WIFO

Mit Unterstützung von Bund und dafne.at

Bundesministerium
Land- und Forstwirtschaft,
Regionen und Wasserwirtschaft

DaFNE

Robuste Versorgungsketten in der Agrar- und Nahrungsmittelwirtschaft

Visualizing the complexity, fragility and risk of supply-chain risks across and within the EU

Philipp Warum, Asjad Naqvi, Franz Sinabell (WIFO) und Christian Folberth (IIASA)

Wissenschaftliche Assistenz: Dietmar Weinberger
Data Scientist: Lukas Schmoigl

Juli 2023
Österreichisches Institut für Wirtschaftsforschung

Visualizing the complexity, fragility and risks of food and nutrient supply-chains across and within the EU

Philipp Warum[1*], Asjad Naqvi[1], Franz Sinabell[1], Christian Folberth[2]

Corresponding author: philipp.warum@wifo.ac.at

[1] Austrian Institute of Economic Research (WIFO)

[2] International Institute for Applied Systems Analysis (IIASA)

Abstract

Food security and food sovereignty have become subjects of intense debate in Europe. Together these concepts refer to the stability and robustness of domestic and cross-border supply chains. These debates were stimulated by events of the past years that have highlighted the trade risks faced by the EU and the countries within its sphere. An important aspect that has become evident during these debates is that food security is not about autarky, but rather building strong ties to key trade partners. The agriculture sector is especially affected by disruptions to key inputs such as energy and fertilizers. Additionally, trade of food imports, key for supplying people with core nutrients, is also impacted. In this paper we explore trade patterns for EU27 countries and for Austria using fertilizers and elementary nutrients (such as proteins and calories) from food and feed as case study products. By assigning a risk weight to each country, we explore the level of embodied risk in imports of these products. We show that while EU as a whole, has increased its diversity of trade partners, it is trading fertilizer mostly with countries that are at risk of political disruptions. In contrast, Austria has reduced its trade diversity, faces higher indirect risks, and also pays a higher unit price for fertilizer imports relative to other countries in the EU. The risk profile of countries supplying basic nutrients is more advantageous. However, because only few risk prone countries dominate global supplies of fertilizer which are key ingredients for nutrients, the situation is only seemingly more advantageous

Content

Figures

1. Introduction

The European Union (EU) is facing various supply-chain risks, especially in the agriculture sector. Global market volatility, rising domestic costs, and price fluctuations impact the competitiveness of agricultural exports. Other shocks such as the COVID-19 pandemic and the Russian invasion of Ukraine have caused logistical disruptions and shortages of raw materials, leading to bottlenecks in the EU economy (Halmai, 2022). Therefore, food security and food sovereignty have become subjects of intense debate in Europe. The security of food supplies is what food security is about, while food sovereignty includes geo-political dimensions that relate to considerations about levels of self-sufficiency, stability of supplies from foreign sources, and self-determination (Lamy, et al., 2023). Together these concepts refer to the stability and robustness of domestic and cross-border supply chains.

The EU is vulnerable to asynchronous policy changes abroad. For example, the one-sided approval of trade of genetically modified soy varieties between the EU and non-EU countries led to disruptions in protein feed imports to Europe (Deppermann et al., 2018). Additionally, the EU, over time, has consolidated trade to fewer countries increasing its sensitivity to external shocks (Duan et al., 2021). An important aspect that has become evident is that food security is not a concept of autarky but rather, strong ties to trade partners. The EU is the largest trading partner in the world, and therefore deeply embedded in the global network. However, not all trade partners equally contribute to improving food sovereignty. To understand the complexity of trade patterns and potential sources of disruptions, the risks associated to the sources where products come from, in this paper we propose a new set of methods and innovative visualizations that can help support the EU understand and evaluate direct and indirect supply chain risks. Using fertilizers as a case product, we show that only a small number of countries are dominating global fertilizer markets. Some of them are associated with high risks and the EU wants to reduce its dependency on them. Furthermore, we show the cross-border flows of core nutrients (among then protein and calories) from food and feed. Because fertilizers are necessary to produce these goods, there is still an indirect dependency on countries from which fertilizers are imported.

We show how innovative tools can highlight risks in complex networks by analyzing the interdependencies and cascading effects. The availability of homogenized data sets and advancements in network analysis provides an opportunity to gain deeper insights in how trade networks evolve that can support proactive risk-management strategies and build resilient and sustainable supply chains.

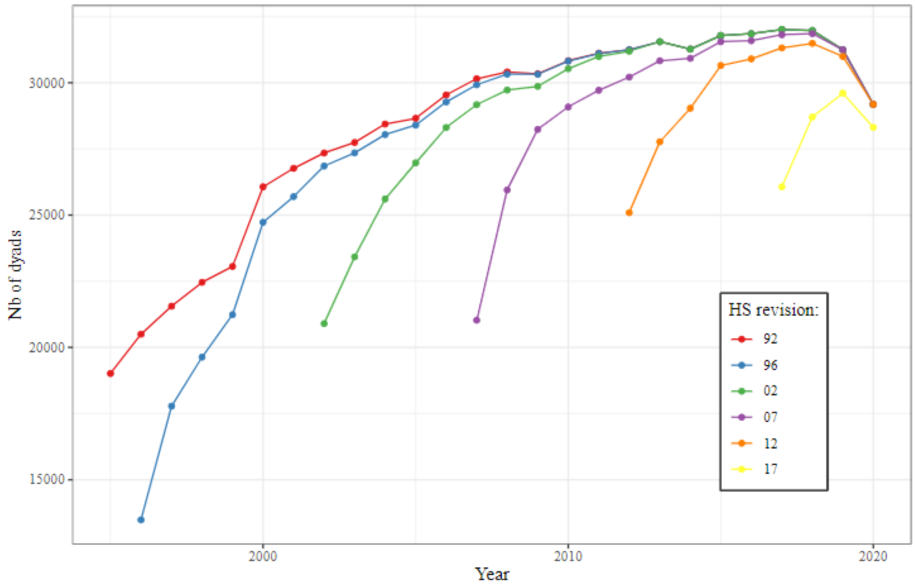
In the following sections, we present the data used for analysis and briefly explain the methods employed for descriptive analysis. We then showcase results from case studies focusing on Austria and the EU. The topics covered include fertilizer analysis as a compound and the fertilizer components nitrogen, phosphate, and potassium. Additionally, we explore core nutrients crucial for human and livestock nutrition, such as crude protein and calories. These nutrients are core elements of crops and drive significant global trade as food and feed. In the concluding section, we offer a concise summary and outline potential avenues for future investigations.

2. Data and Methods

2.1 Comtrade-BACI

The main data source for our analysis comes from COMTRADE-BACI (Gaulier and Zignago, 2010), a homogenized database for bilateral country-country trade flows. While the raw data comes from COMTRADE maintained by the UN, the BACI dataset further refines and homogenizes this information using consistent categorization of traded goods over several years (till 2021 currently), allowing for longitudinal analysis. Products are classified into harmonized system (HS) codes, and information on product descriptions, quantities, values, and units of measurement are also provided.

Figure 1: Data range of COMTRADE-BACI product classifications



Source: CMTRADE-BACI. Own calculations

For our analysis, we use the HS version 1996 (HS96) that provides stable longitudinal temporal coverage. In this dataset we select the 2000-2021 timeframe to understand how indicators evolve over time to where they stand currently. We take Fertilizers, a two-digit aggregated category (31) to understand trade patterns at the EU27 (2023 definitions) level. We also compare the results for bloc with Austria as a case study country that primarily trades with other EU countries. The aim of this is to show how focusing on direct trade partners of a single country does not fully highlight the risks of the complete network.

The BACI database provides trade data in values given in US Dollars (USD), and quantities in tons. The nominal values are converted into Euros (EUR) and deflated using the Homogenized

Indicator of Consumer Prices (HICP) to estimate real values to allow for comparisons over time. Both the time series are provided in Appendix 1.

