as they are among the most traded food commodities globally (Beringer et al. 2022, Adams et al. 2021), and as seen in the assessment above make up a significant part of the total land use abroad for Norwegian food consumption, as well as associated environmental impacts threatening overall resilience of the food production systems. Climate risk for these 6 crops have been analysed using a tool called the SOURCE index developed by Adams et a. (2021), and adapted for the Nordic countries in Beringer, Lager et al (2023), using embedded consumption data for the six commodities, global trade data and climate models impacts to future yields we assess the climate risk embedded in the Norwegian consumption pattern of these commodities.

In Norway, wheat is used primarily for direct human consumption and lesser quality wheat is used as animal feed. Maize and soy are primarily used as inputs to agriculture and aquaculture (soy) as animal feed, whereas rice is predominantly consumed directly and sugarcane highly embedded in other imported products as well as used in industrial food production processes. Coffee differs from the other crops presented in this analysis, as it represents a luxury good, rather than a staple food. Nonetheless, the beverage is of high interest for the Nordics, who are among the most coffee-consuming people in the world, not to mention for the livelihood of the world's ca 60 million smallholder farmers involved in coffee production (Beringer, Lager et al. 2022, Adams et al. 2021).

Data and methodology

Risk is in this analysis to be understood as a combination of a crop's predicted yield losses due to climate change, how important that trading partner is to Norway, and the domestic production of that crop. The higher the predicted decline in yield, and the more dependent a country is on that specific bilateral trade flow, and the smaller the domestic production, the higher the risk. In reverse, opportunities represent trading partners with a predicted increase in yield with a high potential importance for Norwegian bilateral trade. Vulnerability in the sense of "societal change", and other non-climatic drivers are not considered in this analysis. For an in-depth explanation of the methodology, see Beringer et al (2022, Annex IV) and Adams et al. (2021).

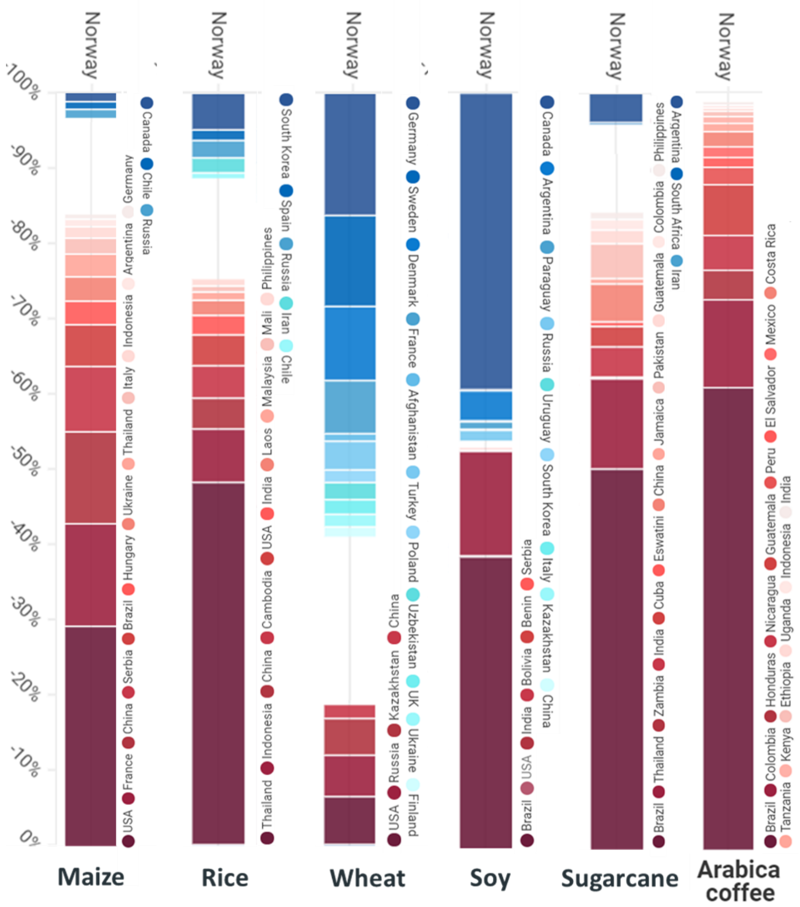

Figure 5. Climate risk in global food trade for Norway, key trading partners Maize, rice, wheat, soy, sugarcane and Arabica coffee. Adapted from Beringer, Lager et al. (2022).

