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Importance of trade dependencies for agricultural inputs: a case study of Finland

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Importance of trade dependencies for agricultural inputs: a case study of Finland

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Abstract

Approximately 80% of the world's population lives in countries that are dependent on food imports to sustain an adequate food supply. Besides these food imports, further dependencies also arise due to the requirements for agricultural inputs, including energy, fertilisers, feed and agricultural machinery. While the trade of agricultural inputs is relatively well represented in economic analysis, the quantification is often in terms of monetary values, and thus the assessments of the actual input quantities are very limited. In this paper, we develop a framework for analysis of the traded input quantities at the country-level and demonstrate its utility through an in-depth analysis of Finland's dependency on agricultural inputs. Further, we assess the importance of these inputs for domestic food production from a resilience perspective. We find that Finland, a country with relatively high food self-sufficiency but also a great dependency on imported agricultural inputs, experienced an increase in its dependency over the period 1996-2016. In case of trading partners, the story is more mixed: while trading partners for soybeans increased, those decreased in case of electricity while no significant change was observed in other commodities. In Finland, the rapeseed dependency on imports (ratio of net imports and consumption) grew from around 0% to almost 50% between the years 1987-2013. Changes for electricity remained substantially smaller, with dependency only slightly growing during the study period. Crude oil and soybean supplies are totally dependent on imports as neither is produced in Finland. Interestingly, the highest dependencies for agricultural inputs were on different countries than that for foodstuff imports. Thus, when identifying and assessing approaches to increase resilience to trade-related shocks, it is essential to understand both foodstuff and agricultural input dependencies within the global food system.

Keywords: agricultural inputs, international trade, resilience, trade dependency

1. Introduction

International trade of agricultural food commodities has grown during the last decades in the terms of volumes (e.g. D'Odorico et al., 2014; Porkka et al., 2013) and values (e.g. Qiang et al., 2019). While this provides valuable information where the food is produced and consumed, and further reveals the dependencies related to international trade, the vital role of agricultural inputs for agricultural production (such as energy, fertilisers, feed and agricultural machinery) is often ignored. This is crucial, since agricultural inputs are essential in every step of the food supply chain – from primary production to consumption (Deutsch, 2004; Gisselquist, 1994; Niemi and Huan-Niemi, 2012; Wesseler et al., 2015) As the shocks and interruptions in the global agricultural trade are increasing (Headey, 2011; Marchand et al., 2016), this also has an impact on the trade of agricultural inputs and the inclusion of inputs in the comprehensive analyses is important.

The agricultural inputs, on the other hand, are included frequently in various established economic models, that vary from simple bilateral trade relations models to more complex computable general equilibrium models (e.g. Goldin, 1990; Keeney and Hertel, 2005; Paiva, 2008; Valenzuela et al., 2007; Wu and Guclu, 2013). While the economic trade models provide key insights into the economic dependencies of agricultural input trade, this reveals only part of the story. Complementing the current knowledge of values with the traded volumes, helps to understand the overall importance of the agricultural inputs for the food system's resilience.

We have identified two research gaps in the food system studies regarding the importance of agricultural inputs. First, even though the import dependency in terms of agricultural inputs has been described to be desirable for the country's self-reliance (López-Ridaura et al., 2002; Schipanski et al., 2016), the relevance of agricultural inputs has not been linked to food system resilience. Second, the comprehensive analyses, including several inputs simultaneously, are missing in the existing literature. Focusing on single inputs (Boerema et al., 2016; Lassaletta et al., 2014; Metha and Gross, 2007; Nesme et al., 2018; Woods et al., 2010) does not allow for an assessment of the overall trading dependency and further, neglects the interdependencies of different agricultural inputs within the food system. However, it is important to clarify that we do not consider international trade as a harmful aspect in this paper – rather, we see trade to have a comparative advantage and the gains from trade should be assessed jointly within a risk framework for resilience.

The main motivation for our study is to explore the "hidden" dependencies included in the agricultural trade, i.e., agricultural inputs. We chose four agricultural input groups based on their importance to agricultural production: energy, fertilisers, feed, and agricultural machinery. Energy is used in all steps of the food supply chain and its price also directly affects the cost of tillage, fertilisers, and other inputs (Woods et al., 2010). Further, fertilisers, such as phosphorus and nitrogen, are traded globally in substantial quantities to support the production of food and feed items (Lassaletta et al., 2014; Nesme et al., 2018). For example, meat production relies on access to inexpensive protein feeds. Therefore, we expect high sensitivity to changes in global markets (e.g., economic fluctuations or disruptions in availability) (Boerema et al., 2016). In addition, the global demand for agricultural machinery has increased steadily since 2000, while machinery production has been dominated by only a few companies (Metha and Gross, 2007) – thus presenting a potential chokepoint in the system.

As a response to the call for national studies to discover the country-specific complexities within the global food system (e.g. Moragues-Faus et al., 2017; West et al., 2014), we develop a framework to analyse key agricultural inputs simultaneously for two decades and link this analysis closely to the trade-related resilience in the food system. We demonstrate the value of this framework through a case study on Finland. Finland is an affluent Nordic country with relatively high self-sufficiency in food production but, at the same time, a great dependence on several agricultural inputs (Niemi et al., 2013). Finland has also gone through major structural change; for example, joining the European Union (EU) in 1995 and opening the international trade (Lehto, 2009). Existing studies on Finland's dependence on agricultural inputs have concentrated fully on monetary values (e.g. Knuuttila and Vatanen, 2015), and thus dependence in terms of quantities, and related perspective on resilience, is still missing. We expand the current understanding of trade dependence of agricultural inputs and, further, link that to the resilience in the Finnish food system.

2. Materials and methods

2.1. Definitions

We first use Peterman et al. (2014) categories for agricultural inputs: i) technological resources (e.g., fertilisers and equipment); ii) natural resources (e.g., irrigation and soil fertility); and iii) human resources (e.g., labour and services). We focus on technological resources, hereinafter referred to generally as "agricultural inputs".

For resilience, we adopt the same definition as Kummu et al. (2020), stating that resilience is the "ability to respond, reorganise and adapt to disruptions while retaining essentially the same function, structure, identity and feedbacks throughout the change" (Folke, 2006; Schipanski et al., 2016). The most important resilience principles, as defined in (Biggs et al., 2012), for this study are maintaining diversity and redundancy; and managing connectivity. To maintain the availability of agricultural inputs, it is important to maintain diversity and redundancy in sources from where the inputs are obtained from, optimally a combination of domestic and external sources to overcome potential local and global shocks in availability. Connectivity is closely linked to multiple trade connections, in case there is strong dependence on imports.

2.2. Framework design

We designed a framework (See Figure 1) that allowed for a joint assessment of the country's bilateral trade for multiple agricultural inputs associated with energy, feed, fertilisers, and agricultural machinery. Further, we include resilience calculations for energy and feed, based on their independency from imports and diversity in import connections, following methods used by Kummu et al. (2020). In particular, for our case study focused on Finland, we examine the evolution of Finland's inventories and trade dependencies with a focus on understanding the impact of EU membership.

The baseline for the analysis is created in the first step (Figure 1) where the relevant inputs for the local context in the country of interest are assessed. For Finland, we selected four agricultural input groups: energy (electricity and oil), feed (all rapeseed and soybean), fertilisers (crude and manufactured), and machinery (agricultural machinery and tractors). The rationale for this input selection is: 1) Finland does not have oil reservoirs (energy), 2) present-day climate conditions are not favourable for soybeans cultivation (feed), 3) soil improvements are occasionally needed (fertilisers), and 4) agriculture is highly mechanised in Finland (machinery). The following steps (steps 2-6) are explained in the Sections below.

2.3. Collecting trade data

Even though there are readily accessible trade data for foodstuff commodities (e.g. Kastner et al., 2011), finding such data for energy, fertilisers, and machinery inputs is more difficult. For these agricultural inputs, no comprehensive country-of-origin based data exists (such as Kastner et al., 2011 for foodstuff). Therefore, we use the reported trade partners as basis of our analysis of trade related resilience.

As coherent bilateral trade statistics (steps 2-4) for the whole study time period were not available for all commodities from the United Nations International Trade Statistics Database (UN Comtrade) or Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), we utilised Finland's International Trade Statistics (Finnish Customs) for bilateral trade data for energy and machinery under the Standard International Trade Classification (SITC 3) (Finnish Customs, 2019). We collected feed from FAOSTAT, based on the Detailed Trade Matrix (FAOSTAT, 2019) and Commodity Balance Sheet (FAOSTAT, 2018). Table 1 shows utilised sources and data for each analysis in our study. The bilateral trade statistics for soybeans and rapeseed included all traded cakes, oils and beans/seeds. For the bilateral trade of fertilisers, only the annual monetary values were reported in Statistics of Finland. Therefore, the quantities of bilateral trade data were assessed by scaling monetary values of the fertiliser fractions using the aggregate trade quantities acquired from FAOSTAT, based on the Fertilizers by Product (FAOSTAT, 2020a).

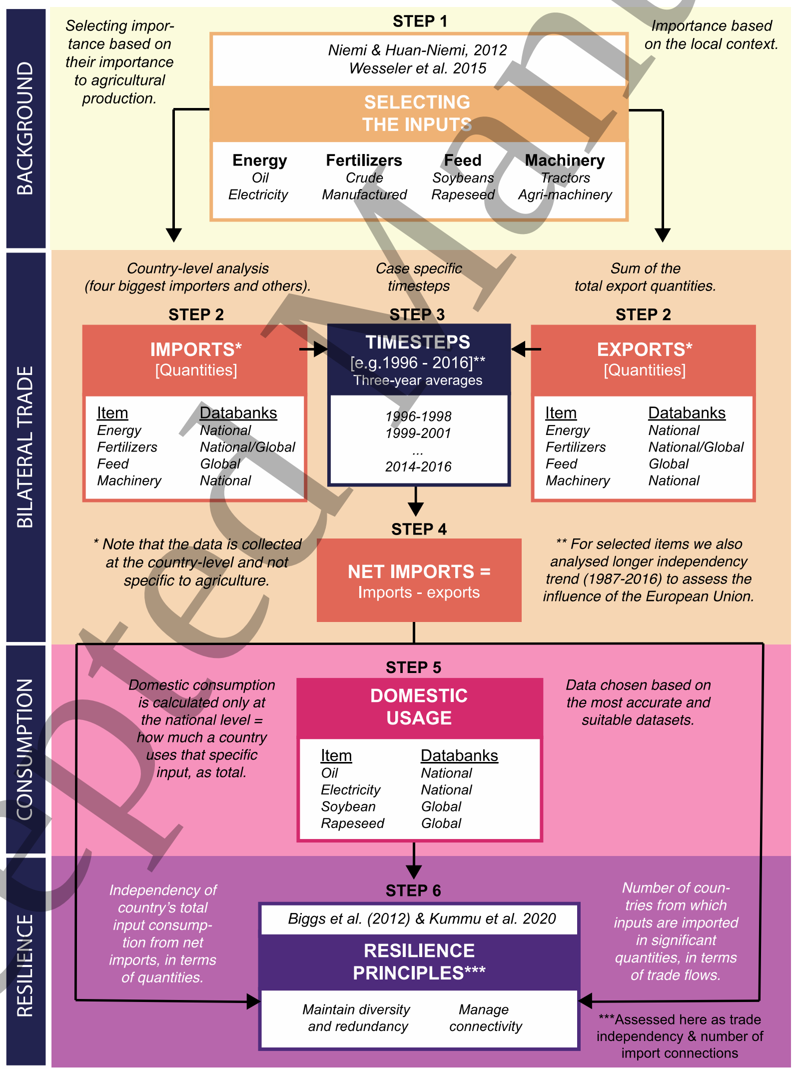

Figure 1. Framework for the study (steps 1-6) and an example how the framework is applied in the case study of Finland

For analysing trade independency (steps 5-6), we used aggregate oil net imports from UN Comtrade (UN Comtrade, 2020) and aggregate electricity net imports from Statistics Finland (Statistics Finland, 2020). The trade independency calculations for soybeans and rapeseed focused only on the seeds/beans, and excluded the oils and cakes from the main analysis. Finland does not produce soybeans but still has some soybean processing facilities, and thus in the absence of proper conversion factors for transforming e.g., soybeans to soybean cake, including cakes and oils would have skewed the trade independency calculations. The production of such processed products is reported as domestic production in FAOSTAT Commodity Balance Sheet, even though 100% of the raw material would be imported. This leads to the unintuitive situation where Finland would not be 100% dependent on soybean imports even though soybean is not grown in Finland. Consumption or usage data for energy and feed were collected from FAOSTAT as "Commodity Balances – Crops Primary Equivalent" (FAOSTAT, 2020b) and from Statistics Finland as "Energy supply and consumption" (Statistics Finland, 2020)(Statistics Finland, 2020).

Due to a lack of comprehensive and comparable data on quantity of fertilisers and machinery, these inputs were included in the analysis of the bilateral trade (steps 2-4) but omitted from the resilience trend analysis (steps 5-6).

2.4. Analysing time series of trade

The time period considered for bilateral trade relations in this study spans from 1996 to 2016. This time period was chosen because no coherent bilateral trade data were found for the earlier years for the majority of the inputs considered in this study. However, data on trade flows (without trade partners) is available for a longer time period and thus, we also provide an analysis of long-term changes in trade independency that covers years from 1987 to 2016. Including a long-term analysis provides a way to analyse major changes (e.g., market access) as Finland joined the EU in 1995, which expanded trade with the rest of Europe.

The trade quantities and number of trading partners fluctuate substantially from year-to-year. To smooth out the annual variation, we divided the whole time period into three-year timesteps (i.e., 1996-1998, 1999-2001, …, 2014-2016). The average within each timestep was then calculated for each input group.

For visualising the most important partner countries for agricultural input trade in Finland, we identified four countries with the largest import for each timestep and the rest were labelled as "others". For export quantities, we focused only on the aggregate exports for each input group, and thus no specific countries were identified.

Due to the nature of global markets, it is not realistic to assume that all imports are used domestically in Finland. Rather, some of the imports may be re-exported directly or imported materials may be processed into new products (e.g., crude oil into petrol), which are then consumed in Finland or exported further. We used the same classification (e.g., input group) for imports and exports, even though there might have been further processing for the inputs and thus some trade flows might not match.

Finally, we used the last timestep (2014-2016) to calculate the average of import shares of the commodities within different input groups (e.g., an average of the electricity and oil import shares for the energy input group) for each trading partner and visualised those in a world map.

Table 1. The used datasets and timelines of the different analyses in this study.

Datasets	FAOSTAT	UN Comtrade	Finnish Customs	Statistics of Finland
Analysis on the bilateral trade and the analysis on the number of trading partners (ENS) (steps 2-4)				
Energy			1996-2016	
Fertilisers	2002-2016		2002-2016	
Feed	1996-2016*			
Machines			1996-2016	
Long term analysis on the independency (steps 5-6)				
Oil		1987-2016		1987-2016
Electricity				1987-2016
Soybeans	1987-2013			
Rapeseed	1987-2013			

** Note, the consumption data was not available for the last timestep (2014-2016). The partner data was available for the last timestep (2014-2016).*

2.5. Estimating resilience

Trade-related resilience was evaluated using methods adapted from Kummu et al. (2020), who assess the trade resilience for nutritional components at the country-level. We apply two of the four indicators from Kummu et al. (2020): i) independency from trade; and ii) a number of import connections. Independency from trade can be seen as a strategy to have more control over food production and supply, thus providing tools to decrease the impact of disturbances within global markets. On the other hand, well-connected systems can overcome and recover from disturbances easier with the power to choose from several partners. The combination of these indicators helps us to understand the complexity of the food system and provide a tool to increase resilience at the country-level Kummu et al.

(2020). Table 2 presents the definitions and calculation principles used in this study.

Table 2. Definitions and calculations of the resilience analysis, modified from Kummu et al. (2020).

	Independency from imported agricultural inputs	Import connectivity of trading partners
Definition	Independency of a country's total consumption from imports, i.e., what share of total consumption could be satisfied with domestic production.	Number of countries from which agricultural inputs are imported.
Calculations	1- the ratio between net imports and national consumption. Independency of 100% means that all consumption could be satisfied with domestic production. Independency below 0% means that in addition to the domestic usage, some of the imports are also exported or processed along the way.	Rate of change in diversity of import connections is estimated using an effective number of species (ENS) from Shannon Diversity Index.

3. Results

3.1. Finland's trading partners for the imported and exported agricultural inputs

Finland's energy (electricity and oil) partners are mainly its neighbouring countries (Figure 2). Electricity imports have risen relatively steadily throughout the study period, and especially the imports from Sweden have been increased at the expense of Russia in the 2010s (Figure 2a). There is no clear trend in the exports for electricity. Oil imports have been relatively constant since 2002-2004 and Finland exports hardly any oil, at least in the form of crude oil that is assessed in this study (Figure 2b). Imports from Russia accounted for most of the total oil imports after 2002-2004. To gain a comprehensive understanding of Finland's current trading partners for energy, Figure 2c presents all the countries that Finland imported energy from during the last timestep (2014-2016). Russia is the most important trading partner followed by Sweden; other countries play a minor role.

Like energy, Finland's feed (soybean and rapeseed) exports are low, and the trade is primarily concentrated on imports (Figure 3a and 3b). Compared to the other imported input groups (energy, fertilisers, and machinery), feed imports seem to have the most diversity in terms of the number of trade partners. Rapeseed imports have increased steadily during the study period (Figure 3a) with Germany standing out as the main exporter, and Russia also playing an important role during the last timestep (2014-2016). Soybean imports have a very different trend with more fluctuations in terms of quantities and diversity of trading partners. Especially during 2008-2010, soybean imports dropped to the lowest level and at the same time, there was a change in the trading partners from the Americas to Europe (Figure 3b). This change led to the situation, in which Germany, Norway and Russia became the most important trading partners of feed in 2014-2016 (Figure 3c).

The most challenging input group to analyse was fertilisers (crude and manufactured), because the import and export quantities before 2002 were not available in the Finnish Customs. Based on the combined data from Finnish Customs and FAOSTAT, Finland is a net exporter of fertilisers measured as aggregate quantities across all fertiliser products. Finland also imports fertilisers from only a few countries, of which Russia has by far the largest share (Figure 4c). However, it should be noted that the importance of imported fertilisers in Finnish agriculture is somewhat limited. For example, in 2016, the imports of inorganic fertilisers were only around 11% compared to the domestic production in Finland (Aakkula et al., 2019). Further, the analysis concerned only the crude and manufactured fertilisers, and did not include, for example, different components needed in fertiliser production.

Machinery (agricultural machinery and tractors) is a very diverse input group. Especially agricultural machinery, where the share of imports from countries labelled "others" is quite substantial and none of the countries really stands out. However, Sweden and Germany have constant shares of the agricultural machinery inputs (Figure 5a). For tractors, North America stands out, especially Mexico, as having a large share of imports in the last timestep (Figure 5b). Interestingly, compared to the other input groups, Russia is not among the most important exporters. The overall picture for the last timestep shows that Finland imports machinery from all continents except Australia (Figure 5c). However, it is vital to acknowledge that these results do not include, for example, the spare parts for the machinery that are crucial for agricultural production. Thus, Finland still could be heavily dependent on some agricultural machinery while exporting other types of machinery.

3.2. Finland's resilience regarding the independency from imports

In addition to the quantities of imports, we also assessed the trends in independency from imports as well as the significant import connections for energy and feed (Figure 6). Independency is decreasing (i.e., increasing dependency) for electricity, oil and rapeseed throughout the study period, and no trend is detected for soybeans (Figure 6). When considering the time periods before and after Finland joining the EU (Figure 7), rapeseed and crude oil show a clear declining trend in independency from imports.

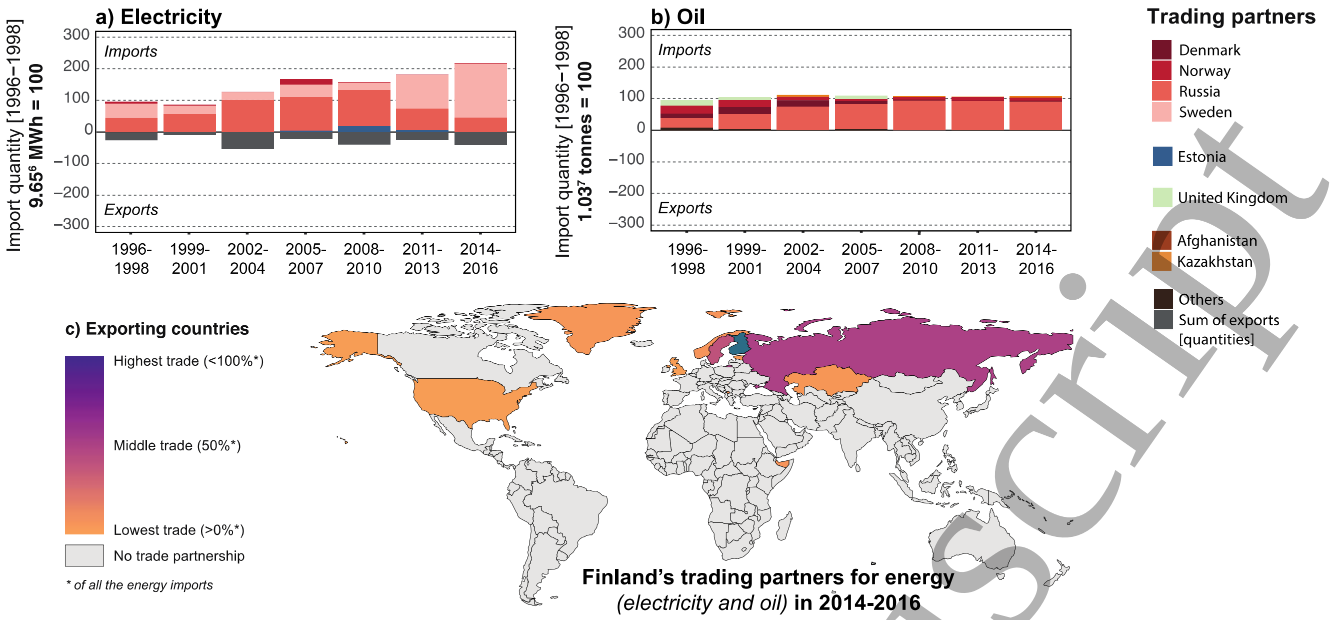

Figure 2. Finland's most important import trading partners for energy (a: electricity and b: oil) during all timesteps (1996-2016) where the first timestep of imports (1996-1998) equals to 100 and other timesteps are scaled accordingly. Positive values represent imports and negative exports. In addition, Finland's trading partners for the last timestep (c: timestep 2014-2016).

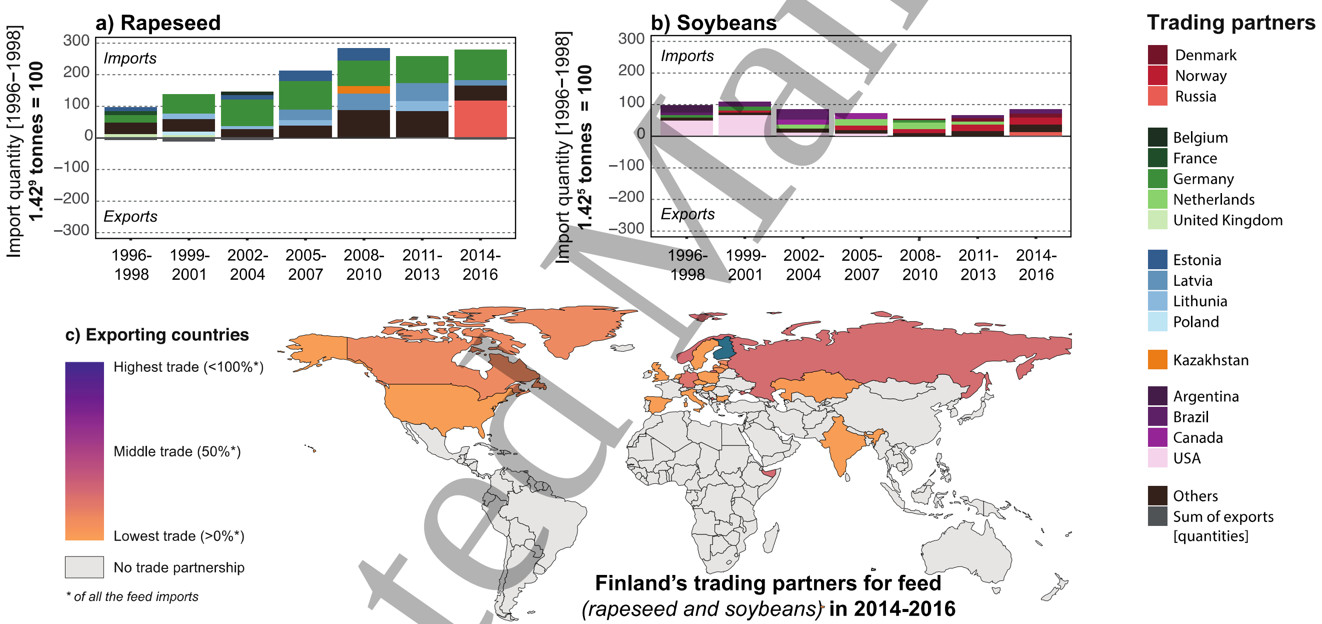

Figure 3. Finland's most important import trading partners for feed (a: rapeseed and b: soybeans) during all timesteps (1996-2016) where the first timestep of imports (1996-1998) equals to 100 and other timesteps are scaled accordingly. Positive values represent imports and negative exports. In addition, Finland's trading partners for the last timestep (c: timestep 2014-2016).

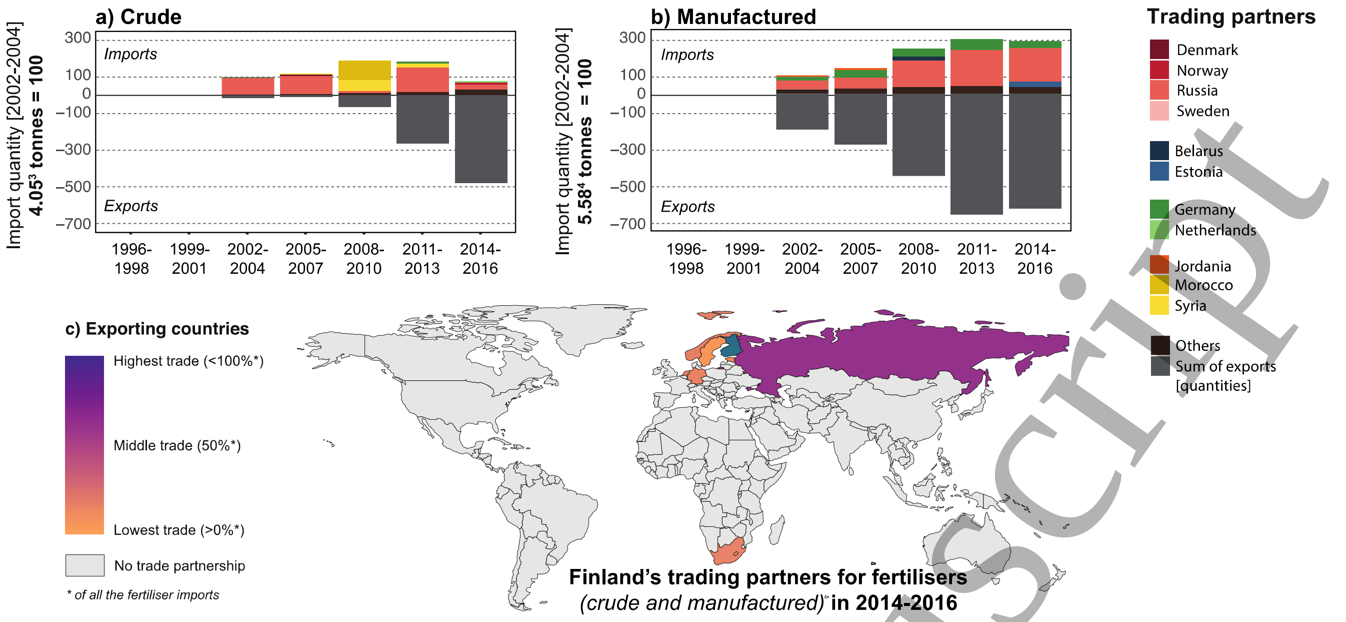

Figure 4. Finland's most important import trading partners for fertilisers (a: crude and b: manufactured) during all timesteps (2002-2016) where the first timestep of imports (2002-2004) equals to 100 and other timesteps are scaled accordingly. Positive values represent imports and negative exports. In addition, Finland's trading partners for the last timestep (c: timestep 2014-2016).

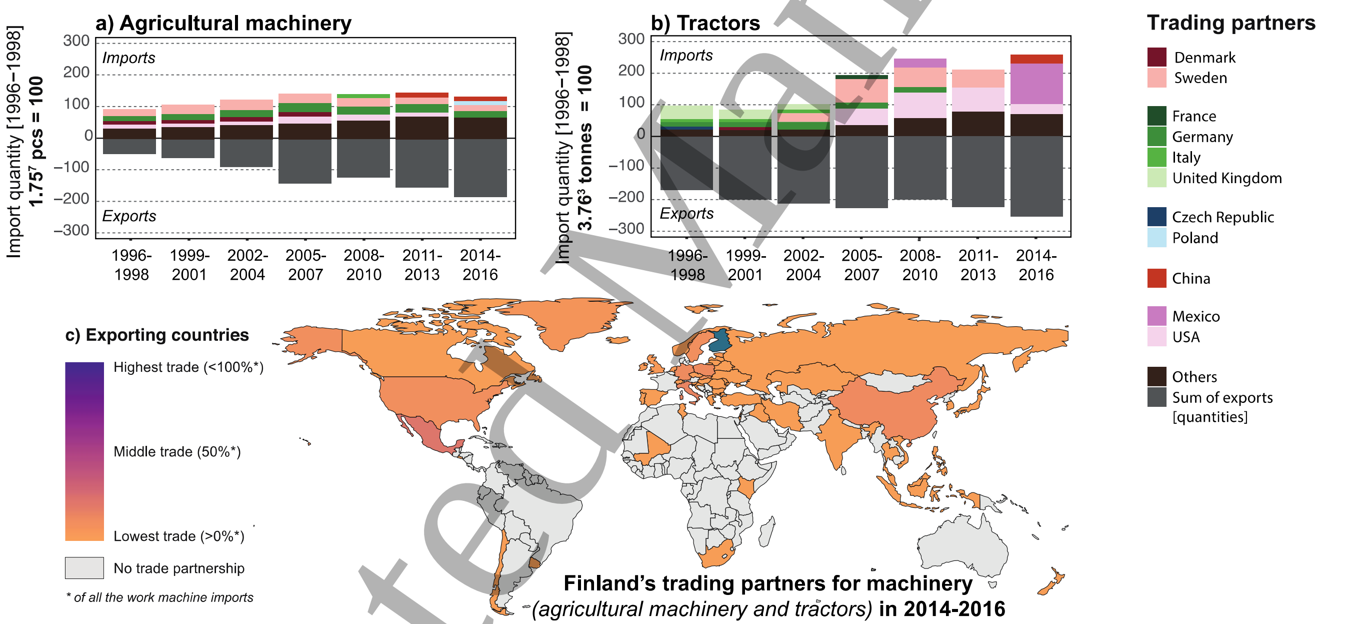

Figure 5. Finland's most important import trading partners for machinery (a: agricultural machinery and b: tractors) during all timesteps (1996-2016) where the first timestep of imports (1996-1998) equals to 100 and other timesteps are scaled accordingly. Positive values represent imports and negative exports. In addition, Finland's all trading partners for the last timestep (c: 2014-2016).

Respectively, the independency for soybeans stays relatively the same (0%) and the fluctuations in electricity are also modest (independency around 75%) regardless of Finland joining the EU.

The soybean independency does not show any significant trend (Figure 6) but the number of trading partners for soybean trade increased (Figure 6). While for rapeseed, the imports increased (Figure 3a) and the number of trading partners (Figure 6) show no significant trend. Of the input types considered in this study, electricity has the highest level of independency from imports, and its self-sufficiency rate at the last timestep (2014-2016) was around 75% (Figure 7). Supplement Figure 1 shows the changes in the number of import partners for all considered agricultural inputs.

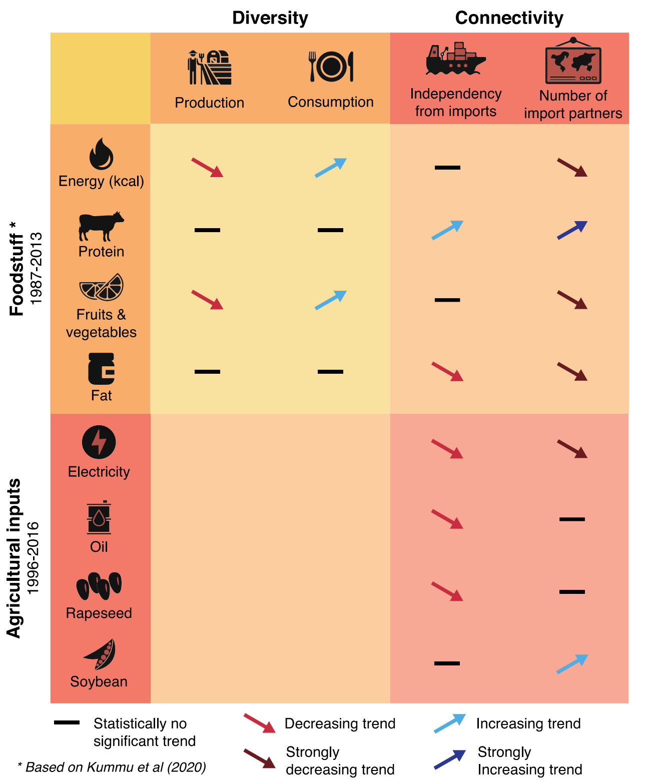

Figure 6. Trends for diversity and connectivity for foodstuff (Kummu et al. 2020) and agricultural inputs (this study). Statistical significance of trend was assessed using non-parametric Spearman test bootstrapped over 1000 steps. "Strongly" indicates when the ratio is above 0.15 or below -0.15.

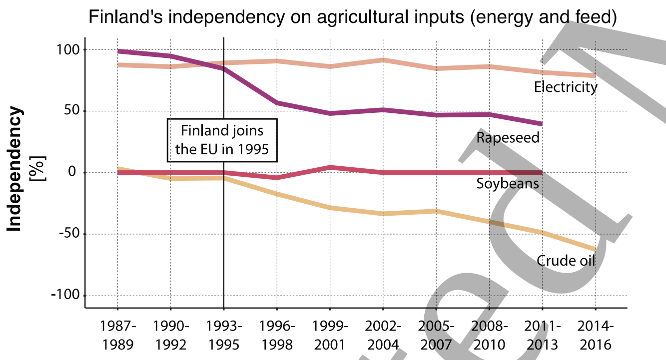

Figure 7. Finland's independency on agricultural inputs (energy and feed). A special emphasis was given to Finland joining to European Union in 1995. The energy (electricity and crude oil) analysis was done for the years 1987-2016 and the feed (soybeans and rapeseed) analysis was done for the years 1987-2013 due to the data limitations. Negative values mean that net imports grow faster than the usage of the good in question. This can occur e.g., due to growing quantities of processed goods where spillage or losses during the process are not accounted for. Another reason can be that imported goods are not used right away but rather stored for later use.

Further, examining the independency from import trends for rapeseed and soybean cakes/oils reveal major differences compared to the independency trends for the not processed, i.e. "raw" rapeseed and soybean (Supplement Figure 2). Rapeseed and, especially soybean, oils show much more volatile trends, with independency levels substantially larger compared to the raw rapeseed and soybean. The probable explanation for this is, that Finland processes these from raw rapeseed and soybeans (of which it mostly imports) to export too. On the other hand, rapeseed and soybean cakes show a steady declining independency trend from 1987 to early 2000s after which the independency from imports levels off at around 50% and 10%, respectively. The discrepancies between the raw materials and different processed products highlight the challenges to assess the resilience within the agricultural input supply chains.

4. Discussion

4.1. Independency from imports

Finland's food self-sufficiency is high compared to many other countries (D'Odorico et al., 2014; Sadowski and Baer-Nawrocka, 2016). However, our results show that looking only at food self-sufficiency, and neglecting agricultural inputs used for food production, creates a potentially distorted illusion of independency. Finnish food system's dependency on international input trade has been increasing over the last two decades (Figure 6) and at the same time, dependency on imported foodstuff has been also consistently increasing (Sandström et al., 2014). Hence Finland is increasingly linked to the global food system, especially after joining the EU in 1995 (Figure 7).

Finland has vast but underused natural resources for food production. As an example, a recent study demonstrates that Finland has the potential to replace rapeseed imports with domestic rapeseed by 98%, and soybeans imports with faba beans and field peas by 100% if the domestic cultivation would be increased (Sandström et al., 2018). Nonetheless, as recognised by Sandström et al. (2018), a surplus in domestic agricultural production often means an added dependency on the input trade, and this trade-off needs to be acknowledged when estimating the overall resilience (López-Ridaura et al., 2002; Schipanski et al., 2016). Moreover, increasing the self-sufficiency of domestic production might be challenging from an economic perspective. This would easily lead to distorted markets, where the comparative advantage of exchange is not utilised and the domestic opportunity cost of food production is unreasonably high and production volumes low (Clapp, 2017; Naylor and Falcon, 2010).

Animal feed offers an interesting case for examining the different interdependencies in the supply chain from feed to food. Following the general trend in changes in feed usage in Europe (Denanot, 2018), Finnish soybean imports (Figure 3b) are being replaced by rapeseed imports (Figure 3a). Further, independency from imports is decreasing for rapeseed, whereas independency for proteins (animal and vegetable) has increased (Figure 6). When comparing these results, we assume that the increased domestic animal-based protein levels are partly achieved with the imported animal feed protein. However, these trends might change in the future, as Finland has potential for the increased legume cultivation due to the changing climate (Peltonen-Sainio et al., 2013). Further, domestic plant-based markets are growing, and more research is focused on the potential to replace imported plant-protein with domestic substitutes (Heikkilä et al., 2019). Lehikoinen and Salonen (2019) presented that Finnish consumers are concerned about the origin of the food and domestic food is favoured. Therefore, the possibility of increased demand for domestic products could make these changes a reality.

4.2. Trading connections

To take a more granular look at Finland's geographical link to global trade, it is important to differentiate between the countries that Finland is dependent on for foodstuff (short-term i.e. the consumption) and for agricultural inputs (long-term i.e. the agricultural production). Finland's top import partners for foodstuff are Germany, Sweden, Netherlands, Norway and Spain (nearly 47% of total import values), and top export partners are Sweden, Estonia, France, Russia and Germany in 2018 (nearly 45% of total export values) (Hyrylä, 2019). Our analysis of the agricultural inputs highlights mainly the same countries for trade, but worth considering is the role of Russia. For foodstuff, Russia is a net exporting country for Finland (Hyrylä, 2019; LUKE, 2019), while for a majority of the agricultural inputs, it is a crucial net importing country (Figures 2-5). In the past, there have been agricultural bans between Finland and Russia (Hyytiä, 2020), and thus Finland's dependency on Russia for exports and imports has also geopolitical aspects, and thus expands beyond economic interests.

When comparing our resilience results to foodstuff ones (Kummu et al., 2020), the number of trading partners for foodstuff has a decreasing trend, while for agricultural inputs the trends show somewhat mixed results (Figure 6). However, it is important to differentiate the contrasting requirements for partnerships with different inputs. For energy, electricity markets are inherently local given the infrastructure constraints of the Nordic neighbours. When taking a closer look at the geography, Finland is having an isolated northern location from continental Europe (Himanen et al., 2016) as over 80% of total imports and exports are transported via the Baltic Sea (Ojala et al., 2018). Equally, our study demonstrates that Finland's main trading partners for the inputs (Figures 2-5), share the Baltic Sea watershed with Finland, and while neglecting the political relations, the shared watershed means that the vital inputs are already in the same geographical area.

4.3 Limitations

We developed the framework that is applicable for countries to study their dependency on the imported agricultural inputs. Our case study, however, revealed that there are challenges in this kind of analysis. The first challenge was data availability, due to the excludable and rivalrous nature of agricultural inputs, as also stated by Smith (2001). The second challenge was data analysis, as some of the imported inputs are further processed, and the initial purpose of the imports is changed (raw materials vs. processed products as presented in Supplementary Figure 2).

In more detail, the country-of-origin data was not available for all the selected inputs, and we needed to rely on data sources that account for the most recent trading partner rather than the actual country of origin for the commodities. This complicated tracing down the dependencies between the actual countries that produce the commodities (exports) and the countries that depend on commodities (imports). We were also looking at the agricultural inputs only at the high-level and not considering, e.g., the chemical components related to fertiliser's production, the preservatives for feed production or different spare parts regarding the machinery. Finally, for the most assessed sectors (feed, manufactured fertiliser, agricultural machinery), the data naturally present agricultural input but for energy, we could not assess the sector-specific inputs. Nevertheless, we believe that our analysis on energy also presents the overall dependence of the agricultural sector. For example, Finland is fully dependent on oil, and so is the agricultural sector as well.

5. Conclusions

We developed a novel framework to assess agricultural input independency from imports on a country-level, and our case study on Finland provides a practical example of trade trends of agricultural inputs. We found that Finland was a net importer of feed and energy, and the country's dependency on these commodities has increased over the study period; potentially decreasing Finland's resilience to the shocks in global markets. At the same time, Finland has been a net exporter of fertilisers and agricultural machinery over the whole study period; potentially increasing Finland's resilience to the shocks in global markets. It is necessary, however, to acknowledge that this does not reflect the economic perspective but applies merely to volumes. Importantly, we also found that while Finland is a net exporter of foodstuff to Russia, it is heavily dependent on agricultural input imports from its eastern neighbour which was not documented previously. This finding highlights the importance of having a more comprehensive understanding of global trade as related to the food system – including both foodstuff and agricultural inputs. Even though a country's dependencies might be relatively regional for single inputs, the simultaneous assessment of multiple inputs could reveal larger geographical connections or focus points.

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