2.2 Worldwide Governance Indicators

We use indicators of the World Bank's Worldwide Governance Indicators (WGI) project (https://info.worldbank.org/governance/wgi/) to assign risk factors to countries. The WGI database offers a comprehensive set of aggregate indicators that assess governance-related dimensions in numerous countries. These dimensions encompass voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. We utilize the WGI database to understand embodied risks in trade flows that we also compare with other measures like import diversification.

2.3 Nutrient flows

The nutritional value embedded in food and feed products is essential for estimations of nutritional supply security of both humans and livestock. We thus link trade volumes of food and feed products through their codification in trade databases to the same commodities' nutritional values as reported in respective databases. This provides a flexible way of harmonizing data to allow for the quantification of material flows in terms of key nutrients in international trade.

For this paper, nutrient contents of selected feed products are taken from the Feedipedia database, maintained by Association Française de Zootechnie (AFZ), the Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (INRAE), the Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), and the UN Food and Agriculture Organization (FAO) (AFZ et al., 2023). The database compiles structured information on the nutritional composition of major animal feedstuffs (Montville et al., 2013).

In addition, trade data is again obtained from the BACI database (CEPII, 2023; Gaulier and Zignago, 2010) and complementary trade volumes of agri-food products are taken from the United Nations Food and Agricultural Organization Statistical (FAOSTAT) database (FAO, 2022). Conversion tables provided by FAO allow for linking FAO codes to the HS system and vice versa.

Our methodology covers the linking of reported nutrient contents of food and feed products to their respective trade volumes to trace associated substance flows. Nutrients here refers to all functional components and values of food and feed, i.e., macronutrients such as protein and fats, elemental nutrients such as phosphorus, and nutritional value such as energy content. Nutrients identified as most critical for this prototype are gross energy (GE), crude protein (CP), fats (F), and phosphorus (P), which are complemented by dry matter content for proper quantification. Crude protein is closely linked to nitrogen (N) content, which was quantified complementary and is in fact typically the basis for CP quantification using the Kjeldahl conversion factor of 6.25.

All of these priority nutrients were researched and linked for a range of priority food and feed products with a focus on key livestock feed imports, i.e., maize and products, soybeans and products, rapeseed and products, sunflower seed and products, and wheat and products (see Appendix Table 2.2). For the subsequent quantification of material flows, i.e., flows of nutritional values in the trade database, total volumes of nutritional content are calculated based on the total trade volume of each commodity, the dry matter content (DM), and the nutritional values of the dry matter (crude protein (CP), gross energy (GE), phosphorus (P), and extractable ether (EE)). Lastly, aggregate material flows were obtained by addition of embedded nutrient values across the feed products listed in Appendix Table 2.2.

While we focus on feed for the purpose of this report, our approach allows to identify nutritional values of trade flows for animal and human consumption. A key difference between the feed and food values is the gross energy content. In the case of food items, energy represents the physiological energy value remaining after losses in digestion and metabolism have been deducted (Montville et al., 2013). In the case of animal feedstuffs, gross energy is measured as the energy released as heat when a compound undergoes complete combustion with oxygen in a bomb calorimeter (AFZ et al., 2023). Actual energy provided to animals from the latter requires the inclusion of an energy digestibility coefficient that varies among livestock groups and was not considered here as eventual consumption by live-stock groups is unknown. For soybean meal, for example, the energy digestibility is 91.6% for ruminants and 87.5% for pigs.

2.4 Network methods

We use recent advances in network analysis to analyze value chain risks. Nodes in global product trade networks, represented by countries, and flows, represented by quantity or values, are evaluated to understand their importance and subsequently vulnerability to supply chain disruptions. For this paper, we modify two network measures, PageRank and HITS, to develop metrics for summarizing direct and indirect risks at global network, and the local country or region level.

- **PageRank**, initially designed for the Google Search engine (Brin and Page, 1998), evaluates the importance of nodes using two key indicators. First, it looks at the number of flows among the nodes (quantity), and second, it also factors in which nodes are sending the flows (quality). The combination of these two gives a ranking of importance in the whole network. The PageRank (PR) formula is defined as follows:

$$PR_i = \frac{1-d}{N} + d \sum_{j \epsilon M_i} \frac{PR_j}{L_j}$$

where $i = 1 \dots N$ are the nodes in the network, $M_i = 1 \dots j$ is the set of neighbors of each node i, L_j is the number of outbound links for neighbor j, and d is the dampening factor that is defined as the probability of linking to node i, and it is usually fixed at 0.85.

- The **HITS** or Hub and Authority measure (Kleinberg, 1998) differentiates between nodes that point to many authorities (Hubs) and nodes that are pointed to by many hubs (Authority). Unlike PageRank, that is a global measure, HITS helps us better understand node-specific attributes within the network by breaking down the direction and importance of flows. Formally, the Hub (H) and Authority (A) scores are calculated as follows:

$$A_i = \sum_{j \in L_i} H_j$$

$$H_i = \sum_{j \in M_i} A_j$$

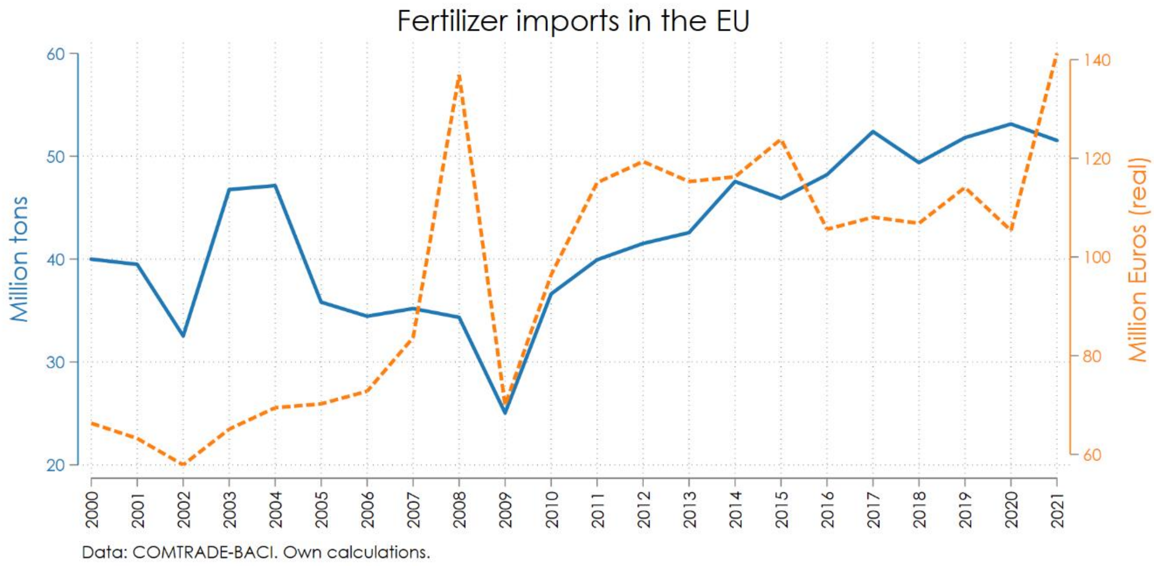
where the same definitions apply as above. In order to avoid the A and H matrices from exploding, they are normalized after each iteration which also allows them to converge.

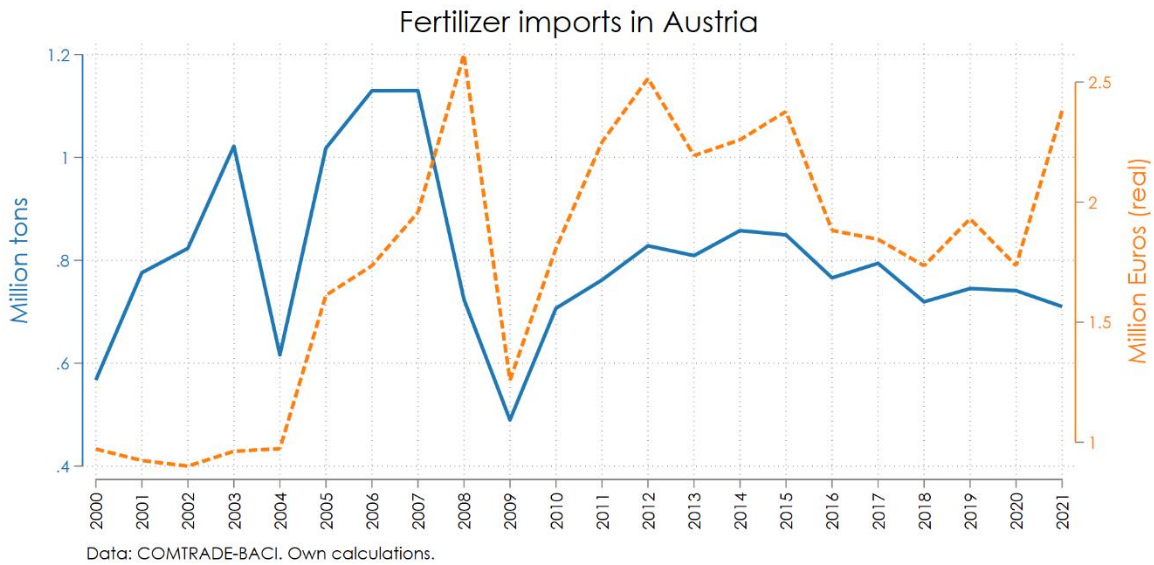
In order to use these measures, two data modifications are implemented. First, flow weights are calculated, defined as bilateral trade value divided by the sum of the total trade in the network for a given year. Second, the directions of imports and exports, are defined such that the importing countries point to the exporting countries to properly capture the importance in our network indicators. For example, by reversing the direction, the countries that export to many countries become more central, as opposed to countries that mostly import. From these modifications, we estimate the **Import Diversity Index**. Similarly, the **Import Risk Index** is calculated by using the values the WGI as the flow variable in the HITS index. We use one minus the score for each country so that an increase in the score implies higher risk.

3. Case study 1: Fertilizer imports in the EU and Austria

Figure 2 shows the evolution of values and quantities of Fertilizer imports to the EU27 and to Austria. We observe that after a dip in 2009, imports in values (blue line) to the EU rose steadily, flattening out slightly after 2017, but ending up at a peak in 2020. In contrast, in Austria we observe that after the peak in 2007, followed by the dip caused by the financial crisis in 2009, the recovery was muted rising slightly till 2014 before declining and reaching a low point in 2021.

Figure 2: Trade of fertilizers (2-digit product code) – imports in the EU and Austria





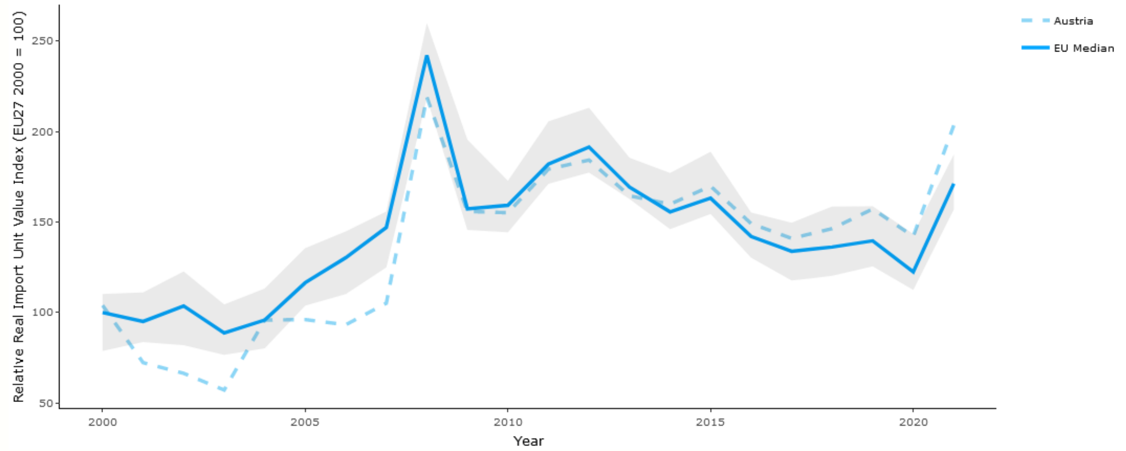
Source: CMTRADE-BACI. Own calculations.

If we observe the real value of these imported goods (orange dashed line, right-hand axis), we see that both the EU and Austria show the same order of magnitude. The value of goods rose sharply after 2009, before flattering out or even declining. The 2020 COVID-19 lockdowns brought another sharp rise in the fertilizer imports, where the bill peaked in 2021.

Figure 3 shows the unit value of imports (real value over quantity), which we index to the 2000 EU27 value. The solid blue line gives the EU median, the dotted blue line is for Austria, while the grey bands show the 25-75th percentile, or the inter-quartile range (IQR), for EU countries. Here we observe that Austria was paying a much lower unit before the 2009 crisis. After this event, the unit value stays close to the EU average, and in 2013-14 reverses to become higher. After

2020, we observe that Austria ends up paying a much high unit value that exceeds the upper 75th percentile for EU countries.

Figure 3: Unit value of imports



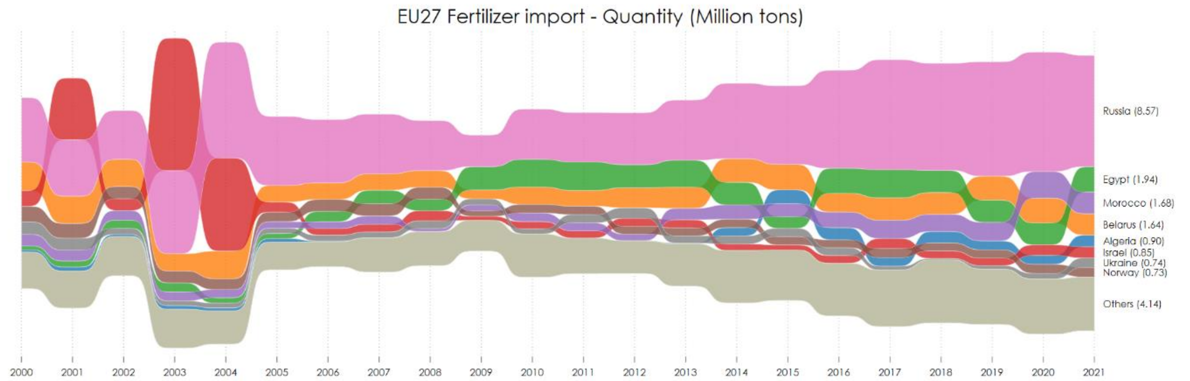
Source: CMTRADE-BACI. Own calculations.

The above graphs show basic time trends for a highly aggregated product category, but even this analysis already uncovers important trade patterns. In order to dig deeper, Figure 4 shows ribbon plots for the top eight trading partners for our two regions in 2021. Each import partner is assigned a unique and its relative position in each year shows its rank for that year. The thickness shows the import quantities.

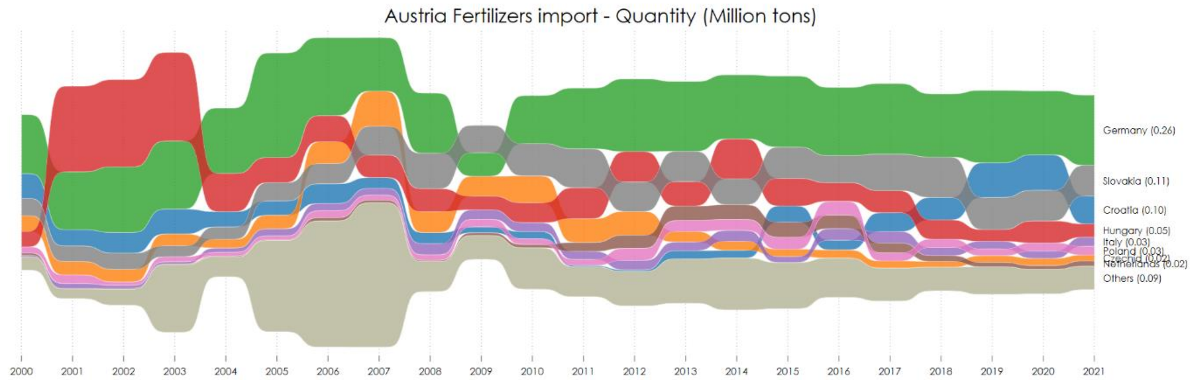
Here we already observe stark differences across the two regions. While Austria primarily trade with neighboring European countries, primarily German, Slovakia, Croatia, and Hungary for its Fertilizer imports, The EU27 bloc, imports from politically volatile countries, including Russia, Egypt, Morocco, and Belarus. Russia maintains its top spot by a large margin, also accounting for most of the Fertilizer imports, while Belarus stays within the top three since 2000. We also observe that Morocco and Egypt become more prominent over the years. Both Russia and Belarus currently face sanctions with the EU, while Ukraine is dealing with the war with Russia. Egypt, Morocco, Algeria have seen high political instability in the last decade.

Figure 4: Trading partners for Fertilizer imports in quantities

(a) EU



(b) Austria



Source: CMTRADE-BACI. Own calculations

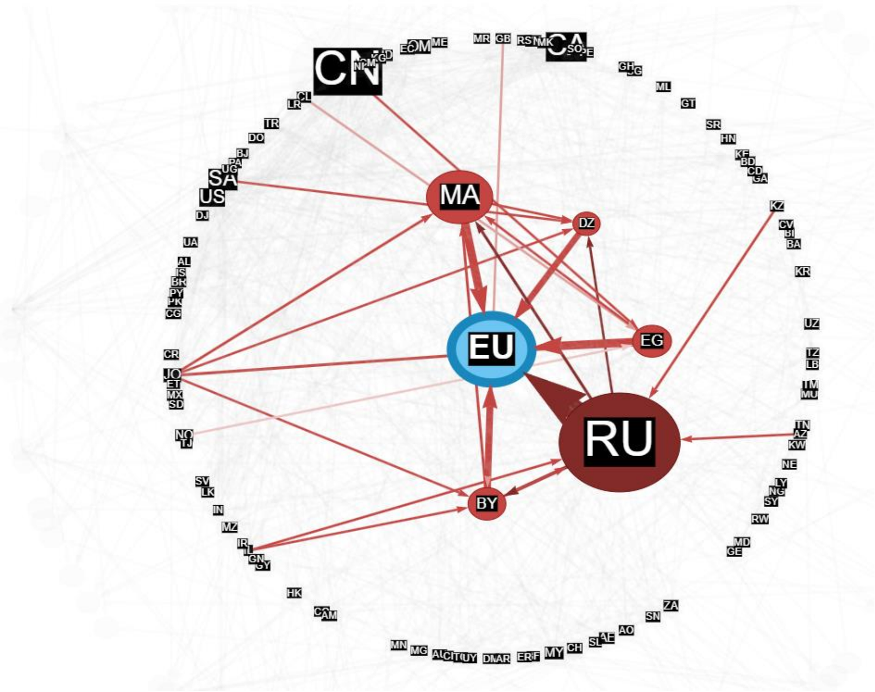
These graphs also highlight that country-specific analysis might presumably show safe countries, but within the large network the direct partners can be trading with riskier countries. In order to evaluate the structure of the larger Fertilizer network, we look at the role of countries in the network as a whole.

Figure 6 shows the 2021 networks of the EU and Austria organized in rings. The inner circle are direct top 5 partners from Figure 4. The outer circle shows the top 5 partners of direct trade partners. Node sides are weighted by total Fertilizer quantity imported, while arrows thickness highlight the flows. Each country is also assigned a color based on its risk value from the WGI database. A darker shade of red indicates higher risk, while lighter blue shades indicate lower risk.

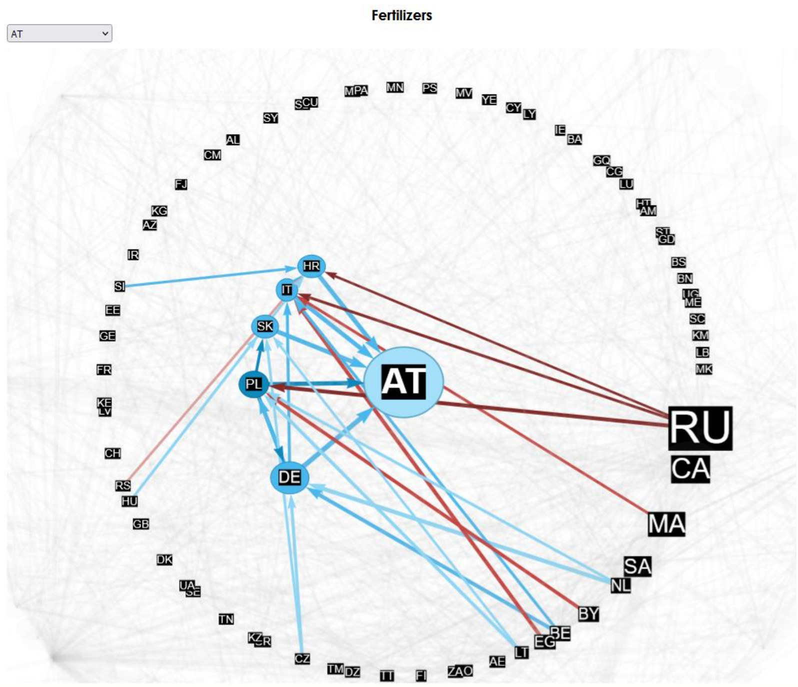
As indicated above, the EU's top 5 direct trade partners already include several high-risk countries. But looking at the second tier of the trade network, we observe that other countries such as China (CN), Kazakhstan (KZ), Azerbaijan (AZ), Saudi Arabia (SA), and Jordan (JO) also feature prominently in the second-tier imports that also highlight that indirect import risks tend to be much higher.

Figure 5: Indirect exposure

(a) EU's network



(b) Austria's network



Source: CMTRADE-BACI. Own calculations

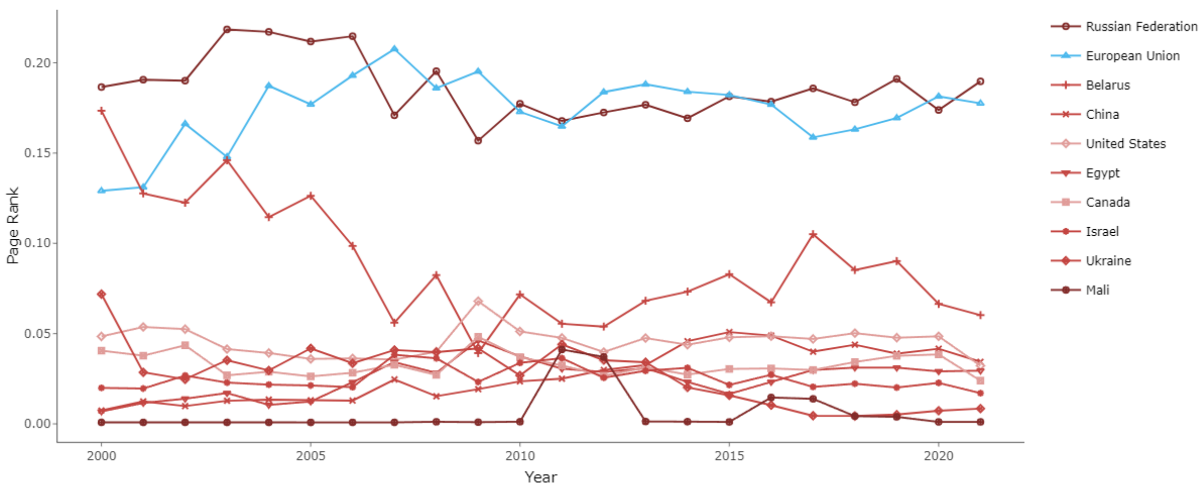
Austria's trade network shows relatively safe EU countries in the inner circle. But the second layer highlights the embedded risks. For example, Russia (RU) is the main trade partner for

Croatia, Italy, and Poland, while Morocco (MA), Egypt (EG), Belarus (BY), and Serbia (RS) also play key roles.

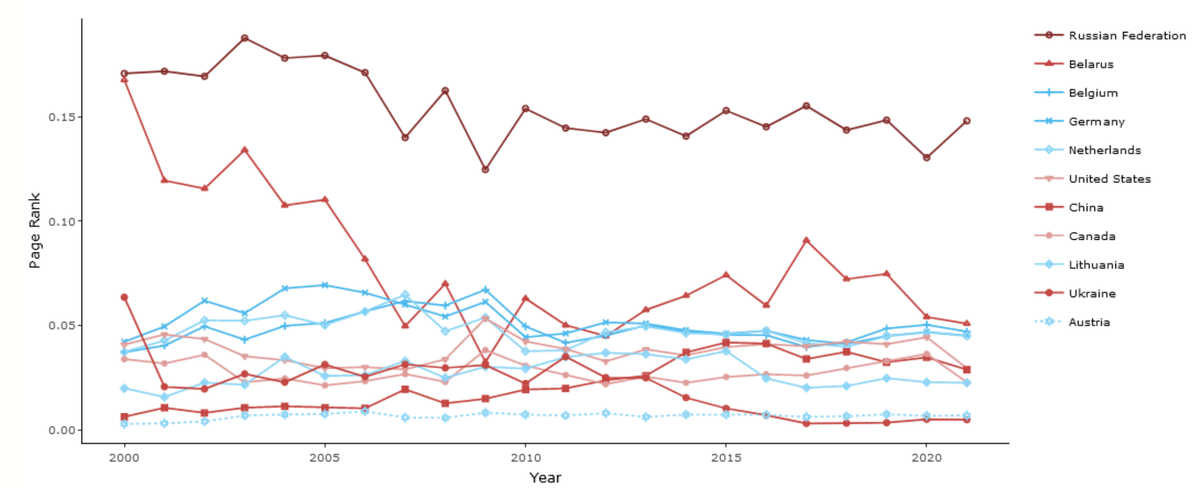
In order to summarize these networks in meaningful measures, Figure 6 shows the PageRank of top ten countries in the EU and the Austrian networks. The difference between the two is that for the former, EU27 countries are collapsed into one category, thus changing the level of flows and the number of nodes. The Austria network takes the raw country-country pairs as they are provided in the BACI database.

Figure 6: Centrality in Fertilizer trade network and risk

(a) EU27's network



(b) Austria's network



Source: CMTRADE-BACI. Own calculations

We observe that Russia and the EU remain very central in the EU27's trade network, with their positions staying relatively constant over time. Belarus, while losing its centrality, still maintains the third spot by a large margin from the next set of countries. These countries include China, USA, and Canada, following by Israel, Ukraine, and Mali. While US and Canada are relatively a lighter share of red, China, Israel, and Mali already are high on the risk spectrum.

If we observe the global trade network shown for Austria, we see that Russia is the most central country followed by Belarus. Belgium, Germany, and Netherlands take the next spots indicating that they are highly central within the EU network. Austria is shows to indicate its position within the global network. We can see that its centrality is fairly low but in recent years it out-performs Ukraine that was once a key exporter of Fertilizers.

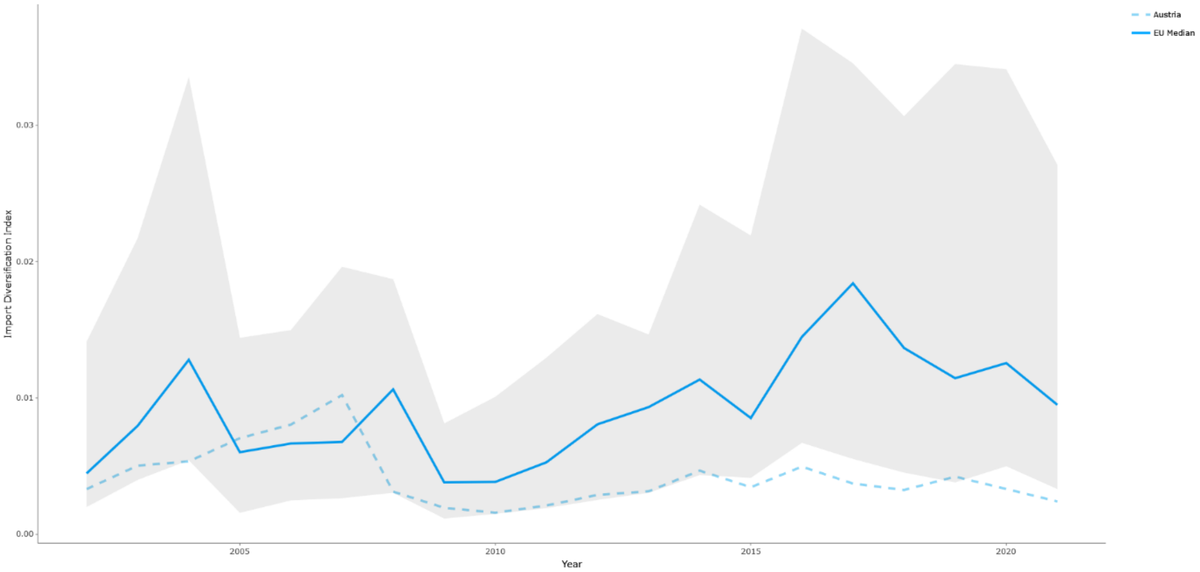
In Figure 7, we estimate two network measures developed for this report. The Import Diversification Index where a higher value indicates more diversity, and the Import Risk Index, where a higher value indicates higher embedded risk based on a country or region's position within the global trade network.

We observe that the import diversification of the EU increases after 2010, reaching a peak in 2017 before declining. The band shows the IQR that increases significantly in width over the years, indicating that countries within the EU have diverged over time in terms of their diversity. We also observe that Austria was keeping pace with the EU in increasing its trade diversification till 2007, and after that dropped to the lower end of the distribution after 2010 and maintained its low diversification rank.

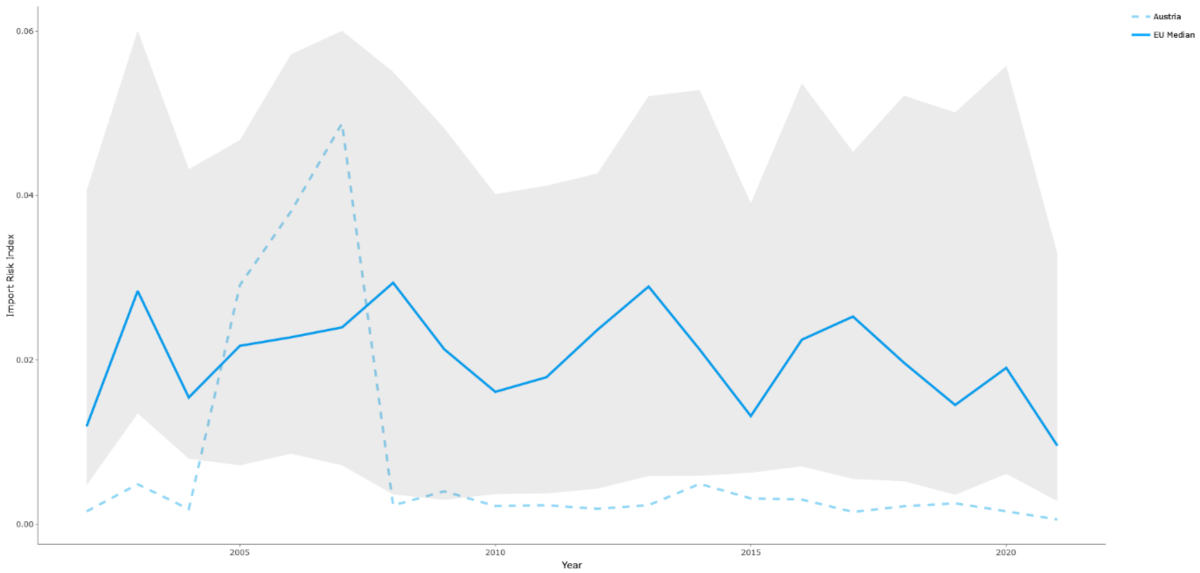
Whether these changes in diversification imply low or higher risk is evaluated in the second figure for the EU and for Austria. We observe that the import risk for the median EU27 country has observed no obvious trend in the past two decades but rather fluctuated and more recently declined. The IQR also shows a very large variation across the countries. In contrast, almost throughout the entire period, Austria displays rather constant low import risk as its index lies below the first quartile line. Only in the brief interval from 2005 to 2007 Austrian import risk is significantly elevated. In recent years, we observe further modest declines in Austrian fertilizer import risk.

Figure 7: Fertilizer Import Diversification Index

(a) Import Diversification Index



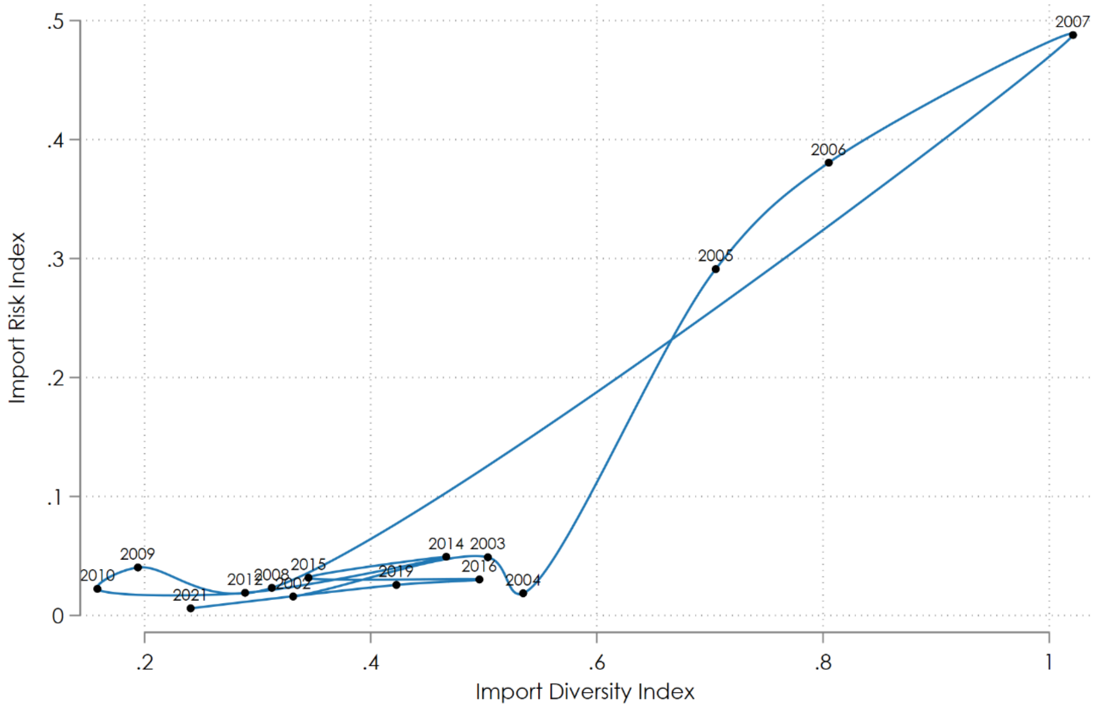
(a) Import Risk Index



Source: CMTRADE-BACI. Own calculations

Finally, Figure 8 plots the time trend of Import Diversity Index on the x-axis and compares it to the Import Risk Index. We observe that the significant increase in import diversity from 2004 was accompanied by declining import risk. Then, a shock is visible in 2007, where diversity dropped significantly till 2009. Since then, Austria has remained in an area in the bottom left of the graph with relatively low diversification and risk. Modest increases in diversification until 2016 came at the cost of somewhat higher risk while a decline to lower diversification values until 2021 has brought down the risk indicator to the lowest levels to date.

Figure 8: Evolution of Austrian Import Diversity versus Risk indices

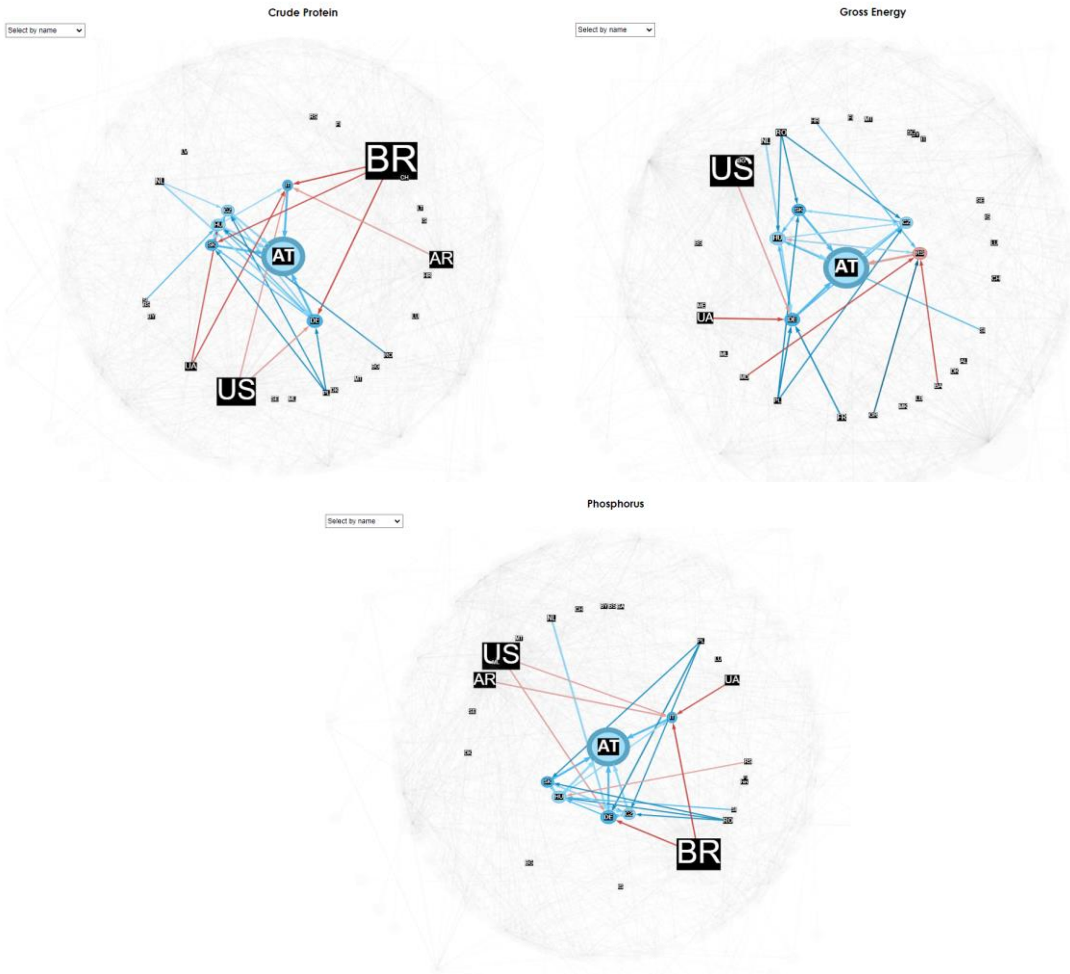


4. Case study 2: Nutrient flows for Austria

In this section, we look at the international flows of key nutrients embedded in the trade of a range of agricultural feed products. In analogy to the previous section, we focus on Austria's dependence on the global trade network for the supply of livestock nutrition. We examine the flows of crude proteins, gross energy, and phosphorous to Austria that are contained in four key feed crops selected for inclusion in the supply chain dashboard prototype based on their importance as animal feedstuffs that are to a large extent imported: maize, soybean, rape-seed, sunflower (see Appendix table 2.2).

Figure 9 below again illustrates Austrian imports in 2021 embedded in the global trade networks, only this time for nutrient flows (in tons) contained in traded agricultural commodities. As above, the top 5 import destinations for each country are shown. Since the nutrient components are proportional to the quantities traded in a certain product, the differences between the different nutrients emerge solely from the differences in bilateral trade composition. Similar to the fertilizer case, Austria's direct feed nutrient imports stem mostly from EU member states. The only exception appears to be Serbia which is among the top 5 import destinations for gross energy imports. In contrast to the fertilizer trade network discussed above, Austria's nutrient trade networks appear to be more diversified when considering the 2nd degree import destinations. Here, large agricultural exporters such as Argentina, Brazil and the US play a prominent role. However, it is noteworthy that Ukraine was an important source of crude protein for Hungary and Italy, an important source of gross energy for Germany and an important source of Phosphorus for Italy.

Figure 9: Network of nutrient flows for Austria

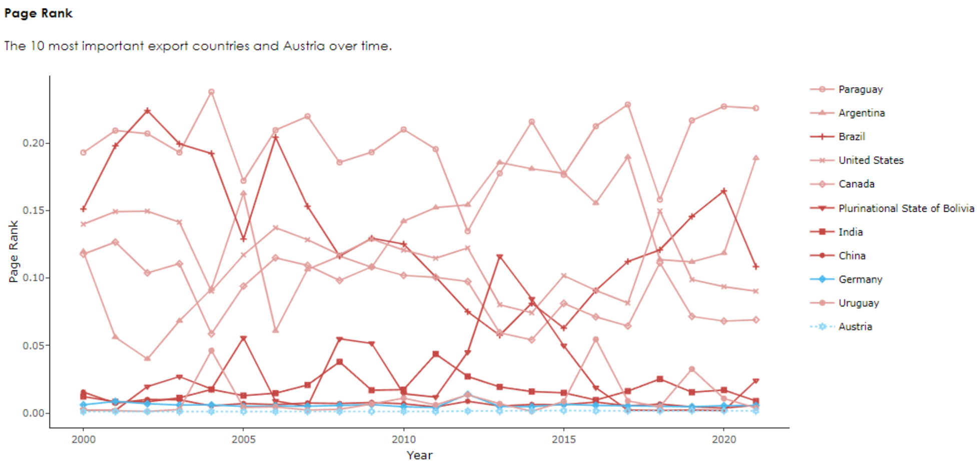


Source: CMTRADE-BACI. Own calculations

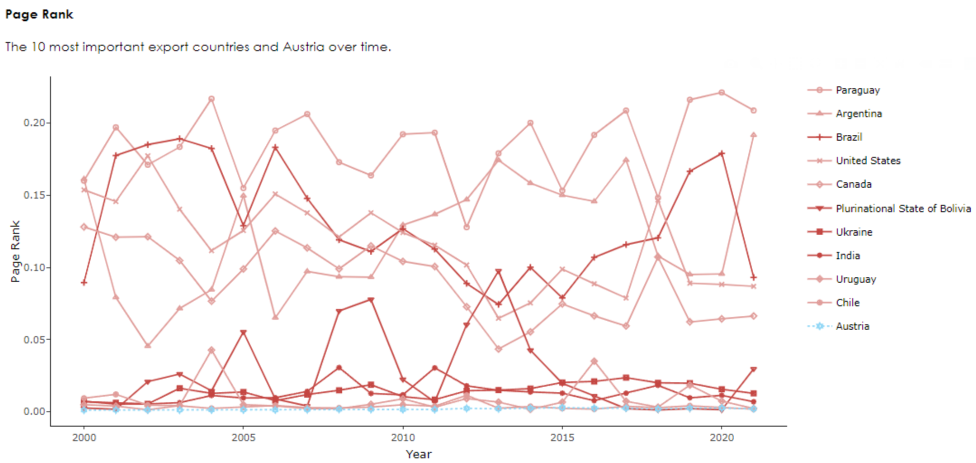
As with global product trade networks, network measures can be utilized to examine global nutrient flow networks. Figure 10 below illustrates the most important countries in the crude protein, gross energy and phosphorus networks by page rank. Unsurprisingly, the measure highlights major agricultural exporters and their closest trading partners. However, it is notable that in contrast to fertilizer trade, EU countries play a less significant role in feed nutrient flow networks.

Figure 10: Central countries in the nutrient trade network

(a) Crude protein



(b) Gross energy



Source: CMTRADE-BACI. Own calculations

5. Summary, conclusions and directions for next steps

This paper examines highly disaggregated trade data to analyze product-level patterns for EU27 countries, focusing on fertilizers and essential nutrients for human and livestock well-being. The study explores the context of food security and food sovereignty, which has sparked intense debates in Europe due to concerns about the stability and resilience of domestic and cross-border food supply chains.

Two opposing positions in the public debate are presented: one advocates strengthening local food production and self-sufficiency, while the other promotes free trade and closer ties to trade partners. The analysis provides fresh insights into long-available data, shedding light on trade patterns and risks related to international supply chains of fertilizers and nutrients to Austria and the EU.

The importance of fertilizers and nutrients for agriculture is well known, and disruptions in their supply can significantly impact food production. The paper reveals trade patterns for fertilizers and nutrients, emphasizing the interdependence of countries relying on imports for food and nutrients derived from fertilizers.

The analysis shows that while the EU has increased trade diversity, it predominantly trades fertilizers with politically unstable countries. In contrast, Austria has reduced trade diversity, facing higher indirect risks and paying higher prices for fertilizer imports compared to other EU countries. Although countries supplying basic nutrients have a more advantageous risk profile, a few risk-prone countries dominate global fertilizer supplies, making the situation less advantageous than it seems.

Various innovative visualizations are presented in the paper and discussed, including changes in trade value and volume, network measures, diversity of trade partners, and embodied risk and nutrient value of trade. These visualizations are accessible through an interactive online dashboard which is available at https://supplychains.wifo.ac.at.

The paper proposes using these measures and tools to support evidence-based debates on food security and food sovereignty, helping to comprehend complex multi-dimensional problems more effectively. Network analytical tools offer valuable insights into the core elements of food security risks.

Future research should encompass essential inputs like antibiotics and amino acids, crucial for livestock production, which contributes significantly to agriculture's value-added share in Austria and other EU Member States. Additionally, integrating fertilizer and nutrient analyses should consider countries' fertilizer production capacities and their dependence on energy imports.

6. Bibliography

Assefa, T., Meuwissen, M., Lansink, A. (2017). Price Risk Perceptions and Management Strategies In Selected European Food Supply Chains: An Exploratory Approach. NJAS: Wageningen Journal of Life Sciences, 1(80), 15-26. https://doi.org/10.1016/j.njas.2016.11.002

Duan, J., Yong, X., Jiang, H. (2021). Trade Vulnerability Assessment In the Grain-importing Countries: A Case Study Of China. PLoS ONE, 10(16), e0257987. https://doi.org/10.1371/journal.pone.0257987

Gaulier, G., and Zignago, S. (2010). BACI: International Trade Database at the Product-Level. The 1994-2007 Version. Working papers, CEPII.

Jagtap, S., Trollman, H., Trollman, F., Garcia-Garcia, G., Parra-López, C., Duong, L., & Afy-Shararah, M. (2022). The Russia-Ukraine Conflict: Its Implications For the Global Food Supply Chains. Foods, 14(11), 2098. https://doi.org/10.3390/foods11142098

Halmai, P. (2022). Covid-19 Crisis and Supply Side Bottlenecks In The Eu. Shorter- And Longer-Term Prospects. MNJE, 4(18). https://doi.org/10.14254/1800-5845/2022.18-4.2

Lamy, P., G. Pons, S. Hub, and A. Lombari (2023). „Revamping Food Sovereignty? Europe's response to changing global dynamics". Europe Chaques Delors - Thinking Europ. http://www.europejacquesdelors.eu/publications/grape-6-revamping-food-sovereignty-europes-response-to-changing-global-dynamics.

Montville, J.B., Ahuja, J.K., Martin, C.L., Heendeniya, K.Y., Omolewa-Tomobi, G., Steinfeldt, L.C., Anand, J., Adler, M.E., LaComb, R.P., Moshfegh, A., 2013. USDA food and nutrient database for dietary studies (FNDDS), 5.0. Procedia Food Science 2, 99–112.

7. Appendix 1: Exchange rates and conversion rates

Year	HICP inflation index (2015=100)	EUR to USD average annual exchange rate
1997	72.87	1.134
1998	73.67	1.1211
1999	74.48	1.0658
2000	76.05	0.9236
2001	77.83	0.8956
2002	79.58	0.9456
2003	81.24	1.1312
2004	82.98	1.2439
2005	84.79	1.2441
2006	86.64	1.2556
2007	88.49	1.3705
2008	91.38	1.4708
2009	91.65	1.3948
2010	93.14	1.3257
2011	95.66	1.392
2012	98.05	1.2848
2013	99.38	1.3281
2014	99.81	1.3285
2015	100	1.1095
2016	100.23	1.1069
2017	101.78	1.1297
2018	103.56	1.181
2019	104.8	1.1195
2020	105.06	1.1422
2021	107.78	1.1827
2022	116.82	1.053

8. Appendix 2: Nutrient trade flows methodology

Commodities in the trade databases are linked to commodities in the food and feed composition databases based on most closely matching terms and expert knowledge. For example, the USDA NDB provides a total of 14 pure soybean products (Table 2.1). Out of these, commodity 16108 was selected as it most closely relates to trade databases that refer to raw products.

Table 2.1. Identification codes (NDB_No) and short descriptions of pure soybean commodities recorded in the USDA NDB database. Uppercase writing has been adopted from the original.

NDB_No	Short Description
11450	SOYBEANS,GREEN,RAW
11451	SOYBEANS,GRN,CKD,BLD,DRND,WO/SALT
11452	SOYBEANS,MATURE SEEDS,SPROUTED,RAW
11453	SOYBEANS,MATURE SEEDS,SPROUTED,CKD,STMD
11454	SOYBEANS,MATURE SEEDS,SPROUTED,CKD,STIR-FRIED
11853	SOYBEANS,GRN,CKD,BLD,DRND,W/SALT
11923	SOYBEANS,MATURE SEEDS,SPROUTED,CKD,STMD,W/SALT
11924	SOYBEANS,MATURE SEEDS,SPROUTED,CKD,STIR-FRIED,W/SALT
16108	**SOYBEANS,MATURE SEEDS,RAW**
16109	SOYBEANS,MATURE CKD,BLD,WO/SALT
16110	SOYBEANS,MATURE SEEDS,RSTD,SALTED
16111	SOYBEANS,MATURE SEEDS,DRY RSTD
16409	SOYBEANS,MATURE SEEDS,CKD,BLD,W/SALT
16410	SOYBEANS,MATURE SEEDS,RSTED,NO SALT ADDED

Table 2.2. Database codes, commodity descriptions, and nutritional contents of the priority animal feeds and derived products.

HS Code (H5)	FAO Code	CPC Code	FAO Item	BACI Description	DM [%]	CP [% DM]	GE [MJ/kg DM]	P [g/kg DM]	EE [% DM]
100510	56	112	Maize (corn)	Cereals; maize (corn), seed	86.3	9.4	18.7	3.0	4.3
100590	56	112	Maize (corn)	Cereals; maize (corn), other than seed	86.3	9.4	18.7	3.0	4.3
110430	57	23140.06	Germ of maize	Cereal; germ of cereals, whole, rolled, flaked or ground	95.1	12.8	28.9	2.2	48.4
120110	236	141	Soya beans	Soya beans; seed, whether or not broken	88.7	39.6	23.6	6.1	21.4
120190	236	141	Soya beans	Soya beans; other than seed, whether or not broken	88.7	39.6	23.6	6.1	21.4
120510	270	1443	Rape or colza seed	Oil seeds; low erucic acid rape or colza seeds, whether or not broken	92.3	20.9	28.8	7.3	46.0
120590	270	1443	Rape or colza seed	Oil seeds; rape or colza seeds, other than low erucic, whether or not broken	92.3	20.9	28.8	7.3	46.0
120600	267	1445	Sunflower seed	Oil seeds; sunflower seeds, whether or not broken	92.8	16.0	28.7	5.7	48.0
230400	238	21910.03	Cake of soya beans	Oil-cake and other solid residues; whether or not ground or in the form of pellets, resulting from the extraction of soyabean oil	88.0	55.2	19.7	7.1	1.7
230630	269	21910.07	Cake of sunflower seed	Oil-cake and other solid residues; […] extraction of sunflower seed oils	89.0	32.4	19.4	11.6	2.2
230641	272	21910.08	Cake of rapeseed	Oil-cake and other solid residues; […] extraction of low erucic acid rape or colza seed oils	89.0	38.1	19.3	12.7	2.4
230649	272	21910.08	Cake of rapeseed	Oil-cake and other solid residues; […] extraction of rape seed oils (other than low erucic acid rape or colza)	89.0	38.1	19.3	12.7	2.4
230690	61	21910.02	Cake of maize	Oil-cake and other solid residues; […] extraction of oils, n.e.c. in heading no. 2306	95.6	25.6	20.7	5.5	8.1

Notes: The HS code provides the link to the BACI database and other common trade databases. The FAO code links to the FAOSTAT database. The CPC code provides a third alternative to link to trade data and is used in parallel in FAOSTAT. The columns FAO item and BACI description provide the respective commodity descriptions that provided the foundation to link to nutritional databases. The nutritional factors all relate to dry matter as fed (column DM) and consist of crude protein (CP), gross energy (GE), phosphorus (P), and crude fat (=ether extract (EE)).

Table 2.2 and **Fehler! Verweisquelle konnte nicht gefunden werden.** show the results of linking database commodity codes and commodities for animal and human consumption, respectively. For the subsequent quantification of material flows, i.e., flows of nutritional values in the trade database, total volumes of nutritional content are calculated based on the total trade volume of each commodity, the dry matter content (DM), and the nutritional values of the dry matter (crude protein (CP), gross energy (GE), phosphorus (P), and extractable ether (EE)).