Results

For Norway, the risk profile is similar to its Nordic neighbours that was part of the original analysis of this data, the highest climate risk for these 6 crops is found in the supply of coffee, where climate risk is present in all production regions. This is in line with general predictions of climate risk in the coffee sector, a crop necessarily grown in tropical regions and as the crop itself is highly vulnerable to changes in temperatures, humidity and rainfall. After coffee the highest risk score for Norwegian consumption is found in maize, where the risk in the supply outweighs the opportunities by a factor of 28 (see Table 3), closely seconded by sugarcane, for which the equivalent risk-to-opportunity ratio is 24 to 1. Wheat is the only commodity with an optimistic prediction for Nordic patterns of imports, with the opportunities outweighing the risks by a factor of 5. **Table 3** provide an overview of the risk characteristics for each crop for Norway. A more in-depth description of the risk typology presented in the table is included as extracted text from Beringer, Lager et al. (2022) in **Appendix I**.

Table 3. Climate risk in major traded food items for Norway. Adapted from Chapter 5 in Beringer, Lager et al. 2022.

Factors assessed	Maize	Rice	Wheat	Soy	Sugarcane	Coffee
Climate risk	High	High	Low	Medium	High	High
Nordic risk-to-opportunity ratio	28:1	4:1	1:5	5:4	24:1	1:0
Global risk-to-opportunity ratio	43:1	6:1	1:1	2:1	25:1	1:0*
Predicted change in yield for major trading partners	decline 10–50%	decline 20–70%	increase 8–50%	from 30% decrease to 110% increase	decline 30–80%	decline 30–60%
Diversity of supply	High	Medium	Medium	Low	High	Medium
Main sourcing regions	North America, Europe and Asia	Dominated by Thailand, alternative sources centred in Asia	Dominated by the Nordics, Germany, and France	Brazil, the US and Argentina, Canada as emerging	Dominated by Brazil, alternative sources in Asia (and Africa)	Dominated by Brazil, alternative sources in South and Central America and Africa
Domestic production	Insignificant	None	High	None	None	None
Embeddedness	Medium	Low	Low	High	High	Low

Deep Dive 2: Time-series and climate risk analysis dependencies of Wheat and Soy

In this report longitudinal sourcing data and climate risk data for wheat and soy have been singled out to support case studies for the wider TransAdapt project. The result of the analysis is presented in this section, and an interactive version of the data graphics can be accessed at https://public.flourish.studio/story/2041355/ for closer examination. The two crops represent two crucial, but very different type of foodstuffs consumed and utilised in Norwegian food systems, as well as their geography. Wheat, predominately grown in the Northern hemisphere and consumed directly as food, and soy, predominately consumed embedded in imported foods, or used as feed in aquaculture and as extra protein for raising poultry, pigs and cattle. This section deep dives into latest climate projections for the two foods as well as time-series data on sourcing regions for wheat and soy for Norway.

Data and methodology

Embedded consumption data for the years 2005-2018 have been extracted from the commodityfootprints.earth website for wheat and soy, all regions including Norway. Climate risk is represented in this analysis for the two crops using an analysis of mean and maximum (negative) yield changes across a range of crop models using a database of a systematic review of crop model results until 2020 by Hasegawa et al. (2022). The result maps show predicted yield changes wheat and soy producing countries respectively for top producing countries globally, constituting an aggregated 95% of total current production. The parameters utilized for the climate risk map for wheat and soy respectively are specified in Table 4.**Table 4**.

Table 4. Specification of parameters utilised for yield change projections.

Crop	Parameters	Source
Wheat, Soy	Climate scenario: RCP4, Mid-century (MC), max risk yield change results (maximum risk i.e. largest negative value), no adaptation (for result consistency). The assessment provides production risk, slow onset changes only.	Hasegawa et al. 2022

Results: Wheat

Wheat is today one of the most important grains in Norway, and only about 10% is produced within the country itself (see numbers above). Despite a 5000-year historic presence in the country, domestic wheat production in Norway has not always been feasible due to a harsh climate, and up until the beginning of the 20th century Norway was importing nearly all the wheat consumed in the country from abroad. Scientific developments and land wins in the early 1900s, including the development of tougher varieties allowed the domestic production of wheat in Norway to commence. In 2021 the total wheat production in the country measured around ca 450 000 tonnes, where interestingly just over 60 % of all embedded wheat produced for commercial purposes in Norway that year is estimated to have been consumed abroad (based on data from commodityfootprints.earth).

Due to the location of global production regions of wheat in the northern hemisphere, where climate change is predicted to be less severe and where temperature increases in cold climates, and in the more optimistic scenarios, could even lead increases in suitable land and yields of wheat in the global north, wheat is not exempt from risk. In Norway, wheat that do not meet the requirements set for baking quality it is instead used for animal feed. Such damage occurs if the grain germinates in the ear before harvest, which can happen in damp weather after ripening. Fresh in memory for Norwegian farmers and consumes is the crises in 2018 where extreme heat and drought brought down most of the Nordic's grain production and reserves, leading to the need to mass-slaughter animals in the most severely hit regions.

