Report on the repercussions associated with traceability, labeling, and coexistence requirements for plants obtained by New Genomic Techniques

Justus Wesseler, Kutay Cingiz, Yan Jin, Maximilian Kardung, Margherita Simonetti

WAGENINGEN UNIVERSITY & RESEARCH

Executive Summary

The EU aims for climate neutrality by the year 2050. This requires reducing greenhouse gas emissions across several sectors, including agriculture. The farm-to-fork strategy is expected to contribute significantly toward climate neutrality in the agricultural sector. Studies on the impact of the farm-to-fork strategy have shown that this will be impossible without further substantial technical change in agriculture. New genomic techniques (NGTs) are among the technologies that can significantly contribute to reducing the climate footprint of European Union (EU) agriculture while also providing additional environmental benefits, including positive impacts on biodiversity.

Currently, plants developed using NGTs fall under the EU regulation for genetically modified organisms (GMOs). The European Commission (EC) has realized that this regulatory approach does not consider the differences between NGTs and the tools in plant breeding for which the GMO regulation was made. The regulation was deemed "not fit for purpose," based on the results of the EC study[1] and the EC has prepared a proposal for plants obtained by certain NGTs: targeted mutagenesis or cisgenesis.

The proposal identifies two categories of NGT plants, NGT1 and NGT2. For both categories, a simplified approval process has been suggested. Crops and products derived from NGT1 are proposed to be excluded from GMO labeling and traceability requirements, except for seeds. The proposal discussion at the European Parliament (EP) resulted in additional amendments, including the request for mandatory labeling and traceability of all NGT-derived crops.

This study analyses the economic effects of EU labeling and traceability policies and the application of coexistence measures for five crops with traits derived from NGTs: maize, oilseeds, wheat, potato, and tomato.

GMO labeling policies are meant to enable informed consumer choices. EU labeling policies require tracking and tracing of NGT-derived products for food throughout the supply chain. Animal products derived from NGT feeds do not need to be labeled and do not require tracking and tracing. Some products derived for non-food and non-feed purposes do not require labeling, tracking, or tracing.

Coexistence measures are meant to avoid the unintended presence of GMOs in conventional or organic products along the supply chain from crop cultivation through harvesting, transporting, storing, and processing. Coexistence measures include minimum distance requirements and additional measures such as information provision and record keeping.

GMO labeling and traceability policies and coexistence measures set the framework of analysis. The economic implications of labeling costs and coexistence measures require a reference scenario. This is called the baseline scenario in this study. The baseline scenario assumes that the adoption of NGTs follows a logistic adoption function and reaches an adoption ceiling of 40% after twenty years. This is a very conservative assumption about the time and scale of the spread of the technology for the five

1 https://food.ec.europa.eu/plants/genetically-modified-organisms/new-techniques-biotechnology/ec-study-new-genomic-techniques_en#:~:text=The%20study%20has%20confirmed%20that,to%20sustainability%2C%20while%20addressing%20concerns.

crops assessed compared to the experiences of adopting genetically modified crops in, e.g., Canada and the United States.

An economic displacement model (EDM) has been applied to assess the economic benefits of NGT application in the five crops. A conservative equivalent increase in yield of 10% has been applied to all crops. The baseline scenario has been modified to include the impact of coexistence measures, labeling and traceability costs, and a combination of the two. The results are compared with the baseline scenario. The differences compared to the baseline scenario indicate the additional costs. The results are summarized in Figure: Comparison of total surplus in each scenario for each crop.

The result of the baseline scenario shows an increase in total welfare in the EU of about 4 793 million Euros on average per year for maize, 1 139 million Euro for oilseed rape, 3 467 million Euro for wheat and 361 million Euro for potato and 337 million Euro for tomato, respectively.

Figure 1: Comparison of total surplus in each scenario for each crop.

Source: Authors' elaboration. Note: the light green color indicates the total surplus under the high labeling cost scenario, the green color indicates the total surplus under the medium labeling cost scenario, and the dark green color indicates the total surplus under the low labeling cost scenario.

These averages per year also allow the following interpretation: every year of delaying the introduction, not considering the effects of labeling policies and coexistence measures, costs the EU the amount mentioned, i.e., if they would be treated like non-GMO crops and would not need to receive approval as under the regulations for GMOs.

The baseline model has been adjusted to assess the implications of coexistence measures, labeling, and related segregation costs for identity preservation of crops and further-processed products that do not need to be labeled as GMOs. Society has to bear the costs of the consequent differences from the baseline scenario results. The identified costs only include the direct costs for participants in the supply chain. Environmental and health benefits associated with cultivating the five crops improved by NGTs are not included. Including these benefits would increase the benefits of the baseline results and the costs related to reduced and delayed adoption.

The analysis of coexistence measures shows that in some EU member states, coexistence measures are prohibitively high, preventing the cultivation of maize, oilseed rape, wheat, potato, and tomato derived by NGTs. Other EU member states have coexistence measures allowing cultivating some crops but not others.

Results show that coexistence measures reduce the size of cultivation possibilities for maize by 32%, oilseed rape by 58%, and wheat by 24%. In the case of potatoes, the cultivation possibilities are reduced by 36%, while for tomatoes, they are reduced by only 4%. Compared to a situation where coexistence measures would not reduce cultivation, the economic losses at the EU level are in the order of 1 523 million Euro on average per year for maize, 664 million Euro for oilseed rape, and 785 million euros for wheat. For potatoes and tomatoes, the average annual costs are 131 and 32 million Euros, respectively.

The assessment of labeling and traceability costs is more complicated. The current labeling and traceability regulations require a verified detection, identification, and quantification method. In most cases, analytical methods are unavailable to detect, identify, and quantify NGTs in plants and food and feed products. The proposal of the EC allows for alternative approaches. Several possibilities of what kind of alternatives could be used are discussed among stakeholders. The costs of these alternatives vary substantially. The costs for labeling and traceability have been assessed under three cost scenarios: high, low, and medium.

The additional labeling and traceability costs under a medium cost scenario would amount to about 2 404 million Euro on average per year for maize, 573 million Euro for oilseed rape, and 1 740 million Euro for wheat. For potatoes and tomatoes, the average annual costs are 180 and 169 million Euros, respectively.

Combining the costs for coexistence and labeling and traceability increases the costs to about 3 162 million Euro on average per year for maize, 902 million Euro for oilseed rape, 2 149 million Euro for wheat, 246 million Euro for potato, and 175 million Euro for tomato, respectively under the medium cost scenario.

Labeling and traceability costs are distributed throughout the supply chain. A more detailed economic displacement model has been developed that differentiates cultivation in the EU (farm level), processing, final consumption, and imports and exports. This differentiation allows for identifying the distribution of labeling and traceability costs. The distribution of the costs has been assessed by comparing the changes in surplus. The changes in surplus include the direct and indirect costs of labeling and traceability. These costs depend on the administrative burden and complexity of labeling and traceability requirements. The strongest effect is on traders, shippers, crushers, and manufacturers of non-genetically modified (GM) products. They bear about 80% or more of the labeling and traceability costs, followed by non-GM producers.

The results show that coexistence measures and the labeling and traceability requirements potentially impact agricultural innovation, including the uptake and availability of NGT products in the EU, compared to other world regions where these requirements do not apply. They act as a barrier to submitting proposals for approval for import and processing of NGTs. None of the NGT crops that have reached markets outside of the EU have been submitted for approval in the EU. Further, representatives of the companies involved have confirmed they do not envision submitting until the EU has implemented a less demanding approval system. This reduces the availability of NGTs for consumers in the EU. The coexistence measures limit the uptake of NGTs. This not only reduces options for farmers but also reduces consumer choice and negatively affects innovators currently investing in NGT products.

Acknowledgments

This report has been prepared for CropLife Europe. For the preparation of the report, we consulted with many individuals involved in trading and processing agricultural and food commodities and colleagues conducting research related to this topic. The report would not have been possible without the insights they have provided. We would also like to thank colleagues of CropLife Europe, who provided comments and suggestions on the outline and the intermediate report, as well as Marilene van Reenen and Mauritz Wesseler for their support in data processing.

The content of this report is the sole responsibility of the authors and may not reflect the views of CropLife Europe or of those we have consulted.

Suggested citation of the report: Wesseler, J., K. Cingiz, Y. Jin, M. Kardung, M. Simonetti (2024). Report on the repercussions associated with traceability, labeling, and coexistence requirements for plants obtained by New Genomic Techniques. Agricultural Economics and Rural Policy Group, Wageningen University, The Netherlands.

Wageningen, November 24, 2024

List of Tables

List of Figures

List of Abbreviations

CAP	Common Agriculture Policy
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CS	Consumer Surplus
CS_{co}	Consumer Surplus Coexistence Scenario
EC	European Commission
EFSA	European Food Safety Authority
EP	European Parliament
EU	European Union
GM	Genetically Modified as defined within EU law
GMO	Genetically Modified Organism as defined within EU law
IP	Identity Preservation
L_h	High-cost Labelling Scenario
L_l	Low-cost Labelling Scenario
L_m	Medium-cost Labelling Scenario
NGT	New Genomic Technique
PCR	Polymerase Chain Reaction
PS	Producer Surplus
PS_{co}	Producer Surplus Coexistence Scenario
SDN	Site-Directed Nuclease
TS	Total Surplus
TS_{co}	Total Surplus Coexistence Scenario

Table of Contents

1. Introduction

1.1. General Introduction

The regulation of new genomic techniques (NGTs) strongly impacts the private sector's incentives to invest in those technologies, which has further implications for the related welfare effects (Wesseler et al., 2017). Many scientists and organizations have indicated the importance of NGTs for addressing the challenges that agriculture and food systems face both in the near future and in the long run (e.g., FAO, 2022). In the European Union (EU), a debate about the regulations of NGTs has emerged. The European Commission (EC) has developed a proposal on including NGTs applied to plants in the current regulatory environment, and introduced two categories. Category NGT1 relates to small changes in the DNA of the targeted plant and has been proposed to be regulated similarly to conventional bred plants. This applies to plants where the changes could occur naturally or could have been obtained by traditional breeding methods. Category NGT2 relates to changes in all other same or crossable plants. The remaining third category includes plants not under categories 1 and 2. This includes plants developed using genetic material from non-crossable species.

A debate has emerged about whether plants and derived food products under the NGT1 category need to be labeled and if traceability and coexistence measures apply. Coexistence measures and labeling and traceability policies result in additional costs at the development, production, processing, and retail levels (Kalaitzandonakes et al., 2016). These additional costs may render the cultivation, import, and processing of NGT1 in the European market unviable.

This study assesses the welfare costs of applying coexistence measures and labeling and traceability policies to crops cultivated in the EU derived from category 1 NGTs. The reference scenario for the assessment is one where NGT1 crops are treated as crops developed by "traditional breeding" methods. The impacts of coexistence measures and labeling and traceability policies of NGT1s will be assessed crop-specific. For the assessment, five crops have been selected: maize, oilseed rape, potato, tomato, and wheat. They have been chosen for their importance in international trade, with also significant production in the EU (maize, oilseed rape, wheat) and their specific importance within the EU (potato and tomato). Further, these crops are affected by climate change, and improvements to these crops are relevant. Additionally, many NGT1-related improvements for these crops are ongoing. As the focus is on individual crops, partial equilibrium displacement models for each crop will be applied and calibrated on data for the EU.

The study is structured as follows: First, the international and EU policy environment for NGT1-derived crops and NGT1-derived crops under development are presented to set the stage. Section 2 introduces the generic partial equilibrium displacement model applied. The theoretical model (section 2.1) already allows us to draw some general conclusions about the potential effects of coexistence measures and labeling and traceability policies. The details of modeling coexistence measures (section 2.2.1) and labeling and traceability policies (section 2.2.2) are presented before a summary of the implications from a theoretical perspective.

Section three presents the results for the five crops under consideration. Special attention is given to the distribution of costs along the food supply chain. Section 4 summarizes the overall results. Section 5 concludes. The appendix includes the statistical database used to describe the EU markets for the five crops and their respective supply chains. A link is provided to the detailed implementation of the model and the modeling results.

1.2. Overall policy environment

New genomic techniques are regulated differently around the globe. In the EU, they are currently considered GMOs and are regulated as such. New Zealand follows a similar approach. In the US and Canada, regulation is more trait-specific, and NGTs are regulated accordingly; that is, the specific trait for a crop will be assessed and, depending on the trait, demands for approval concerning the information submitted differs. Argentina follows a similar approach, where data requirements for approval are identified depending on the trait in combination with the breeding technology. In Australia, distinctions are made between the outcomes of different applications of site-directed nucleases, whereby CRISPR-edited plants are classified as SDN-1 organisms (Hernández-Soto and Gatica-Arias, 2024).

As the approval for crops is done at the national level and at different points in time, asynchronous approval can be expected. This can result in disruptions in international trade. A crop might be approved for cultivation and processing in one country but not another. Export from the producing country to the importing country is not allowed in most cases, as non-approval also includes import bans. The implementation of an import ban requires enforcement. Border controls are needed to test a specific crop. This requires the availability of test protocols/identification methods. However, these identification methods are not always available. In a country where an NGT received approval, trait-specific identification methods might not be required.

As presented in Table 1, only a handful of products have been marketed as NGT-derived food products. That is why there is little empirical information on the market performance of NGT products. No NGT-derived plant products have been authorized for the EU market, either for import or cultivation, and they are classified as GMOs under the current EU GMO regulations. Still, as shown below, many traits are under development and are expected to enter the market sooner or later.

Table 1: Examples of NGT applications with the market release.

Crop	Country	Trait	Developer
Apple	Canada, US	Quality: non-browning	Okanagan Specialty Fruits
Banana	Philippines	Quality: lowering the browning process for prolonged shelf-life.	Tropic Biosciences
Lettuce	US	Non-browning romaine lettuce	Intrexon
Maize	Japan	Quality: Waxy corn, Corn with high starch content	Corteva Agriscience
Mustard Greens	US	Quality: adjusted flavor (less bitter)	Pairwise
Oilseed rape/Canola	Canada, US	Quantity: herbicide tolerance	Cibus
Potato	US	Quality: less prone to bruising and black spots increasing shelf-life	Simplot
Soybean	US	Quality: oil with approximately 80 % oleic acid content and 20 % less saturated fatty acids compared to commodity soybean oil	Calyxt
Soybean	China	Quality: high oleic acid content	Shandong BellaGen Biotechnology Co.
Tomato	Japan	Quality: high levels of gamma-aminobutyric acid (GABA), amino acid supposed to aid relaxation and to help lower blood pressure	Sanatech Seed
Wheat	China	Quantity: powdery mildew resistant wheat	Suzhou, Chinese Academy of Sciences

Sources: https://crispr-gene-editing-regs-tracker.geneticliteracyproject.org/colombia-crops-food/ and those available via the hyperlinks.

Labeling policies vary from country to country. Some countries require mandatory labeling, while others have voluntary labeling systems (see Table 2). In addition, the thresholds for the percentage of GM material that can be present in a product without requiring labeling also vary. Certain countries, such as Argentina, have no labeling requirements for GM products. The Argentine Secretariat of Agriculture states that food products that are substantially equivalent to a conventional food product should not be subject to specific mandatory labeling and that substantially different products may be labeled according to their food characteristics, not according to environmental or production process aspects (GAIN, 2022).

Table 2: NGT labeling policies.

Country	Labeling	Thresholds (%)
EU	Mandatory Seeds (?), currently mandatory	0.9 and 0.1
China	Mandatory	*
Australia/New Zealand	Mandatory & Voluntary	1.0
Japan	Mandatory & Voluntary	5.0
US	Voluntary	5.0
Canada	Voluntary	5.0

* no specific content requirement

Sources: European Union (2003); Food Compliance International (2020); Food Standards Australia New Zealand (2023); Government of Canada (Government of Canada, 2021); Thomson (2002); USDA (USDA, 2018).

1.3. EU Policy Environment

In the EU, NGTs, at this point in time, fall under the regulations governing the use of GMOs. This includes the Directive 2001/18 for release into the environment regulations for tracking, and tracing and labeling. Seed breeding companies can apply for cultivation and import and processing in the EU and for import and processing only. Approval for cultivation and import and processing takes substantially more time than approval for import and processing only. History has shown that receiving approval for cultivation in the EU is almost impossible. At this point in time, only one GMO has been approved for cultivation: The maize event MON810. Many events have received approval for import and processing. To obtain approval for cultivation and/or import and processing, applicants must submit an application for risk assessment to a national competent authority in one of the EU member states. The national competent authority assesses the applications and forwards them to the European Food Safety Authority (EFSA) for further assessment. EFSA prepares a risk assessment that is submitted to the European Commission (EC). Based on the risk assessment, the EC prepares a recommendation to be voted for by Member States in the responsible standing committee, which is decided by a qualified majority. Suppose the vote in the standing committee does not result in a qualified majority either in favor or against the EC recommendation. In that case, the EC can either update the recommendation and resubmit for a vote or forward the recommendation to the appeal committee, which also votes on the recommendation by a qualified majority. If no qualified majority has been reached, the EC decides. The history of submissions to the standing committee and the appeal committee shows that no qualified majority in favor or against the proposed recommendation of the EC has been reached. History also shows that the EC has always approved applications. This is unsurprising as it is hard to expect the EC to decide against its own proposal, which is based on the assessment of its own scientific body, EFSA. It is also not surprising that the decisions are in favor of approval. The application process is costly and time-consuming for the applicant. If, at the EFSA level already, concerns are expressed, which may result in a negative risk assessment, applicants withdraw their application. Often, even before applications are submitted, applicants have an idea about the success of their submission.

The approval process for release into the environment and/or for import and processing is costly and time-consuming (Kalaitzandonakes et al., 2007; Smart et al., 2015, 2017). Many stakeholders have expressed concerns about using NGTs and the costly approval process, particularly questioning arguments concerning the risks of NGTS to the environment. The EC has been asked by member states to assess the situation and provide a proposal for revising the approval process for NGTs. A proposal has been prepared and discussed at the European Parliament. Several amendments have been suggested by the EP and forwarded to the Council of the EU. A number of recommendations are noteworthy. First, the proposal recommends a differentiation between two categories of NGTs. NGT1s are GMOs where only small changes in the genome are made and are regulated as conventional plants, and the second category, NGT2, includes those where larger changes have been made. These categories should be regulated differently than under the current regulations for GMOs. In particular, the proposed regulation for NGT1s is of interest as they are currently widely used in plant breeding. The proposal foresees that those events are exempted from the current GMO regulation and are treated similarly to crops developed by what is legally called "conventional breeding" methods. They would not undergo a risk assessment by EFSA as the risks are considered similar to those crops developed by "conventional breeding" methods. Still, a verification request has to be submitted to a national authority. Seeds produced with NGT1s would be labeled, and the EP added labeling requests throughout the supply chain. They would be excluded from use in organic agriculture. What was not explicitly mentioned in the Commission proposal is that member states can apply coexistence measures for NGT1 crops. Labeling of NGT1s along the whole supply chain will incur additional costs for parties involved in handling and processing labeled products. These additional costs may reduce the market for the specific products or even render their introduction too costly.

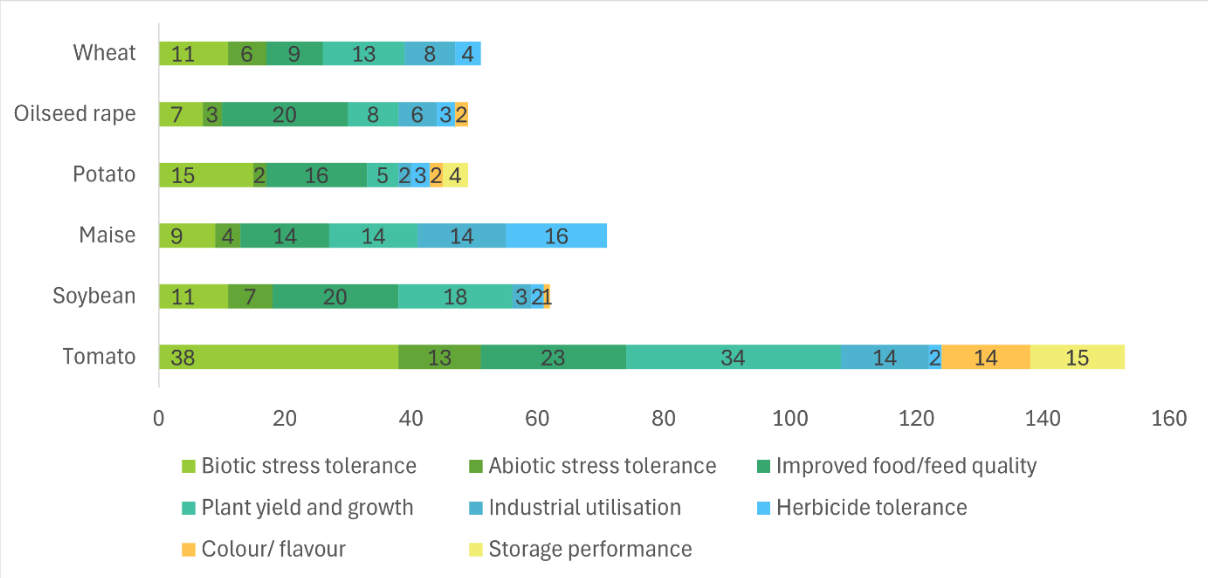
1.4. NGTs under Development

A number of crops derived from NGTs are under development. The European Sustainable Agriculture Through Genome Editing database (EU Sage Database) collects information about genome editing applications in agriculture. They include in total 911 entries, with 881 classified as SDN1, similar to the NGT1 category in the EU proposal, 24 classified as SDN2, and six as SDN3 as of September 22. Among those are 139 applications for tomato, 63 for maize and wheat, and 39 for potato and oilseed rape. China is the leading country with 552 entries, followed by the United States with 181 entries. The EU member states have in total 131 entries (not counting three double entries), with entries by France and Germany at 31, Italy at 19, The Netherlands at 14, Belgium at 12, Spain at 10, Sweden 6, the Czech Republic 5, Hungary 3, Denmark, Poland, Portugal each 2, and Austria and Greece each 1. The number of entries, counting those with more than one EU partner, is 116 for the EU.

Figures 2 and 3 provide a more detailed overview of the research on NGTs in plants by EU member state, crop, and trait.

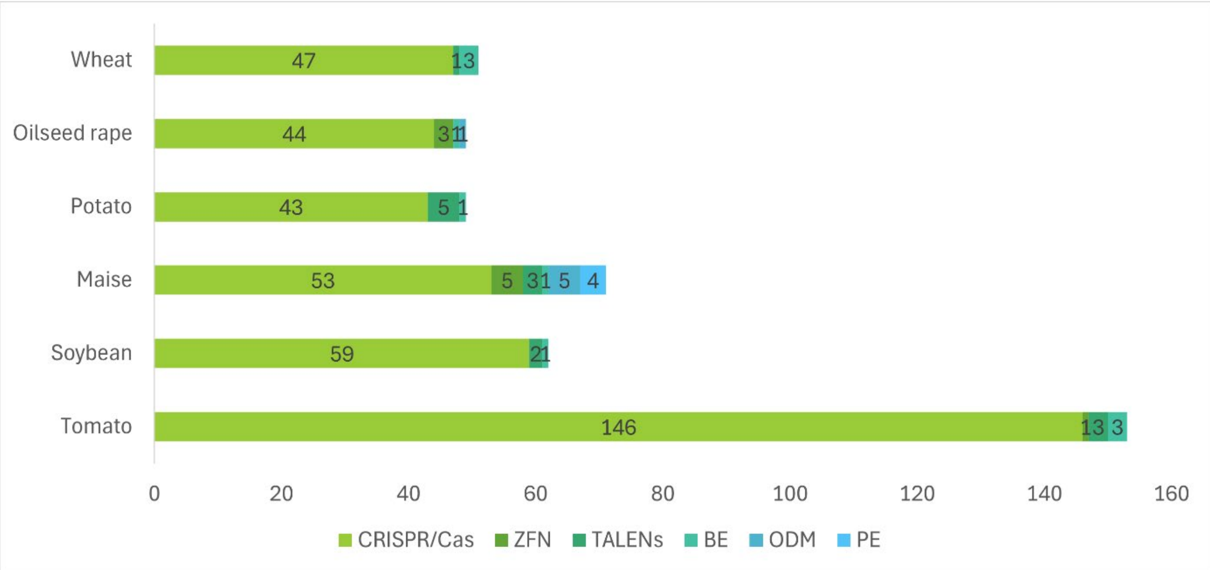
As Figures 2 and 3 show, most of the traits under development have a yield-increasing effect per unit area, such as those addressing damages due to biotic (pests and diseases) and abiotic (drought tolerance) stress.

Figure 2: Traits introduced using NGTs per crop.



Source: Elaborated from the [EU Sage Database.](#)

Figure 3: NGT technique used per crop.



Source: Elaborated from the [EU Sage Database.](#)

2. Methodological Approach

As the focus is on crops, as mentioned above, partial equilibrium displacement models (EDM) for each of the crops will be applied and calibrated on data for the EU. Partial equilibrium displacement models are widely recommended in the literature for such kinds of assessments (see, e.g., Alston et al., 1998). They are widely applied when the specificities of the crop are of relevance. This also simplifies the analysis as remaining markets for competing products and countries are captured by the supply and demand elasticities applied. We explain the EDM model in subsection 2.2.2.

More emphasis has been placed on describing the supply chains and the adoption of the technology over time, as this has a stronger effect on the results than adding additional details on the market structure. This does not imply that modeling market structures is not relevant, but it is less so in this study's context.

2.1. Generic Model

We apply a simplified welfare economic framework for the EU to regulate the approval of NGT-derived crops. It is a dynamic framework that considers the effects an introduction will have on consumers' and producers' surplus, the uncertain external social costs as perceived by the EU, and the implications for the environment. The external social costs cover responses the EU decision-makers care about. The statements by EU member states reflect these concerns. Austria has pointed out the problems the introduction of NGTs may cause for its agriculture sector if it loses its status as a GMO-free country. Other EU member states are concerned about the implications for the farm sector. NGOs have also expressed concerns about GMO-free Europe. Environmental groups, together with some farmer organizations in France, have also been very vocal against the introduction of NGTs. An experimental field trial in Italy has recently been destroyed. Many societal groups, e.g., have declared their intention to protest against the introduction of NGT crops and warn about the negative implications for international trade and long-term implications for agriculture sustainability (Bennett et al., 2013; Paarlberg, 2009; Qaim, 2016).

More formally, we denote the introduction of an NGT crop as a change in approval policy $F(t)$, $\Delta F(t)$, from the current approval policy, F_0, to a new approval policy, F_1. At time t=0, the government's view is that the perceived costs, G_{c_0}, of introducing the NGT crop exist and are high, $G_{c_0} \gg 0$, while other benefits and costs discussed in more detail below are assumed to be known. Hence, all remaining uncertainty is captured under perceived costs. Over time, further information about the perceived costs arrives and at the time, T, either the strategy will be successful and perceived costs be small, $\underline{G_c}$, with probability, (1-q), or confirmed to be high, $\overline{G_c}$, with probability, q. Hence, the introduction of NGT crops mainly depends on the perceived costs. Based on this, the national government may decide whether the strategy will be introduced immediately (T=0) or postponed (T>0), with T as the optimal time to introduce the NGT crop.

Considering these uncertainties, the objective of the decision-maker can be described as follows:

$$(1) \qquad \max_T E_o \ \sum_{t=o}^{\infty}(\Delta CS_t, \Delta PS_t, \Delta Env_t, G_c),$$

with E_0 the expectation operator, ΔCS_t the change in consumer surplus, ΔPS_t the change in producer surplus, $\Delta\ Env_t$ the change in environmental and health impact, G_c defined as follows with a symmetric rise or fall indicating that decision-makers a priori are not biased towards benefits nor costs., i.e., the future can either be good or bad:

$$(2) \qquad E[G_c] = \begin{cases} \overline{G_c} = (1+d)G_{c_0},\ with\ probability\ q = 0.5 \\ \underline{G_c} = (1-d)G_{c_0},\ with\ probability\ (1-q) = 0.5 \end{cases}$$

and the current value of $G_{c_0} \triangleq \left(0.5(1+d)G_{c_0} + 0.5(1-d)G_{c_0}\right)$.

The annual change in producer and consumer surplus can be derived from a partial equilibrium model. If we assume linear supply and demand functions, we get (e.g., Alston et al., 1995):

$$(3) \qquad \Delta CS = \sum_{t=0}^{\infty}\left(P_T Q_T Z_t(1 + 0.5 Z_t \eta)\right) q^{-t},$$

(4) $\Delta PS = \sum_{t=0}^{\infty}\left(P_T Q_T (K_t - Z_t)(1 + 0.5Z_t\eta)\right) q^{-t}$,

where $Z_t = K_t\varepsilon/(\varepsilon + h)$, $K_t = \left[\frac{\Delta y}{\varepsilon}\right] a_t$, ε the supply elasticity, η the absolute value of the own-price elasticity of demand, *P* the product price and *Q* the product quantity at time *T* of the introduction of food policy F_1, Δy the percent yield increase of the NGT crop, and a_t the adoption rate in year *t, q=(1+r),* with *r* being the discount rate. Both ΔCS and ΔPS can be converted into average annual surpluses by multiplying both by *r* and will be denoted by CS_a and PS_a respectively. Not all NGT-derived events are necessarily yield-increasing, such as quality-enhancing events. They are converted into the equivalent yield-increasing effect.

The model describes the potential increase in producer and consumer surplus, assuming an instantaneous adoption of 100% among all producers at equilibrium. This does not consider that adoption progresses over time and that not all producers may adopt the new technology. The GABA tomato or a powdery mildew-resistant wheat trait may not be used by all producers for a number of reasons. This will be considered by adjusting the K-factor. The initial yield increase Δy will be reduced by calculating the equivalent yield increase as a result of the adoption over time and the adoption ceiling. The change in quantity over time will change the supply and demand elasticity at each point in time. The elasticities are adjusted accordingly using the new equilibrium price and quantity.

In this model, the producer surplus captures the benefits of farmers and the upstream sector, such as seed suppliers and others. The consumer surplus includes the downstream sector, which includes grain handlers, processors, retailers, and final consumers.

In this study, we are particularly interested in how labeling policies and coexistence measures may affect the producer and consumer surplus. The effects of these policies are assessed in parts and then added together. Implications for the environment are not quantified but are discussed qualitatively as they are very diverse depending on the specific event under consideration.

2.2. Specific Model

In the following section, we first introduce the specific model capturing the impacts of coexistence measures on the producer surplus. Coexistence policies have an impact on the adoption at the farm level (Beckmann et al., 2006) as they affect the decision of an individual farmer to adopt an NGT-derived crop. As this is a decision under uncertainty and flexibility, farmers can either immediately adopt an NGT crop or postpone the decision to a later point. As we will show below, coexistence policies increase the incentive to adopt an NGT crop at a later point in time, that is, delaying adoption.

2.2.1. Modelling Coexistence

Many EU member states have coexistence measures governing the cultivation of GM and non-GM crops in their country. Coexistence measures ask GM farmers to comply with a number of ex-ante measures before being allowed to sow a GM crop on their farm. They also include a number of ex-post liabilities after the GM crop has been sown in case cross-pollination with crops cultivated on neighboring farms happens and the neighboring farm wants to maintain a GM-free status. This is particularly relevant for farms cultivating crops according to organic standards in the EU (Beckmann et al., 2006) and farms that produce under a GM-free label (Venus et al., 2018). Those farms may observe economic losses if the crops they cultivate are not considered GMO-free anymore. (Venus et al., 2018). Table 3 provides an overview of the coexistence policies present in EU member states.

Table 3: Ex-ante regulations and ex-post liability rules governing coexistence among European Union Member States.

Policy	**EU Member States apply and intend to apply**
ex-ante regulations	
Prohibition and approval procedures	
prohibition of planting GM-crops in specific areas	AT, DE, HU, LU, PT, SK
case by case approval for each field by local authorities	AT*, HU, IE, SK
compulsory training of farmers planting GM-crops to be paid by the GM farmer	DK, HU, SK
consent from landowner needed	AT, BE, HU, LU, SK
consent from neighbours needed	AT, BE, HU, LU, SK
Registration and information duties	
registration of areas in publicly available database	AT*, DE, DK, GR, LV, LT, SK
registration of areas in publicly available database, restricted access	AT*, PT, EE, FI, FR, HU, NL, PL
informing neighbouring farmers and landowners	DK, AT, HU, NL, PL, SK
record keeping	DE, DK, PT, CZ, ES, HU, IT, NL, PL
Technical segregation measures	
minimum distance requirements	AT, BG, CZ, DE, DK, EE, FR, HU, NL, PL, RO, SK
buffer zones	AT, CZ, EE, FR, PL, SK
rotation intervals	GR, LT, SE
Biotech free zones	BE
Insurance measures	
compensation fund paid by GM-farmers (levy on GM crops) plus support from the central government	DK
compensation fund paid by private stakeholders	PT, IE, FR, NL
liability fund	BE
private insurance against damages	AT*, LU
ex-post liability rules	
Legal liability for damages	
liability based on civil law	CZ, EE, HU, SK
fault based liability	AT*, DK, FR, NL
strict liability for GM-farmers	AT*, DE, IE, PL
joint and several liability	DE
Proving damage	
burden of proof lies with GM farmer	AT, DE, FR, IT
burden of proof lies with non-GM farmer	IE
Penalties	
fines for non-compliance with ex-ante regulations	AT, CZ, EE, FR, IT, LV, LT, LU, PL, PT, SK

Source: European Commission (2006a)*, several GAIN reports* (2023a, 2023b)*, and additional national documents. Adapted from Beckmann et al.* (2006).
Countries are indicated by their two-digit ISO code: AT-Austria, AT- specific regions of Austria only, BE-Belgium, BG-Bulgaria, HR-Croatia, CY-Cyprus, CZ-Czech Republic, DE-Germany, DK-Denmark, EE-Estonia, ES-Spain, FI-Finland, FR-France, GR-Greece, HU-Hungary, IE-Ireland, IT-Italy, LT-Lithuania, LU-Luxemburg, LV-Latvia, MT-Malta, NL-The Netherlands, PL-Poland, PT-Portugal, SE-Sweden, RO-Romania, SI-Slovenia, SK-Slovak Republic.*

The model to assess the economic impact of coexistence policies has been derived from Beckmann et al. (2006). The objective function of a farmer is to maximize their expected income from cultivating an NGT crop, considering the uncertainty related to the incremental net income from NGT crop cultivation and the coexistence policies. The incremental net income refers to the alternative non-NGT crop, illustrated by the delta in the equation (5) below, but also depends on the ex-ante measures r_i, the liability, abbreviated with tl_i, and the irreversible costs related to the adoption of the NGT crop.

$$(5) \qquad F\left(\Delta \widetilde{vc}_{G_i}^{\ell}\right) = max\, E\left[\left(\sum_T^{\infty} \Delta \widetilde{vc}_{G_i}^{\ell}\ (v_{G_i}, v_{N_i}, r_i, tl_i) e^{-\rho(t-T)} - IR_i^{\ell}\right)(1+\rho)^{-T}\right]$$

where ℓ stands for mandatory labeling for NGT products, i for farmer, G for MGT crop, N for non-NGT crop, G_i for NGT farmer i, ρ for discount rate, T for the time entering NGT crop cultivation.

One of the most common coexistence policies, the minimum distance requirement to neighboring fields, is a crucial aspect of our research. This distance varies by crop and is a key factor in understanding the implications of coexistence policies for GM crop cultivation in the EU. For some crops, such as maize, they range from a few meters, such as 25 meters in the Netherlands, to 600 meters such as in Luxembourg. Some member states require a larger distance to organic crops. While minimum distance requirements have not been defined for all the five crops covered in this study, it is reasonable to expect that EU member states will define those if crops become available for cultivation. Minimum distance requirements that EU member states have reported are summarized in Table 4.

Table 4: Minimum distance requirements for selected crops in meters.

Country	Maize	Oilseed rape	Sugar beet	Potato
Bulgaria	(4000-30000)			
Czech Republic	70 (200)			3-10 (20)
Denmark	150 (150)		20 (20)	10 (10)
Germany	150 (300)			
Hungary	400 (400)			20-40 (30-60)
Ireland	50 (75)			
Latvia	200	4000	200	50
Lithuania	200	4000	50	20
Luxemburg	600		100	50
Netherlands	25 (250)		1.5 (3.0)	3 (10)
Portugal	200 (300)			
Romania	200			
Slovakia	200 (300)			
Sweden	50		3	

Note: Numbers in brackets refer to distances to organic crops. Sources: based on country reports summarized at https://food.ec.europa.eu/plants/genetically-modified-organisms/reports-and-studies_en and USDA GAIN country reports. The minimum distance requirement for Bulgaria has been placed into brackets as this is only a proposal.

The minimum distance requirements not only directly affect the farm size necessary for adopting NGTs but also generate spillover effects on neighboring farms (Demont et al., 2009; Groeneveld et al., 2013). In the literature, this has been called the "domino effect" (Demont et al., 2008).

In addition to minimum distance requirements, several EU member states require reporting and information (see Table 3). This includes registrations in databases, some of which are publicly available, informing neighboring farmers about the intention to grow a GM crop, receiving consent from landowners, and more.

Depending on the specific measure, they can increase either ex-ante variable costs at the farm level, e.g., informing neighboring farms, the sunk costs related to cultivation, e.g., mandatory training if a farmer intends to grow an NGT crop, or ex-post, after cultivation, costs, such as penalties for not complying with ex-ante measures. These measures have an effect on the adoption of NGTs at the farm level as well as neighboring farmers, in addition to the domino effect (Beckmann et al., 2011) and the economic value of coexistence.

The coexistence measures may provide incentives for farmers to build clubs (Furtan et al., 2007; Punt & Wesseler, 2018) or relative advantages for existing clubs, such as cooperatives, in comparison to individual farmers to reduce the farm-level costs of coexistence measures (Skevas et al., 2010).

2.2.2. Modelling Labelling and Traceability

Assessing the cost implications of labeling and traceability is not a trivial exercise. The purpose of labeling is relevant for the economic implications.

Mandatory food labeling in the EU, in general, provides health-related information for consumers. They include nutritional information and information about relevant ingredients for consumers who are sensitive to those ingredients. Examples include peanut contents relevant to consumers allergic to peanuts. Voluntary labels highlight product characteristics that address consumers with preferences that are not necessarily health-related. Examples include organic, animal welfare, GMO-free, or sustainability labels. Some of these labels are discussed to become mandatory. Voluntary health-related labels are also available, such as lactose-free products for consumers with lactose intolerance.

There is a clear distinction between mandatory and voluntary labels regarding who bears the costs. In the case of mandatory labels, the product provider must provide the information, bear the relevant costs, and apply it to all relevant products on the market. In contrast, with voluntary labels, product providers can provide the information and produce the product according to voluntary labeling standards, depending on their preferences and cost considerations.

The costs and welfare effects of labeling NGTs depend on the labeling policy. NGT labeling is not a health-related label. Products using NGTs that enter the market have been assessed for their health safety prior to entering the market. Mandatory NGT labeling differentiates from health-related labeling. One concern with mandatory NGT labeling is that consumers may link them with health-related labels. Several consumer surveys have shown that GMO-labeled products demand a lower price. However, these survey results are based on stated preferences and not revealed preferences. Price discounts in the US for GMO-labeled products available on the market have not been documented so far. The major explanation for the difference between stated and revealed preferences is that consumers, when purchasing products, in the majority of cases, do not look for the GMO label and that other product attributes, such as taste and convenience, are more important. Hence, it is reasonable to expect that no significant price differentiation between NGT-labeled and comparable products without a label will emerge in the market. This is supported by a recent consumer survey comparing an NGT and GMO-labelled product, showing a higher willingness to pay for an NGT than GMO-labelled yogurt (Pokrivcak et al., 2024). These observations do not imply that consumers do not support NGT labeling. They generally do, but this preference is not observed in the market. It is questionable whether consumers are willing to support mandatory labeling when they are confronted with possible additional costs. Further, Kolodinsky and Lusk (2018) show a decrease in the opposition to GMOs after the introduction of a mandatory label in the case of Vermont. Many studies assessing mandatory labeling costs confirm low costs along the supply chain if they only have to declare that the product may contain GMOs, as in the US (Food & Water Watch, 2015). How costs can change dramatically with respect to the details of the labeling policy is discussed down below.

In the case of voluntary NGT-free labeling, the producers providing the products will bear the costs of complying with the standard. Voluntary markets have developed for a number of food products. Consumers who care about product properties have the choice to identify products according to their preferences and decide if they are willing to pay the price. A market for GMO-free labeled food products has emerged in several EU member states. If consumers demand NGT-free products, a voluntary market for NGT-free products is expected to develop. Such a development has been observed in the GMO market. A voluntary GMO-free labeled market has emerged in several EU member states (Venus et al., 2018). The market mainly covers food products derived from animals that are fed with GMO-free feeds, as food products derived from animals fed with GMO feed do not need to be labeled. For example, VLOG has established standards for GMO-free labels in Germany. The costs for the GMO-free labeled product market are borne by the market participants. Consumers demanding GMO-free products have the choice to select their respective products. While this market mainly addresses food products derived from animals, this might expand to those derived from NGTs. Such credence good markets are not unusual. Similar product markets have emerged for vegetarian and vegan food markets as well as for organic food markets.

Table 5: GMO labeling requirements in the EU.

GM product	**Example**	**Labeling requirement**
GM plants, seeds, and food	Maize, maize seed, cotton seed, soybean sprouts, tomato	Yes
Food produced from GMOs	Maize flour, soybean oil, rape seed oil	Yes
Food additive/flavoring produced from GMOs	Highly filtered lecithin extracted from GM soybeans	Yes
GM feed	Maize	Yes
Feed produced from a GMO	corn gluten feed, soybean meal	Yes
Food from animals fed on GM feed	Eggs, meat, milk	No
Food produced with the help of a GM enzyme	Bakery products produced with the help of amylase	No

Note: Adopted from Wesseler and Kalaitzandonakes (2019) and Gabriel and Menrad (2014).

In the EU, labeling for NGTs is currently mandatory as they fall under the GMO regulation (Table 5). Currently, there are only a few GMO-labelled products available. Major retailers in the EU try to avoid food products labeled as GMOs, as indicated by their company reports (Wesseler, 2014). Ihle and Wesseler (2024) report that less than 1 percent of retail food products in the Netherlands have a GMO label. A price discount has not been observed. Some retailers have announced support for mandatory NGT labeling because, in their view, this supports consumer choice. This move indicates they would be willing to list NGT-labelled products, which may increase consumer trust in the food market. A study on introducing GMO labeling in the US shows increased consumer trust in the market (Kolodinsky & Lusk, 2018).

The proposal of the EC foresees labeling for NGT seeds but not further down the supply chain. Amendments to the proposal call for labeling along the whole supply chain. The costs of labeling along the whole supply chain depend on the specificities of the labeling requirements. Labeling of NGTs will be relatively inexpensive if a declaration is sufficient. The costs will increase for those participants in the supply chain who want to avoid labeling. They must show that their products contain NGTs below the threshold level, which requires testing and reliable testing protocols. These testing protocols are currently not available, and even if they become available, they will require a change in the current regulation as the regulation only includes PCR tests. A change in the regulation is expected to take several years. Further, even with reliable testing protocols, introducing segregated supply chains will become very costly (Menrad et al., 2009). Market participants who want to avoid NGT labeling would also face liabilities in case of non-compliance. The cost of non-compliance can be extremely high, as demonstrated by the appearance of unapproved events in the food chain. Maintaining segregation along the supply chain will be difficult for NGTs under a mandatory labeling policy. This requires that all participants in the supply chain are willing to accept NGT products and label them according to that, and food processors and retailers agree to provide and list those products.

The introduction of mandatory GMO labeling was widely discussed in the literature. A number of studies on the costs indicated a substantial rise in costs if GM labels on products were introduced (Table 6). The mandatory labeling in the US requires product information to be provided via a scanner code. The advantage of such labeling is the low cost. Consumers interested in product characteristics can find them via the scanner code. At the same time, food companies can provide additional product information and advertise their product. So far, the supply chain is able to cope with this labeling policy, and it has not resulted in drastic increases in food prices.

Table 6: Labeling costs reported in the literature.

Type of labeling cost	Amount
Median labeling cost estimates for a household of four in California[1]	348 - 401 USD per year
Median labeling cost estimate for a household of four in Washington State[1]	360 – 490 USD per year
Midpoint labeling estimate per capita in New York State[1]	200 USD per year
Segregation, certification and monitoring in New York state[1]	9 USD per capita and year
On-time labeling costs per product in California[2]	1 104 USD per product
Products need to be labeled mandatory in the US[2]	3% price increase
Increase in food retail prices mandatory labeling in Canada[3]	9% - 10%
Instituting mandatory labeling in Canada[4]	161.75 million USD
Recurring annual costs of mandatory labeling[4]	28.37 million USD per year
Increase in cost for Filipino food manufacturers[5]	11% – 12%

Sources: (1) Lesser (2014); (2) Bovay and Alston (2018); (3) KPMG (2000); (4) Cloutier (2006); (5) de Leon et al. (2004).

Table 7: Identity preservation costs for non-GM production.

Type of identity preservation cost	Amount
Oilseed rape and maize, increase in costs, processing level[1]	2.46 €/t
Elevator, increase in costs[2]	14.6%
Maize starch processors, increase in costs[2]	11%
Corn and soybean input cost increase at farm level in the US [3]	10%
Segregation, certification, and monitoring (costs per capita and year)[4]	36.60 USD
Additional costs along the supply chain from production to processing[5]	7% – 14%
IP system for GM-free products along the supply chain, additional cost at farm level[6]	6% – 17%
Costs per ton of grain at elevator level[7]	7.00 USD
Extra costs for wheat seed[8]	1.4%
Costs per ton of wheat at farm level in Germany (Denmark)[9]	10.85 €/t (4.87 €/t)
Costs per ton of wheat for starch at elevator level in Germany[9]	13.65 – 16.09 €/t
Costs per ton of wheat for feed at elevator level in Denmark[9]	11.72 – 13.55 €/t
Costs per ton of bread-quality wheat at elevator level in Denmark[9]	6.91 €/t

Costs per ton of wheat starch at the processing level in Germany[9]	~ 26 – 39 €/t
Costs per ton of wheat compound feed at the processing level[9]	~ 14 – 17 €/t
Costs per ton of wheat flour and bran at the processing level[9]	~ 11 €/t
Extra costs for sugar beet seed in Germany[9]	8.1%
Costs per ton of sugar at the processing level in Germany[9]	~ 28 €/t
Costs per ton of sugar at the processing level in Germany[9]	~ 17 – 22 €/t
Extra costs for rapeseed oil seed[9]	10% – 20%
Cost per ton of rapeseed oil at farm level in Germany (Denmark)[9]	74.4 €/ha (40.1 €/ha)
Cost per ton of rapeseed oil at elevator level in Germany[9]	17.29 €/t
Cost per ton of rapeseed oil at processing level in Germany (Denmark)[9]	74.1 €/t (83.16 €/t)
Price increase for frozen pizza[10]	26.56 €/t
Cost for frozen pizza in percent of turnover[10]	0.47%
Price increase for chocolate[10]	24.13 €/t
Cost for chocolate in percent of turnover[10]	0.67%

Sources: (1) Gawron and Theuvsen (2008); (2) Gabriel and Menrad (2014); (3) Lesser (2014); (4) Alston and Sumner (2012); (5) EC (2023); (6) Miraglia et al. (2004); (7) Maltsbarger and Kalaitzandonakes (2000); (8) Tolstrup et al. (2003); (9) Menrad et al. (2009); (10) Gabriel and Menrad (2014).

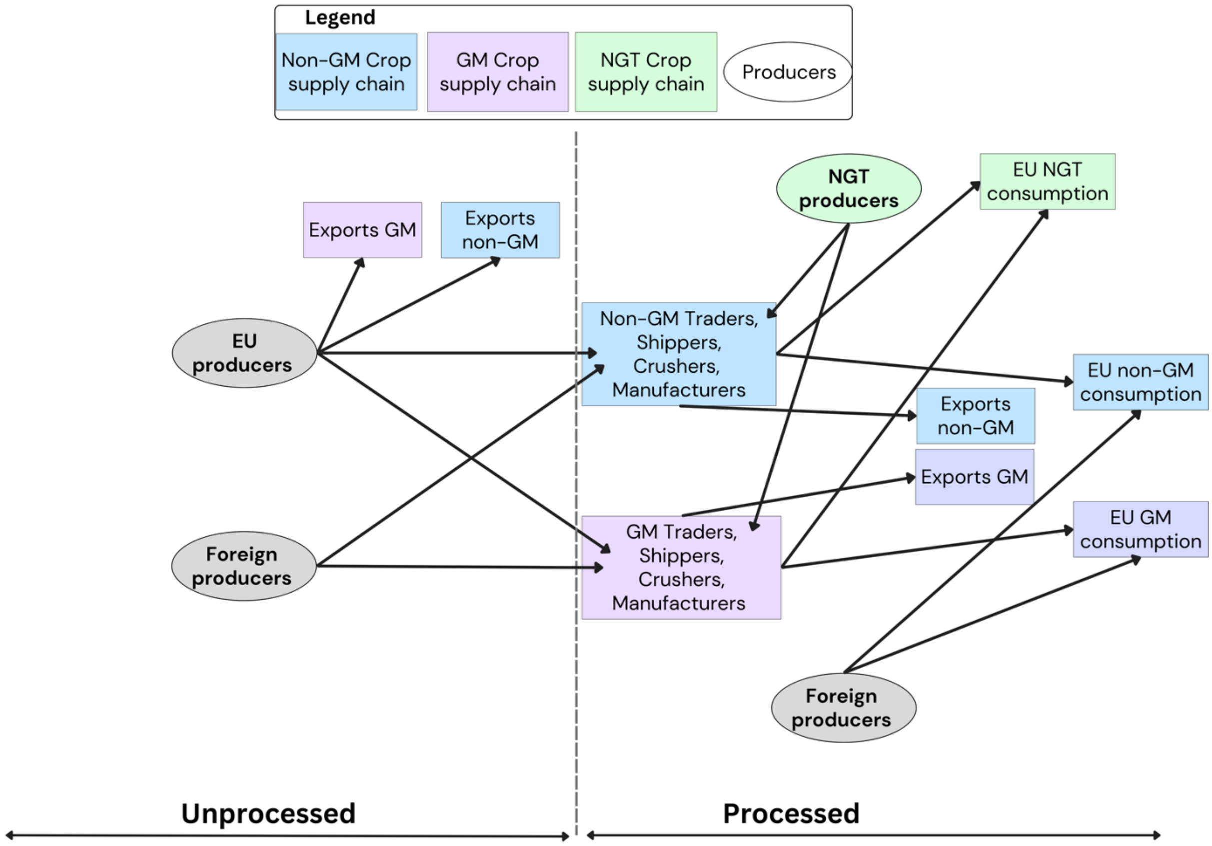
An EU mandatory NGT labeling policy has implications for imports of agricultural products into the EU. In this case, imports may decline as traders cannot provide the information on whether a shipment contains NGTs or not and may not be willing to take the risk of importing shipments from countries where NGTs are cultivated, nor are exporters able to provide the necessary evidence. The issue will become even more complicated for imports from the US. Under the Lanham Act, companies can be held liable for introducing products into the US market that negatively impact the export of agricultural products (Westerman, 2017). The export of oilseeds and protein crops alone has a value of more than 3.9 billion USD in 2023 (European Commission, 2024). This is a third in value of all agricultural commodities exported into the EU. Giving up this market might not be in the interest of the agriculture sector. The Wheat Board of Canada decided not to introduce herbicide-resistant wheat for not losing the EU market. Similarly, Canada did not introduce the triffid flax seed. When traces appeared in shipments to the EU, trade was stopped, costing Canada about 30 million Canadian Dollars (Ryan & Smyth, 2012).

The cost of labeling includes the provision of evidence by using PCR tests assessed with about 200 € per test (Gabriel and Menrad, 2014) and the costs of segregating NGTs from non-NGTs. This has been referred to as identity preservation (IP) in the literature. In the case of IP, the costs are borne by market participants interested in IP.

Several studies provide valuable insights in examining the costs associated with labeling, traceability, and IP (Table 7). De Leon et al. (2004) identify mandatory labeling as resulting in an 11%-12% increase in manufacturing costs. Menrad et al. (2009) conducted interviews with major oil milling companies in Germany and Denmark, where they found that additional coexistence costs for rapeseed were approximately €74 per ton in Germany and €83 per ton in Denmark, amounting to 8.3% of product turnover. Nantel (2016) compares the findings of the Quebec Department of Agriculture, Fisheries and Food (Cloutier, 2006) with those of a KPMG study (2000), revealing that KPMG's cost estimates are six times higher and that mandatory GMO labeling would increase retail prices by 9%-10% in Canada.

We apply two approaches to assess the costs of labeling, tracing, and IP. In the first approach, we use the baseline model and reduce the size of the equivalent yield gain to reflect an increase in costs. The scenarios include a reduction in yield gain by 20%, 50%, and 80%. We combine this with the results of coexistence.

Figure 4: Crop supply chain in the EU.



This approach only allows for identifying changes in surplus for the whole upward and downward chain. To have a more detailed insight into the cost distribution related to labeling, traceability, and IP preservation, we utilize an equilibrium displacement model that includes several stages and participants of the food supply chain. The modeling approach we use is derived from the model introduced by Wohlgenant (2011), which is a market model designed to evaluate changes in equilibrium driven by exogenous variables using existing data on price, quantity, and elasticity for a specific crop. Lusk et al. (2021) describe a recent application for introducing plant-based meat alternatives.

The model is constructed through a series of equations that trace the supply chain of a crop in the European Union (EU). These equations provide insights into the supply, demand, prices, and quantities of commodities based on linear demand and supply theory. Within the model, two commodities are treated as endogenous (non-GM and GM crops), while one (NGT crop) is considered exogenous. This structure allows for evaluating potential changes in the EU market should NGT crops be introduced. The crop supply chain in the EU is illustrated in Figure 4.

Although the production of GM crops is included in the model for the sake of completeness, it is important to emphasize that GM crop cultivation is limited to one maize event in the EU (European Commission, n.d.-b). Therefore, while the model includes GM crop production to provide a comprehensive representation of the market, the actual values for this variable are set to zero in all relevant calculations for all crops apart from maize in accordance with the current regulatory framework.

We assume that testing kits or alternative methods are readily available, as with transgenic crops. We indirectly estimate labeling and traceability costs as 18% of the total cost per ton for GM products (8% of the price per ton is for traceability and 10% for labeling), a percentage derived from the literature (de Leon et al., 2004; Menrad et al., 2009; Nantel, 2016).

A key distinction in the model is the separation between unprocessed and processed crops within the supply chain. In Europe, crops are produced, imported, and exported in processed and unprocessed form. The model preserves this distinction, accounting for unprocessed and processed crops' production, import, and export. Additionally, it assumes that the crops reaching European consumers have been processed. The model operates through a set of equations that define the quantity flow illustrated in Figure 44. For more detailed figures, please see Appendix subsection A.13.

Another critical aspect of the model is the determination of crop prices (refer to equations 16-17 in the Appendix). Beyond the costs of raw materials, manufacturing, and processing, the model includes costs associated with labeling and traceability, which are particularly relevant for NGT products in the EU. These costs are represented by the variable $\widehat{w}_3$, with different values assigned depending on whether the cost is due to labeling, traceability, or both. The model presents three scenarios: costs related to labeling only, traceability only, or both combined. These scenarios are defined by the parameter α, with $0 \leq \alpha \leq 1$. When $\alpha=0$, the crop incurs none of these additional costs, indicating it is non-GM. For any value of α greater than 0, the crop is classified as GM and incurs the relevant costs.

Once the model is fully specified, it includes 29 endogenous variables, 12 potential exogenous demand or supply shifters, and a set of technology and preference parameters. Table 1 in the Appendix provides a detailed overview of the 29 endogenous variables within the model. These variables adjust in response to changes in the exogenous variables listed in Table 2 of the Appendix.

The model's focus on labeling and traceability costs reflects the broader context of the EU's food labeling requirements. The EDM model underscores the economic implications of these requirements by analyzing the introduction of labeling and traceability costs for crops derived from NGTs.

Box: Labelling specificities to be considered.

Under the assumption that mandatory labeling will be required, similar to the one for GMOs, the costs will be prohibitively high. The costs of labeling will be higher than the economic gains to be expected from NGTs. Supply chain participants have to identify the specific event. Assuming a test kit would be available, and the costs are similar to the test for transgenic crops, about ten tests need to be conducted. This applies to one event only; if several events are included, test costs will increase. Note that this is based on the assumption that tests must be done by the participant who is aware of the presence of the NGT. The situation becomes more complicated if segregation is the objective; that is, an NGT supply chain coexists with a non-NGT supply chain. Maintaining a non-NGT supply chain will become difficult.

Labeling costs can be reduced if the EU changes the requirements for labeling. One labeling policy that reduces the costs is based on a declaration by the parties involved but does not require testing to prove that the specific event is indeed included in the product. In this case, the labeling costs can be substantially reduced and would not be much more than the ink on the label. Traceability would also be linked with this system as is already required under the due diligence regulation.

Labeling of products is also related to the approval process. The approval process currently requires a verified identification test for NGTs. There is an ongoing debate about whether this will be possible. Testing based on varieties instead of events has been proposed as a potential solution. As events are introduced in several varieties, the number of tests increases exponentially with an increase in events (Wesseler & Kalaitzandonakes, 2019). Currently, tests for multiple varieties and events in a single test are unavailable, so this is not a viable solution. Another solution involves documentation along the supply chain as is done in, for example, organic agriculture. As events are introduced in several varieties, the number of tests increases exponentially with an increase in events (Wesseler & Kalaitzandonakes, 2019). As testing for several varieties for several events in one test is currently unavailable, this is not a viable solution. Another solution is related to documentation along the supply chain as is done, e.g., for certified organic products. As product specifications are part of the documentation in trade, this can be a viable possibility from a cost perspective.

Labeling potatoes and tomatoes might be different, as segregation will be easier. They can be cultivated in dedicated areas under contract with specific supply chains. We observe this in both markets, such as a differentiation between starch and consumption potatoes and between different types of tomatoes. In those cases, the labeling costs can be low.

2.2.3. Summary of Impact of Coexistence and Labelling and Traceability Policies

Coexistence measures differ by EU member state. Some EU member states, such as Austria or Germany, have stringent coexistence measures prohibiting the cultivation of NGTs. These measures act as an indirect ban on NGT cultivation. Minimum distance requirements discriminate against smaller farms. The larger the farm, the easier the compliance with minimum distance requirements will be. Information duties such as informing all neighboring farms or even getting their consent can, in combination with minimum distance requirements and liability, also act as a barrier to adoption. The adoption barrier increases with the legal uncertainty related to liability. In many cases, the information requirements are not well defined.

Labeling and traceability policies will increase the costs of production, which will reduce the adoption benefits. The relevant k-shift in the model will be reduced. The k-shift sets the limit for labeling and traceability costs. If those costs exceed the benefits of the downward supply shift, they become prohibitively high. If too high, labeling costs can negate the economic incentives for adopting NGTs due to the additional expenses imposed on producers. In this case, the labeling costs result in foregone benefits for producers and consumers. Moreover, consumers do not even have the option to decide whether they like to purchase NGT or non-NGT food products. An important requirement for traceability is the availability of a detection and identification tool. Currently, only PCR-based methods are allowed. For NGTs, such tests do not yet provide a reliable solution. Alternative solutions, such as tracing using blockchain approaches, documentation, or identifying crop varieties, might be possible but create additional problems. Alternatives to the PCR method require a change in the current regulation, which will be quite time-consuming. Identification based on testing for varieties would result in an exponential increase in tests as NGT-derived traits can be expected to be introduced in many varieties.

In cases where we observe strong vertical integration in the supply chain, labeling and traceability might be possible. Still, they do not offer a general solution and limit the application of NGTs to niche markets.

3. Quantification of Implications of Coexistence Measures and Labelling and Traceability Requirements

3.1. Baseline scenario

The baseline scenario assumes that NGT-derived crops are treated similarly to others from a regulatory perspective. As mentioned above, a logistic adoption function will be assumed to reach 40% adoption after 20 years. This is a pessimistic assumption, but being safe reduces the chances of overestimating impacts. The calibration of the baseline model requires the identification of the initial prices and quantities. They have been taken from Eurostat using the three-year averages from 2021 to 2023. The details are provided in the appendix.

The supply elasticities are taken from the publication by Jongeneel and Gonzalez-Martinez (2020). They report own-price yield elasticities for several crops. We derive the supply elasticity by multiplying the reported elasticities by a factor of two to account for the area effect for maize, oilseed rape, and barley. This increases the own price supply elasticity more than observed in reality and allows it to stay on the safe side. The supply elasticities for tomatoes and potatoes are on the higher end. They are reported in the literature to be between 0.5 and 1.5. Again, to be on the safe side, we use a value of 0.5 for tomato and 1.5 for potato.

The absolute value of the own price demand elasticity we set for all crops is 0.2. This is a low value. Setting the same value can be justified by the low impact a change in value has on the results. The lower the absolute value, the lower the welfare effects. Again, using a low value tends to underestimate rather than overestimate the aggregate welfare effects. The results of the baseline scenario are summarized in Table 8 below and are calculated as annuities.

Table 8: EU-wide producer and consumer surplus changes in million Euros per year.

	Maize	**Oilseed rape**	**Wheat**	**Potato**	**Tomato**
Δ PS	1769	599	1488	52	96
Δ CS	3024	539	1979	310	241
Δ TS	4793	1139	3467	361	337

Note: Model details and parameter values as mentioned in the report derived from Eurostat (2024). Detailed information is provided in the appendix. Main assumptions: 40% adoption after 20 years and a discount rate of 10%.

The largest benefits are expected with the cultivation of maize. They are approximately 4 800 million Euro per year, followed by wheat (3 467 million Euro), oilseed rape (1 139 million Euro), potato (361 million Euro), and tomato (337 million Euro). Producers gain the most in the case of maize and oilseed rape. In the case of wheat, potato, and tomato, the consumer surplus is larger than the producer surplus.

The producer surplus will be distributed between farmers and other participants along the upstream supply chain. We do not calculate the distribution of the producer surplus explicitly. Previous studies have shown that about 80 percent of the producer surplus stays with farmers in the first years, and 20 percent is redistributed among the upstream sector, mainly seed suppliers and other farm-input suppliers (Falck-Zepeda et al., 2000). Over the long run, the benefits tend to increase land prices and will be redistributed to landowners, and owner-operator farmers will gain more than farmers renting land. This effect is not captured explicitly in the model. As adoption follows a logistic function, the average annual benefits will stay longer with farmers than otherwise.

The consumer surplus will be distributed along the downstream sector and includes traders, processors, retailers, and consumers (Just et al., 2005). In the long run, the gains will be more evenly distributed with zero profits at the margin.

3.2. General Implications Coexistence

The impact of coexistence measures on welfare has been calculated by reducing the area that will be available for the adoption of specific NGT crops. The reduction in area has been assessed at the EU member state level derived from the coexistence measures circulated by the respective member state (see section 2.2.1). The reduction in the area available for cultivation has been reported in Table 9. Not surprisingly, area reduction is the largest for wheat, followed by maize and oilseed rape. The relative impact, i.e., the change in the adoption ceiling, has been highest for tomatoes. The adoption ceiling decreases to 39%. The adoption ceilings for wheat declined to 31% and for wheat to 27%. The decline in the case of tomatoes from 40% to 39% is marginal.

Table 9: Reduction in adoption area due to coexistence and changes in producer and consumer surplus compared to the baseline scenario results.

	Maize	Oilseed rape	Wheat	Potato	Tomato
Δ Area (1000ha)	14693	5818	24066	1356	222
Adoption Ceiling (%)	0.27	0.17	0.31	0.26	0.39
Δ PS_{Co} (mio. Euro)	1207	250	1134	33	93
Δ CS_{Co} (mio. Euro)	2063	225	1508	197	232
Δ TS_{Co} (mio. Euro)	3270	475	2642	230	325
Δ Baseline Results (mio. Euro)	-1523	-664	-842	-131	-13
Δ Baseline Results (%)	68	42	76	64	96

Note: Model details and parameter values are in the Appendix. The symbol Δ indicates change. Differences can be caused by rounding errors. The subscript Co refers to the coexistence scenario. The change in comparison to the baseline results indicates a decline in million Euros and in percent compared to the baseline results.

The reduction in the area available reduces the producer and consumer and the total surplus. The relative change is the largest for oilseed rape, with a decline of about 58% to 42% in relation to the baseline results. The smallest effect can be observed for tomatoes. The surplus declines by about 4% to about 96% compared to the baseline scenario without coexistence policies. The largest effect can be observed for maize, with a decline of about 1523 million Euros on average per year in absolute numbers. These calculations do not include the costs farmers may face in cultivating NGT-derived crops and implementing coexistence policies, and hence, they tend to be on the higher side.

3.3. Labelling scenario

The changes due to labeling and traceability have been modeled using a decline in the relative k-shift reflecting the cost increase. The important notice is that the previous calculations already provide an upper limit for the labeling costs. They need to be below the numbers reported in the baseline results. If the labeling costs exceed those numbers, economic incentives for introducing those crops do not exist. As already mentioned, labeling costs largely depend on the labeling policy. Hence, the impact of labeling has been calculated using a high-, medium-, and low-cost scenario. The results are presented in Table 10.

The low labeling cost scenario refers to the situation where the labeling costs only require simple statements such as “genetically modified” or “includes ingredients from a genetically modified plant” without further specification. In the medium labeling cost scenario, the different plants need to be mentioned, and in the high-cost scenario, the specific events need to be identified. Hence, additional testing costs apply. In this case, the implicit assumption has been made that approved testing protocols are available.

Table 10: Changes in surplus with labeling and traceability requirements (low, middle, high).

	Maize	Oilseed rape	Wheat	Potato	Tomato
			Scenario Low Labelling Costs		
Δ PS_{Ll} (mio. Euro)	1413	488	1189	41	77
Δ CS_{Ll} (mio. Euro)	2416	431	1581	248	192
Δ TS_{Ll} (mio. Euro)	3829	910	2769	289	269
Δ Baseline Results (mio. Euro)	-963	-229	-697	-72	-68
Δ Baseline Results (%)			80		
			Scenario Medium Labelling Costs		
Δ PS_{Lm} (mio. Euro)	882	298	741	26	48
Δ CS_{Lm} (mio. Euro)	1507	269	986	155	120
Δ TS_{Lm} (mio. Euro)	2389	567	1727	180	168
Δ Baseline Results (mio. Euro)	-2404	-572	-1740	-181	-169
Δ Baseline Results (%)			50		
			Scenario High Labelling Costs		
Δ PS_{Lh} (mio. Euro)	352	119	296	10	19
Δ CS_{Lh} (mio. Euro)	602	107	393	62	48
Δ TS_{Lh} (mio. Euro)	954	226	689	72	67
Δ Baseline Results (mio. Euro)	-3839	-913	-2777	-289	-270
Δ Baseline Results (%)			20		

Note: Model details and parameter values are in the appendix. The symbol Δ indicates change. The subscripts L_l, L_m, and L_h refer to low, medium, and high labeling costs. The change compared to the baseline results indicates a decline in million Euros and in percentage compared to the baseline results.

The labeling costs can substantially reduce the welfare benefits of NGTs. Retail price differences between "GMO-free" labeled food products and conventional products indicate the costs for segregated food supply chains. The price differences are in the order of 50% and more for dairy products, vegetables, and fruits (e.g., Castellari et al., 2018; Dolgopolova & Roosen, 2018; Venus et al., 2018). Those differences do not cover the additional yield benefits assumed in our calculations. NGT-derived food products must substantially lower production costs to cover the additional labeling and related segregation costs.

The situation might be different for niche markets such as potato (e.g., Devaux et al., 2021) and tomato (e.g., Čechura et al., 2020) markets, where supply chains are more strongly vertically integrated than in the markets for maize, oilseed rape, and wheat. Still, in the markets for maize, oilseed rape, and wheat, supply chains for NGTs might emerge where labeling and related segregation costs can more easily be implemented. Examples include segregated markets for waxy corn or high oleic acid oilseed rape only sold to a limited number of customers.

The decrease in welfare in comparison to the baseline scenario is linear. The reduction in welfare illustrates the costs of mandatory labeling requirements. The effects are the largest for maize and wheat in absolute numbers.

3.4. Labelling and coexistence scenario

The results reported in Table 9 indicate a strong effect of coexistence measures on welfare gains. Even without labeling, the welfare benefits for maize, oilseed rape, and potato decline by more than 30%. The results in Table 11 show a combination of labeling policies and coexistence measures combined and again by low, medium, and high labeling costs, as shown in Table 10 above.

Table 11: Changes in surplus due to labeling and traceability requirements (low, middle, high) in combination with coexistence measures.

	Maize	Oilseed rape	Wheat	Potato	Tomato
Scenario Low Labelling Costs + Coexistence Measures					
Δ PS_{Ll} (mio. Euro)	964	200	906	26	74
Δ CS_{Ll} (mio. Euro)	1649	180	1205	158	185
Δ TS_{Ll} (mio. Euro)	2614	380	2112	184	259
Δ Baseline Results (mio. Euro)	-1523	-664	-824	-131	-13
Δ Baseline Results (%)	55	33	61	51	77
Scenario Medium Labelling Costs Coexistence Measures					
Δ PS_{Lm} (mio. Euro)	602	124	565	16	46
Δ CS_{Lm} (mio. Euro)	1029	112	752	99	116
Δ TS_{Lm} (mio. Euro)	1631	237	1317	115	162
Δ Baseline Results (mio. Euro)	-3162	-902	-2149	-246	-337
Δ Baseline Results (%)	34	21	38	32	48
Scenario High Labelling Costs Coexistence Measures					
Δ PS_{Lh} (mio. Euro)	240	50	226	7	18
Δ CS_{Lh} (mio. Euro)	411	45	300	39	46
Δ TS_{Lh} (mio. Euro)	652	95	526	46	65
Δ Baseline Results (mio. Euro)	-4141	-1044	-2941	-315	-272
Δ Baseline Results (%)	14	8	15	13	19

Note: Model details and parameter values are in the appendix. The symbol Δ indicates change. The subscripts Ll, Lm, and Lh refer to low, medium, and high labeling costs. The change in comparison to the baseline results indicates a decline in million Euros and in percent in contrast to the baseline results.

3.5. General implications of coexistence measures and labeling policies

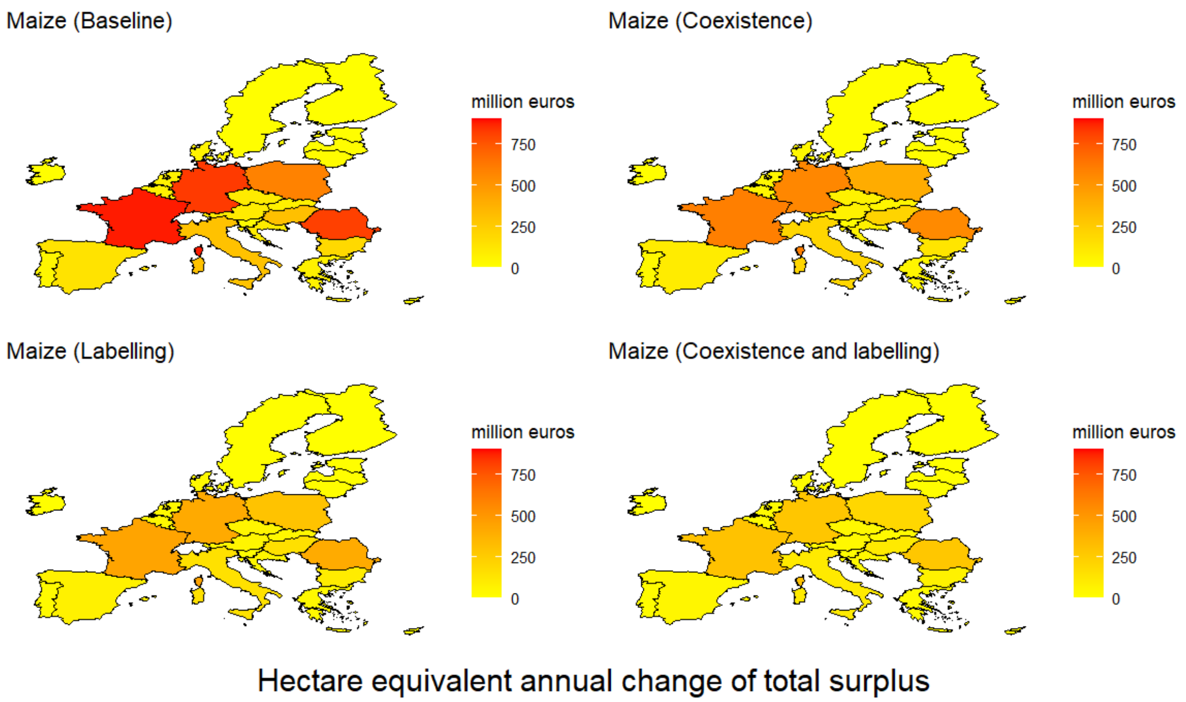
Figures 5 to 9 visualize the hectare equivalent annual change of total surplus for maize, oilseed rape, potato, tomato, and wheat, respectively. We estimate the change of total surplus in each EU member state weighted by their acreage of cultivating each crop. The results are presented in hectare equivalence. The general pattern shows that the change in total surplus would be the largest in the baseline, followed by the coexistence scenario, the labeling scenario, and finally, the scenario of combining coexistence and labeling. This general pattern applies to maize, wheat, potato, and tomato. For oilseed rape, the change of total surplus in the labeling scenario is larger than the one in the coexistence scenario. The difference by crop is due to price differences and coexistence effects.

As our baseline scenario assumes that NGT-derived crops are treated similarly to other crops, it is the least strict version. Therefore, it can generate the largest increase in total surplus. The last scenario, the combination of coexistence and labeling, is the most stringent scenario with restrictions and additional costs, and therefore, it generates the least increase in total surplus.

For maize, the largest beneficiaries include France (880 million euros), Germany (827 million euros), and Romania (812 million euros) due to their largest acreage of maize cultivation among all European countries. For oilseed rape and wheat, the largest beneficiaries include France (232 million euros for oilseed rape and 730 million euros for wheat), Germany (213 million euros for oilseed rape and 423 million euros for wheat), and Poland (207 million euros for oilseed rape and 353 million euros for wheat). For potatoes, Germany, Poland, and France would gain the largest total surplus with 70 million euros, 55 million euros, and 53 million euros, respectively. Regarding tomatoes, the largest beneficiaries include Italy (151 million euros), Spain (77 million euros), and Romania (27 million euros).

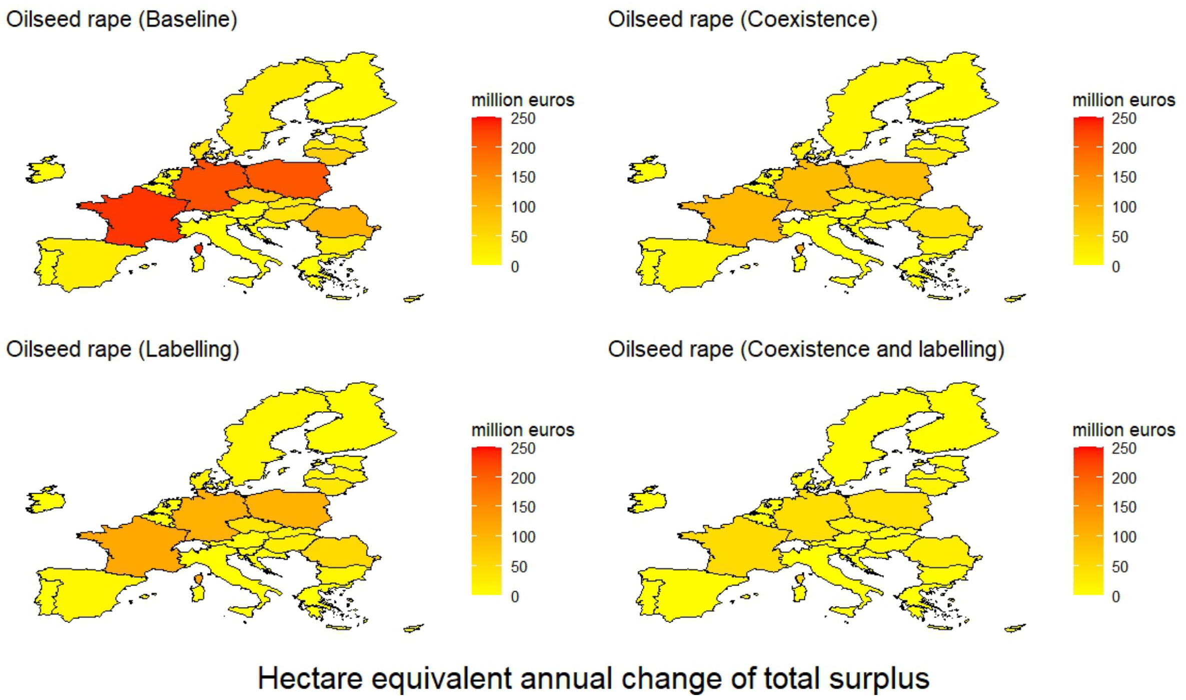
In Figure 10, we compare the change of total surplus in each scenario by crop. Different colors in the labeling scenario and the combination scenario of labeling and coexistence (the last two bars in each figure) indicate high, medium, and low labeling costs, respectively.

Figure 5: Hectare equivalent annual change of total surplus for Maize in EU-27.



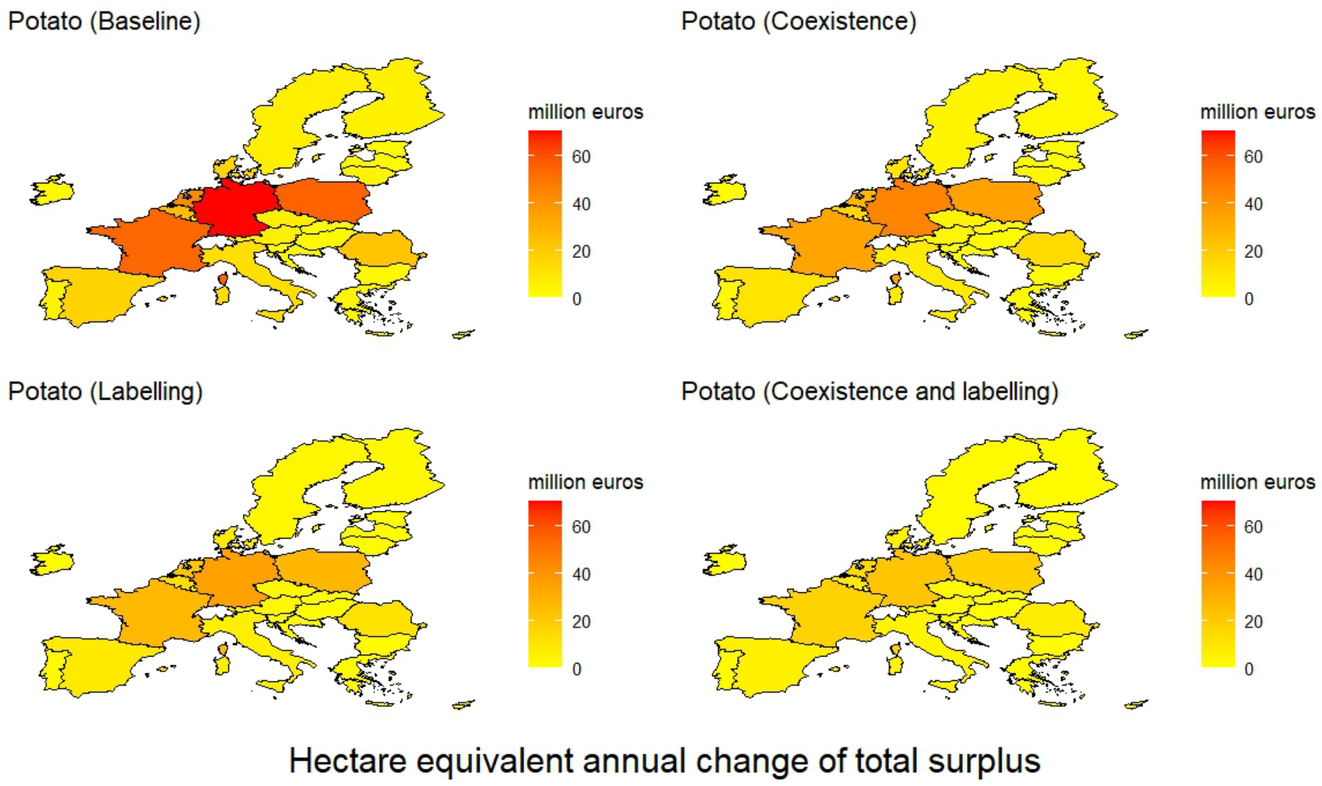
Source: Authors' elaboration.

Figure 6: Hectare equivalent annual change of total surplus for Oilseed rape in EU-27.



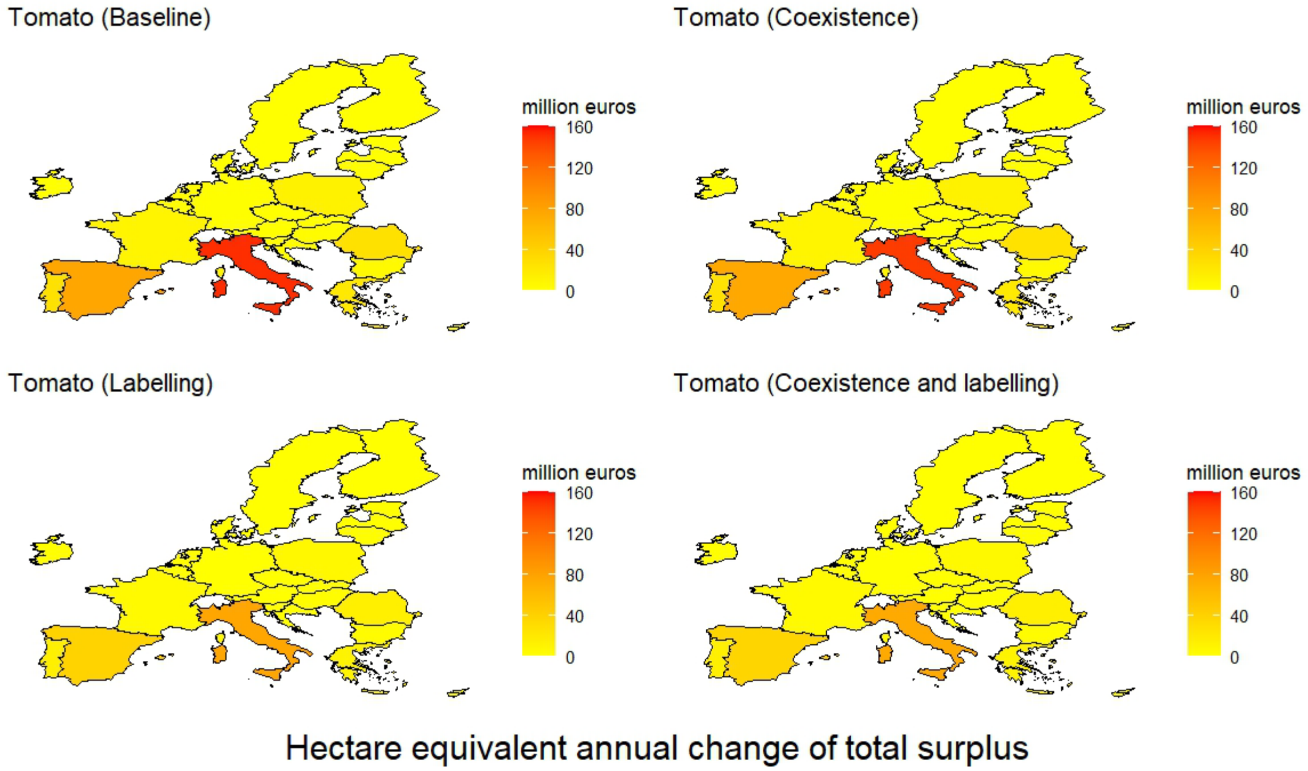
Source: Authors' elaboration.

Figure 7: Hectare equivalent annual change of total surplus for Potato in EU-27.



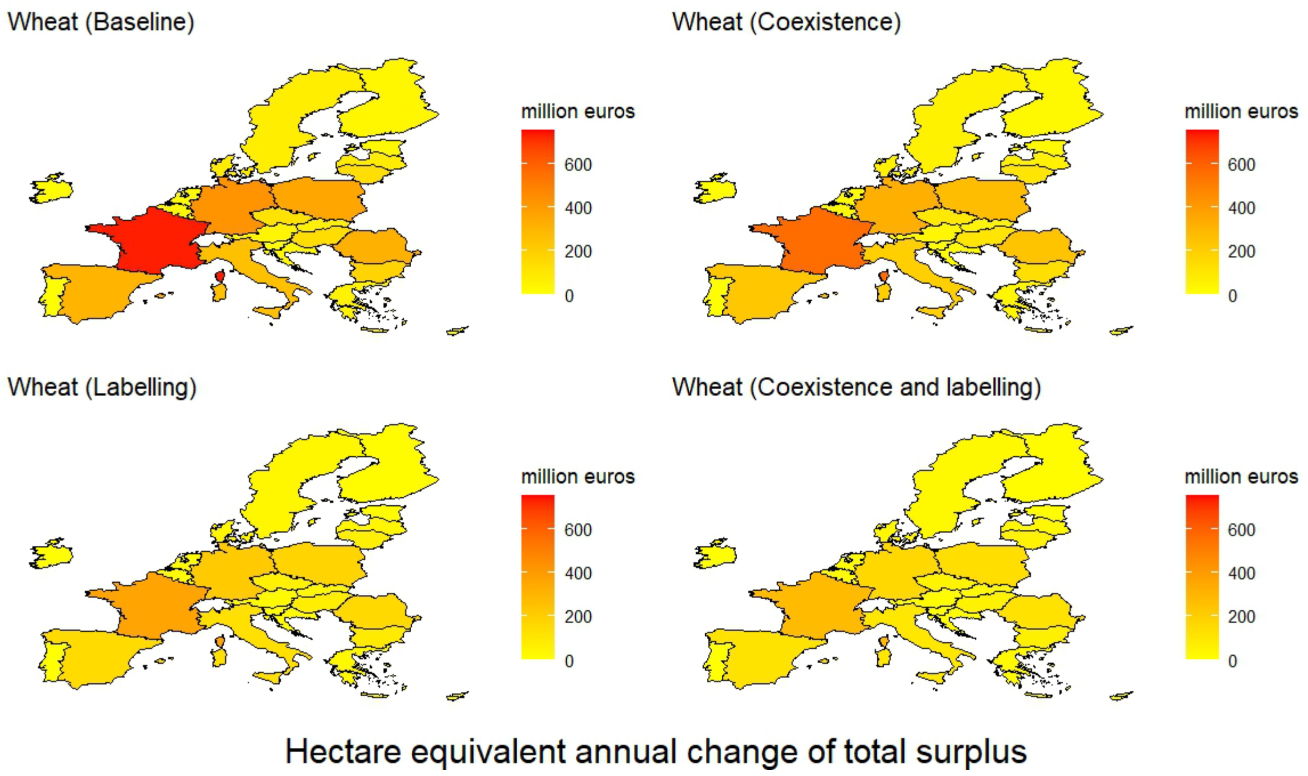
Source: Authors' elaboration.

Figure 8: Hectare equivalent annual change of total surplus for Tomato in EU-27.



Source: Authors' elaboration.

Figure 9: Hectare equivalent annual change of total surplus for Wheat in EU-27.



Source: Authors' elaboration.

The results show that the largest increase in total surplus happens in the baseline where the regulation is the least strict; meanwhile, the least growth in total occurs in the combination scenario of labeling and coexistence due to the additional regulatory requirements and costs. However, except for tomato, it is ambiguous for maize, oilseed rape, wheat, and potato whether the coexistence scenario or the labeling scenario would benefit more, depending on various levels of the labeling cost: the lower the labeling cost, the higher the total surplus. Maize would benefit the most, up to 1523 million euros, if it does not need to follow the coexistence requirements compared with oilseed rape (664 million euros), wheat (825 million euros), potato (131 million euros), and tomato (12 million euros).

Figure 10: Comparison of total surplus in each scenario for each crop.

Source: Authors' elaboration.

Note: the light green color indicates the total surplus under the high labeling cost scenario, the green color indicates the total surplus under the medium labeling cost scenario, and the dark green color indicates the total surplus under the low labeling cost scenario.

3.6. Supply chain implications at crop level

3.6.1. Maize

The entry of NGT maize into Europe's market is poised to create considerable shifts. With an introductory price of €190 per ton, NGT maize is estimated to achieve a production level of 129 million tons over 20 years, capturing 40% of the European market share. This growth is expected to foster increased market efficiency, generating a market surplus of €1.8 billion. Consumer surplus is anticipated to grow by €1.1 billion, while producer surplus could see a €700 million uplift, highlighting broad benefits for producers and consumers of the NGT maize. Table 7 illustrates the changes in the rest of the supply chain. Manufacturers of GM and non-GM both face losses of €16 million and €669 billion, respectively. This is because both crops are reduced in imports and production due to the introduction of NGT maize, as well as the imposition of traceability costs. Non-GM producers face a loss in welfare of €132 million. NGT producers face a loss of €77 million (unprocessed) and €133 million (processed) due to labeling costs (Table 13).

Table 12: Changes in the surplus of maize due to the introduction of NGT in the market and the presence of traceability for non-GM producers along the supply chain.

	ΔTS	ΔCS	ΔPS
Δ Importers of unprocessed GM (mio. Euro)	-19	-9	-9
Δ Importers of unprocessed non-GM (mio. Euro)	-16	-6	-10
Δ Traders, shippers, crushers, manufacturers GM (mio. Euro)	-33	-17	-16
Δ Traders, shippers, crushers, manufacturers non-GM (mio. Euro)	-1 721	-1 022	-669
Δ Importers of processed GM (mio. Euro)	-0 812	-0 519	-0 292
Δ Importers of processed non-GM (mio. Euro)	2	-1	-0 938
Δ non-GM producers (mio. Euro)	-326	-193	-132

Source: Authors elaboration. Model details are explained in the text.

Table 13: Changes in maize NGT surplus due to the presence of labeling for NTG producers.

	ΔTS	ΔCS	ΔPS
Δ NGT producers unprocessed (mio. Euro)	-189	-112	-77
Δ NGT producers processed (mio. Euro)	-327	-194	-133

Source: Authors elaboration. Model details are explained in the text.

3.6.2. Oilseed Rape

The European market's adoption of NGT oilseed rape brings noteworthy prospects. Priced initially at €534 per ton, the production volume is projected to reach 10.3 million tons within two decades, with a market penetration of 40% in Europe. This advancement is expected to contribute to a market surplus of €792 million. Specifically, the consumer surplus may increase by €257 million, with the producer surplus also expected to see a €534 million rise, underlining balanced benefits for both market sides. Table 14 illustrates the positive changes in the rest of the supply chain. GM and non-GM manufacturers lose €6 million and €272 million, respectively. This is because the increase in NGT production leads to a decrease in GM and non-GM quantities in the market, and additional traceability costs. The costs of labeling lead to losses of €57 million and €35 million for processed and unprocessed NGT producers (Table 15).

Table 14: Changes in the surplus of oilseed rape due to the introduction of NGT in the market and the presence of traceability for non-GM producers along the supply chain.

	ΔTS	ΔCS	ΔPS
Δ Importers of unprocessed GM (mio. Euro)	-11	-5	-6
Δ Importers of unprocessed non-GM (mio. Euro)	-31	-16	-14
Δ Traders, shippers, crushers, manufacturers GM (mio. Euro)	-6	-3	-3
Δ Traders, shippers, crushers, manufacturers non-GM (mio. Euro)	-272	-88	-183
Δ Importers of processed GM (mio. Euro)	-0.436	-0.143	-0.292
Δ Importers of processed non-GM (mio. Euro)	3	-1	-2
Δ non-GM producers (mio. Euro)	-119	-110	-230

Source: Authors elaboration. Model details are explained in the text.

Table 15: Changes in oilseed rape NGT surplus due to the presence of labeling for NTG producers (10%).

	ΔTS	ΔCS	ΔPS
Δ NGT producers unprocessed (mio. Euro)	-84	-27	-57
Δ NGT producers processed (mio. Euro)	-51	-16	-35

Source: Authors elaboration. Model details are explained in the text.

3.6.3. Wheat

NGT wheat's integration into Europe's market landscape is expected to drive notable change. Initially priced at €236 per ton, NGT wheat production could expand to 53 million tons over 20 years, securing a 40% market share in Europe. This addition is predicted to optimize market dynamics, culminating in a total surplus increase of €1.9 billion. Specifically, the consumer surplus may rise by €1.6 billion, with an anticipated €363 million gain in producer surplus, highlighting the advantageous effects for both consumer and producer markets. Table 16 illustrates the changes in the rest of the supply chain. Traders, shippers, crushers, and manufacturers of non-GM face losses of €567 million due to decreased production and traceability costs. From Table 16, we can observe that labeling costs cause losses for NGT producers unprocessed and processed of €29 million and €111 million.

Table 16: Changes in wheat surplus due to the introduction of NGT in the market and traceability for non-GM producers along the supply chain.

	ΔTS	ΔCS	ΔPS
Δ Importers of unprocessed non-GM (mio. Euro)	-0.280	-0.265	-0.016
Δ Traders, shippers, crushers, manufacturers non-GM (mio. Euro)	-3 497	-2 930	-567
Δ Importers of processed non-GM (mio. Euro)	-0.094	-0.049	-0.144
Δ non-GM producers (mio. Euro)	-311	-260	-50

Source: Authors elaboration. Model details are explained in the text.

Table 17: Changes in tomato NGT surplus due to the presence of labeling for NTG producers (10%).

	ΔTS	ΔCS	ΔPS
Δ NGT producers unprocessed (mio. Euro)	-183	-153	-29
Δ NGT producers processed (mio. Euro)	-686	-575	-111

Source: Authors elaboration. Model details are explained in the text.

3.6.4. Potato

The inclusion of NGT potatoes into the European marketplace suggests impactful developments. Starting at a price point of €408 per ton, NGT potato production is expected to reach 19.3 million tons within 20 years, covering 40% of the market. This addition would bring on a total market surplus increase of €12 million. Within this, the consumer surplus may see a €4 million boost, while the producer surplus could grow by €8 million, demonstrating gains across both the supply and demand sectors. Table 18 illustrates the changes in the rest of the supply chain. Overall, the market experiences losses. This is because the rise in NGT production results in a reduction of non-GM quantities in the market, with traceability costs. Most notably, traders, shippers, crushers, and manufacturers of non-GM potatoes incur a welfare loss of €4 billion. NGT producers face loss in welfare due to costs of labeling of €421 million (unprocessed) and €937 million (processed) (Table 19).

Table 18: Changes in the surplus of oilseed rape due to the introduction of NGT in the market and the presence of traceability for non-GM producers along the supply chain.

	ΔTS	ΔCS	ΔPS
Δ Importers of unprocessed non-GM (mio. Euro)	-0.203	-0.023	-0.180
Δ Traders, shippers, crushers, manufacturers non-GM (mio. Euro)	-8 905	-4 092	-4 813
Δ Importers of processed non-GM (mio. Euro)	-0.127	-0.019	-0.107
Δ non-GM producers (mio. Euro)	-1 334	-613	-721

Source: Authors elaboration. Model details are explained in the text.

Table 19: Changes in potato NGT surplus due to the presence of labeling for NTG producers (10%).

	ΔTS	ΔCS	ΔPS
Δ NGT producers unprocessed (mio. Euro)	-779	-358	-421
Δ NGT producers processed (mio. Euro)	-1 734	-796	-937

Source: Authors elaboration. Model details are explained in the text.

3.6.5. Tomato

The European introduction of NGT tomato is set to bring significant outcomes. Entering the market at €1 193 per ton, NGT tomato is forecasted to reach a production capacity of 2.98 million tons over 20 years, securing 40% market coverage. This development is likely to enhance market performance, with a projected total market surplus of €4 billion. The consumer surplus is expected to rise by €1 billion, while the producer surplus could increase by €2.9 billion, indicating positive impacts for both stakeholders. Table 20 illustrates the changes in the rest of the supply chain. The decrease in welfare is due to decreased production and traceability costs. Producers of NGT tomatoes face losses due to labeling costs (Table 21).

Table 20: Changes in the surplus of tomatoes due to the introduction of NGT in the market and the presence of traceability for non-GM producers along the supply chain.

	ΔTS	**ΔCS**	**ΔPS**
∆ Importers of unprocessed non-GM (mio. Euro)	-60	-1	-42
∆ Importers of processed non-GM (mio. Euro)	-1 805	-585	-1 219
∆ non-GM producers (mio. Euro)	-465	-151	-314

Source: Authors elaboration. Model details are explained in the text.

Table 21: Changes in tomato NGT surplus due to the presence of labeling for NTG producers (10%).

	ΔTS	**ΔCS**	**ΔPS**
∆ NGT producers unprocessed (mio. Euro)	-421	-106	-314
∆ NGT producers processed (mio. Euro)	-482	-122	-359

Source: Authors elaboration. Model details are explained in the text.

3.7. Summary of the supply chain implications at the Crop Level

The analysis of the impact of labeling and coexistence policies on the economic viability of NGT-derived crops demonstrates how varying levels of regulatory costs can significantly influence total surplus across different crops.

Coexistence policies reduce the area available for cultivation. They will have the strongest effects on the area allocated to oilseed rape, followed by potato and maize. They have the least effect on the cultivation of tomatoes. This is mainly due to the effect of country-level coexistence. Cultivation in some countries, such as Germany and Austria, under their coexistence policies will not be possible. They are not major tomato-producing countries.

If too high, labeling costs can negate the economic incentives for adopting NGTs due to the additional expenses imposed on producers. This cost sensitivity is highlighted by the three labeling scenarios (low, medium, and high cost), where each step up in labeling rigor results in a noticeable decline in surplus. With low labeling costs, surplus reductions are less severe across all crops, but as costs increase, the financial viability of these crops diminishes. This emphasizes that labeling costs must remain under a threshold for NGT crops to be economically feasible; otherwise, the benefits do not justify their introduction.

For individual crops, maize consistently exhibits the greatest surplus gains under each scenario due to its widespread cultivation and demand across the EU. The crops like oilseed rape, wheat, and tomato show progressively smaller surpluses, as each is less economically resilient to regulatory costs. When both coexistence and labeling requirements are imposed, the surplus for all crops drops further, with a notable decrease in economic gains by 30% or more, even in low-cost scenarios, as observed in Table 7. This aligns with the findings, where the baseline scenario (with no labeling or coexistence) yields the highest total surplus, followed by coexistence, then labeling, and finally, the combination of both, which produces the least surplus. This suggests that although these policies are aimed at enhancing consumer choice and market transparency, they have substantial trade-offs in terms of economic efficiency.

These findings point to two key implications. First, the regulatory environment plays a central role in determining the economic impact of NGT crops. As the baseline shows, less restrictive policies generate the highest economic benefits. Second, there is a need for careful cost-benefit analysis in setting labeling standards, especially since high labeling costs can disincentivize producers and diminish potential gains for key agricultural players like France, Germany, and Italy. The economic losses are somewhat mitigated for niche markets with more integrated supply chains, such as potato and tomato, where specific production and labeling requirements can be more readily implemented. Conversely, maintaining low labeling costs and fewer coexistence requirements for widespread staples like maize and wheat generate additional benefits across the EU.

Investigating the NGT crops—such as maize, oilseed rape, potato, tomato, and wheat— the European market is projected to undergo significant shifts in market dynamics and overall welfare for both consumers and producers. These crops are expected to capture a considerable portion of the market over the next 20 years, with each securing up to 40% of their respective markets. This shift is largely driven by the higher efficiency of NGT crops, which contributes to higher production volume and lower costs, resulting in overall gains in market surplus. For example, NGT maize alone is expected to increase market surplus by €1.8 billion, while NGT potato stands out with a €3.8 billion surplus gain. These surplus increases reflect balanced benefits across both consumer and producer sectors, indicating that both groups will likely experience positive effects from introducing NGT crops. However, this growth does not come without consequences for traditional GM and non-GM crop producers. The rise of NGT crops reduces the demand for these varieties, leading to lower production levels and welfare losses for GM and non-GM producers across all the analyzed crop types. Non-GM potato producers, for example, face a significant decline in welfare, from €25 billion to €9.5 billion, as NGT potatoes capture market share. Similarly, other GM and non-GM crop segments experience welfare declines due to reduced demand and competition with the more efficient NGT varieties. The broader supply chain also undergoes considerable adjustment as NGT crops gain traction. Traders, manufacturers, exporters, and importers of GM and non-GM crops see losses because the increased presence of NGT varieties reduces imports and production volumes for traditional crops.

In general, the market effects of NGT crops tend to be balanced across consumer and producer segments, with both sectors experiencing increases in surplus. Overall, while NGT crops promise greater efficiency and market gains, their rise leads to significant adjustments in the agricultural landscape. The gains achieved by NGT crops come at the expense of GM and non-GM segments, with substantial welfare losses anticipated in those sectors. Thus, while NGT crops bring benefits and new efficiencies to the market, they also prompt considerable shifts for traditional crop producers.

4. Discussion of the Results

In the analysis, we assumed that products can be sold in retail stores, independent of the respective scenario. This does not necessarily have to hold. Major retailers have submitted a statement asking for labeling of NGT-derived food products for consumer choice (bioPress, 2023). A strong bias can be observed in the debate on NGT labeling (e.g., a report on German TV only suggests one solution). The possibility of positive labeling, i.e., “does not contain NGTs”, for consumer choice is often not considered, while these markets have emerged in several countries. Some science groups also support labeling but call for complete labeling of products derived from genetic engineering. They argue that the current labeling is severely biased, as many products derived from genetically modified microorganisms are excluded from labeling. Animal products derived from animals fed with GMOs are also excluded from labeling, while sugar and oils derived from GM sugar beets and soybean and oilseed rape, respectively, need to be labeled. Some have considered this to be an inconsistency in the arguments for labeling.

Still, in our model, we assume an introduction following a logistic function with slow adoption in the early years and an adoption level of 40% after twenty years. This is a reasonable assumption, allowing retailers sufficient time to adjust their policies like what has been overserved in other markets.

Labeling costs are intricately tied to policy decisions, as different labeling frameworks impose varying financial and logistical burdens on producers and retailers. For instance, testing crop varieties rather than individual events could streamline the regulatory process. Still, they may also increase overall costs, as broader testing requires more extensive resources and infrastructure. A voluntary NGT-free label could offer flexibility, like existing GMO-free labels, allowing choice without imposing high costs across the supply chain. Such markets allow consumers to select products aligned with their preferences without imposing high costs across the entire supply chain. Additionally, the approval process for NGT-derived products plays a critical role in market dynamics; a lengthy or uncertain approval process may deter investment and delay market entry, ultimately affecting consumer access and product adoption rates. The introduction of NGT crops into the European market is anticipated to drive significant shifts in market dynamics. This adoption of NGTs is expected to enhance welfare, evidenced by the increase in market surplus. The breakdown of welfare gains shows broad benefits across stakeholders. These gains indicate that NGT crops could bring substantial economic advantages. The growth in NGT crop production is likely to come at the expense of traditional non-GM crop producers, as the production of non-GM crops and imports would decrease to compensate for the increase in NGT production. Regardless of the reduction in production, these sectors still face a positive change in welfare. The overall market is expected to benefit from the increased consumer and manufacturer welfare. These gains underscore the potential for NGT crops to create a consumer-driven shift in the market, benefiting those who adopt and integrate NGT crops into their production or consumption patterns. In summary, while NGT crops are poised to boost consumer and producer welfare significantly, they also raise competitive pressures for non-GM producers and importers.

We observe that the share of consumer surplus is greater than that of producer surplus in total surplus for maize, wheat, tomatoes, and potatoes. Only for oilseed rape the share of producer surplus is higher. This difference can be attributed to the fact that oilseed rape can be processed into many products, such as feed, biofuels, and others. However, the significant potential for consumer surplus by introducing NGT wheat, tomatoes, and potatoes may not be fully realized in practice. Our modeling approach assumes that consumers do not differentiate explicitly between NGT and non-NGT products. However, research on consumer acceptance indicates that consumers are more likely to purchase NGT products if they are offered at lower prices (Pokrivcak et al., 2024). Our modeling approach results in a price decline and does not contradict these results. Still, Casati et al. (2024) show that product labeling alternatives impact consumer purchase intentions. Most consumers have a neutral or positive view of NGTs after receiving unbiased information (Pokrivcak et al., 2024). As we assume a relatively slow adoption of NGT products over 20 years, consumer acceptance could increase enough over time.

The analysis shows that welfare benefits are generally observed across all studied crops with the introduction of NGT crops, with significant variation in surplus distribution between consumers and producers. Maize, potato, and tomato consumer surplus gains larger than producer surplus gains.

The baseline scenario, which treats NGT-derived crops similarly to conventional ones, leads to the highest total surplus increase, followed by the coexistence scenario, labeling scenario, and finally, the combined coexistence and labeling scenario, which has the strictest regulations and yields the lowest surplus. The implementation of coexistence measures, which limit the area available for certain crops, reduces producer and consumer surplus and total economic surplus. This effect is particularly notable in the case of oilseed rape, where the adoption ceiling is most significantly impacted. Additionally, while labeling costs have an upper limit, stricter labeling and traceability requirements consistently reduce welfare gains across all studied crops. As the requirements increase in stringency, the welfare gain diminishes further. When both coexistence measures and labeling and traceability requirements are applied together, the surplus gains for all crops decline even more substantially, underscoring the compounded impact of these regulatory constraints.

For maize, the largest beneficiaries are France, Germany, and Romania, while France, Germany, and Poland gain most from oilseed rape and wheat. For potatoes, Germany, Poland, and France see the highest surplus gains, and for tomatoes, Italy, Spain, and Romania benefit the most. The variations by crop are due to differing prices and coexistence impacts.

Apart from welfare gain, research has shown that accelerating the adoption of NGTs benefits both developed and developing countries with a pronounced spillover impact on food security and economic welfare, especially in China, India, and other low- and middle-income countries (Jin et al., 2024).

NGTs are not only relevant to the food sector (Trigo et al., 2023). They are also relevant to the wider circular bioeconomy and can contribute to achieving the EU Green Deal objectives. Further, they contribute to lower food prices and reduce inflationary pressures, supporting in particular low-income households.

5. Conclusions

The results show substantial welfare gains for consumers and producers in the EU if farmers are allowed to grow crops derived from NGTs and consumers are allowed to buy food products derived from those crops.

The traits currently available and under development are mainly targeted towards food quality enhancements, which provide mainly health benefits. Consumers will mainly directly benefit from such crop improvements. They have not been quantified, but research on biofortification shows those benefits can be substantial and, depending on the case, even greater than the benefits measured here using consumer surplus (Qaim, 2009; Wesseler et al., 2019; Wesseler & Zilberman, 2014). Still, the challenge of avoiding double counting in benefit assessment must be considered.

Similarly, some traits address yields via improved pest and disease resistance, drought tolerance, improved nitrogen efficiency, and more. These traits increase producer surplus and generate environmental benefits due to decreased fertilizer and pesticide use and indirect savings in land use. Indirect land use savings and reduced fertilizer and pesticide use lower the emission of greenhouse gases and have positive biodiversity effects. Over time, the producer surplus is redistributed increasingly to consumers. Hence, the reported welfare benefits are below the total benefits expected, and the consumer surplus is on the lower side. The distributional effects of these benefits among different consumer groups have not been considered. Nevertheless, as the overall price level for food will be lower, low-income households will be the main beneficiaries. Hence, considering the income distribution in the EU, particularly EU member states such as Bulgaria, Hungary, Poland, and Romania, will benefit from the introduction of NGTs.

The results show a decrease in welfare in the EU if the cultivation of crops derived from NGTs requires compliance with coexistence regulations. These costs are substantial in the case of oilseed rape and wheat. Farmers, particularly in Bulgaria and Romania, will face losses. The coexistence regulations for oilseed rape and wheat will make cultivation of NGT-derived crop varieties impossible.

Labeling and traceability requirements further increase these costs and substantially reduce the welfare benefits linked with the introduction of NGTs. Depending on the labeling policy, economic impacts can be substantial. At this point in time, there is a high level of uncertainty linked to legally acceptable labeling and traceability methods delaying the introduction of NGTs in European agriculture. The delays caused by this uncertainty are substantial, as the results of the baseline scenario show. Solving this uncertainty is expected to generate substantial welfare gains.

The adoption of NGT crops in the European market presents significant opportunities for growth. Through enhanced market efficiency with economic benefits that support both consumers and producers, the NGT crop sector could significantly contribute to the agricultural landscape, fostering value creation across the entire supply chain. This forward-looking development underscores the potential of NGTs to drive growth within the sector. NGTs are not only applied for food and feed products. They are also important for precision fermentation and derived non-food and feed products. Consumer responses are much more positive toward applications allowing the substitution of fossil-based products (Weisenfeld et al., 2023).

They can further contribute to reducing inflationary pressures on food prices and other sectors of the EU economy and increasing the competitiveness of the EU.

The results show coexistence measures and the labeling and traceability requirements potentially impact agricultural innovation, including the uptake and availability of NGT products in the EU compared to other world regions where these requirements do not apply. They act as a barrier to submitting proposals for approval for import and processing of NGTs. None of the NGT crops that have reached markets outside of the EU have been submitted for approval in the EU. Further, representatives of the companies involved have confirmed they do not envision submitting until the EU has implemented a less demanding approval system. This reduces the availability of NGTs for consumers in the EU. The coexistence measures limit the uptake of NGTs. This not only reduces options for farmers but also reduces consumer choice and negatively affects innovators currently investing in NGT products.

References

AgBiosafety. (n.d.). *Glossary of Terms*. Retrieved September 29, 2024, from https://agbiosafety.unl.edu/glossary.htm

Alston, J. M., Norton, G. W., & Pardey, P. G. (with International Service for National Agricultural Research). (1995). *Science under scarcity: Principles and practice for agricultural research evaluation and priority setting*. Cornell University Press.

Alston, J. M., & Sumner, D. A. (2012). *Proposition 37 – California food labeling initiative: Economic implications for farmers and the food industry if the proposed initiative were adopted*. https://web.archive.org/web/20120921204539/http://www.noprop37.com/files/Alston-Sumner-Prop-37-review.pdf

Beckmann, V., Soregaroli, C., & Wesseler, J. (2006). Coexistence Rules and Regulations in the European Union. *American Journal of Agricultural Economics*, *88*(5), 1193–1199. https://doi.org/10.1111/j.1467-8276.2006.00932.x

Beckmann, V., Soregaroli, C., & Wesseler, J. (2011). Chapter 8 Coexistence of Genetically Modified (GM) and Non-Modified (non-GM) crops: Are the Two Main Property Rights Regimes Equivalent with Respect to the Coexistence Value? In *Genetically Modified Food and Global Welfare* (world; Vol. 10, pp. 201–224). Emerald Group Publishing Limited. https://doi.org/10.1108/S1574-8715(2011)0000010013

Bennett, A. B., Chi-Ham, C., Barrows, G., Sexton, S., & Zilberman, D. (2013). Agricultural Biotechnology: Economics, Environment, Ethics, and the Future. *Annual Review of Environment and Resources*, *38*(1), 249–279. https://doi.org/10.1146/annurev-environ-050912-124612

bioPress. (2023, November 14). *Neue Gentechnik: Aldi und Rewe für Kennzeichnung, Lidl und Edeka für Deregulierung*. https://www.biopress.de/de/inhalte/details/9619/neue-gentechnik-aldi-und-rewe-fuer-kennzeichnung-lidl-und-edeka-fuer-deregulierung.html

Black, J., Hashimzade, N., & Myles, G. D. (2017). *A Dictionary of Economics*. Oxford University Press.

Bovay, J., & Alston, J. M. (2018). GMO food labels in the United States: Economic implications of the new law. *Food Policy*, *78*, 14–25. https://doi.org/10.1016/j.foodpol.2018.02.013

Canadian Seed Growers' Association. (n.d.). *Identity Preservation and Traceability*. Retrieved October 8, 2024, from https://seedgrowers.ca/food-processors/identity-preservation-and-traceability/

Casati, M., Varacca, A., & Soregaroli, C. (2024). *Impact of Alternative Regulatory Labeling Requirements on Consumer Purchase Intentions for Processed Foods Derived from New Genomic Techniques* [For CropLife Europe]. Università Cattolica del Sacro Cuore, Department of Agricultural and Food Economics.

Castellari, E., Soregaroli, C., Venus, T. J., & Wesseler, J. (2018). Food processor and retailer non-GMO standards in the US and EU and the driving role of regulations. *Food Policy*, *78*, 26–37. https://doi.org/10.1016/j.foodpol.2018.02.010

Čechura, L., Jamali Jaghdani, T., & Samoggia, A. (2020). *Imperfections in Italian Tomato Food Chain*. https://doi.org/10.22004/AG.ECON.305591

Cloutier, M. (2006). *Études économiques sur les coûts relatifs à l'étiquetage des filières génétiquement modifiées (GM) versus non-GM au niveau québécois* [In French only]. Quebec Department of Agriculture, Fisheries and Food (MAPAQ). https://www.mapaq.gouv.qc.ca/fr/Publications/EtudeOGMMAPAQoct2006.pdf

de Leon, A., Manalo, A., & Guilatco, F. C. (2004). The Cost Implications of GM Food Labeling in the Philippines. *Crop Biotech Brief*, *4*(2).

Demont, M., Daems, W., Dillen, K., Mathijs, E., Sausse, C., & Tollens, E. (2008). Regulating coexistence in Europe: Beware of the domino-effect! *Ecological Economics*, *64*(4), 683–689. https://doi.org/10.1016/j.ecolecon.2007.10.016

Demont, M., Dillen, K., Daems, W., Sausse, C., Tollens, E., & Mathijs, E. (2009). On the proportionality of EU spatial ex ante coexistence regulations. *Food Policy*, *34*(6), 508–518. https://doi.org/10.1016/j.foodpol.2009.04.003

Devaux, A., Goffart, J.-P., Kromann, P., Andrade-Piedra, J., Polar, V., & Hareau, G. (2021). The Potato of the Future: Opportunities and Challenges in Sustainable Agri-food Systems. *Potato Research*, *64*(4), 681–720. https://doi.org/10.1007/s11540-021-09501-4

Dolgopolova, I., & Roosen, J. (2018). Competitive niche in milk pricing: Analyzing price dynamics of GMO-free, organic, and conventional milk in Germany during 2009–2010. *Food Policy*, *78*, 51–57. https://doi.org/10.1016/j.foodpol.2018.02.006

EFSA. (n.d.). *Glossary*. Retrieved October 31, 2024, from https://www.efsa.europa.eu/en/glossary-taxonomy-terms

ENGA. (2024). *Non-GMO Soy—Non-GMO Maize—Non-GMO Rapeseed* (Market Report 01/November). https://www.donausoja.org/wp-content/uploads/2024/02/non-GM_Multicrop_Market_Report.pdf

European Commission. (n.d.-a). *Appeal committees—European Commission*. Retrieved October 31, 2024, from https://food.ec.europa.eu/horizontal-topics/committees/appeal-committees_en

European Commission. (n.d.-b). *GMOs—European Commission*. Retrieved October 1, 2024, from https://joint-research-centre.ec.europa.eu/scientific-activities-z/gmos_en

European Commission. (n.d.-c). *New techniques in biotechnology*. Retrieved October 31, 2024, from https://food.ec.europa.eu/plants/genetically-modified-organisms/new-techniques-biotechnology_en

European Commission. (n.d.-d). *PAFF committees*. Retrieved October 31, 2024, from https://food.ec.europa.eu/horizontal-topics/committees/paff-committees_en

European Commission. (2006a). *Commission staff working document—Annex to the Communication from the Commission to the Council and the European Parliament—Report on the implementation of national measures on the coexistence of genetically modified crops with conventional and organic farming {COM(2006) 104}*. https://eur-lex.europa.eu/legal-content/SV/ALL/?uri=CELEX:52006SC0313

European Commission. (2006b). *Report on the implementation of national measures on the coexistence of genetically modified crops with conventional and organic farming* (COM(2006) 104 Final). https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0104:FIN:EN:PDF

European Commission. (2023). *Potential, Challenges, and Threats for the Application of New Breeding Techniques by the Private Plant Breeding Sector in the EU* [Accompanying the document proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on plants obtained by certain new genomic techniques and their food and feed, and amending Regulation (EU) 2017/625. SWD(2023) 412 final].

European Commission. (2024). *Monitoring EU agri-food trade.* [Dataset]. https://agridata.ec.europa.eu/extensions/FADNPublicDatabase/FADNPublicDatabase.html

European Union. (2003, September 22). *Regulation (EC) No 1830/2003 of the European Parliament and of the Council of 22 September 2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC*. http://data.europa.eu/eli/reg/2003/1830/oj/eng

Eurostat. (2024a). *Comext* [Dataset]. https://ec.europa.eu/eurostat/comext/newxtweb/submitresultsextraction.do

Eurostat. (2024b). *Crop production in EU standard humidity* [Dataset]. https://ec.europa.eu/eurostat/databrowser/product/page/APRO_CPSH1

Eurostat. (2024c). *Selling prices of crop products (absolute prices)—Annual price (from 2000 onwards)* [Dataset]. Eurostat. https://doi.org/10.2908/APRI_AP_CRPOUTA

Falck-Zepeda, J. B., Traxler, G., & Nelson, R. G. (2000). Rent creation and distribution from biotechnology innovations: The case of bt cotton and Herbicide-Tolerant soybeans in 1997. *Agribusiness*, *16*(1), 21–32. https://doi.org/10.1002/(SICI)1520-6297(200024)16:1<21::AID-AGR3>3.0.CO;2-F

FAO. (2001). *Glossary of Biotechnology for Food and Agriculture—A Revised and Augmented Edition of the Glossary of Biotechnology and Genetic Engineering*. https://www.fao.org/4/y2775e/y2775e00.htm#Contents

FAO. (2022). *Gene editing and agrifood systems*. FAO. https://openknowledge.fao.org/handle/20.500.14283/cc3579en

Food & Water Watch. (2015). *How Much Will Labeling Genetically Engineered Foods Really Cost?* https://foodandwaterwatch.org/wp-content/uploads/2021/03/GMO-Labeling-Cost-FS-Jan-2015.pdf

Food Compliance International. (2020). *Regulation and Labelling of Genetically Modified Food in China*. https://foodcomplianceinternational.com/industry-insight/news/1220-regulation-and-labelling-of-genetically-modified-food-in-china

Food Standards Australia New Zealand. (2023). *Genetically modified (GM) food labelling*. https://www.foodstandards.gov.au/consumer/gmfood/labelling

Furtan, W. H., Güzel, A., & Weseen, A. S. (2007). Landscape Clubs: Co-existence of Genetically Modified and Organic Crops. *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie*, *55*(2), 185–195. https://doi.org/10.1111/j.1744-7976.2007.00087.x

Gabriel, A., & Menrad, K. (2014). The Costs of GM and Non-GM Co-existence in Processed Food Systems – Demonstrated for the Cases of the German Supply Chains of Chocolate and Frozen Pizza. *Journal of Agricultural & Food Industrial Organization*, *12*(1), 141–158. https://doi.org/10.1515/jafio-2013-0013

GAIN. (2022). *Agricultural Biotechnology Annual* (Biotechnology and Other New Production Technologies AR2022-0023; Country: Argentina). https://fas.usda.gov/data/argentina-agricultural-biotechnology-annual-6

GAIN. (2023a). *Agricultural Biotechnology Annual – Romania* (BU2023-0015). United States Department of Agriculture. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Agricultural%20Biotechnology%20Annual_Sofia_Bulgaria_BU2023-0015.pdf

GAIN. (2023b). *Agricultural Biotechnology Annual – Romania* (BU2023-0010). United States Department of Agriculture.

https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Agricultural+Biotechnology+Annual_Bucharest_Romania_RO2023-0010.pdf

Gawron, J.-C., & Theuvsen, L. (2008). Kosten der Verarbeitung gentechnisch veränderter Organismen: Eine Analyse am Beispiel der Raps- und Maisverarbeitung. *Proceedings "Schriften Der Gesellschaft Für Wirtschafts- Und Sozialwissenschaften Des Landbaues e.V.," 43*. https://ideas.repec.org//a/ags/gewipr/259633.html

Goffart, J.-P., Haverkort, A., Storey, M., Haase, N., Martin, M., Lebrun, P., Ryckmans, D., Florins, D., & Demeulemeester, K. (2022). Potato Production in Northwestern Europe (Germany, France, the Netherlands, United Kingdom, Belgium): Characteristics, Issues, Challenges and Opportunities. *Potato Research*, *65*(3), 503–547. https://doi.org/10.1007/s11540-021-09535-8

Government of Canada. (2021). *Voluntary labelling and advertising of foods that are and are not products of genetic engineering*. https://publications.gc.ca/collections/collection_2021/ongc-cgsb/P29-32-315-2021-eng.pdf

Groeneveld, R. A., Wesseler, J., & Berentsen, P. B. M. (2013). Dominos in the dairy: An analysis of transgenic maize in Dutch dairy farming. *Ecological Economics*, *86*, 107–116. https://doi.org/10.1016/j.ecolecon.2012.11.011

Ihle, R., & Wesseler, J. (2024). *Ontwikkelingen rond gg-voedsel in de Nederlandse winkelschappen—Marketing patterns of genetically modified food in Dutch grocery stores*. Wageningen University. https://doi.org/10.18174/660236

Jongeneel, R., & Gonzalez-Martinez, A. R. (2020). Estimating crop yield supply responses to be used for market outlook models: Application to major developed and developing countries. *NJAS: Wageningen Journal of Life Sciences*, *92*(1), 1–13. https://doi.org/10.1016/j.njas.2020.100327

Just, R. E., Hueth, D. L., & Schmitz, A. (2004). *The Welfare Economics of Public Policy: A Practical Approach to Project and Policy Evaluation*. Edward Elgar Publishing Ltd.

Kalaitzandonakes, N., Alston, J. M., & Bradford, K. J. (2007). Compliance costs for regulatory approval of new biotech crops. *Nature Biotechnology*, *25*(5), 509–511. https://doi.org/10.1038/nbt0507-509

Kalaitzandonakes, N., Phillips, P. W. B., Wesseler, J. H. H., & Smyth, S. J. (2016). *The Coexistence of Genetically Modified, Organic and Conventional Foods: Government Policies and Market Practices*. Springer. https://doi.org/10.1007/978-1-4939-3727-1

Kolodinsky, J., & Lusk, J. L. (2018). Mandatory labels can improve attitudes toward genetically engineered food. *Science Advances*, *4*(6), eaaq1413. https://doi.org/10.1126/sciadv.aaq1413

KPMG. (2000). *Phase 1 Report. Economic Impact Study: Potential Costs of Mandatory Labeling of Food Products Derived from Biotechnology in Canada* (Appendix A; p. A-1).

Lesser, W. (2014). *Costs of labelling Genetically Modified Food Products in N. Y. State*. Cornell University. https://publications.dyson.cornell.edu/docs/LabelingNY.pdf

Lusk, J., Blaustein-Rejto, D., Shah, S., & Tonsor, G. T. (2021). Impact of Plant-Based Meat Alternatives on Cattle Inventories and Greenhouse Gas Emissions. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3961790

Maltsbarger, R., & Kalaitzandonakes, N. (2000). Direct and Hidden Costs in Identity Preserved Supply Chains. *AgBioForum*, *3*(4), 236–242.

Menrad, K., Gabriel, A., & Gylling, M. (Eds.). (2009). *COSTS OF CO-EXISTENCE AND TRACEABILITY SYSTEMS IN THE FOOD INDUSTRY IN GERMANY AND DENMARK*. https://doi.org/10.22004/ag.econ.91301

Miraglia, M., Berdal, K. G., Brera, C., Corbisier, P., Holst-Jensen, A., Kok, E. J., Marvin, H. J. P., Schimmel, H., Rentsch, J., Van Rie, J. P. P. F., & Zagon, J. (2004). Detection and traceability of genetically modified organisms in the food production chain. *Food and Chemical Toxicology*, *42*(7), 1157–1180. https://doi.org/10.1016/j.fct.2004.02.018

Nantel, L. (2016). *What would be the costs of enacting mandatory GMO labelling regulations in Quebec?* Vigilance. https://www.ourcommons.ca/Content/Committee/421/AGRI/WebDoc/WD8559103/421_AGRI_reldoc_PDF/AGRI_VigilanceOGM_GMA-e.pdf

Paarlberg, R. (2009). *Starved for Science: How Biotechnology Is Being Kept Out of Africa* (1st edition). Harvard University Press.

Pokrivcak, J., Rajcaniova, M., & Lazorcakova, E. (2024). *Report on consumer and stakeholder acceptance of NGTs* (Deliverable 1.2). GeneBEcon. https://genebecon.eu/wp-content/uploads/2024/10/GeneBEcon_Deliverable1.2.pdf

Punt, M. J., & Wesseler, J. (2018). The Formation of GM-free and GM Coasean Clubs: Will They Form and If So How Much Can They Achieve? *Journal of Agricultural Economics*, *69*(2), 413–438. https://doi.org/10.1111/1477-9552.12235

Qaim, M. (2009). The Economics of Genetically Modified Crops. *Annual Review of Resource Economics*, *1*(1), 665–694. https://doi.org/10.1146/annurev.resource.050708.144203

Qaim, M. (2016). *Genetically Modified Crops and Agricultural Development*. Palgrave Macmillan US.

Ryan, C. D., & Smyth, S. J. (2012). Economic implications of low-level presence in a zero-tolerance European import market: The case of Canadian Triffid flax. *AgBioForum*, *15*.

Skevas, T., Fevereiro, P., & Wesseler, J. (2010). Coexistence regulations and agriculture production: A case study of five Bt maize producers in Portugal. *Ecological Economics*, *69*(12), 2402–2408. https://doi.org/10.1016/j.ecolecon.2010.07.007

Smart, R. D., Blum, M., & Wesseler, J. (2015). EU member states' voting for authorizing genetically engineered crops: A regulatory gridlock. *German Journal of Agricultural Economics*, *64*(4), 244–262.

Smart, R. D., Blum, M., & Wesseler, J. (2017). Trends in Approval Times for Genetically Engineered Crops in the United States and the European Union. *Journal of Agricultural Economics*, *68*(1), 182–198. https://doi.org/10.1111/1477-9552.12171

Thomson, J. A. (2002). *Genes for Africa: Genetically Modified Crops in the Developing World*. Juta and Company Ltd.

Tolstrup, K., Andersen, S. B., