

# **Reducing import dependency through sustainable and strategic nitrogen fertilizer solutions in the European Union**

Insights from Finland

Master's Degree Programme in Agricultural, Environmental and Resource Economics

Master's thesis

Agricultural Economics

Author:

Juulia Kemiläinen

Supervisor:

Fabio Santeramo & Xavier Irz

4.5.2026

Helsinki

**Faculty:** Faculty of Agriculture and Forestry

**Degree programme:** Master's Programme in Agricultural, Environmental and Resource Economics

**Study track:** Agricultural Economics

**Author:** Juulia Kemiläinen

**Title:** Reducing import dependency through sustainable and strategic nitrogen fertilizer solutions in the European Union: Insights from Finland

**Level:** Master's thesis

**Month and year:** 5/2026

**Number of pages:** 69

**Keywords:** nitrogen, ammonia, mineral fertilizer, organic fertilizer, self-sufficiency, fertilizer import, agricultural policy, factors of production, circular economy, food security.

**Supervisor:** Professor Fabio Santeramo, University of Helsinki; Professor Xavier Irz, University of Helsinki

**Where deposited:** Helda, Helsinki University Library

### **Abstract:**

This study examines nitrogen fertilizer use and production in the European Union (EU) and particularly in Finland from the perspectives of policy, market dynamics, and the resilience of food system at the national level. Nitrogen is a critical input for crop production, yet its availability, pricing, and environmental impacts pose increasing challenges for farmers in its use.

The research utilized a quantitative analysis of nitrogen fertilizer consumption, trade flows, and price development data together with the Herfindahl-Hirschman Index, which in turn was used to measure the concentration of nitrogen fertilizer import shares. These were combined with qualitative insights from three expert interviews representing the perspectives of technology, farmers, and government. The findings show that both the EU and Finland are still vulnerable to external market shocks. Finland remains highly exposed, due to its high dependence on imported nitrogen fertilizers and ammonia, largely sourced from Russia.

Although EU legislation, such as the Common Agricultural Policy, the Green Deal, the Carbon Border Adjustment Mechanism, and the proposed RENURE initiative, aim to reduce environmental impacts and strengthen sustainability, interviewees highlight persistent regulatory fragmentation, limited transparency in fertilizer markets, insufficient long-term investment incentives, and lack of cooperation. Sustainable alternatives, including recycled nitrogen fertilizers, regenerative agriculture methods, and green ammonia, offer potential alternatives but face logistical, technological, and economic challenges.

The study concludes that enhancing domestic resilience requires improved risk management, targeted public investments, and clearer regulatory guidance supported by long-term policy frameworks. Achieving these goals also requires enhanced cooperation across different sectors, such as agricultural, energy, chemical, and technological, as achieving sustainable fertilizer solutions requires multidisciplinary collaboration. While mineral nitrogen fertilizers will remain necessary for maintaining adequate yields and ensuring food safety, a proportion of them can be gradually substituted with more sustainable alternatives. This requires that supportive policies, technological advancements, and market conditions are ensured in the future.

**Tiedekunta:** Maa- ja metsätaloustieteellinen

**Tutkinto-ohjelma:** Maatalous-, ympäristö- ja luonnonvarataloustieteen maisteriohjelma

**Opintosuunta:** Maatalousekonomia

**Tekijä:** Juulia Kemiläinen

**Otsikko:** Tuontiriippuvuuden vähentäminen kestävien ja strategisten

typpilannoiteratkaisujen avulla Euroopan Unionissa: Näkemyksiä Suomesta

**Työn laji:** Maisterintutkielma

**Kuukausi ja vuosi:** 5/2026

**Sivumäärä:** 69

**Avainsanat:** typpi, ammoniakki, mineraalilannoite, orgaaninen lannoite, omavaraisuus, lannoitetuonti, maatalouspolitiikka, tuotantopanos, kierrätystalous, ruokaturva

**Ohjaaja:** Professori Fabio Santeramo, Helsingin yliopisto; professori Xavier Irz, Helsingin yliopisto

**Säilytyspaikka:** Helda, Helsingin yliopiston avoin julkaisuarkisto

## **Tiivistelmä:**

Tässä tutkimuksessa tarkastellaan typpilannoitteiden käyttöä ja valmistusta erityisesti Suomessa ja laajemmassa kontekstissa Euroopan unionissa (EU) politiikan, markkinadynamiikan sekä kansallisella tasolla ruokajärjestelmien sietokyvyn kannalta. Typpi on kriittinen ravinne viljelykasvien tuotannossa, mutta sen saatavuus, hinnoittelu ja ympäristövaikutukset asettavat yhä suurempia haasteita viljelijöille sen käytössä.

Tämä tutkimus hyödynsi lannoitteiden kulutusta, markkinavirtoja ja hintakehityksen kvantitatiivista data-analyysiä yhdessä Herfindahl-Hirschman -indeksin kanssa, jota puolestaan käytettiin typpilannoitteiden tuontiosuuskien keskittymisen mittaamiseen. Nämä yhdistettiin kolmen asiantuntijahaastattelun laadullisiin näkemyksiin, jotka edustavat teknologian, maatalousyrittäjien ja hallinnon näkökulmia. Tulokset osoittavat, että molemmat EU ja Suomi ovat edelleen alttiita ulkoisille markkinashokeille, mutta näistä Suomi on erityisen altis, sillä se on erittäin riippuvainen pääosin Venäjältä tuoduista typpilannoitteista ja ammoniakista.

Vaikka EU-lainsäädännöt, kuten yhteinen maatalouspolitiikka, vihreän kehityksen ohjelma, hiilirajamekanismi ja ehdotettu RENURE-aloite, pyrkivät vähentämään ympäristövaikutuksia ja vahvistamaan kestävyttä, haastateltavat korostavat jatkuvaa sääntelyn pirstaloitumista, läpinäkymättömyyttä lannoitemarkkinoilla, riittämättömiä pitkän aikavälin investointikannustimia sekä yhteistyön puutetta. Kestävät vaihtoehdot, kuten eri tavoin kierrätetyt typpilannoitteet, uudistava maanviljely sekä vihreä ammoniakki, tarjoavat potentiaalisia vaihtoehtoja, mutta niihin liittyy logistisia, teknologisia ja taloudellisia haasteita.

Tutkimuksessa todetaan, että kotimaisen selviytymiskyvyn parantaminen edellyttää parempaa riskienhallintaa, kohdennettuja julkisia investointeja ja selkeämpää sääntelyohjeistusta, jota tukevat pitkän aikavälin poliittiset päätökset. Näiden tavoitteiden saavuttaminen edellyttää myös tehostettua yhteistyötä eri sektoreiden, kuten maatalouden, energian, kemian ja teknologian välillä, sillä kestäväpien lannoiteratkaisujen saavuttamiseksi tarvitaan monitieteistä yhteistyötä. Vaikka mineraalilannoitteet ovat edelleen välttämättömiä riittävien satojen ylläpitämiseksi ja elintarviketurvallisuuden varmistamiseksi, osa niistä voidaan vähitellen korvata kestävämmillä vaihtoehtoilla. Tämä edellyttää sitä, että tukevat politiikat, teknologisten ratkaisujen käyttöönotto ja markkinaolosuhteet varmistetaan jatkossa.

## Table of contents

|          |                                                                                                     |           |
|----------|-----------------------------------------------------------------------------------------------------|-----------|
| <b>1</b> | <b>Introduction</b>                                                                                 | <b>6</b>  |
| <b>2</b> | <b>Background and context on nitrogen fertilizers</b>                                               | <b>9</b>  |
| 2.1      | <b>Nitrogen in agricultural use</b>                                                                 | <b>9</b>  |
| 2.1.1    | Production of inorganic nitrogen fertilizers                                                        | 10        |
| 2.1.2    | Sustainable options and circular alternatives                                                       | 11        |
| 2.2      | <b>Policies behind nitrogen use in agriculture</b>                                                  | <b>12</b> |
| 2.2.1    | EU's agricultural policy and regulatory framework                                                   | 12        |
| 2.2.2    | National fertilizer regulation and agricultural support measures in Finland                         | 15        |
| 2.3      | <b>Fertilizer market dynamics</b>                                                                   | <b>16</b> |
| 2.3.1    | Import dependence and strategic resilience                                                          | 17        |
| 2.3.2    | Fertilizer price volatility and economic impacts                                                    | 18        |
| 2.3.3    | Global shocks in fertilizer trade and prices                                                        | 20        |
| <b>3</b> | <b>Methods and data</b>                                                                             | <b>22</b> |
| 3.1      | <b>Quantitative data</b>                                                                            | <b>22</b> |
| 3.1.1    | Databases                                                                                           | 22        |
| 3.1.2    | Data search                                                                                         | 23        |
| 3.1.3    | Herfindahl-Hirschman Index                                                                          | 24        |
| 3.2      | <b>Qualitative data</b>                                                                             | <b>24</b> |
| <b>4</b> | <b>Results</b>                                                                                      | <b>27</b> |
| 4.1      | <b>Nitrogen fertilizer consumption, trade dynamics, and price development in Finland and the EU</b> | <b>27</b> |
| 4.1.1    | Nitrogen consumption patterns                                                                       | 27        |
| 4.1.2    | Nitrogen fertilizer and ammonia trade flows and import dependencies                                 | 29        |
| 4.1.3    | Price dynamics in the EU                                                                            | 32        |
| 4.2      | <b>Insights from expert interviews</b>                                                              | <b>33</b> |
| 4.2.1    | Market disruptions and vulnerabilities                                                              | 34        |
| 4.2.2    | Sustainable opportunities and recycled nitrogen fertilizers                                         | 35        |
| 4.2.3    | Regulation and policies                                                                             | 37        |
| 4.2.4    | Investing and cooperation                                                                           | 39        |
| <b>5</b> | <b>Discussion</b>                                                                                   | <b>42</b> |
| 5.1      | <b>Challenges with nitrogen fertilizers</b>                                                         | <b>43</b> |
| 5.2      | <b>Strategies for more self-sufficient production and sustainable practices</b>                     | <b>44</b> |

|            |                                                           |           |
|------------|-----------------------------------------------------------|-----------|
| <b>5.3</b> | <b>Policy framework updates</b>                           | <b>46</b> |
| <b>5.4</b> | <b>Recommendations for Finland and the EU</b>             | <b>47</b> |
| 5.4.1      | Finland's constraints                                     | 47        |
| 5.4.2      | Recommendations for Finland                               | 48        |
| 5.4.3      | EU-level actions                                          | 49        |
| <b>5.5</b> | <b>Research limitations and future research</b>           | <b>49</b> |
| <b>6</b>   | <b>Conclusions</b>                                        | <b>51</b> |
|            | <b>References</b>                                         | <b>54</b> |
|            | <b>Appendix A: English-translated interview questions</b> | <b>59</b> |
|            | <b>Appendix B: Supplementary figures and tables</b>       | <b>63</b> |
|            | <b>Appendix C: The use of AI</b>                          | <b>69</b> |

# 1 Introduction

Nitrogen fertilizers are among the most important fertilizers for plants that feed a significant portion of the global food population, accounting for approximately 50 % of plants' fertilizer need (Ahvo et al., 2023; Jansik et al., 2021; Sitra, 2022). The use of nitrogen has enabled better yields, thereby increasing global food security. Without nitrogen and other fertilizers, there would be a greater demand for agricultural land, leading to various environmental and socio-economic challenges. (Ahvo et al., 2023; Elser et al., 2014; Kaufmann et al., 2022)

Ammonia is essential for the production of inorganic nitrogen fertilizers and it is produced in an energy-intensive process (Vainio, 2022). Consequently, countries with low energy costs have a competitive advantage in ammonia production, making the price of ammonia highly dependent on energy prices (Alexander et al., 2023; Glauber & Laborde, 2023; Lehtikainen et al., 2021). Natural gas is a commonly used resource in ammonia production, and EU member states import a large share of their natural gas from Russia (European Commission, n.d.a; Vainio, 2022).

Alternative options include organic fertilizers and various agricultural practices aimed at preserving nitrogen already present in the ecosystem. Nutrients can be recycled back into the system for use as fertilizers, primarily sourced from manure, although other waste materials are also utilized. However, this approach has disadvantages, as recycled nutrients often lose a significant portion of their nutrient content during the recycling process, raising concerns about the ability of recycled fertilizers to maintain adequate nutrient levels. (Vainio, 2022) The EU has policies regarding nitrogen use, but the implementation is largely left to individual member states, resulting in considerable variability across the EU. Additionally, the EU has initiated other mechanisms, such as Carbon Border Adjustment Mechanism (CBAM), to enhance ammonia and nitrogen production within its borders, although the effectiveness of these initiatives remains to be seen.

Fertilizer markets primarily consist of the trade of inorganic fertilizers. At the EU level, Finland is a relatively small user of nitrogen fertilizers, but its dependency on these makes it vulnerable, as over half of Finland's nitrogen fertilizers are sourced from Russia. (Directorate-General for Agriculture and Rural Development, 2025c) Overall, Russia is a significant partner in nitrogen fertilizer trades across the EU

(Fertilizers Europe, 2022; Glauber & Laborde, 2023). Fertilizer markets are susceptible to external shocks, which can lead to price increases; the most recent shock being the ongoing Russian invasion of Ukraine, which caused the energy prices to increase (Alexander et al., 2023; European Commission, 2022). Such shocks can impact the quantity and quality of fertilizers used, potentially threatening national and global food security (Lago-Oliveira et al., 2023).

In the light of recent political events and other factors, Finland and other EU countries are exploring ways to achieve more sustainable nitrogen fertilizer use and production. Implementing these methods can minimize nutrient runoff while enhancing self-sufficiency and security of supply in nitrogen fertilizer production. A more self-sufficient fertilizer production system would reduce dependency on imports, which are highly volatile in crisis situations. (European Commission, 2023; Finnish Government, 2023)

Regarding terminology, self-sufficiency denotes a country's ability to produce the goods necessary for its own use, a capability which importance is emphasized during disruptions (Lehikoinen et al., 2021). Security of supply is closely related, referring to a state's capacity to withstand and manage disruptions with minimal harm (Janskik et al., 2021). Some countries are unable to achieve self-sufficiency in certain inputs, such as fertilizers, because they lack the necessary production facilities or natural resources, making them dependent on imports. (Clapp, 2017.)

The aim of this thesis is to explain strategies for reducing dependency on imported nitrogen fertilizers and their raw materials. Recent crises have placed farmers in a vulnerable position, as fertilizer prices are subject to market volatility. Price increases can lead to insufficient fertilizer use, thereby threatening food security. This issue is examined by addressing the following questions:

1. Can self-sufficient nitrogen fertilizer production be enhanced without compromising efficiency and food security?
2. What decisions and actions are necessary to transition to more sustainable nitrogen fertilizer use and more self-sufficient production, and thus to ensure better security of supply?

This thesis employs both quantitative and qualitative methods. Quantitative methods will illuminate the current state of nitrogen fertilizer markets and consumption levels, while qualitative methods will be based on expert interviews with three professionals, exploring their perspectives on the necessary actions to achieve more sustainable use of nitrogen and greater self-sufficiency in its production.

## **2 Background and context on nitrogen fertilizers**

To understand the background of this research and nitrogen fertilizer use, this chapter provides an overview of the factors influencing the use of nitrogen fertilizers in agriculture. First, it discusses the significance of nitrogen itself, including its essential role in agriculture and the processes involved in its production. Second, it examines the legislation at both the European Union (EU) and national level that guide the use of nitrogen fertilizers in agricultural practices. Finally, the chapter explores the various factors that affect the markets and pricing of nitrogen fertilizers.

Several terms require clarification before proceeding. Security of supply refers to a state's capacity to withstand and manage disruptions with minimal harm during crises (Jansik et al., 2021). Self-sufficiency is closely related, denoting a country's ability to produce necessary goods for its own use; importance which is heightened in periods of disruption (Lehikoinen et al., 2021). However, some countries are unable to achieve self-sufficiency in certain inputs, such as fertilizers, as they lack the necessary production facilities or natural resources, making them import dependent. Moreover, pursuing self-sufficiency may reduce external demand and thereby lower farmers' incomes. (Clapp, 2017.)

### **2.1 Nitrogen in agricultural use**

Efficient farming requires inputs to produce an adequate amount of food. Fertilizers are among the most important agricultural inputs and serve as the backbone of modern agriculture. (Ahvo et al., 2023; Jansik et al., 2021) Thanks to fertilizers, global agricultural yields have improved, and the quality of produce has also increased (Lago-Oliveira et al., 2023). Additionally, fertilizers have allowed population growth (Elser et al., 2014) and enhanced food safety (Fertilizers Europe, 2022; Kaufmann et al., 2022). Therefore, fertilizer use is justified for securing global food security (Ahvo et al., 2023; Kaufmann et al., 2022; Lago-Oliveira et al., 2023).

Nitrogen is one of the most important fertilizers in farming, accounting for over half of the fertilizers applied to plants (Ahvo et al., 2023; Jansik et al., 2021; Rose et al., 2023; Sitra, 2022). While soil can provide some nutrients to support short-term yields, additional nitrogen is essential for optimal plant growth. Hence, nitrogen

plays a vital role in crisis situations, as it significantly affects crop yields. (Jansik et al., 2021)

### 2.1.1 Production of inorganic nitrogen fertilizers

Ammonia serves as the raw material for all nitrogen fertilizers. The Haber-Bosch process is a method that produces ammonia from nitrogen and hydrogen under high pressure, with nitrogen typically sourced from the air and hydrogen derived from an affordable energy source. (Fertilizers Europe, 2022; Vainio, 2022) This process is energy-intensive, and when, for example, natural gas is used to produce hydrogen, up to 90 % of the production costs of ammonia come from natural gas (The Central Union of Agricultural Producers and Forest Owners, 2026). Thus, nations with low energy costs have a competitive advantage in ammonia production (Glauber & Laborde, 2023; Jansik et al., 2021; Vainio, 2022). Consequently, the pricing of nitrogen fertilizers is highly dependent on the pricing of the energy source used.