Figure 6 show fluctuation in sourcing patterns for wheat for Norway between 2005-2018. Included in the graph are the top 10 contributors of wheat consumption of foreign origin for Norway, including Germany, Denmark, China, France, Sweden, Russia, India, United Kingdom, Kazakhstan, Ukraine and Poland. These countries are the top contributors of embedded wheat consumption for Norway either over the entire time period 2005-2018, or over the latest "normal" 3-year period 2015-2017 (excluding the drought year of 2018). Wheat is traded and sold on the global markets, and yearly fluctuations on sourcing regions based on price, yields, quality, and demand is quite common, as shown in the fluctuation of volumes from sourcing regions on a yearly basis.

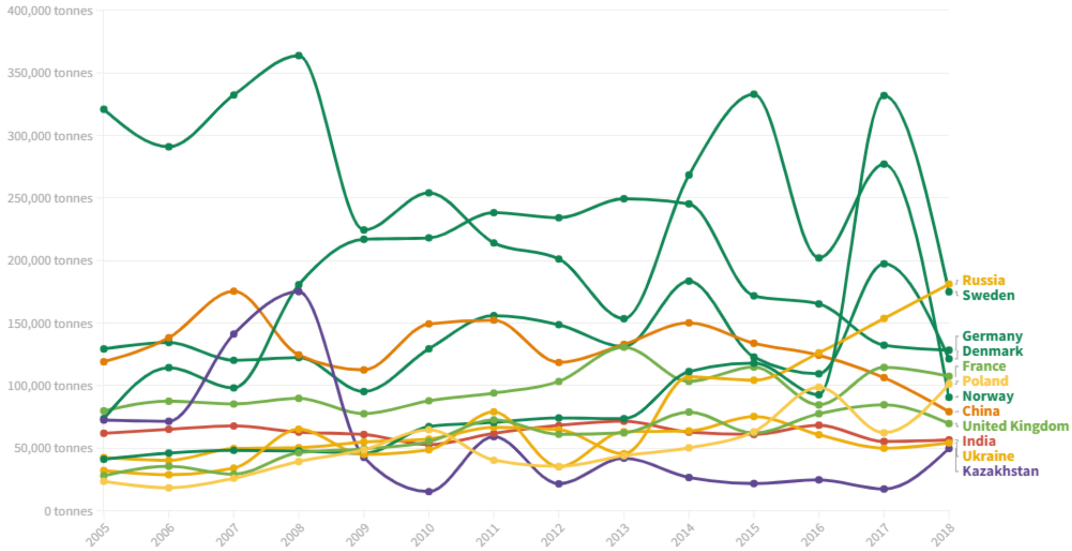

Figure 6. Historical consumption of embedded wheat for Norway (in tonnes) between 2005 and 2018. Based on data from commodityfootprint.earth.com. Image shows Top 10 producers for Norwegian consumption (including Norway).

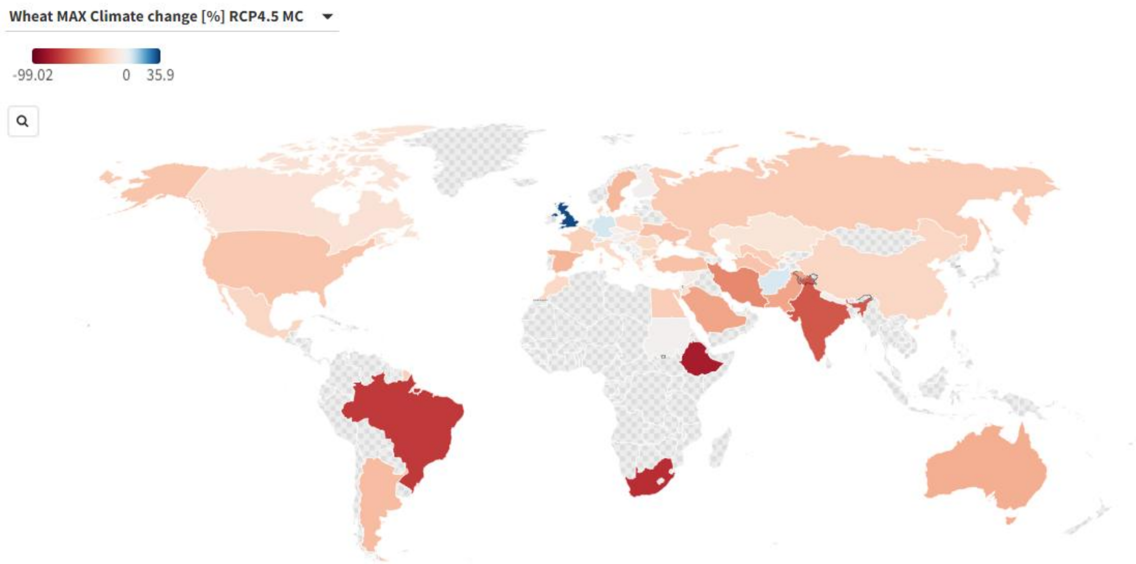

Figure 7. Predicted yield changes in top wheat producing countries globally (constituting an aggregated 95% of total current production), based on a systematic review of crop model results until 2020 (Hasegawa et al. 2022). The result parameters chosen for the selection are Climate scenario: RCP4.5, Mid-century (MC), max risk yield change results (maximum risk i.e. largest negative value), no adaptation (for result consistency). The assessment provides production risk, slow onset changes only.

In turn **Figure 8** depicts aggregated climate risk across global and regional crop models for yield changes in wheat based on a middle-of-the-road scenario (representation concentration pathway RCP4.5) to mid-century. According to the systematic model review, out of the 10 top sourcing regions for Norwegian wheat, all countries but the United Kingdom and Germany are expected and to decrease their wheat yields in the coming decades. In turn, shortage of wheat on the global markets might lead to price effects, or in more extreme cases even difficulties to source produce on the global market.

Results: Soy

Globally soy is predominantly used as feed in animal production systems, for cattle (meat and dairy), pigs and poultry and in Norway aquaculture is an important sector. Globally soy is produced in a few key regions, Brazil, Argentina and the US making up the largest soy producing countries in the worlds. Norwegian legislation prohibits the use of genetically modified (GM) soy, hence restricting potential importing regions to countries that Only GM-free (Genetically modified) soy is permitted to enter Norwegian soil. This mean in effect that sourcing regions for Norway are restricted to those regions that produces and certifies non-GM soy, predominately direct soy imports to Norway originates from Brazil. (Lager and Benzie, 2022)

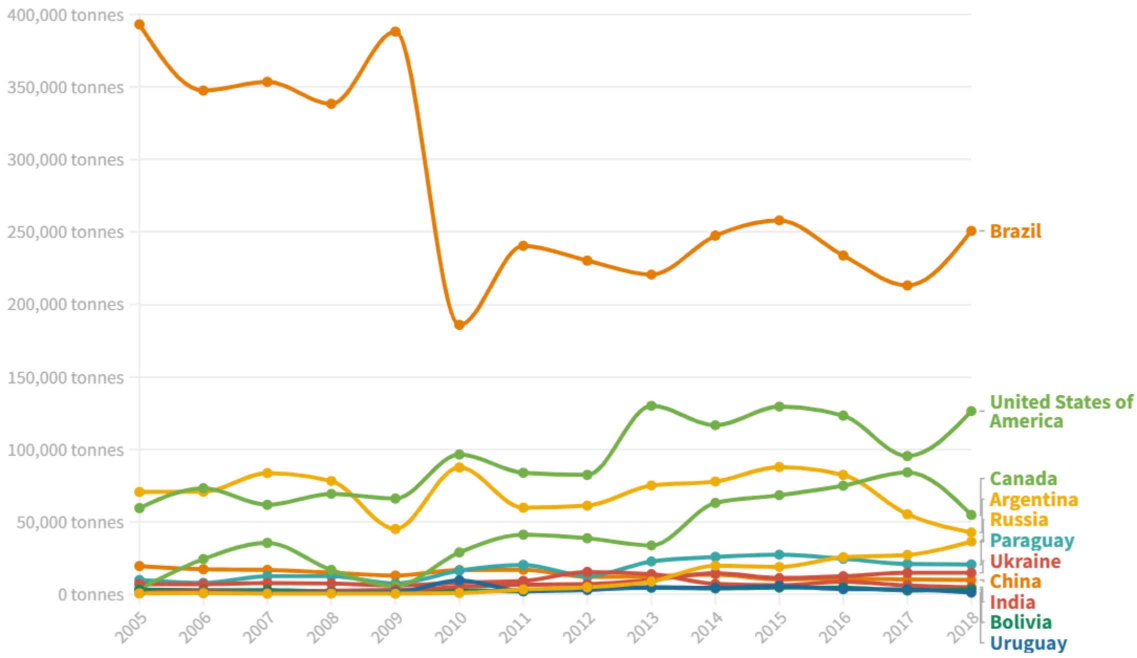

Figure 8. Historical consumption of embedded soy for Norway (in tonnes) between 2005 and 2018. Based on data from commodityfootprints.earth. This data excludes the import of soy for aquaculture included in exports. Image shows top 10 producers for Norwegian consumption (including Norway).