In Europe, Russia is the primary producer of natural gas, giving it an advantage in producing ammonia at lower costs (Alexander et al., 2023). More environmentally friendly alternative method, known as green ammonia, utilizes the electrolysis of water. Albeit investments have been made for new production facilities, this method remains a weaker competitor compared to traditional production methods. (Vainio, 2022) Nevertheless, Finland is interested in adopting this new approach to increase its self-sufficiency in nitrogen production and to enhance security of supply (Finnish Government, 2023).

While Russia exports nitrogen fertilizers to the EU, the EU produces a large share of their own nitrogen fertilizers: approximately 72 % of the nitrogen fertilizers used within the EU are produced domestically. In 2021, EU countries produced about 22 million tonnes of ammonia. (Vainio, 2022) However, the EU remains dependent on Russian natural gas for ammonia production, leading to an expected increase in ammonia imports to Europe in the future (European Commission, 2022; Glauber & Laborde, 2023). Up to 80 % of ammonia used in Finland is sourced from Russia, and if Finland were to produce ammonia domestically, its dependency on natural gas

would tightly link it to Russia (Vainio, 2022). Consequently, the production of nitrogen fertilizers is closely tied to ammonia production.

### 2.1.2 Sustainable options and circular alternatives

In addition to the dependency on fossil energy for nitrogen fertilizer production, excessive nitrogen use has negative environmental effects (Pradhan et al., 2015; Vainio, 2022). The EU regulates fertilizer use primarily from an environmental perspective by promoting improved fertilizer cycles. This approach simultaneously supports the self-sufficiency goals of farms and nations. (European Commission, 2020) There are multiple ways to utilize more sustainable methods to preserve nitrogen already present in the cycle.

One method for reintegrating nitrogen into the system is through recycled nitrogen. In agricultural contexts, recycled nitrogen is typically produced from manure, although other waste streams can also serve as sources. (Vainio, 2022) Recycling is beneficial for the environment and enhances the security of supply in fertilizers (Finnish Government, 2023). Recycled fertilizers could increase national food security by facilitating access to them and minimizing imports (Elser et al., 2014). However, discussions are needed to assess the acceptable levels of harmful substances in recycled products (Ministry of Agriculture and Forestry, 2017; Sitra, 2022). While recycled fertilizers may reduce dependence on mineral fertilizers, they can also increase labor requirements and potentially reduce yields (Nilsson et al., 2022). According to Vainio (2022), one potential solution to replace natural gas and ammonia in production is to explore alternatives, such as utilization of biogas in ammonia production.

Another approach to enhance nitrogen availability in the soil involves the use of leguminous plants, which can fix atmospheric nitrogen through their root nodules (Elser et al., 2014; European Commission, n.d.b; Vainio, 2022). This capability reduces the need for additional fertilizers. To utilize nitrogen more efficiently, cultivating various plants alongside legumes can help enhance nutrient uptake. (Nilsson et al., 2022; Vainio, 2022) There is significant potential in utilizing legumes in farming (Finnish Government, 2023) and according to Vainio (2022), Finland's nitrogen requirements could be halved with leguminous plants. Together with crop

rotation, legumes can increase yields while minimizing the need for nitrogen fertilization.

Crop rotation promotes soil health and enhances food security (Ahvo et al., 2023; Lago-Oliveira et al., 2023; Ministry of Agriculture and Forestry, 2017). Lago-Oliveira et al. (2023) emphasize the importance of understanding the effects of different plants on soil to achieve optimal results. Additional factors that can improve nitrogen utilization efficiency include precision farming techniques, which rely on technology to assess soil condition (Ministry of Agriculture and Forestry, 2017).

## **2.2 Policies behind nitrogen use in agriculture**

Legislation at the EU level guides the use of fertilizers, ensuring that farmers apply them to secure food production while minimizing environmental impacts (European Commission, 2020). Thus, legislation primarily emphasizes the environmental aspects of fertilizer use, while simultaneously enhancing the self-sufficiency of farmers (Ministry of Agriculture and Forestry, 2017). Next, the chapter examines the regulatory frameworks at the EU and national levels.

### **2.2.1 EU's agricultural policy and regulatory framework**

At the time of this research, Common Agricultural Policy (CAP) 2023-2027 is in effect. CAP is regulated by the EU and aims to establish common regulations for all member countries. However, it is impossible to cover every circumstance, and some countries may be eligible to additional or complementary support. (Ministry of Agriculture and Forestry, n.d.b) The current CAP is closely aligned with the European Green Deal, which sets targets for environmental protection and climate change mitigation (European Commission, 2023). Additionally, CAP emphasizes the importance of functioning food markets and food security (Ministry of Agriculture and Forestry, n.d.c).

The support system of CAP is divided into two pillars. The first pillar includes direct support and market measures, while the second pillar is dedicated to projects that promote the sustainable development of rural areas. From the perspective of

fertilizers, the first pillar includes regulatory tools for farmers to minimize nitrogen fertilizer emissions. Moreover, the current period prioritizes the increased cultivation of plant proteins, the enhancement of organic farming, and implementation of mixed farming practices. These actions improve farmers' risk management and help them navigate through crisis situations. (European Commission, 2020, 2023). The second pillar focuses on support for environmental protection and the modernization of farms (European Commission, 2024).

Through these divided support pillars, the current CAP has decoupled support from previous production volume regulations (European Commission, n.d.b). This change aims to promote the use of renewable and recycled materials through crop rotation, the cultivation of leguminous plants, and the application of organic and recycled fertilizers. Additionally, many EU countries plan to increase their production of leguminous plants to reduce their dependence on legume imports. This strategy simultaneously decreases the need for added nitrogen fertilizers due to the nitrogen-fixing capabilities of legumes. (European Commission, 2023) Together with organic fertilizers derived from recycled manure, sludge, or compost, these options assist in fertilizer planning and encourage farms to enhance their levels of self-sufficiency. Farms can also optimize their fertilizer management using technologies that provide real-time data on fertilizer levels, thereby helping to reduce the overall amount of fertilizers required. (European Commission, 2023)

In addition to promoting the use of organic fertilizers, CAP encourages member countries to reduce their overall fertilization levels. Some countries have established individual targets to increase the proportion of organic fertilizers compared to inorganic options. (European Commission, 2023) To support this shift towards organic fertilizers, the European Commission (2025) has proposed the Recovered Nitrogen from Manure (RENURE) initiative to amend the Nitrates Directive, aiming to replace inorganic nitrogen fertilizers with recycled alternatives. This initiative is expected to benefit the environment while also reducing costs and increasing the autonomy of the EU agricultural sector.

A core component of the Green Deal, Farm to Fork strategy, aims to reduce emissions by decreasing fertilizer use and promoting organic farming practices (European Commission, 2020). Water eutrophication is a consequence of fertilizer application in agriculture, and nitrogen fertilizers also contribute to climate emissions. The target is

to reduce nutrient runoff by 50 % compared to levels recorded from 2012 to 2015, achieving this without compromising soil fertility. Additionally, there is an aim for a 20 % reduction in fertilizer use by 2030. (European Commission, 2020, 2023) These targets are pursued through improved fertilizer action plans, precision farming, sustainable methods, and the increased use of organic fertilizers. Furthermore, access to the internet plays a crucial role; to implement these methods effectively, internet connectivity should be available to all farmers. (European Commission, 2020) These environmentally focused strategies generally support the EU's self-sufficiency objective and improve risk resilience.

The latest initiative by the EU, the Carbon Border Adjustment Mechanism (CBAM), is an instrument that imposes taxes on certain products imported from non-EU countries (Ministry of Economic Affairs and Employment of Finland, n.d.). As part of the Fit for 55 package, the aim of CBAM is to reduce greenhouse gas emissions within the EU by imposing taxes on imports from high-emission sectors, one of which includes fertilizers. This mechanism is designed to counteract imports from countries with less stringent environmental regulations and carbon pricing, thereby preventing carbon leakage. CBAM seeks to integrate environmental standards into trade policy while simultaneously reducing dependency on non-EU trading partners. (Ministère de l'Agriculture, de l'Agro-alimentaire et de la Souveraineté alimentaire, 2025; Santeramo & Jelliffe, 2024) Through these measures, the EU aims to support its environmental goals, preserve the competitiveness of EU industries, and encourage other countries to adopt more ambitious climate policies. Overall, this initiative represents a strategy to export EU standards to other regions of the world. (Ministère de l'Agriculture, de l'Agro-alimentaire et de la Souveraineté alimentaire, 2025)

However, a significant concern is that CBAM may negatively impact the competitiveness of European fertilizer exports. The EU fertilizer industry produces mineral fertilizers with the lowest carbon footprint globally, an achievement obtained through substantial investments in sustainable practices. (Fertilizers Europe, 2023) Additionally, European exporters already face disadvantages in the market due to the absence of an emission trading scheme (ETS) in other regions. Consequently, as the EU is a major importer of agricultural products, the costs associated with CBAM are likely to be passed down the value chain. This situation distorts market dynamics, making European agricultural goods a less attractive option compared to cheaper

alternatives from third countries. (Ministère de l'Agriculture, de l'Agro-alimentaire et de la Souveraineté alimentaire, 2025)

### 2.2.2 National fertilizer regulation and agricultural support measures in Finland

Finland is situated significantly farther north than other EU countries, which limits the applicability of support from CAP. Therefore, national support is also necessary. (Ministry of Agriculture and Forestry, n.d.c) This regulation allows EU countries to set additional goals for enhancing sustainable development. In the context of fertilizers, countries can, for example, define the width of buffer strips to protect water from eutrophication. (European Commission, 2023)

All additional regulations, which are based on the fundamental rules established at the EU level, are further specified at the national legislative level. In addition, farmers can receive financial support for agricultural investments. (Ministry of Agriculture and Forestry, n.d.c) Among these investment funds is the “Ravinteiden kierrätyksen kokeiluohjelma” funding, which aims to invest in machinery, facilities, and buildings that process manure or biogas into high-quality fertilizers or nutrient products (Ministry of Agriculture and Forestry, n.d.-a).

Finland aims to develop agricultural sustainability without compromising competitiveness. Events following year 2022 have strengthened this approach, making it increasingly important to ensure national security levels in agriculture. The latest CAP also emphasizes food markets and food security. (Ministry of Agriculture and Forestry, n.d.c) While Finland is generally considered a food-secure nation, it faces challenges regarding agricultural inputs, which are often scarce materials (Huan-Niemi et al., 2021).

Moreover, national-level reports provide insights how to renew the country's agriculture and food system to become a more sustainable competitor while simultaneously strengthening the food chain. In Finland, the “Ruoka 2030” report examines the challenges and issues within the Finnish food system. (Ministry of Agriculture and Forestry, 2017) Fertilizers are one part of this report, and the section emphasizes the need for Finland to enhance the use of recycled fertilizers, despite

some risks associated with them remain unknown. Recycled fertilizers are also suitable for organic farming. (Ministry of Agriculture and Forestry, 2017)

Another strategy to minimize fertilizer use involves improving soil health. This can be achieved through practices such as crop rotations, precision farming and modern technology. Crop rotation can enhance soil quality, particularly when combined with nitrogen-fixing plants that transfer nitrogen from the air to the soil. Precision farming, together with modern technologies, helps observing the soil fertility. (European Commission, 2020; Ministry of Agriculture and Forestry, 2017) Nitrogen-fixing plants also contribute to farms' self-sufficiency by providing feed for livestock, and collectively, these practices can elevate the level of self-sufficiency while reducing dependency on imported nitrogen fertilizers (Alexander et al., 2023; Kaufmann et al., 2022).

### **2.3 Fertilizer market dynamics**

Fertilizers prices are generally prone to fluctuations (Ahvo et al., 2023). The price of inorganic nitrogen fertilizers is closely linked to the prices of fossil fuels and electricity due to their production methods (Vainio, 2022). These price changes can affect trade markets and they can thereby threaten global food security (Alexander et al., 2023).

Typically, price fluctuations are caused by various shocks that disrupt markets. Especially with agricultural inputs, self-sufficiency and their security of supply become primary objectives during crises, helping countries protect themselves from external shocks (Clapp, 2017; Jansik et al., 2021; Kaufmann et al., 2022). Being self-sufficient in foodstuffs is different from security of supply in its production. While consumers may become more aware of the sources of their food, the origins of food inputs may be less transparent. (Lehikoinen et al., 2021)

Both the European and the global markets have experienced various shocks that have influenced prices and complicated trade (Glauber & Laborde, 2023; Kaufmann et al., 2022). The 2008 food crisis led to an extremely high spike in fertilizer prices (Glauber & Laborde, 2023). More recently, COVID-19 pandemic (Huan-Niemi et al., 2021) and the Russian invasion of Ukraine have caused significant market

disruptions (Alexander et al., 2023; Glauber & Laborde, 2023), and the latest is the conflict in the Middle-East region.

### 2.3.1 Import dependence and strategic resilience

In general, nations are increasingly motivated to increase their level of independence in agricultural inputs, although they may not fully recognize the connection between these inputs and food security (Lehikoinen et al., 2021). Finland has a high level of food security and is self-sufficient in foodstuff production. Despite this, both Finland and the EU remain dependent on fossil fuels for fertilizer production, rendering the whole food chain vulnerable. The dependence on imported fertilizers in Finland has increased since 1996, after when Finland joined the EU. Consequently, Finland is integrated into the global food production system. (Huan-Niemi ym., 2021; Lehikoinen ym., 2021) For instance, Finland is highly dependent on imported ammonia, making domestic production nearly impossible. Hence, imports are necessary, and both the trade and logistics of fertilizers must remain secure. Organic fertilizers can provide relief by enhancing the elasticity of supply security. (Huan-Niemi et al., 2021; Jansik et al., 2021)

In response to recent shocks, the EU has increased financial support and cooperation among member states while encouraging the adoption of greener fertilizer options (European Commission, 2022). A practical example of this is the recent RENURE proposal, which is to amend the Nitrates Directive by promoting the use of recycled nitrogen fertilizers derived from organic sources. This enhances reducing dependency on mineral nitrogen fertilizers, simultaneously mitigating environmental impacts and enabling more affordable nitrogen fertilizers for farmers. (European Commission, 2025)

According to Huan-Niemi et al. (2021), food is primarily produced for domestic consumption, with exports as a secondary focus. Clapp (2017), however, identifies potential threats associated with increasing self-sufficiency, as it may conflict with efficient farming practices and weaken global food security. Clapp also notes that self-sufficiency can lead to decreased demand, negatively impacting farmers' income. Natural disasters and pandemics can also threaten self-sufficiency (Nesme et al.,

2018). Additionally, self-sufficiency in fertilizers may distort trade in the long run, resulting in higher market prices that can weaken production incentives. Glauber & Laborde (2023) argue that diversity and scale in international trade contribute to stability, as countries are better equipped to confront threats and shocks when united rather than acting independently.

However, dependencies on imported and inorganic fertilizers pose risks to countries. These risks expose nations to global shocks, leading to potential yielding losses; increasing self-sufficiency in fertilizers can mitigate these risks. (Ahvo et al., 2023) Furthermore, reliance on inorganic fertilizers is energy-intensive and contributes to greenhouse gas emissions (Pradhan et al., 2015). Reducing fertilizer use can simultaneously enhance farmers' resilience to economic and social challenges (Zhang et al., 2023). Self-sufficiency protects nations from external shocks, and the primary incentive for achieving this goal is to secure domestic food production. Moreover, it strengthens the agricultural sector and fosters national pride in the ability to ensure its food security. (Clapp, 2017)

### 2.3.2 Fertilizer price volatility and economic impacts

Fertilizer prices have nearly doubled since the early 2000s (Aakkula et al., 2019; Elser et al., 2014). According to Aakkula et al. (2019), fertilizers accounted for approximately 4 % of agricultural production costs in Finland in 2016, while they represented 20–37 % of all input costs. Although the share of overall production costs appears relatively modest, it nonetheless constitutes a substantial financial burden for farmers, while even a modest decrease in prices has little impact on the profitability of Finnish farms (Aakkula et al., 2019). On the EU level, fertilizer costs contribute to 6–12 % of agricultural input costs (European Commission, 2022; Ministère de l'Agriculture, de l'Agro-alimentaire et de la Souveraineté alimentaire, 2025). Nevertheless, Finland's fertilizer prices are among the highest in Europe, especially during the peaks along with Sweden and Denmark (The Central Union of Agricultural Producers and Forest Owners, 2026). Continuously elevated prices are due to years 2012-2013, when fertilizer prices in Finland continued to rise while they began to decrease in other parts of the EU. Although price reductions started between

2014 and 2016, prices remained elevated compared to the general level. (Aakkula et al., 2019)

When fertilizer prices rise too high, farmers tend to reduce their fertilizer usage. This reduction can lead to decreased yields, and in extreme cases, additional land area is cleared for new fields. (Alexander et al., 2023) Farmers must decide if they can invest in fertilizers, as price increases in primary production are often reflected in consumer prices after a delay. Consequently, high input costs place farmers in a weak position and afflict social sustainability. (Clapp, 2017; Glauber & Laborde, 2023; Lago-Oliveira et al., 2023) Price fluctuations affect the ability of poorer countries to purchase fertilizers, directly impacting their food security (Ahvo et al., 2023; Moshkin et al., 2023).

Elser et al. (2014) see little chance in returning to affordable fertilizer prices, suggesting that this situation may prompt a transition toward more sustainable fertilizer use, where smaller quantities are applied more efficiently. These increased fertilizer costs are often passed on to food prices, which could redirect more funds toward primary production, making it more profitable and enabling further investment in innovations. For these reasons, policies supporting fertilizer use should be implemented cautiously: poorly designed policies can prohibit progress toward greater sustainability. (Alexander et al., 2023) Additionally, Moshkin et al. (2023) argue that if organic fertilizer prices were 30–46 % lower than those of inorganic fertilizers, their adoption would be faster. Mineral fertilizers are prone to price fluctuations, as they are used more (Ahvo et al., 2023).

The Central Union of Agricultural Producers and Forest Owners (2026) recommends removing fertilizer duties to develop more competitive behavior within the European fertilizer industry relative to non-EU producers. According to the union, eliminating these duties would improve supply conditions and increase the use of European-made fertilizers, which currently struggle to compete on price with imports, such as those from the United States. Additionally, storing methods for ammonium nitrates differ between Finland and the rest of the EU as there are tight regulations considering the storing in Finland. As a result, nitrogen fertilizers are stored in farms in Finland and in stores elsewhere in the EU, which impacts the ability to buy nitrogen fertilizers in store in advance. The union also proposes greater price transparency from fertilizer suppliers, including information about the quantities

released to the markets. Without such transparency, farmers may face inflated costs and be compelled to make purchasing decisions under conditions of asymmetric information. (The Central Union of Agricultural Producers and Forest Owners, 2026)

### 2.3.3 Global shocks in fertilizer trade and prices

Fertilizer prices have experienced significant increases over the past decade. The 2008 food crisis also impacted fertilizer prices, causing them to triple. (Glauber & Laborde, 2023) This is due to nonlinear actions rather than typical market dynamics, and similar disruptions may occur in the future (Elser et al., 2014). Such price increases have led to hunger, malnutrition, and poverty (Glauber & Laborde, 2023).

Following the 2008 food crisis, there was a ten-year period during which fertilizer prices steadily declined. The COVID-19 pandemic had a minimal effect on prices but significantly impacted logistics; as borders were closed, fewer imports could be delivered (Glauber & Laborde, 2023). The pandemic sparked discussions about the need for a more self-sufficient food system (Kaufmann et al., 2022), because while markets continued to operate, the pandemic highlighted the importance of securing supply (Jansik et al., 2021). Supply networks also play a crucial role in these situations, ensuring the availability of fertilizers (Huan-Niemi et al., 2021; Jansik et al., 2021). Huan-Niemi et al. (2021) emphasize that during crises, it is essential to secure the imports and exports of goods.

Shortly after the delivery challenges caused by the pandemic, restrictions imposed by China in 2021 and the Russian invasion of Ukraine in 2022, together with earlier increase in grain prices, led to another surge in fertilizer prices (Glauber & Laborde, 2023; The Central Union of Agricultural Producers and Forest Owners, 2026). As previously mentioned, nitrogen fertilizer prices are closely tied to energy prices, particularly in ammonia production (Aakkula et al., 2019; Alexander et al., 2023). Energy prices surged following Russia's invasion (Alexander et al., 2023; European Commission, 2022). The war has created additional challenges for exports, which subsequently reflect in grain prices and, in turn, in fertilizers. Although fertilizer prices have decreased since their peak in May 2022, they remained twice as high in August 2022 compared to early 2021 (Alexander et al., 2023). By improving self-

sufficiency in fertilizers, the impacts of these crises could be mitigated (Alexander et al., 2023; European Commission, 2022, 2023).

### 3 Methods and data

This thesis employs a mixed-method approach, combining the analysis of quantitative data with structured interviews. Quantitative data on nitrogen fertilizer markets is utilized to illustrate the flows of nitrogen fertilizers in Europe, in terms of volume and monetary value, but also of trade partners. For qualitative part, three expert interviews are conducted to gain a broader perspective on the situation. By integrating both methods, the problem can be understood at a deeper level (Arsel, 2017). The following sections explain how the data was collected in both quantitative and qualitative forms.

#### 3.1 Quantitative data

Quantitative data provides information on the volumes of nitrogen fertilizers currently imported, produced, or used. It serves as a valuable tool for highlighting the value of these market flows and allows to see how external shocks have impacted the market. Additionally, it offers trendlines that illustrates how the consumption has changed over time and enables comparisons between countries. Together, these quantitative methods establish the scale and urgency of the problem. This section represents the databases utilized and how they were used, focusing on aspects of nitrogen fertilizer consumption, trade, production, and prices.

##### 3.1.1 Databases

One source of quantitative data is the International Fertilizer Association's (IFA) database, which offers estimates of fertilizer consumption by product, country, and year. Data can be searched for uses, activities, timeseries, and units, and the database is publicly accessible. It is updated annually and when real consumption data is unavailable, estimated consumption figures are provided. (International Fertilizer Association, 2025)

The European Commission's Directorate-General for Agriculture and Rural Development (DG AGRI) maintains three different databases: fertilizer trade,

production, and prices. The fertilizer trade database retrieves its data from the Eurostat reference database, except for the last two months it is retrieved from the Customs Surveillance system, which operates under the European Commission's Directorate-General for Taxation and Customs Union (DG TAXUD). Since this database follows international trade, it includes only trade between EU member states and external partner countries, excluding intra-EU trade. The United Kingdom is consistently classified as a partner country, despite its withdrawal from the EU. (Directorate-General for Agriculture and Rural Development, 2025c)

Fertilizer production database monitors the levels of inorganic fertilizer production among member countries. Data may be unavailable for some member states due to confidentiality concerns. Additionally, this database retrieves its information from Eurostat. (Directorate-General for Agriculture and Rural Development, 2025b)

Lastly, for monitoring fertilizer prices, DG AGRI calculates aggregated prices based on market data provided to them by third parties. These calculations are derived from the most commonly used fertilizer products and reflect the overall price developments at the EU level. (Directorate-General for Agriculture and Rural Development, 2025a)

### 3.1.2 Data search

To understand the consumption of nitrogen fertilizers, consumption levels were studied at both the EU and Finnish levels. For this thesis, timeline from 2000 to 2025, or otherwise notified, was used to analyze the development of nitrogen fertilizer consumption volumes and trades. Phosphate and potash products were excluded; thus, only products categorized as nitrogen products in the databases were included in the search. Ammonia was treated as a separate product group in the EU database, which is why it is analyzed as an independent category.

When searching for Finland's data from IFASTAT, nitrogen fertilizer types NP (N), NK (N), Ammonium nitrate (N), Ammonium phosphate (N), Ammonium sulphate (N), and Other (N) were reported as zero during the observed period; therefore, they were excluded from the analysis. The use of urea was reported at a maximum of 2000 kg per year; thus, it was also ignored. Eurostat's estimate of Finland's total nitrogen

fertilizer consumption was included for comparative purposes. Eurostat provides data on total nitrogenous fertilizers consumption in agriculture, while IFASTAT releases general consumption levels.

Due to the variance and extensive amount of consumption data from other EU countries together, their nitrogen fertilizer usage is presented as total volume or value of nitrogen products in this thesis. At times, other EU countries are used as a reference to provide context regarding the situation in other parts of the EU compared to Finland. For this information, Eurostat was utilized as it provides more flexible and diverse data on nitrogen fertilizer flows.

### 3.1.3 Herfindahl-Hirschman Index

The Herfindahl-Hirschman Index (HHI) is a widely used method for measuring market concentration within an industry. Market shares are expressed as points on a scale ranging from 0 to 10 000, reflecting the proportion of total market share. Under conditions of perfect competition, the HHI value approaches zero, while higher values indicate increasing market concentration, with extreme values suggesting monopolistic structures (Eurostat, n.d.). The formula for calculating the HHI is as follows:

$$HHI = \sum_{i=1}^n s_i^2$$

where  $s_i$  represents the import share of each country, and the HHI values range from 0 to 10 000.

In this thesis, HHI was applied to analyse the concentration of nitrogen fertilizer import shares. The data utilized in the HHI analysis was initially compiled in Excel from the EU fertilizer trade database, and all figures were generated using Stata.

## 3.2 Qualitative data

Qualitative data is an explanatory method, aiming to understand the mechanisms underlying the current situation reflected in the quantitative data. It delves deeply

into the issue, observing which factors influence the current situation and identifying potential solutions. (Arsel, 2017) Structured interviews were selected for this thesis to obtain more in-depth responses from the participants.

For this research, three expert interviews were conducted. The interviewees were selected from fields of technological, farming, and governmental solutions to provide diverse perspectives on the problem. Technological perspectives can introduce innovative solutions and strategies for implementing necessary changes. The farmers' perspective highlights the concerns of farmers, which is essential when addressing decisions that affect their daily lives. The governmental perspective offers valuable insights of the policies that connect all EU countries, alongside a comprehensive understanding of Finland's situation. Together, these viewpoints create a more holistic understanding of the problem, which is crucial for addressing the complex challenges of food production.

The interviewees were first contacted in December 2025, after which interview sessions were scheduled. The interviews were arranged for early February, and they were conducted in a private setting, lasting approximately one hour in total. Participants were contacted one week prior to the interviews to provide them the questions that were going to be asked, allowing them time to prepare. They were assured that their responses would remain anonymous, with names and company information kept confidential. However, the field of expertise of each participant is provided to give readers context for their responses. Participants were given the option to conduct the interview online or in person.

Two of the interviews were held in via online meetings, while one was conducted in person. Microsoft Teams was used to record and transcribe all interviews. Additionally, a phone's recording app was used as a backup for recording. Participants were informed at the beginning of each interview that the session was being recorded and were reminded about the anonymization of the results.

The interviews were structured around four questions (see Appendix A). The first two questions were consistent for all participants, while the last two were tailored specifically to each participant's area of expertise. Interviews were conducted and transcribed in Finnish, but parts of transcriptions were since translated into English for the results.

After the interviews, the transcriptions were reviewed for accuracy. Interview transcripts were analysed by a thematic analysis. Certain themes arose from the transcripts, that were then used to divide participants' answers into different categories, which were yet refined into broader themes in the results section.

## 4 Results

This section presents the findings of the analysis of both quantitative and qualitative data. First, quantitative data on nitrogen fertilizer flows in the EU area is presented. This is followed by the results of interviews with participants labelled as participant A, B, and C. Exceptionally, Participant B consists of two participants, while Participant A and C are individual participants, but for easier readability, the two participants are referred to as Participant B.

Together, the qualitative and quantitative data aim to clarify the mechanisms that have led to the current situation and how they can be changed. The interviews in this thesis aim to understand different perspectives on the problem, while the quantitative data illustrates its magnitude (Arsel, 2017).

### 4.1 Nitrogen fertilizer consumption, trade dynamics, and price development in Finland and the EU

#### 4.1.1 Nitrogen consumption patterns

Figure 1 presents estimate of total nitrogen fertilizer consumption in Finland, derived from both Eurostat and IFASTAT. Eurostat's data is derived from agricultural nitrogen fertilizer consumption, while IFASTAT's data includes overall nitrogen consumption. The total consumption of nitrogenous fertilizers exhibits a wider variety of products.

There is minimal variation in consumption amounts in Finland. High nitrogen fertilizer costs resulted in declined consumption in 2022 that was caused by the Russian invasion of Ukraine. In 2023, consumption levels returned to previous rates. This suggests that, despite EU regulatory measures on fertilizer usage, they have a limited impact on Finnish agriculture as nitrogen fertilizers are already used quite efficiently in western EU countries (Santeramo & Jelliffe, 2024).

When comparing nitrogen fertilizer consumption generally at the EU level in Figure 2, a slight decline in total amounts can be observed starting in 2017. In 2022, the EU countries did not have same kind of a drop in used quantities as Finland in Figure 1, suggesting that countries engaged in trade with partners other than Russia were less

adversely affected by the conflict. Therefore, their nitrogen fertilizer trade was disrupted in lesser extent.

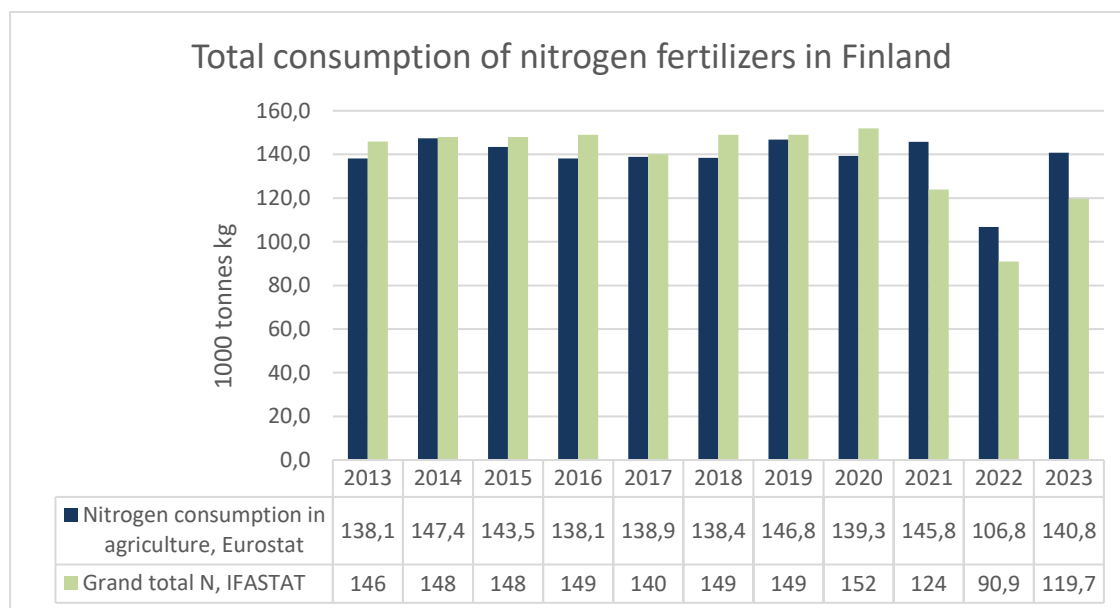


Figure 1. Total nitrogen fertilizer consumption in Finland, based on both Eurostat and IFASTAT data in 2013–2023, which correlate with each other to some extent.

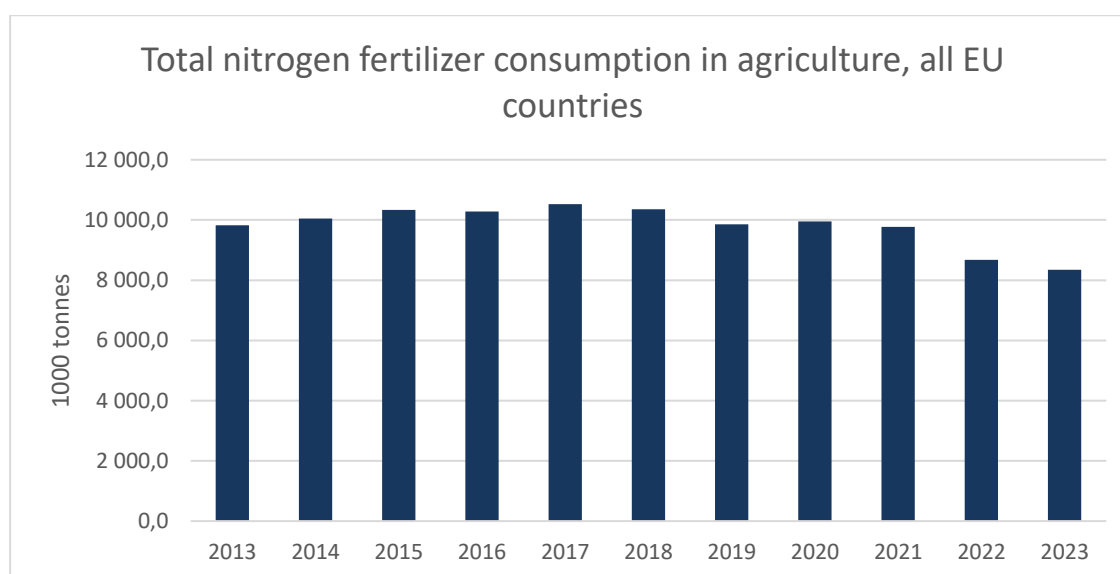


Figure 2. Total nitrogen fertilizer consumption in agriculture across all the EU countries in 2013–2023. Source: DG AGRI

Overall, the consumption of nitrogen fertilizers in the EU declined almost 20 % between 2017 and 2023. In Appendix B, Figure 6 depicts how each member country has changed their nitrogen consumption levels when comparing the averages between years 2012–2014 and 2021–2023. Finland is reaching the EU average level

of declining use, while Romania is on average at the highest end of the change in nitrogen use in the EU area. Figure 7 in Appendix B illustrates the consumption of nitrogen fertilizers by country from 2015 to 2025, indicating that several countries have higher consumption levels than Finland. Also in Appendix B, Figure 8 depicts the shares of nitrogen production in the EU from 2000 to 2024, with Germany identified as the primary producer, followed by France and Poland.

#### 4.1.2 Nitrogen fertilizer and ammonia trade flows and import dependencies

Figure 3 illustrates the total shares of imported nitrogen in volume from trade partners for all EU member states between years 2015 and 2025, with Russia, Egypt, and Algeria as the major importers of nitrogenous fertilizers. The trend is similarly observed in Finland in Figure 4, where Russia accounts for approximately 96 % of Finland's nitrogen fertilizers imports. This 96 % equals to 716,32k euros during the given timeframe. Additionally, Russia is the largest trade partner for ammonia, accounting for 69,4 % of Finland's imports and 31,3 % for all EU countries combined between 2015–2025. (Directorate-General for Agriculture and Rural Development, n.d.)

#### EU Trade by Partners, Quantity in tonnes

flow: IMPORT, product group: Nitrogenous fertilisers, all subgroups, all member states, all partners, Year:

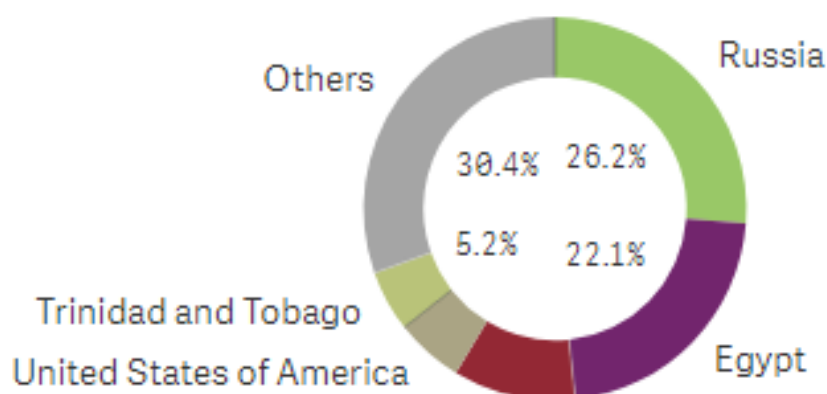


Figure 3. Import trade partner shares for all EU member countries in 2015–2025. Third largest part belongs to Algeria by 10,4 %. Source: DG AGRI

Countries in Eastern Europe, particularly those sharing borders or possessing historical ties with Russia, exhibit a higher degree of trade engagement with the country during the same timeframe. For example, Estonia, Latvia, Lithuania, and Poland trade nitrogen fertilizers and ammonia with Russia, varying between Poland's 48,7 % share and Estonia's 94,1 % share. (Directorate-General for Agriculture and Rural Development, n.d.)

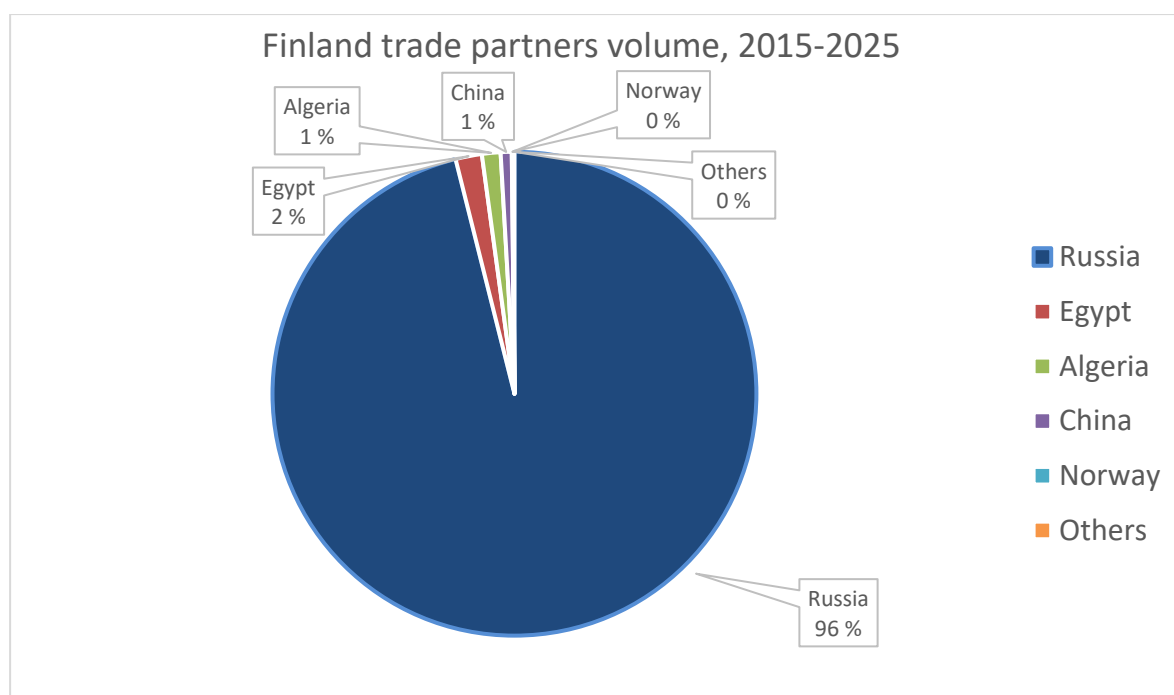


Figure 4. Proportions of Finland's trade partners in nitrogen fertilizer volume between 2015–2025.  
Source: DG AGRI

The HHI analysis was conducted to assess how Finland's import concentration compares with the overall import structure of the EU. Figure 5 presents a comparison between Finland and EU-27 over the period 2015–2025, revealing a substantial and persistent difference between the two. Finland's import sourcing became more diversified after 2021, especially in 2023, a year after the Russian invasion in Ukraine. Overall, the EU-27 exhibits evidently lower degree of market concentration than Finland throughout the entire period, with HHI values remaining mostly below 3,000 points.

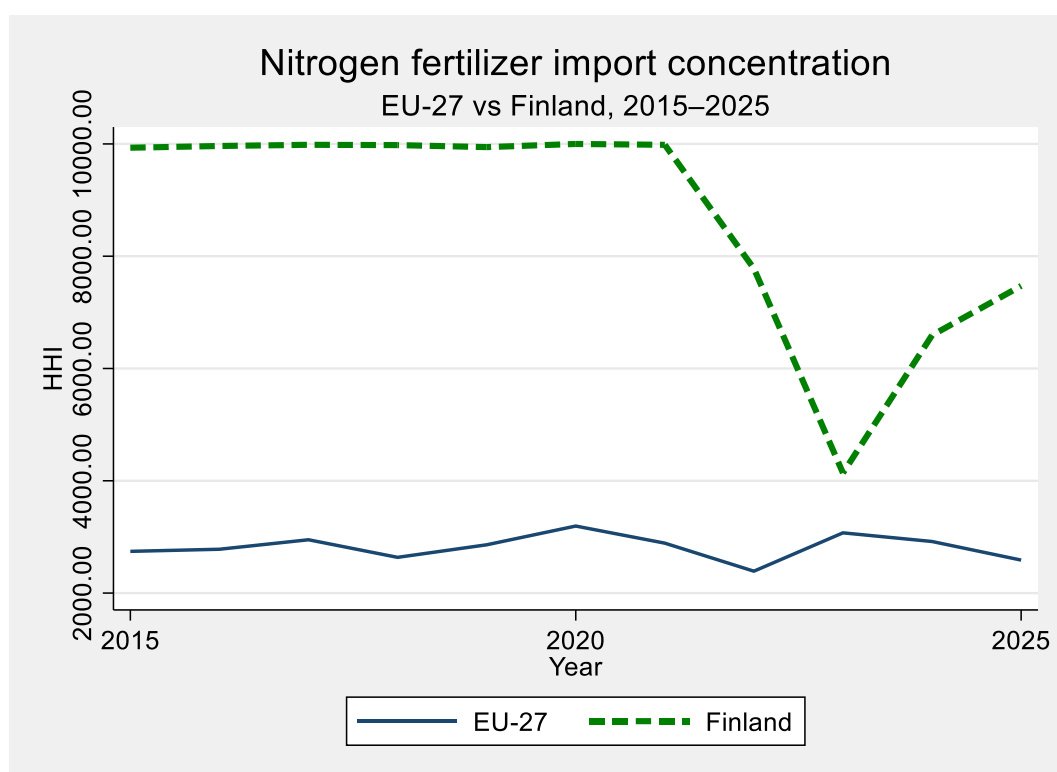


Figure 5. The HHI comparison of nitrogen fertilizer import concentration between EU-27 and Finland in 2015–2025.

Table 1. The median HHI table for period 2015–2025 of all countries included in the HHI analysis.

| Year | EU27    | Estonia | Finland  | France  | Spain   | Sweden  |
|------|---------|---------|----------|---------|---------|---------|
| 2015 | 2743,46 | 7531,45 | 9932,73  | 1556,73 | 1451,11 | 5338,43 |
| 2016 | 2780,90 | 9701,01 | 9963,17  | 1901,75 | 1849,87 | 4907,74 |
| 2017 | 2950,18 | 9769,56 | 9985,33  | 2146,61 | 2112,05 | 5023,12 |
| 2018 | 2636,84 | 9972,73 | 9979,04  | 2093,77 | 1541,32 | 5036,64 |
| 2019 | 2860,55 | 9940,54 | 9943,26  | 1863,90 | 1798,89 | 4958,07 |
| 2020 | 3194,09 | 9761,95 | 10000,00 | 2305,40 | 2084,27 | 5358,99 |
| 2021 | 2889,80 | 9000,70 | 9984,27  | 2090,24 | 1745,72 | 4457,88 |
| 2022 | 2390,51 | 7138,46 | 7781,79  | 1682,19 | 1679,63 | 7235,75 |
| 2023 | 3073,58 | 2243,60 | 4138,76  | 1890,58 | 2761,00 | 9506,61 |
| 2024 | 2919,07 | 5072,67 | 6593,31  | 1908,81 | 3505,83 | 9585,99 |
| 2025 | 2588,19 | 6492,85 | 7471,40  | 1928,02 | 2162,42 | 9731,50 |

To provide a more granular regional perspective, additional analyses were done to compare Finland with its Nordic and Baltic neighbours Estonia and Sweden, as well as to the largest importers in the EU, France and Spain (Directorate-General for

Agriculture and Rural Development, 2025c). The yearly median HHI indexes for all countries are displayed in Table 1. For the comparison between Sweden and Estonia, Finland and Estonia display broadly similar patterns in import concentration during the early years of the sample, with the HHI values close or up to 10,000 points, indicating a strong dependence on Russian imports for both (Directorate-General for Agriculture and Rural Development, 2025c), as shown in Figure 9 in Appendix B. From 2020 onwards, both countries began to diversify their import sources, leading to declining HHI values. In contrast, Sweden follows a different trajectory. After 2021, Sweden's nitrogen fertilizer imports became increasingly concentrated, primarily due to a growing reliance on Norway as its dominant supplier.

Figure 10 in Appendix B further compares Finland with France and Spain to illustrate scale-related differences in import concentration. Both France and Spain exhibit relatively lower level of concentration than the EU-27 aggregate as can be seen in Table 1, with HHI values remaining mostly below 2,000 points throughout the observed period. As large importers, France and Spain may face fewer constraints in accessing alternative suppliers, which can facilitate a more diversified import structure. For transparency and replicability, Tables 2 and 3 in Appendix B report the HHI values for all or main importers in 2015–2025 used in the main analysis for Finland and EU-27. Tables for Estonia, France, Spain and Sweden were left out as they were only used as a control group for this study.

#### 4.1.3 Price dynamics in the EU

As previously stated, trade prices are highly volatile and sensitive to external shocks. This is depicted in Figure 6, which illustrates the price evolution of nitrogen fertilizers in the EU in 2019–2025. In 2019, the COVID-19 pandemic elevated the prices and created bottlenecks and route disruptions in the market. As economies and demand began to rise in 2021, the prices started elevating. The Russian invasion of Ukraine in 2022 led to another spike in prices, which was caused by the imposition of economic sanctions on Russia by the EU and other nations.

It is important to note that the war had relatively minimal impact on the volumes used as was illustrate in Figure 1 and Figure 2 (Rice & Vos, 2024) Furthermore, in

Appendix B, Figure 11 highlights the differences in prices per year between 2019–2025, showing that prices in 2022 were considerably higher and have remained elevated compared to those in 2019.

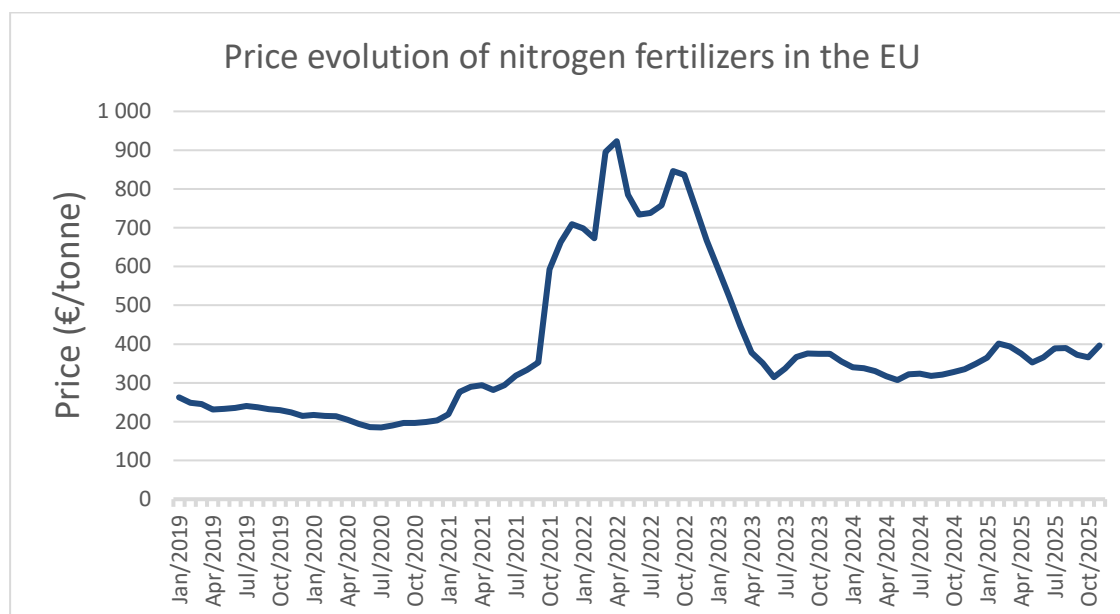


Figure 6. Nitrogen fertilizer price evolution for the EU between 2019–2025. Source: DG AGRI

## 4.2 Insights from expert interviews

This section is divided into four thematic schemes that were noticed when analysing the transcripts: market disruptions and vulnerabilities, sustainable aspects and recycling of nitrogen, regulation and policies, and investing and cooperation. As a reminder, participants are referred as to A, B, and C for clarity. Each participant brings a distinct background that informs their responses to the questions.

Participant A, with a focus on technology and recycling, offers insights on innovative practices from the perspective of an organization focusing on sustainable solutions.

Participant B, representing farm owners, provides a practical perspective on the challenges faced by farmers. Participant C, working in a governmental role, highlights regulatory and policy aspects that impact the nitrogen fertilizer industry.

#### 4.2.1 Market disruptions and vulnerabilities

All participants agree that the EU, particularly Finland, remains extremely vulnerable to market disruptions. The Russian invasion of Ukraine and the COVID-19 pandemic have underscored Finland's susceptibility in accessing nitrogen fertilizers.

Considering these challenges, participants unanimously advocate for increased domestic nitrogen production and the expansion of sources for both raw materials and end products within the EU. This proactive approach is essential for building resilience against future market shocks.

Moreover, Participant A emphasizes that market risks have escalated significantly, outpacing the capacity for effective risk management. Participant B criticizes the EU's responses to market disruptions, which are described as inadequate, as evidenced by the continued existence of anti-dumping and protective duties. This has resulted in an inelastic market situation, highlighting the urgent need for a more functional internal market as a foundation for support. Addressing these regulatory challenges is crucial for stabilizing the nitrogen fertilizer market and ensuring its sustainability.

In addition to market dynamics, the repercussions of the Russian invasion of Ukraine have elevated national food security and supply security as critical components of Finland's security policies, hence fertilizers have become a crucial element of Finland's national food strategy for 2040 and the broader food system. In times of crisis, Finland could rely on its own nitrogen fertilizer production to some extent; however, it is generally believed that primary production will predominantly come from within the EU. This belief stems from the logistical challenges experienced during the pandemic, which have underscored the necessity for Finland to maintain a degree of self-sufficiency in nitrogen fertilizer production. Consequently, finding solutions for organic fertilizers becomes essential for ensuring Finland's food security in any situation.

Recognizing these vulnerabilities, all participants highlight the urgent need for enhanced storage solutions to prepare for future disruptions. While the spike in demand for recycled nitrogen fertilizers following the Russian invasion presents an opportunity, mineral fertilizers continue to pose formidable competition. Farmers have long relied on mineral fertilizers and are familiar with their functionality, making it challenging to shift their preferences.

As a result, the agricultural sector is viewed as a secondary target for the adoption of recycled nitrogen fertilizers. Although the fertilizer crisis has increased demand for organic alternatives, the established mineral fertilizer market remains a significant barrier to transition. This situation requires a substantial change in mindset for mineral fertilizer users to begin incorporating organic options into their practices.

Currently, the burden of investments falls heavily on the industry, and low market prices for recycled nitrogen fertilizers make these investments appear highly risky. Furthermore, fertilizer producers face uncertainty regarding the future costs of carbon certificates by CBAM, which complicates pricing and undermines confidence in the market. This uncertainty not only affects investment decisions but also highlights the need for clearer regulatory frameworks to support the transition to more sustainable practices.

In summary, the interplay of market vulnerabilities, regulatory challenges, and the need for increased self-sufficiency underscores the importance of a comprehensive approach to strengthening Finland's nitrogen fertilizer sector. By addressing these interconnected issues, stakeholders can work towards a more resilient and sustainable agricultural future.

#### 4.2.2 Sustainable opportunities and recycled nitrogen fertilizers

Participant A identifies several significant obstacles in adopting recycled nitrogen fertilizers, including the lack of technological solutions for trapping nitrogen from waste sources. Currently, biogas plants primarily focus on energy production rather than nutrient recovery, which limits their potential in the agricultural sector. Furthermore, pure nitrogen sourced from wastewater is typically directed towards industrial applications instead of agriculture, leaving unused potential in the utilization of recycled waste sources. In this context, Participant B emphasizes the importance of energy production by biogas plants but underscores the need for more efficient use of other waste streams in wastewater treatment facilities, particularly within biogas plants. Participant C adds that the domestic production of green ammonia is crucial for addressing the challenges.

The participants highlight that logistical issues, along with handling, dispensing, and spreading challenges, significantly impede the adoption of recycled nitrogen fertilizers. These obstacles are costly to overcome, particularly in Finland, where the division between crop and livestock farms complicates manure logistics. Additionally, northern climatic conditions create difficulties in managing water-containing substances during certain times of the year. The challenge of expanding biogas production in southern Finland is exacerbated by a lack of inputs, as husbandry is concentrated in specific areas. Therefore, diversifying the inputs used in biogas plants based on their geographical location is essential.

When resolving these challenges, Participant A notes that significant nitrogen losses occur during the handling of organic materials and waste. One potential solution is to improve nitrogen trapping during these processes. It is also crucial to eliminate the negative connotations associated with the term "waste," as these perceptions can hinder the acceptance of recycled products. Agricultural biomasses are often underutilized resources, and biogas plants could enhance the controlled trapping of nitrogen without releasing it into the atmosphere.

Despite advancements in technology leading to cleaner end products, concerns about potentially harmful substances remain. Recycling waste can introduce various harmful substances into the final product, making it essential to ensure high quality to gain the trust and approval of farmers and to guarantee safe food production. Although quality standards for recycled agricultural inputs are high, the quality of recycled nitrogen fertilizers in Finland has exceeded these values. Sewage treatment plants have successfully monitored and improved the quality of their sewage sludge over the years, thanks to technological advancements. At the EU level, Finland boasts very clean waste streams that do not threaten recycling goals in agriculture. However, the EU's outdated sewage sludge directive complicates these efforts. This highlights the need for control measures to facilitate increased recycling, as demonstrated by Luonnonvarakeskus' OHRAKE project, noted by Participant A.

An alternative way for more sustainable practices is to reduce the amount of nitrogen fertilizers used. Given the current varying weather conditions, farmers have resorted to using additional nitrogen fertilization during the growing season to ensure adequate nutrient intake for their crops. While achieving high yield levels is one objective, it is equally important to consider quality. For instance, depending on the

intended use of the grain, it must contain specific protein levels, which are ensured through adequate nitrogen application. Otherwise, the yield may remain unused in the food industry. To meet the demand for reduced nitrogen fertilizer levels, Participant B advocates plant breeding that allows for high yields with less nitrogen. A new legal package is currently being introduced in the EU to support these efforts.

Historically, crop rotation has been a method for reducing nitrogen needs; however, its adoption in Finland has faced challenges due to a lack of markets for legumes and oilseeds. While these crops are becoming more economically viable, they require significant land area to function effectively within crop rotation. Consequently, smaller farms struggle to achieve sufficient yields for the market. This situation could be improved by prioritizing the acceptance of Finnish oilseeds and legumes in maintenance security warehouses.

Despite these potential solutions, Participant C notes that farmers remain skeptical about the production levels of organic nitrogen fertilizers. Their competitiveness is further undermined by low quantities and high logistical costs, which continue to be significant barriers to widespread adoption. Moreover, Participant C expresses concern that farmers perceive organic nitrogen fertilizers as producing lower yields and quality compared to mineral fertilizers. This perception poses a barrier to adoption, as farmers are hesitant to switch to alternatives that they believe may not meet their productivity needs. To ensure national and global food security, organic nitrogen fertilizers alone are insufficient for now; mineral fertilizers will continue to play a vital role. However, there must be a shift in mindset towards primarily using organic fertilizers, with mineral fertilizers serving as a secondary option.

#### 4.2.3 Regulation and policies

All participants underscore the government's responsibility to guide farms toward more sustainable practices through funding research and innovation. Participant C calls for clearer and more consistent guidance from the EU regarding fertilizer regulation, as the current framework places a heavy burden on individual member countries. At the national level, the Ministry of Agriculture and Forestry is tasked with implementing strategies, but as Participant C points out, this ministry is heavily

dependent on EU actions, complicating its ability to respond effectively to national issues. Moreover, Participant B expresses a concern that the EU's greening policies are misleading, as they are based on weak arguments. For example, at some point Russian natural gas was classified as green energy. Participant C specifically notes the lack of long-term policies for investment support, which further complicates the situation.

While there are interested users of organic alternatives, Participant A notes that market availability remains limited. This limitation is largely due to pricing; users recognize the benefits of recycled nitrogen fertilizers but are often reluctant to pay more than for mineral fertilizers. Consequently, a larger systemic change at a higher level is necessary to facilitate the use of recycled fertilizers. The outdated sewage sludge directive, which has not kept pace with advancements in nitrogen recovery technologies, further complicates this process further, as it perpetuates negative connotations associated with the term "waste". This has created stigma around the use of sewage sludge, posing challenges for the entire sector.

To ensure the safety of recycled fertilizers for both humans and the environment, compliance with waste and environmental legislation, as well as the fertilizer act established by the Ministry of Agriculture and Forestry, is essential. Currently, the status of waste is closely tied to the final product, and without this label, the market could be more open to recycled alternatives. Environmental legislation introduces additional cleanliness criteria, which is a positive development that can lead to high-quality products. However, new policy measures are urgently needed, as this sector is unlikely to evolve in a market-driven manner alone. Participant C emphasizes that organic nitrogen fertilizers require standardization to elevate them to the same level as mineral fertilizers, which is necessary for fostering trust among farmers.

Another notable concern is the CBAM, particularly regarding the fact that sold nitrogen fertilizers may contain inputs from various sources. Producers must calculate the proportions of fertilizers' origins, and the EU then determines the costs of CBAM based on these origins. Given the EU's import dependency, farmers often find themselves at the mercy of larger market contributors. Fertilizer producers have made plans to prepare for CBAM, yet farmers are left to accept whatever prices are offered.

Participant B observes that fertilizer sale practices differ significantly between Finland and other EU countries, noting that nitrogen fertilizers are not stocked in retail stores in Finland. This lack of transparency means that the quantities and prices of nitrogen fertilizers released to the market are not publicly disclosed. Greater openness regarding nitrogen fertilizer prices would help alleviate some of these issues; however, the fact that CBAM operates under DG TAXUD rather than DG AGRI complicates matters, often leaving farmers' interests behind.

The lack of transparency in the nitrogen fertilizer market is a significant issue raised by Participants B and C. To address these challenges, Participant B suggests removing duties, following the example set by the United States, to secure competitive prices for farmers. Anti-dumping and protective duties have hindered the fertilizer industry's ability to enhance its competitiveness, leading to calls for better leadership within the EU. Participant C emphasizes the need for clearer horizontal leadership and long-term policy decisions that extend across multiple regulatory periods.

From the farmers' perspective, there are strong expectations for long-term policies regarding income support and risk management tools. Trust in organic products must be enhanced, and it should be recognized that initial years may yield lower production levels. This necessitates that all EU countries adhere to the same rules while allowing for flexibility in experiments, research projects, and pilot initiatives at the national level. Currently, the EU has only set directives, which leaves significant room for each country to develop its practices. Participant C believes that binding regulations at the EU level, coupled with some degree of freedom at the national level for innovative methods, are essential for future progress. Looking ahead, government financial support will be vital, even as the economic situation presents challenges.

#### 4.2.4 Investing and cooperation

There are several potential solutions on the brink of deployment, but these require substantial investments. Considering these challenges, all participants advocate for increased investments and collaboration among ministries, research institutions, technology organizations, and universities, as these entities play a vital role in

fostering new innovations. Participant C highlights that the agricultural sector is closely linked to the energy and chemistry sectors in addressing nitrogen fertilizer issues, underscoring the need to form new networks.

When looking from farmers' perspective, collaboration with cooperatives is viewed as a minor option for acting as nitrogen fertilizer buyers for larger purchases and thus in equalizing costs, as they also carry risks that are comparable to those faced by individual farmers. Additionally, the CBAM is perceived as an added cost for farmers, despite its intended purpose of levelling the fertilizer market. This situation highlights the ongoing push for greening initiatives, as the idea behind CBAM was to escalate green investments in nitrogen production; however, this mechanism was introduced when it was still incomplete.

Transitioning to new regulations and practices inevitably incurs additional costs at the outset. Therefore, it is crucial to consider the necessary support during this transition period, which should be addressed by the EU. However, it is important to acknowledge that the EU is also operating within a limited budget. The initial years of this transition will require substantial support from both the government and the EU. Consequently, more research is needed on the nutrient levels of organic fertilizers and how these can be manipulated to achieve yields comparable to those of mineral fertilizers. At the same time, there should be flexibility for experiments, research projects, and pilot initiatives at the national level to facilitate innovation and adaptation.

As mentioned, the current economic situation has made the transition towards more sustainable nitrogen fertilizer use difficult. Participant C emphasizes the importance of domestic production start-up of green ammonia as such initiatives would simultaneously create new jobs, although significant investment is required. Participant B emphasizes the critical role of biogas plants, especially small and medium-sized, advocating for their deployment on a larger scale to enhance farmers' participation as shareholders in these ventures. Another strategy involves increasing Finland's food production to boost exports, which would raise the potential for new investments in recycled nitrogen fertilizers.

Alternative way of investing involves investing in soil quality and plant breeding. These are effective strategies for reducing necessary nitrogen levels. Better soil

quality can be achieved through improved liming and drainage practices, as well as long-term investments in rented fields. Participant B points out that in Finland, five-year rental agreements are the most common, with 46% of cultivated arable land being rented. Longer rental agreements would facilitate investments in soil quality, thereby enhancing agricultural sustainability. New plant breeds could result in same yield levels with less applied nitrogen.

Overall, investments from both farmers and the government together with factors such as plant breeding and field structure, can contribute to a decrease in fertilization levels. This effort is supported by the upcoming CAP and investment initiatives, although it still requires more research funding and technological advancements. However, the EU lacks long-term policies for investment support, which further complicates efforts to promote these sustainable practices.

## 5 Discussion

This thesis examines how the EU, particularly Finland, can enhance self-sufficiency in nitrogen fertilizer production without compromising yield levels and food security. It also explores the necessary steps to adopt more sustainable methods in nitrogen fertilizer production. The analysis combines quantitative and qualitative methods, providing comprehensive insights into the magnitude of the issue and potential solutions that could influence outcome.

Over time, Finland's nitrogen use has been relatively stable, while the EU has achieved to decrease its consumption levels approximately 20 % between 2017 and 2020 (Figure 2). Both Finland and the EU largely depend on Russia as an importer, particularly evident among countries bordering Eastern Europe; between 2015 and 2025, 96 % of Finland's nitrogen fertilizer imports were sourced from Russia (Figure 4 and Table 2). Several geopolitical shocks have impacted fertilizer markets, leading to price spikes and creating vulnerable situations in countries with little to no domestic nitrogen fertilizer production. Following these shocks, prices have only partially normalized, leaving nitrogen fertilizer prices higher than levels observed in 2019 (Figure 6).

Interviews prove the presence of vulnerability that can be seen from the quantitative data and HHI analyses. Therefore, diversification of import sources, strategic storage within the EU, and the activation of green ammonia production are essential tools for managing the risks faced by the EU and Finland today. Achieving these objectives require clearer and more long-term policies that address the obstacles to the adoption of organic fertilizers, with the help of technology, innovative logistics, and functioning markets.

Overall, while the EU and particularly Finland, demonstrates efficient use of nitrogen fertilizers, they remain structurally fragile due to import concentration, policy uncertainty, and barriers to scaling recycled fertilizers. A successful transition requires coordinated technological, infrastructural, and policy measures.

## 5.1 Challenges with nitrogen fertilizers

Finland has already implemented the most accessible measures to reduce nitrogen fertilizer use, leaving fewer opportunities for further optimization. Consequently, additional reductions are difficult to achieve despite of policy targets. (Santeramo & Jelliffe, 2024) Greater self-sufficiency can be pursued through two main pathways: reducing nitrogen fertilizer use or increasing domestic production. If Finland opts to expand domestic production, the primary options are to develop green ammonia capacity or to enhance organic fertilizer production, for example via biogas plants and other nutrient-recovery technologies (Finnish Government, 2023; Ministry of Agriculture and Forestry, 2017).

At the EU level, the aim is to lower overall fertilizer use while simultaneously diversifying import sources (European Commission, 2022). Trade exposure remains particularly concentrated in Finland and its neighbouring countries, as illustrated in Figure 9. A substantial share of Finland's nitrogen fertilizer imports originate from Russia, a trend that is also evident in Estonia, according to the data in Table 2 (Directorate-General for Agriculture and Rural Development, 2025c). This concentration helps to explain the sharper decline Finland's nitrogen fertilizer consumption in 2022 relative to the EU average, as depicted in Figures 1 and 2. In contrast, other member states, such as France and Spain (Figure 10), have relied on more diversified import sources.

The HHI index analyses presented in Figures 5, 9, and 10 indicate that smaller countries tend to exhibit a higher level of concentration in their import sources, reflecting limited market power. External shocks can significantly alter this balance, as evidenced by Finland, Estonia, and Sweden. Following the Russian invasion of Ukraine, both Finland and Estonia began to diversify their import sources, while Sweden increased its reliance on imports from Norway. In contrast, the war resulted in minimal to modest changes in the HHIs for EU-27 as an average and individually for France and Spain.

While a small increase in the HHI is observable in the figures due to the COVID-19 pandemic, the impact of the war was markedly more substantial. Although the HHI analysis does not definitively indicate whether a more diversified sourcing strategy is more beneficial, it does suggest that such diversification may provide greater

elasticity during crisis situations. Nevertheless, on EU-27 scale, Russia continued to account for approximately one-quarter of nitrogen fertilizer imports from 2015 to 2025, making it the largest supplier, ahead of Egypt and Algeria in Figure 3.

Regarding price dynamics, multiple factors contributed to the elevation of nitrogen fertilizer prices. The COVID-19 pandemic generated logistical challenges, while the Russian invasion of Ukraine introduced sanctions, heightened risk premia, and further supply chain disruptions (Glauber & Laborde, 2023; Huan-Niemi et al., 2021; Jansik et al., 2021; Kaufmann et al., 2022). These shocks increased prices without producing proportional declines in volumes (Alexander et al., 2023). Additional contributors included stockpiling behaviour ahead of anticipated policy changes and market structures characterized by imperfect competition and trade defence measures, which limited price elasticity, as noted by Participant B.

Interviewees identified several structural vulnerabilities: highly concentrated import sourcing, insufficient storage capacity, and limited market transparency. Additionally, duties and anti-dumping regimes may have reduced competitive actions EU-based producers (The Central Union of Agricultural Producers and Forest Owners, 2026). Furthermore, CBAM introduced additional uncertainty, with partial implementation in 2026 and full implementation scheduled in 2027, complicating expectations for embedded carbon costs and pricing (Ministère de l'Agriculture, de l'Agro-alimentaire et de la Souveraineté alimentaire, 2025). According to participants B and C, non-transparent nitrogen fertilizer pricing exposes farmers to volatility and constrains strategic purchasing and storage decisions. This can place fertilizer producers in a monopoly-like position. Improved price transparency and clearer policy signals would not only alleviate financial pressures on farmers but also facilitate the transition toward increased use of organic and recycled fertilizers.

## **5.2 Strategies for more self-sufficient production and sustainable practices**

The EU's import dependence on a limited set of supplier countries is substantial and should be addressed by increasing domestic production within both Finland and the EU (European Commission, 2022). According to the interviewees, most promising options include developing Finland's own green ammonia production, enhancing biogas infrastructure, and improving waste management systems to recover nutrients

more efficiently from sludge and waste streams. Among these, green ammonia production warrants prioritization at least at the EU level. All options require significant financing, from both public and private sources.

As emphasized by all participants, cross-sectoral cooperation is essential for addressing fertilizer-related problems. Fertilizers cut across multiple policy and industrial domains, yet no single actor has clear ownership. Sustained dialogue that integrates perspectives across sectors is needed to ensure coherent decision-making. Closer coordination among the chemistry, energy and agriculture sectors is necessary to develop shared infrastructure and aligned incentives, supported by new collaborative networks.

Consistent with stable consumption levels, Participant B notes that current farming practices in Finland are already relatively efficient and further reductions in nitrogen use are difficult without risking yield and marketability (Santeramo & Jelliffe, 2024). Instead, investments in soil health can help to reduce nitrogen requirements over time. Improved liming, drainage, and longer land tenure can enable such investments. Furthermore, incorporating legumes and oilseeds into rotations can enhance biological nitrogen fixation, though this requires further market development to scale these crops. (Ahvo et al., 2023; Finnish Government, 2023; Ministry of Agriculture and Forestry, 2017; Nilsson et al., 2022; Vainio, 2022) In long-term, plant breeding targeting higher yields with lower nitrogen inputs could deliver additional reductions (Ministère de l'Agriculture, de l'Agro-alimentaire et de la Souveraineté alimentaire, 2025), pending regulatory progress.

While some crops fix nitrogen from the atmosphere, the effectiveness of recycled nutrient strategies depends on preventing nitrogen losses. Technological solutions that capture, concentrate, and convert waste-derived nitrogen back into usable fertilizers are needed to minimize volatilization and improve product uniformity (Ministry of Agriculture and Forestry, 2017). Standardization and contamination control are critical to building trust in organic and recycled alternatives and should be supported by clear regulatory frameworks and certification, as stated by participants A and C.

Geography poses an additional constraint: much of the biomass suitable for recycling originates from manure, and Finland's spatial separation of crop and livestock

production creates substantial logistics challenges (Vainio, 2022). Practical solutions include preprocessing and densification to lower transportation costs and leveraging existing mineral nitrogen fertilizer distribution systems where feasible. This will require cooperation with fertilizer producers and distributors.

Biogas plants are a promising candidate for integrating energy production with nutrient recovery. According to Participant A, their use is currently focused on energy production; investment incentives should be calibrated to steer operations towards nutrient recycling, including support for small and medium-sized facilities (Vainio, 2022). Clearer regulations can facilitate such investments and ensure consistent quality standards for recovered products.

Transitions to new technologies and practices entail upfront costs and potential short-term impacts on yields or quality, making targeted transitional support therefore warranted. Further research and development are needed in nutrient product specification, delivery technologies, and plant breeding to optimize performance under reduced mineral nitrogen inputs. In the long-run, organic and recycled nitrogen fertilizers are expected to substitute a larger share of mineral fertilizers. However, in the short term, mineral nitrogen fertilizers will remain necessary to ensure adequate levels of food safety while alternative systems scale.

### **5.3 Policy framework updates**

Before new investments in nitrogen fertilizer production can proceed, clear and stable policy foundations are to be set. Investors require predictable, long-term commitments to justify capital-intensive projects. Long-term policy in this context means decisions that are maintained across multiple political terms, thereby increasing credibility and allowing markets to adjust accordingly. At the EU level, binding rules for all member states would help ensure consistency and reduce policy fragmentation. Stronger horizontal leadership is also needed; particularly in CBAM, coordination between DG AGRI and DG TAXUD regarding the design and implementation. Additionally, outdated directives – especially those governing sewage sludge – should be updated to reflect advances in waste stream technologies, as highlighted by Participant A.

The EU's regulatory framework aims to accelerate the transition towards more sustainable fertilizer options (European Commission, 2020). However, markets responses have lagged, partly because current rules are insufficiently clear. CBAM was partially implemented while still under development, creating short-term uncertainty (Ministère de l'Agriculture, de l'Agro-alimentaire et de la Souveraineté alimentaire, 2025). In this environment, fertilizer producers have limited incentives to provide transparent pricing, and markets have experienced elevated price volatility (The Central Union of Agricultural Producers and Forest Owners, 2026). More effective coordination between DG TAXUD and DG AGRI is needed to ensure that CBAM operates as intended. Ideally, CBAM should enhance investments in green ammonia and other sustainable pathways; to date, design and implementation shortcomings have constrained this potential.

As emphasized throughout this thesis, policy reform is crucial to advance self-sufficiency in nitrogen production. Priorities include establishing EU-wide standards and labeling for organic and recycled nitrogen fertilizers to build user trust and updating the sewage sludge directive to accommodate newer recovery technologies. These steps would enhance the adoption of sustainable nitrogen fertilizer options. Also, to ensure the EU has an adequate amount of nitrogen fertilizers to use during crises, there needs to be strategic storage (The Central Union of Agricultural Producers and Forest Owners, 2026).

All these measures require long-term policy commitments that endure over multiple policy terms to build investor confidence. This includes sustained support for green ammonia and nutrient recovery at multiple scales, with dedicated provisions for small and medium-sized farms, for example through appropriately supported biogas plants.

## **5.4 Recommendations for Finland and the EU**

### **5.4.1 Finland's constraints**

Finland differs from most other EU member states in both location and consumption levels. As shown in Figures 1 and 7, Finland's fertilizer use is relatively low compared with larger agricultural producers (e.g., France, Spain) and several Eastern European

countries (e.g., Poland, Romania, Lithuania). Consequently, import volumes are smaller and the market is less attractive to global suppliers. Finland's northern location and Baltic Sea geography also add logistical complexity, increasing transport costs and limiting alignment with major trade routes.

#### 5.4.2 Recommendations for Finland

To reduce dependence on mineral nitrogen fertilizers, Finland should expand the use of legumes and oilseeds in crop rotations. This requires developing functioning markets to support wider adoption and considering strategic procurement measures to create stable demand signals, for example including domestic legumes and oilseeds in emergency stocks. Investments in soil health and farm planning – such as promoting longer hand-lease agreements to incentivize liming, drainage, and other structural improvements – would enhance nitrogen-use efficiency.

For recycled nitrogen fertilizers, updating sewage and sludge regulations in line with current treatment and nutrient-recovery technologies would increase safe recycling of nutrients from clean waste streams. Additionally, prioritizing closed-system handling to reduce nitrogen volatilization should be encouraged. Investment support should be directed to biogas plants, including those on small and medium-sized farms, to integrate nutrient capture alongside energy production.

Because organizing new nitrogen production facilities is time-consuming, the short-term priority is to diversify import sourcing. Reducing Finland's dependency on Russian nitrogen fertilizers and ammonia by expanding sourcing to established partners used elsewhere in the EU (e.g., Egypt, Algeria, the United States, Trinidad and Tobago) is a viable option. Regional alternatives such as Norway should also be explored where feasible, as Sweden has done since 2022 (Directorate-General for Agriculture and Rural Development, 2025c). Diversification mitigates crisis exposure even if Russian routes are logistically convenient (Clapp, 2017).

Establishing structured dialogue and joint planning between the Ministry of Agriculture and Forestry and the Ministry of Economic Affairs and Employment would align strategies across the agriculture, energy, and chemical sectors. This can reduce investment risks, support job creation and exports, and accelerate domestic

green ammonia and nitrogen recovery projects. Concurrently, The Ministry of Agriculture and Forestry should determine the location and governance of national short-term storage for nitrogen fertilizers, while coordinating with EU-level reserves as the primary protective mechanism.

#### 5.4.3 EU-level actions

EU-level strategic storage for nitrogen fertilizers should be centrally located to facilitate equitable access. As shown in Figure 8, Germany, France, and Poland are the largest nitrogen fertilizer producers in the EU, suggesting their suitability as potential hubs for such storage. Regarding consumption, Figures 2 and 6 indicate that some member states have greater potential to reduce nitrogen application without compromising yields or quality. Consumption and agronomic data should be used to identify these countries, with targeted training and advisory services to improve fertilizer management before pursuing marginal reductions in already efficient systems.

While member states should retain some level scope for national experimentation (e.g., pilots suited to local agroecology, as countries are so widely spread over different vegetation zones), clearer and more uniform EU regulations are needed to ensure consistent standard and practices. Involving farmers, including organic producers, in designing recycled fertilizer standards and deployment strategies will enhance practicality, uptake, and better stakeholder engagement.

### 5.5 Research limitations and future research

The quantitative data were mainly sourced from EU databases, as IFASTAT provided limited open-access coverage. Some inconsistencies were observed between EU and IFA data (Figure 1), and, depending on the timing of extraction, certain entries were missing from the EU database. For broader analyses of global trade flows, alternative sources such as Food and Agriculture Organization and the World Bank could be employed. On the qualitative side, a key limitation is the small interview sample, as only three participants were introduced, which raises the possibility for selection bias

and robustness of results. Lastly, generalizing findings from Finland to other EU member states may lead to false interpretations.

Conversely, the mixed-methods approach strengthens the study by integrating quantitative trends and qualitative insights (Arsel, 2017). The interviewees represented distinct organizational perspectives, broadening the analytical lens, and Finland acts as a revealing example of EU dependence in nitrogen fertilizer markets. Overall, both data strands indicate that the EU and Finland are vulnerable to shocks in nitrogen fertilizer trade. The EU, and especially Finland, remains dependent on Russian imports, and both quantitative and qualitative evidence point to continued exposure to price volatility.

Future research could incorporate fertilizer producer perspectives to illuminate supply-side dynamics. It would be valuable to assess the impacts of CBAM over the coming years on both producers and farmers. This could be done in addition to evaluating how concurrent policy changes, such as the new CAP, may influence investment behavior. Additionally, the same analysis could be done to phosphorus and potassium, as has been done here for nitrogen.

The transition towards utilization of organic and recycled nitrogen fertilizers will take time. Mineral fertilizers will remain necessary in the near term to ensure food security. Potential research avenues could include scenario analyses estimating the number and configuration of biogas plants required to materially increase Finland's self-sufficiency of nitrogen production, and adoption studies evaluating the extent and determinants of farmers' uptake of organic fertilizer alternatives.

## 6 Conclusions

The aim of this thesis was to examine how the EU, and especially Finland, can strengthen self-sufficiency in nitrogen fertilizer production and use without compromising yields or food security. By employing a mixed-methods approach, the study integrated quantitative data on consumption, trade flows, price dynamics and HHI analysis with qualitative insights from expert interviews from technological, farming, and governmental perspectives. Together, these data illuminate both the scale of the EU's and Finland's dependence on imported nitrogen and the practical pathways and policy conditions required to enhance resilience.

The quantitative data shows that Finland's nitrogen use has remained relatively stable over the past decade, while the consumption level in the EU in general has declined. Finland imports majority of its nitrogen fertilizer and ammonia from Russia, while some other EU member states are less dependent on Russian supply. Price data illuminates the impact of different shocks, such as the 2008 food crisis, COVID-19, and the Russian invasion of Ukraine, and show only partial normalization after 2019 (Alexander et al., 2023; Glauber & Laborde, 2023). Persistently elevated prices point to structural vulnerabilities in supply security that extend beyond short-term disruptions (Finnish Government, 2023) and the HHI analyses reveal the concentration of the trade markets.

These vulnerabilities are confirmed also by the interviews. Key risks include focused import sourcing, insufficient strategic storage, non-transparent nitrogen fertilizer pricing, and policy uncertainty. Trade remedies and phased, incomplete implementation of CBAM have resulted in inelastic markets and short-term volatility, while lack of coordination and horizontal leadership have weakened investing possibilities. Simultaneously, the interviewees highlighted alternative methods for enhancing self-sufficient nitrogen use and production by diversifying import sources, establishing strategic storage within the EU, developing domestic green ammonia capacity, and expanding technologies that recover and recycle nitrogen from existing waste streams. They also emphasized the potential of organic and recycled nitrogen fertilizers, provided that technological, logistical, and quality standardization challenges are addressed.

Overall, the findings indicate that it is possible to improve self-sufficiency in nitrogen fertilizer use and production in the EU and Finland without jeopardizing food security. In the short-term, mineral nitrogen fertilizers remain essential to meet yield and quality requirements, though there are research that organic farming methods can achieve same yield levels. However, approximately one third of Finland's agricultural production could be replaced with organic alternatives already (Vainio, 2022). Soil health investments, precision practices, and crop rotations that include legumes and oilseed, can further support this transition. Furthermore, adoption of new technologies to capture nitrogen from different waste streams would accelerate the progress towards more self-sufficient nitrogen fertilizer production (Ministry of Agriculture and Forestry, 2017). In the long-term, adoption of recycled nitrogen fertilizers and green ammonia can reduce import dependence and exposure to price shocks (Finnish Government, 2023; Vainio, 2022). To achieve this, more coordinated and stronger cross-sectoral cooperation among the agriculture, energy, and chemical industries is needed in addition to public and private investments.

To reach these targets, clearer and updated legislation and guidance is needed. Decisions must be valid for multiple political terms to reduce investment risk and build credibility. Therefore, policies play a central role. According to the interviewees, updating the sewage sludge directives is necessary to enhance new advances in nutrient recovery technologies. EU-wide standards and labelling for organic and recycled nitrogen fertilizers are needed to build trust and support farmer adoption. Developing strategic nitrogen fertilizer storage at the EU level, together with enhanced market transparency, would help to mitigate volatility and strengthen risk management (The Central Union of Agricultural Producers and Forest Owners, 2026).

Given the study's limitations, caution is advised in generalizing results beyond Finland. Nevertheless, quantitative and qualitative data agree on the main conclusions: the EU, and Finland in particular, use nitrogen relatively efficiently, while remaining structurally vulnerable due to uniform import sources and policy design. Stabilizing the system will require diversification of supply, strategic storage, clearer and long-term rules, and acceleration of recycled and green nitrogen adoption. With supportive policies, appropriate infrastructure, and technological advances, recycled nitrogen fertilizers and green ammonia can increasingly substitute

mineral fertilizers, reduce import dependency, and improve resilience without compromising yields or food security.

In summary for the recommendations, Finland can reduce its reliance on mineral nitrogen fertilizers through agronomic measures such as expanded legume and oilseed rotations and soil health investments, accelerated nutrient recovery supported by updated regulation and biogas plant incentives, and short-term diversification of import sources, while coordinating national storage with EU-level strategic reserves. At the EU scale, centrally located strategic storage, harmonized quality standards for recycled nitrogen fertilizers, and targeted capacity building in countries with greater reduction potential can improve resilience and sustainability. These actions, coupled with cross-sector coordination and durable policy frameworks, would strengthen self-sufficiency without compromising yields or food security.

## References

- Aakkula, J., Berlin, T., Irz, X., Jansik, C., Karhula, T., Kiviranta, H., Latukka, A., Mannio, J., Niskanen, O., Ovaska, S., Salo, T., & Suomi, J. (2019). Mahdollisuudet helpottaa epäorgaanisten lannoitteiden tuontia. *Maa- Ja Metsätalousministeriö*, 84. <http://urn.fi/URN:ISBN:978-952-453-893-0>
- Ahvo, A., Heino, M., Sandström, V., Chrisendo, D., Jalava, M., & Kummu, M. (2023). Agricultural input shocks affect crop yields more in the high-yielding areas of the world. *Nature Food*, 4(12), 1037–1046. <https://doi.org/10.1038/s43016-023-00873-z>
- Alexander, P., Arneth, A., Henry, R., Maire, J., Rabin, S., & Rounsevell, M. D. A. (2023). High energy and fertilizer prices are more damaging than food export curtailment from Ukraine and Russia for food prices, health and the environment. *Nature Food*, 4(1), 84–95. <https://doi.org/10.1038/s43016-022-00659-9>
- Arsel, Z. (2017). Asking Questions with Reflexive Focus: A Tutorial on Designing and Conducting Interviews. *Journal of Consumer Research*, 44(4), 939–948. <https://doi.org/10.1093/jcr/ucx096>
- Clapp, J. (2017). Food self-sufficiency: Making sense of it, and when it makes sense. *Food Policy*, 66, 88–96. <https://doi.org/10.1016/j.foodpol.2016.12.001>
- Directorate-General for Agriculture and Rural Development. (n.d.). *European Commission | Fertiliser trade*. Retrieved 18 January 2026, from <https://agridata.ec.europa.eu/extensions/DashboardFertiliser/FertiliserTrade.html#>
- Directorate-General for Agriculture and Rural Development. (2025a). *European Commission | Fertiliser prices*. <https://agridata.ec.europa.eu/extensions/DashboardFertiliser/FertiliserPrices.html#>
- Directorate-General for Agriculture and Rural Development. (2025b). *European Commission | Fertiliser production*. <https://agridata.ec.europa.eu/extensions/DashboardFertiliser/FertiliserProduction.html#>
- Directorate-General for Agriculture and Rural Development. (2025c). *European Commission | Fertiliser trade*.

- <https://agridata.ec.europa.eu/extensions/DashboardFertiliser/FertiliserTrade.html>
- Elser, J. J., Elser, T. J., Carpenter, S. R., & Brock, W. A. (2014a). Regime Shift in Fertilizer Commodities Indicates More Turbulence Ahead for Food Security. *PLOS ONE*, 9(5), e93998. <https://doi.org/10.1371/journal.pone.0093998>
- Elser, J. J., Elser, T. J., Carpenter, S. R., & Brock, W. A. (2014b). Regime Shift in Fertilizer Commodities Indicates More Turbulence Ahead for Food Security. *PLOS ONE*, 9(5), e93998. <https://doi.org/10.1371/journal.pone.0093998>
- European Commission. (2020). *Farm to Fork Strategy*. [https://food.ec.europa.eu/document/download/472acca8-7f7b-4171-98b0-ed76720d68d3\\_en?filename=f2f\\_action-plan\\_2020\\_strategy-info\\_en.pdf](https://food.ec.europa.eu/document/download/472acca8-7f7b-4171-98b0-ed76720d68d3_en?filename=f2f_action-plan_2020_strategy-info_en.pdf)
- European Commission. (2022). *Ensuring availability and affordability of fertilisers—European Commission*. [https://agriculture.ec.europa.eu/common-agricultural-policy/agri-food-supply-chain/ensuring-availability-and-affordability-fertilisers\\_en](https://agriculture.ec.europa.eu/common-agricultural-policy/agri-food-supply-chain/ensuring-availability-and-affordability-fertilisers_en)
- European Commission. (2023). *Approved 28 CAP Strategic plans (2023-2027)*. <https://agriculture.ec.europa.eu/system/files/2023-06/approved-28-cap-strategic-plans-2023-27.pdf>
- European Commission. (2024, April 23). *Ilmastonmuutoksen torjunta*. [https://agriculture.ec.europa.eu/sustainability/environmental-sustainability/climate-change\\_en](https://agriculture.ec.europa.eu/sustainability/environmental-sustainability/climate-change_en)
- European Commission. (2025). *Commission welcomes RENURE agreement in Nitrates Committee—Environment*. [https://environment.ec.europa.eu/news/commission-welcomes-renure-agreement-nitrates-committee-2025-09-19\\_en](https://environment.ec.europa.eu/news/commission-welcomes-renure-agreement-nitrates-committee-2025-09-19_en)
- European Commission. (n.d.a). *Soil and land—European Commission*. [https://environment.ec.europa.eu/topics/soil-and-land\\_en](https://environment.ec.europa.eu/topics/soil-and-land_en)
- European Commission. (n.d.b). *Tietoa tulotuesta—Euroopan komissio*. [https://agriculture.ec.europa.eu/common-agricultural-policy/income-support/income-support-explained\\_fi](https://agriculture.ec.europa.eu/common-agricultural-policy/income-support/income-support-explained_fi)
- Eurostat. (n.d.). *Glossary:Herfindahl Hirschman Index (HHI)*. Retrieved 25 April 2026, from [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Herfindahl\\_Hirschman\\_Index\\_\(HHI\)](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Herfindahl_Hirschman_Index_(HHI))

- Fertilizers Europe. (2022). *Fertilizer industry Facts & Figures 2022*.  
<https://www.fertilizerseurope.com/wp-content/uploads/2022/09/Industry-Facts-and-Figures-2022.pdf>
- Fertilizers Europe. (2023). *Fit for 55 Package: CBAM and ETS*.  
<https://www.fertilizerseurope.com/fitfor55-ets-cbam/>
- Finnish Government. (2023). *Maatalouden tulos- ja kehitysnäkymien parlamentaarisen arviointiryhmän loppuraportti* (p. 30). Maa- ja metsätalousministeriö. <https://urn.fi/URN:ISBN:978-952-383-526-9>
- Glauber, J., & Laborde, D. (2023). *The Russia-Ukraine conflict & global food security*.  
<https://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/136772/file/name/136984.pdf>
- Huan-Niemi, E., Knuuttila, M., Vatanen, E., & Niemi, J. (2021). Dependency of domestic food sectors on imported inputs with Finland as a case study. *Agricultural and Food Science*, 30(3), Article 3.  
<https://doi.org/10.23986/afsci.107580>
- International Fertilizer Association. (2025). *IFASTAT | Consumption*.  
<https://www.ifastat.org/databases/plant-nutrition>
- Jansik, C., Huuskonen, H., Karhapää, M., Keskitalo, M., Leppälä, J., Niemi, J., Niskanen, O., Perttilä, S., & Rinne, M. (2021). *Maatalouden tuotantopanosten saatavuuden riskit: Kriiseihin varautuminen ruokahuollon turvaamisessa*. Luonnonvarakeskus. <https://jukuri.luke.fi/handle/10024/547961>
- Kaufmann, L., Mayer, A., Matej, S., Kalt, G., Lauk, C., Theurl, M. C., & Erb, K.-H. (2022). Regional self-sufficiency: A multi-dimensional analysis relating agricultural production and consumption in the European Union. *Sustainable Production and Consumption*, 34, 12–25.  
<https://doi.org/10.1016/j.spc.2022.08.014>
- Lago-Oliveira, S., Rebolledo-Leiva, R., Garofalo, P., Moreira, M. T., & González-García, S. (2023). Environmental and economic benefits of wheat and chickpea crop rotation in the Mediterranean region of Apulia (Italy). *Science of The Total Environment*, 896, 165124.  
<https://doi.org/10.1016/j.scitotenv.2023.165124>
- Lehikoinen, E., Kinnunen, P., Piipponen, J., Heslin, A., Puma, M. J., & Kummu, M. (2021). Importance of trade dependencies for agricultural inputs: A case study

- of Finland. *Environmental Research Communications*, 3(6), 061003.  
<https://doi.org/10.1088/2515-7620/ac02d0>
- Ministère de l'Agriculture, de l'Agro-alimentaire et de la Souveraineté alimentaire. (2025). *The European Union's Carbon Border Adjustment Mechanism: Challenges and Prospects for the Agricultural Sector – Analysis n°207*.  
<https://agriculture.gouv.fr/european-unions-carbon-border-adjustment-mechanism-challenges-and-prospects-agricultural-sector>
- Ministry of Agriculture and Forestry. (n.d.-a). *Ravinnekierrätys ja bioenergia*. Maa- ja metsätalousministeriö. Retrieved 30 November 2025, from  
<https://mmm.fi/ravinteetkiertoon>
- Ministry of Agriculture and Forestry. (2017). *Ruoka 2030*.  
<https://mmm.fi/documents/1410837/1923148/Ruokapoliittinen+selonteko+Ruoka2030/d576b315-41fe-4e9d-9d02-8462c5ae5895/Ruokapoliittinen+selonteko+Ruoka2030.pdf?t=1486504109000>
- Ministry of Agriculture and Forestry. (n.d.b). *Maatalouden tukijärjestelmä*. Maa- ja metsätalousministeriö. <https://mmm.fi/maataloustuet>
- Ministry of Agriculture and Forestry. (n.d.c). *Maatalouspolitiikka*. Maa- ja metsätalousministeriö. <https://mmm.fi/ruoka-ja-maatalous/politiikka/maatalouspolitiikka>
- Ministry of Economic Affairs and Employment of Finland. (n.d.). *Hiilirajamekanismi*. Retrieved 18 January 2026, from  
<https://tem.fi/hiilirajamekanismi>
- Moshkin, E., Garmendia Lemus, S., Bamelis, L., & Buysse, J. (2023). Assessment of willingness-to-pay for bio-based fertilisers among farmers and agricultural advisors in the EU. *Journal of Cleaner Production*, 414, 137548.  
<https://doi.org/10.1016/j.jclepro.2023.137548>
- Nesme, T., Metson, G. S., & Bennett, E. M. (2018). Global phosphorus flows through agricultural trade. *Global Environmental Change*, 50, 133–141.  
<https://doi.org/10.1016/j.gloenvcha.2018.04.004>
- Nilsson, P., Bommarco, R., Hansson, H., Kuns, B., & Schaak, H. (2022). Farm performance and input self-sufficiency increases with functional crop diversity on Swedish farms. *Ecological Economics*, 198, 107465.  
<https://doi.org/10.1016/j.ecolecon.2022.107465>

- Pradhan, P., Fischer, G., Velthuisen, H. van, Reusser, D. E., & Kropp, J. P. (2015). Closing Yield Gaps: How Sustainable Can We Be? *PLOS ONE*, 10(6), e0129487. <https://doi.org/10.1371/journal.pone.0129487>
- Rice, B., & Vos. (2024, March 21). Who's afraid of high fertilizer prices? *IFPRI*. <https://www.ifpri.org/blog/whos-afraid-high-fertilizer-prices/>
- Rose, Pahlmann, I., & Kage, H. (2023). Modified crop rotations for a sustainable intensification? A case study in a high-yielding environment with recurrent nitrogen surplus. *European Journal of Agronomy*, 142. <https://doi.org/10.1016/j.eja.2022.126644>
- Santeramo, F. G., & Jelliffe, J. (2024). *CBAM and Agriculture: Opportunities, Challenges, and Perspectives*.
- Sitra. (2022). *Venäjän sodan seuraukset—Ratkaisuja aatalouden ravinteiden riittävyyden turvaamiseksi*. <https://www.sitra.fi/app/uploads/2022/05/asiantuntijaryhma-tyopaperi-27-05-2022.pdf>
- The Central Union of Agricultural Producers and Forest Owners. (2026). *Lannoitemarkkinat ja kauppatavat*.
- Vainio, E. (2022). *Maatalouden typpihaaste—Vaihtoehtoja ja ratkaisuja: Synteesiraportti*. Luonnonvarakeskus. <http://urn.fi/URN:ISBN:978-952-380-458-6>
- Zhang, J., Akyol, Ç., & Meers, E. (2023). Nutrient recovery and recycling from fishery waste and by-products. *Journal of Environmental Management*, 348, 119266. <https://doi.org/10.1016/j.jenvman.2023.119266>

## Appendix A: English-translated interview questions

### Common questions

1. During the last couple of decades, nitrogen fertilizer markets have faced several different crisis situations. Efforts have been made to answer these, e.g. by the EU by facilitating the import of nitrogen fertilizers (European Commission, 2022).
  - How have these recent shocks (nitrogen fertilizer price spikes, the Russian invasion of Ukraine, the pandemic) impacted on the vulnerability of the EU and Finland's nitrogen fertilizer system, and how can we be prepared for them in the future?
  - Which mechanisms could stabilize the price fluctuation of nitrogen fertilizers and ammonia in the EU market?
2. Recycling of nutrients has been one of the joint goals of the ministries (Ministry of the Environment, 2019), but according to fertilizer statistics maintained by the EU, Finland is highly dependent on nitrogen and ammonia imported from Russia.
  - What are the biggest obstacles in the introduction of organic fertilizers and in starting a more self-sufficient production of nitrogen fertilizers in Finland?
  - Who should be responsible for promoting these issues and which parties' cooperation would be particularly useful in moving things forward and why?

### Participant A:

3. The production of mineral nitrogen fertilizers is very energy-intensive, and the money of fertilizer purchases flows from Finland to Russia (Directorate-General for Agriculture and Rural Development, 2025). The EU emphasizes the diversification of fertilizer supply sources in overall and increasing recycled

fertilizers in agricultural use among its member countries (European Commission, 2022), but investing level seems to be low in Finland.

- Which technological innovations or process improvements are considered the most effective in saving energy and costs in the production of nitrogen fertilizers while simultaneously staying at the current yield level? Which solutions are closest to large-scale adoption, and which factors slow it down?
4. According to Aakkula et al. (2019), the nitrogen content of recycled cow manure remains relatively low. In the utilization of waste streams, possible harmful substances are often encountered and thus the question of their suitability for agricultural use (Ministry of Agriculture and Forestry, 2017). The use of recycled fertilizers must also pass the EU's strict screenings.
- Can recycled fertilizer products become competitive alternatives to synthetic nitrogen fertilizers without new policy measures?
  - If not, what kind of regulations, subsidies or control measures would be needed?

### **Participant B:**

3. The prices of nitrogen fertilizers have remained high for a longer period, and they are susceptible to price fluctuations. Statistically speaking, the share of all fertilizers in farm expenditure in Finland is quite small (4% of total expenditure in Finland in 2016, approximately 6-12% in the EU in general), but as a one-time purchase it seems large and may affect the farmer's willingness to buy. The price is thus one big factor at the time of their purchase (Aakkula et al., 2019).
- What kind of financing and business models could encourage farmers to introduce more cost-effective and self-sufficient nitrogen fertilizer production and technology?
  - For example, do you see opportunities for farmers in the Carbon Border Adjustment Mechanism (CBAM) to become more self-sufficient in

nitrogen fertilizer use and production, or could cooperatives be a part of reducing farmers' nitrogen fertilizer costs?

4. In recent years, the total amount of nitrogen fertilizers used by Finland has remained relatively stable, although this total amount is in a downward trend in the EU. The EU constantly intervenes in the use of nitrogen fertilizers and has set goals for its member countries to reduce the amount of nitrogen fertilizer used and increase the proportion of recycled fertilizer (European Commission, 2022).
  - How can Finnish farmers respond to this tightening regulation? Can Finnish farmers survive with even less mineral nitrogen fertilizers?
  - What actions should they take in their work to reduce external nitrogen fertilizers?
  - Can this be promoted, for example, with knowledge sharing and training?

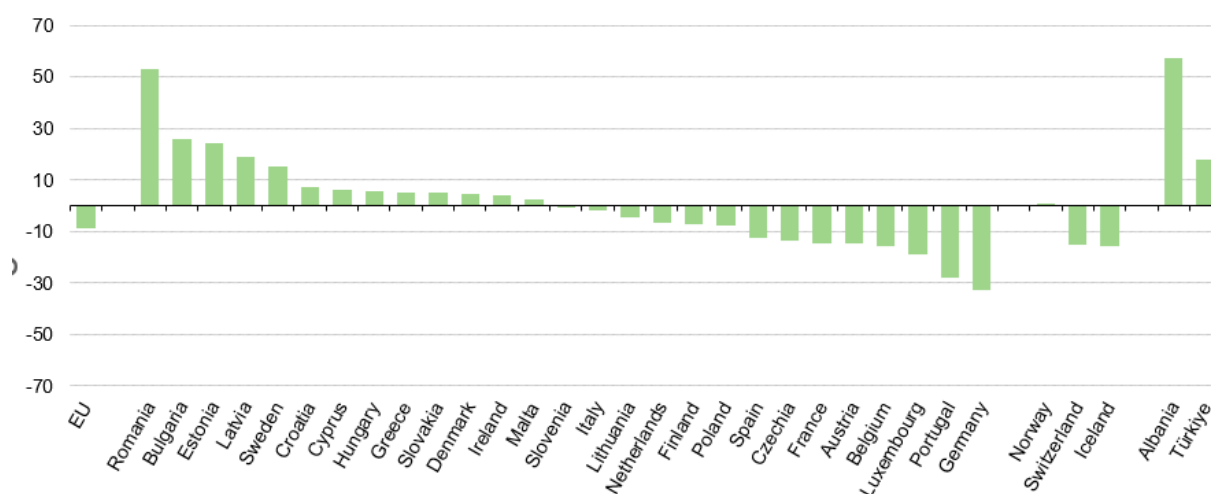
### **Participant C:**

3. As previously mentioned, according to statistics maintained by the EU, Finland relies on Russia largely for nitrogen fertilizers and ammonia supply. Additionally, the price fluctuations of nitrogen fertilizers have caused concerns for the farmers' finances (e.g. Aakkula et al., 2019; European Commission, 2022). CBAM is also likely to have a negative impact on farmers' incomes (Ministère de l'Agriculture, 2025).
  - How will the EU and Finland (together or separately) ensure comprehensive food security and the well-being of farmers in this situation?
  - What kind of investments, incentives or political actions are necessary to achieve a higher level of self-sufficiency in nitrogen fertilizer use and production in Finland?

- Should Finland ensure its own nitrogen fertilizer production or would more self-sufficient production within the EU be sufficient?
4. According to Aakkula et al. (2019), the demand for organic nutrients is not very high. In addition to this, they may contain various harmful substances, but the integration of organic fertilizers as part of fertilizer production is necessary to increase the percentage of nutrient recycling (Vainio, 2022).
- What measures should be taken to ensure that the organic nitrogen fertilizers on the market are a more competitive and attractive alternative compared to mineral fertilizers?
  - How does the EU regulatory body (CAP, Green Deal, RENURE, CBAM) affect the operating conditions of the Finnish nitrogen fertilizer industry?
  - Do they primarily bring additional costs or also opportunities for new markets and innovations?
  - Should the regulation come from the EU or from the national level?

## Appendix B: Supplementary figures and tables

### Overall change in nitrogen fertiliser consumption in agriculture (%, average for 2012–2014 compared with average for 2021–2023)



Note: Estimates for the period 2020–2023 made for the purposes of this publication

Source: Eurostat (online data code: aei\_fm\_usefert)

Figure 6. Overall change in nitrogen fertilizer consumption in agriculture. Source: Eurostat

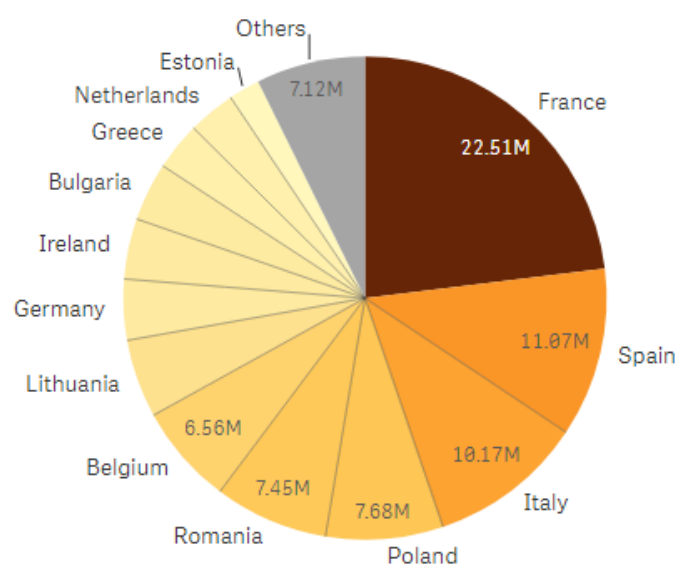


Figure 7. Used nitrogen consumption in tonnes on a country level, 2015–2025. Source: DG AGRI

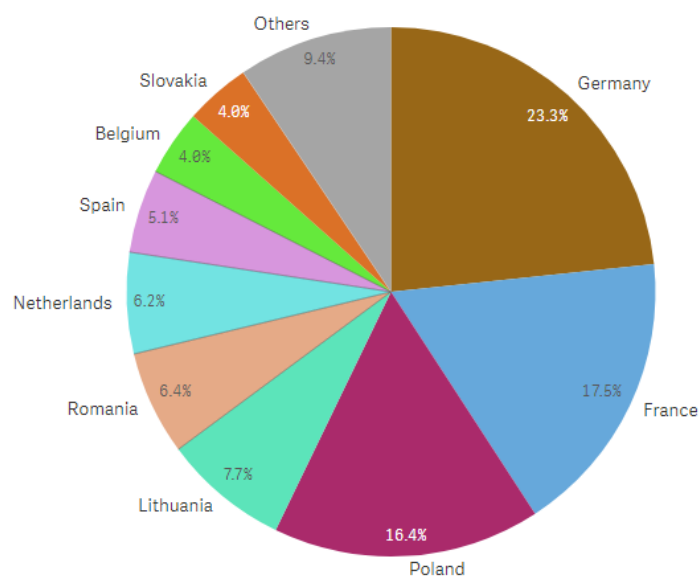


Figure 8. Nitrogen fertilizer production shares within EU member states, 2000–2024. Source: DG AGRI

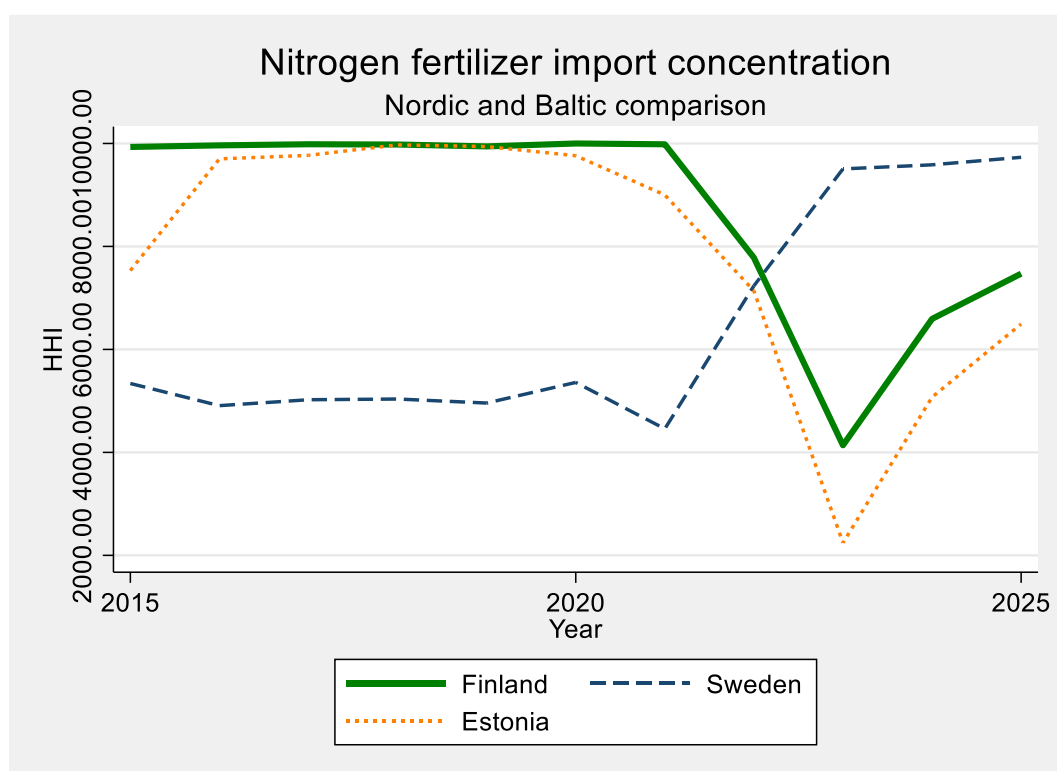


Figure 9. HHI comparison between Finland, Estonia, and Sweden in period 2015–2025. Source: DG AGRI/Stata

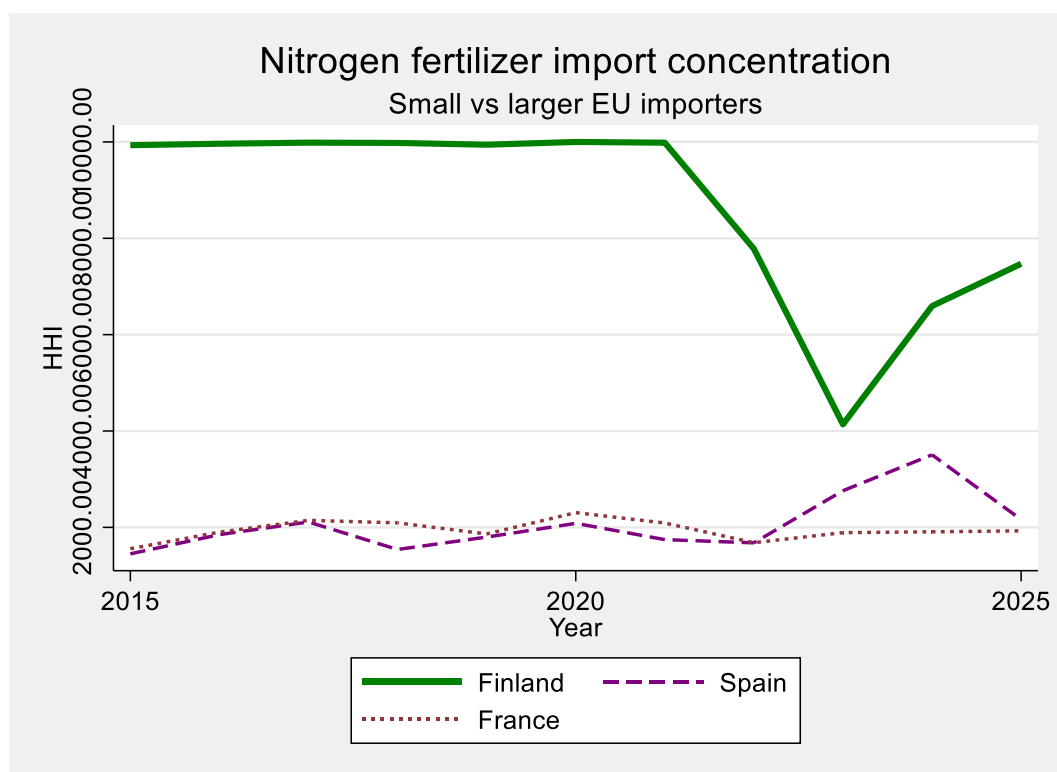


Figure 10. The HHI comparison between Finland, France, and Spain in period 2015–2025. Source: DG AGRI/Stata

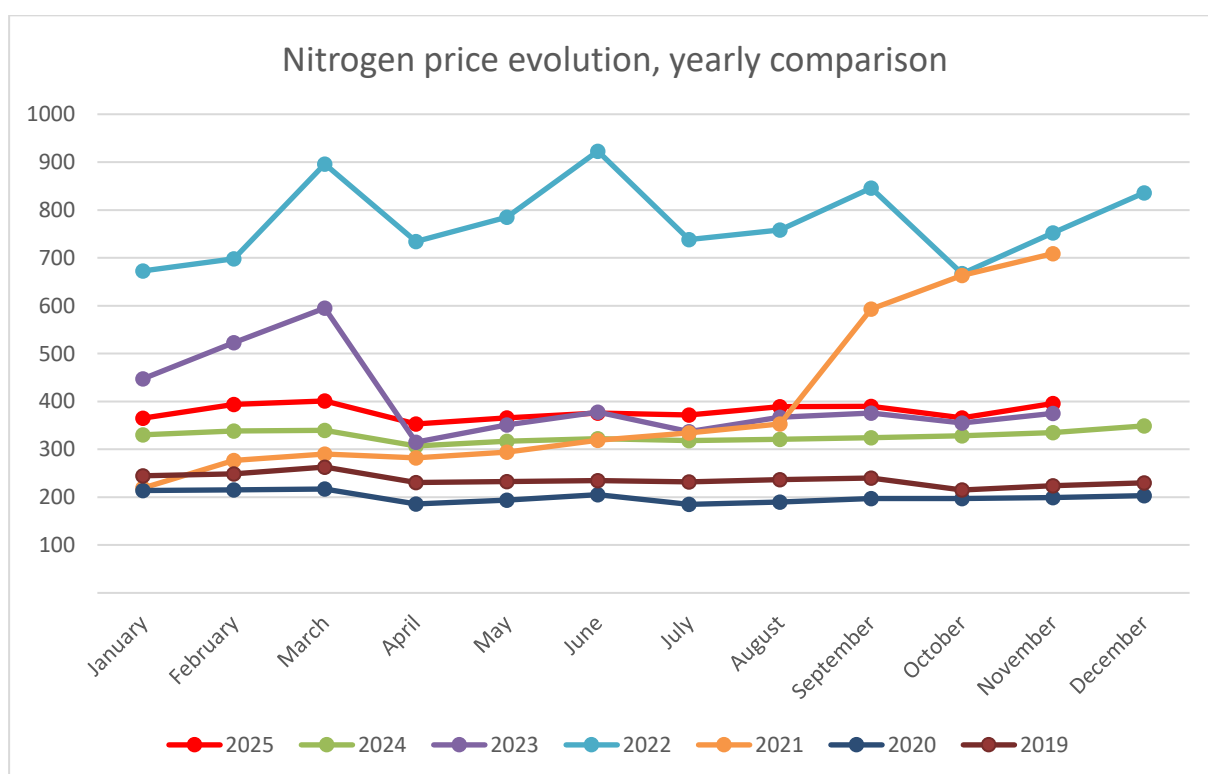


Figure 11. Nitrogen price comparison for EU between years 2019-2025. Source: DG AGRI

Table 2. The HHI table of Finland for period 2015–2025 of its nitrogen fertilizer importers. Source: DG AGRI

| Year | Partner country | Imports (tonnes) | Share    | Share^2  |
|------|-----------------|------------------|----------|----------|
| 2015 | Russia          | 72371            | 0,996626 | 0,993264 |
| 2015 | China           | 20               | 0,000275 | 0,000000 |
| 2015 | Norway          | 217              | 0,002988 | 0,000009 |
| 2015 | United Kingdom  | 8                | 0,000110 | 0,000000 |
| 2016 | Russia          | 75241            | 0,998156 | 0,996315 |
| 2016 | China           | 48               | 0,000637 | 0,000000 |
| 2016 | Norway          | 23               | 0,000305 | 0,000000 |
| 2016 | United Kingdom  | 68               | 0,000902 | 0,000001 |
| 2017 | Russia          | 81680            | 0,999266 | 0,998532 |
| 2017 | United Kingdom  | 60               | 0,000734 | 0,000001 |
| 2018 | Russia          | 79043            | 0,998951 | 0,997903 |
| 2018 | United Kingdom  | 83               | 0,001049 | 0,000001 |
| 2019 | Russia          | 86297            | 0,997157 | 0,994323 |
| 2019 | Norway          | 114              | 0,001317 | 0,000002 |
| 2019 | United Kingdom  | 107              | 0,001236 | 0,000002 |
| 2019 | Switzerland     | 25               | 0,000289 | 0,000000 |
| 2020 | Russia          | 94347            | 1,000000 | 1,000000 |
| 2021 | Russia          | 119333           | 0,999213 | 0,998426 |
| 2021 | Norway          | 24               | 0,000201 | 0,000000 |
| 2021 | United Kingdom  | 70               | 0,000586 | 0,000000 |
| 2022 | Russia          | 57867            | 0,876627 | 0,768474 |
| 2022 | China           | 1479             | 0,022405 | 0,000502 |
| 2022 | United Kingdom  | 10               | 0,000151 | 0,000000 |
| 2022 | Serbia          | 20               | 0,000303 | 0,000000 |
| 2022 | Egypt           | 6325             | 0,095817 | 0,009181 |
| 2022 | Turkey          | 310              | 0,004696 | 0,000022 |
| 2023 | Russia          | 13259            | 0,556493 | 0,309684 |
| 2023 | China           | 3948             | 0,165701 | 0,027457 |
| 2023 | United Kingdom  | 19               | 0,000797 | 0,000001 |
| 2023 | Egypt           | 6600             | 0,277008 | 0,076734 |
| 2024 | Russia          | 20368            | 0,785015 | 0,616249 |
| 2024 | Algeria         | 5382             | 0,207431 | 0,043028 |
| 2024 | United Kingdom  | 3                | 0,000116 | 0,000000 |
| 2024 | Egypt           | 193              | 0,007439 | 0,000055 |
| 2025 | Russia          | 16587            | 0,851751 | 0,725480 |
| 2025 | Algeria         | 2866             | 0,147171 | 0,021659 |
| 2025 | Belarus         | 21               | 0,001078 | 0,000001 |

Table 3. The HHI table of the EU-27 for period 2015–2025 of their most popular nitrogen fertilizer importers. Source: DG AGRI

| Year | Partner country     | Imports (tonnes) | Share    | Share^2  |
|------|---------------------|------------------|----------|----------|
| 2015 | Russia              | 2 378 684 788    | 0,440119 | 0,193705 |
| 2015 | Algeria             | 983 109 472      | 0,181901 | 0,033088 |
| 2015 | Belarus             | 712 681 274      | 0,131865 | 0,017388 |
| 2015 | United Kingdom      | 671 677 358      | 0,124278 | 0,015445 |
| 2015 | Egypt               | 655 703 995      | 0,121322 | 0,014719 |
| 2015 | Others              | 2780866,715      | 0,000515 | 0,000000 |
| 2016 | Russia              | 2 658 253 715    | 0,417018 | 0,173904 |
| 2016 | Egypt               | 1 653 226 399    | 0,259352 | 0,067264 |
| 2016 | Algeria             | 923 580 206      | 0,144888 | 0,020993 |
| 2016 | Ukraine             | 591 136 129      | 0,092735 | 0,008600 |
| 2016 | USA                 | 545 743 308      | 0,085614 | 0,007330 |
| 2016 | Others              | 2500745,718      | 0,000392 | 0,000000 |
| 2017 | Russia              | 2 569 465 034    | 0,395754 | 0,156621 |
| 2017 | Egypt               | 2 195 036 592    | 0,338084 | 0,114301 |
| 2017 | USA                 | 636 879 536      | 0,098093 | 0,009622 |
| 2017 | Algeria             | 636 321 976      | 0,098008 | 0,009605 |
| 2017 | Trinidad and Tobago | 452 992 634      | 0,069771 | 0,004868 |
| 2017 | Others              | 1886262,683      | 0,000291 | 0,000000 |
| 2018 | Russia              | 2 396 735 282    | 0,385988 | 0,148987 |
| 2018 | Egypt               | 1 623 477 481    | 0,261457 | 0,068360 |
| 2018 | USA                 | 909 686 364      | 0,146503 | 0,021463 |
| 2018 | Algeria             | 906 192 815      | 0,145940 | 0,021298 |
| 2018 | Trinidad and Tobago | 371 338 948      | 0,059803 | 0,003576 |
| 2018 | Others              | 1921785,09       | 0,000309 | 0,000000 |
| 2019 | Russia              | 2 251 995 368    | 0,407486 | 0,166045 |
| 2019 | Egypt               | 1 666 155 321    | 0,301481 | 0,090891 |
| 2019 | Algeria             | 655 543 847      | 0,118617 | 0,014070 |
| 2019 | Belarus             | 536 839 459      | 0,097138 | 0,009436 |
| 2019 | Trinidad and Tobago | 414 059 538      | 0,074922 | 0,005613 |
| 2019 | Others              | 1969117,641      | 0,000356 | 0,000000 |
| 2020 | Russia              | 1 612 484 316    | 0,472850 | 0,223587 |
| 2020 | Egypt               | 1587414,41       | 0,000465 | 0,000000 |
| 2020 | Algeria             | 729 862 825      | 0,214027 | 0,045808 |
| 2020 | Belarus             | 620 260 206      | 0,181887 | 0,033083 |
| 2020 | Ukraine             | 443 724 708      | 0,130119 | 0,016931 |
| 2020 | Others              | 2222944,229      | 0,000652 | 0,000000 |
| 2021 | Russia              | 1 980 271 468    | 0,369312 | 0,136391 |
| 2021 | Egypt               | 1 727 960 374    | 0,322257 | 0,103849 |
| 2021 | Algeria             | 962 729 788      | 0,179545 | 0,032236 |
| 2021 | Ukraine             | 688 837 295      | 0,128465 | 0,016503 |
| 2021 | Trinidad and Tobago | 396108,28        | 0,000074 | 0,000000 |

|             |                     |               |          |          |
|-------------|---------------------|---------------|----------|----------|
| <b>2021</b> | Others              | 1864954,225   | 0,000348 | 0,000000 |
| <b>2022</b> | Russia              | 2 475 294 412 | 0,317250 | 0,100647 |
| <b>2022</b> | Egypt               | 2 253 466 727 | 0,288819 | 0,083416 |
| <b>2022</b> | Algeria             | 1 323 266 643 | 0,169598 | 0,028764 |
| <b>2022</b> | USA                 | 1 061 598 692 | 0,136061 | 0,018513 |
| <b>2022</b> | Trinidad and Tobago | 685 133 088   | 0,087811 | 0,007711 |
| <b>2022</b> | Others              | 3592227,003   | 0,000460 | 0,000000 |
| <b>2023</b> | Russia              | 2 329 721 833 | 0,374134 | 0,139976 |
| <b>2023</b> | Egypt               | 2 259 474 124 | 0,362853 | 0,131662 |
| <b>2023</b> | Algeria             | 974 926 739   | 0,156565 | 0,024513 |
| <b>2023</b> | USA                 | 921784,23     | 0,000148 | 0,000000 |
| <b>2023</b> | China               | 659 223 273   | 0,105866 | 0,011208 |
| <b>2023</b> | Others              | 2708704,573   | 0,000435 | 0,000000 |
| <b>2024</b> | Egypt               | 2 684 311 605 | 0,373027 | 0,139149 |
| <b>2024</b> | Russia              | 2 548 909 814 | 0,354211 | 0,125465 |
| <b>2024</b> | Algeria             | 949 882 692   | 0,132001 | 0,017424 |
| <b>2024</b> | USA                 | 514 458 128   | 0,071492 | 0,005111 |
| <b>2024</b> | Trinidad and Tobago | 496 313 481   | 0,068970 | 0,004757 |
| <b>2024</b> | Others              | 2152748,201   | 0,000299 | 0,000000 |
| <b>2025</b> | Egypt               | 3 491 589 568 | 0,366120 | 0,134044 |
| <b>2025</b> | Russia              | 2 675 495 264 | 0,280546 | 0,078706 |
| <b>2025</b> | China               | 1 547 794 516 | 0,162298 | 0,026341 |
| <b>2025</b> | Algeria             | 1 173 693 789 | 0,123071 | 0,015146 |
| <b>2025</b> | Trinidad and Tobago | 645 472 819   | 0,067683 | 0,004581 |
| <b>2025</b> | Others              | 2683056,6     | 0,000281 | 0,000000 |

## **Appendix C: The use of AI**

In this thesis, the large language model (LLM) CurreChat, a tool aimed for the students and personnel in University of Helsinki, was utilized during the research process. For the writing, free version GPT-4o-mini was applied. The AI tool was employed to identify key themes from the anonymized interview material, but all content was verified and refined by the author, as it was not allowed to change the content of the text. Additionally, CurreChat was used to improve grammar, enhance the clarity and flow of the text, and generate ideas for section structure. All outputs produced by the AI were carefully reviewed, and the final written content is the author's original work. LLM was not used for the abstracts.