Figure 6 show fluctuation in sourcing patterns for soy for Norway between 2005-2018. Included in the graph are the top 10 contributors of embedded soy consumed in Norway, where Brazil and the US are the largest sources, followed by smaller volumes originating in Canada and Argentina. The distinction between embedded produce and directly imported is of great importance for soy and to understand dependencies and vulnerabilities as it is often consumed indirectly, as ingredients in ready made products or meat. Conversely, the bulk of soy imported to be used in feed for Norwegian aquaculture sold for export is not represented in the Norwegian consumption of soy (but in the country of end consumption).

Figure 8 depicts aggregated climate risk across global and regional crop models for yield changes in soy based on a middle-of-the-road scenario (representation concentration pathway RCP4.5) to mid-century. According to the systematic model review, all major producing soy areas globally are expected see a decrease their wheat yields in the coming decades. From a 30% decrease in the US, 54 % in Brazil to 80 % in India. As with wheat, shortage of soy on the global markets might lead to price effects, or in more extreme cases even difficulties to source produce.

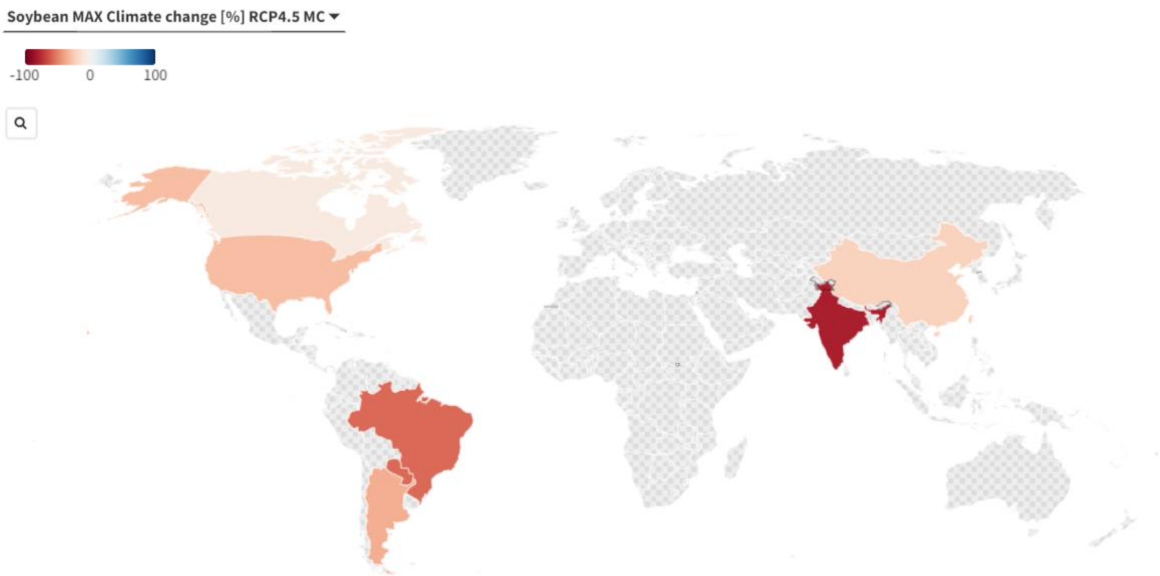

Figure 9. Predicted yield changes in top soy producing countries globally (constituting an aggregated 95% of total current production), based on a systematic review of crop model results until 2020 (Hasegawa et al. 2022). The result parameters chosen for the selection are Climate scenario: RCP4.5, Mid-century (MC), max risk yield change results (maximum risk i.e. largest negative value), no adaptation (for result consistency). The assessment provides production risk, slow onset changes only.

For soy, a third set of datapoints however have also been explored, shown in **Figure 10**, originally designed for an earlier case study on sub-national production regions, drought risk and to consider climate risk to the transport system as well as the production of a crop (for full methodology and analysis of these datasets see Lager and Benzie 2022). Brazil is a huge country, and the impacts of cliamte change will vary across the country. Norway, partly due to the need to control origin of soy into the country due the GM-restrictions, source the vast majority of its soy from Brazil from very few municipalities. The particular regions where Norwegian soy is sourced has among the lowest drought risk in the country. For soy, drought risk is one of the more challenging climate impacts as most soy cultivation is rain-fed. This information offers quite the contrast to an assessment when the entire risk for the country is presented as aggregate values. When taking into account landslide and flash flood risk from cliamte change to the road systems, areas important for Norwegian soy consumption have much higher risk of cliamte change disruptions. We include the results for Norwegian soy consumption from Brazil in this analysis to showcase how more granular information for several parts of the supply chain be crucial in informing us of the risk landscape and to hopefully inspire future assessment of risk to Norwegian food systems. The granularity and context specific information is crucial to understand what type of intervention or adaptation action can be meaningful and effective to mitigate the risk.

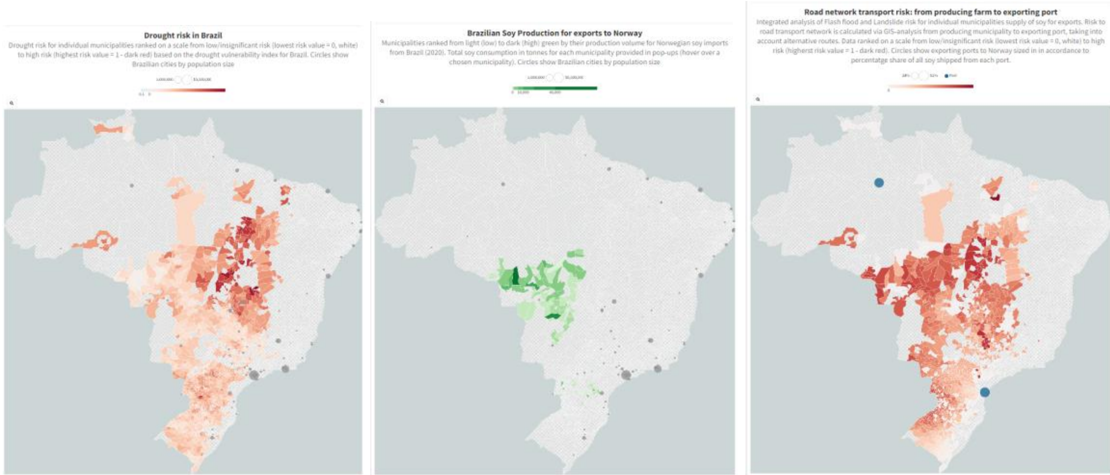

Figure 10. Maps of Brazilian Municipalities showing climate risk in Brazilian Soy production and transport system: for Norway-bound soy. Left: Drought risk for individual municipalities in Brazil, ranked on a scale from low/insignificant risk (lowest risk value = 0, white) to high risk (highest risk value = 1 - dark red) based on the drought vulnerability index for Brazil. Circles show Brazilian cities by population size. Centre map: Middle: Key production regions for Norway-bound soy produced in Brazil, largely in the Mato Grosso Area. Right: Flash flood and landslide risk to the road transport system from producing municipality to port, and key ports for exports to Norway. Data based on Debortoli et al. 2018, Trase (2022), Croft et al. 20xx)

Concluding remarks

This report consolidates several previously published datasets and methodologies to provide an overview of key dependencies and in the Norwegian food system and associated cliamte and environmental risk. It shows that significant climate risk to the Norwegian food systems originates outside of the country's own border, making the case for Norway to engage in adaptation and resilience building actions abroad. The aim of the report has been to provide relevant data for a comprehensive analysis of the Norwegian food system resilience in the face of climate change, focusing on transboundary and cascading climate risk. It will inform further policy-oriented work and stakeholder engagement under the TransAdapt project.

Future analysis of a similar kind could go further by pinpointing key strategic or interesting foodstuffs (other than the 6 main crops) main crops and deep dive into production regions, actors and their influence over the supply chain, and identify commodity specific vulnerabilities and solutions. It could also go beyond assessing cliamte risk to production, and also include climate risk to transport and processing facilities infrastructure in global food trade to supplement the analysis. Future quantitative assessments could also focus on nominal data, identifying core actors and their interactions, 'stickiness' of supply chains and commodities (i.e. how easy or hard it is to switch commodity or supplier in cases of shortage or price rise). Furthermore, non-food inputs to the Norwegian food system and domestic food production such as fertilizers, machinery and fuel could also complement the assessment made in this report and provide a more all-encompassing picture of core dependencies of the Norwegian food system.

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ChatGPT was utilised for rendering R script for data management for this report.

Appendix : Nordic risk profiles for 6 globally traded crops

Below risk profile for each of the crops maize, soy wheat, sugarcane and coffee is extracted from Beringer, Lager et al (2022).

Maize
Typology traits: High risk – diverse sources – geographically spread – low domestic production – medium high embeddedness: inputs to agriculture

Agriculture in the Nordics has a strong focus on animal production, due to the short growing seasons and landscape types, as well as agricultural and culinary traditions. Imported maize for feed for cattle (for meat and dairy), pigs and poultry ar**e** an important input to the domestic agricultural systems. Denmark, with its large agricultural production and export, including its large pig industry, imports the largest volumes of maize of all the Nordic countries (total and per capita inputs).

The climate risk in the supply of maize for the Nordic countries is high, the risk outweighing opportunities by a factor of 28. The crop yields for the Nordics' major trading partners are projected to decline by 10–50%. The sourcing patterns for the Nordics show a diverse portfolio, and sourcing countries are spread across several continents, including North America, Europe and Asia. The largest risk share derives from the US, followed by France and China. There are a few minor opportunity markets in the maize supply chain in Canada, Chile and Russia. They are currently minor global producers and exporters of maize to the Nordics, but future yield predictions look optimistic. The only country in the Nordics with a recorded domestic production of maize is Denmark, representing 1% of total maize inputs for the country. The actual domestic production may be somewhat higher, as animal farms may have in-farm production of maize that is not recorded in national statistics. Maize should be treated as a medium-high embedded commodity for the Nordics, due to the substantial input of maize to domestic production systems. Nordic citizens also consume maize in embedded form, such as in Polish milk that is an ingredient of a chocolate bar processed in Switzerland, to give one example.

The high diversity of sourcing patterns, spread of geography, and small but emerging opportunity markets mean that although the risk is high in the maize market for the Nordics, there is a chance that the market can deal with at least some of the risk. Alternatives for action include changing suppliers – as one region might be more affected by decreased yield one year but another not – and in the long term, look towards new markets, or even increase domestic production. However, the increased demand of food, and especially animal products worldwide, could put even more pressure on future markets and drive price hikes. Diversifying might not be enough to secure Nordic supplies of maize to future farmers.

Rice

High risk – dominant high-risk partner, with alternative options – no domestic production (but alternative crops) – low embeddedness

Rice is not produced in the Nordic countries, and it is a fairly new addition to the Nordic diets. In the Nordics, consumption of rice is lower than for the other staple crops studied, but it has grown exponentially over the past few decades.

The climate risk in the supply of rice for the Nordic countries is medium high, the risk outweighing opportunities by a factor of 4. The predicted decline in yield for the major trading partners in the Nordics ranges from 20% to 70%. The sourcing patterns for the Nordics are dominated by Thailand, but with a diversity of trading partners throughout Asia, such as China, Vietnam and Indonesia. There are a few opportunity markets in the rice market, mainly represented by the predicted increase in yield in South Korea. The Nordic countries have no domestic production of rice, although the consumption of rice could be substituted by domestic grains based on wheat (wheat corn, bulgur, etc.). Rice is used as a staple in its own right and has low embeddedness.

The high risk, dominant but existing diversity of suppliers for the Nordics, and the possibility of substituting rice for other types of grains in the Nordic consumption suggest that a shortage of rice on global markets could be handled by first changing suppliers, and second, switching to other foods, if available.

Wheat *Low risk – high diversity – geography dominated by the Nordics, Europe and central Asia – high domestic production – low embeddedness* Wheat constitutes a staple in the Nordic diets, consumed in bread, cereal, porridge and pasta. However, the consumption of wheat is growing in complexity for the Nordic countries, from a high consumption of wheat in its refined form to an increased consumption of processed wheat in ready-baked breads and pasta, to give a few examples. The risk in the wheat market for the Nordics is relatively low, opportunities outweighing risks by a factor of 5. There is a high diversity of supplies of wheat in Nordic imports. The geography of imports is dominated by production in the Nordic countries themselves and by European neighbours such as Germany and France, followed by countries in Central Asia and Russia. Iceland sources the bulk of its wheat from Denmark. There is a substantial domestic production of wheat in the Nordic countries. Denmark produces the majority of its wheat for exports, followed by Sweden, which matches the domestic production with its overall consumption rates. As discussed above, wheat has a low-to-medium but increasing embeddedness related to the complexity of the global food systems and supplies. The outlook for domestic Nordic production of wheat is optimistic, with predictions of increased yields between 8% in Norway to 50% in Sweden. The climate risk related to wheat is relatively low, considering the production of wheat in the Nordics and the sourcing geography centred on Europe. The analysis even suggests a potential increase of domestic production of wheat for the Nordics, which could lead to increased exports. In case of global shortage of wheat supplies, there is a good chance that the Nordic countries could reduce their exports and focus on domestic provision of wheat for their own use.
Soy *Medium risk – low diversity of sources – geographically locked (few alternatives) – no domestic production (alternative crops) – high embeddedness* Soy is rich in protein and oils, and a major source of animal feed protein globally. As such, similarly to maize, the majority of soy imports for Nordic consumption are found within the animal production systems, for cattle (meat and dairy), pigs and poultry. Soy is also used as fish feed in the large aquaculture industries especially in Norway, Finland, Denmark and Iceland. Climate risk in the soy market for the Nordics is medium-high, with a near-equal opportunity-to-risk ratio. The market is dominated by a few actors, with Brazil and the US presenting the largest risk markets, and Argentina and Canada providing future potential opportunity markets. Denmark diverges from its Nordic neighbours, with a higher opportunity than risk, based on current sourcing patterns, due to its larger share of soy inputs from Argentina. Denmark is

also the largest importer of soy by volume of all the Nordic countries, largely related to its large animal production system.

Although risk-to-opportunity ratios are even in the soy market, it is important to note that the opportunity markets for soy should be read with extra caution. The high opportunity in the Canadian market is based on predicted yield increases of 117%, and the volume of soy produced in Canada is currently low. The yield prediction models for soy are also known for an optimistic interpretation of the potential for increased yields due to the increased atmospheric CO2 fertilisation.

There is no domestic production of soy in the Nordics. However, there are possibilities of substituting soy with other high protein-crops that can be grown domestically. Soy is a highly embedded commodity in food products as diverse as an American candy bars, Polish sausages, or meat and dairy in a ready-made lasagne, with multiple origins of input components.

Response options for the Nordics to climate risk in the supply chain for soy again look different from the other crops discussed. For the direct use of soy in Nordic agricultural systems, the risk analysis points to a future opportunity to perhaps be able to switch suppliers from Brazil to Argentina or Canada if those production systems are less affected, at least in theory. Being the number one global protein for animal feed and a highly embedded commodity, however, a shortage of soy in the global markets is likely to result in global shortages and price hikes across a number of commodities. As a result, we might see a bidding frenzy and difficulty to secure supplies in the future market. The prospect of substituting soy with other high-protein crops is tempting, but the volume of inputs needed are substantial, and it is not clear whether domestic or even European production can bear the load.

Sugarcane

High risk – dominant high-risk partner, with alternative options – several geographical core regions – no domestic production (but alternative crops) – high embeddedness

The embedded consumption of imported sugarcane is among the highest by volume for the Nordic countries. The climate risk in the supply of sugarcane for the Nordic countries is high, with risks outweighing opportunities by a factor of 24. The predicted changes in yield for the major trading partners in the Nordics are at a 30–80 percentage decline. The sourcing patterns for the Nordics are dominated by inputs from Brazil, but with a diversity of smaller trading partners in Asia, such as Thailand and China. Interestingly, Finland stands out in its sourcing patterns, with the highest total import of sugarcane across all the Nordic countries. Finland also has a different geographical sourcing pattern, focused predominantly on inputs from African countries, including Eswatini and Zambia, as well as Brazil and Caribbean islands. While the Nordics have no domestic production of sugarcane, they produce sugar beet (especially Denmark and Sweden), which is not accounted for in this data. Sugarcane is a highly embedded commodity, included in complex food production systems globally.

With a high-risk, high-embeddedness profile, it is likely that climate impacts in the sugarcane supply chain will predominantly result in price increases across a basket of products. Although the domestic production of sugar beet could, in theory, replace the consumption of imported sugar, the complexity of the system it is embedded in might make such a shift difficult as a strategy to avoid the risk in the sugarcane supply chain for the Nordics.
Coffee *High risk – dominant high-risk partner, with alternative options – three dominant geographical regions – no domestic production (no alternatives) – low embeddedness* Coffee is different from the other crops studied here, as it is a luxury good. However, coffee is culturally important for the Nordic countries; they are among the biggest coffee consumers in the world on a per capita basis. More than 80% of all coffee consumed across the Nordics is of the Arabica bean, a higher quality bean predominantly grown in South and Central America. The climate risk in the coffee supply chain is the highest of all crops studied in this analysis. All current significant production systems in the coffee market for the Nordics report predicted declines in yield, for both the Arabica and the Robusta bean. The predicted decline in yield for the major trading partners in the Nordics varies between 20 and 60%. The Nordic sourcing patterns for the Arabica bean, the preferred high-quality bean, are dominated by inputs from Brazil, but with a diversity of smaller trading partners in South and Central America, such as Colombia and Honduras, and East African countries, such as Tanzania and Kenya. For the Robusta bean, the geography is slightly different, with the highest risk shares, aside from Brazil, deriving from Asian countries, such as Vietnam and Indonesia, and a slightly different set of African countries, such as Uganda and Tanzania. Because of its specific growing conditions (altitude, climate etc.), domestic cultivation of coffee in the Nordics is not possible. The coffee supply chain outlook is plain when it comes to response mechanisms for the Nordics. If we want to keep drinking our morning coffee, there are no low-risk alternative markets to turn to. Even if we alter bean preferences and start drinking the Robusta bean, mostly used for the production of instant coffee, the risks in the supply chain remain high. The only real adaptation option left from a Nordic perspective, is to support adaptation efforts in the producing areas, increasing the chances that the predominantly small-scale coffee farmers can adapt to a changing climate.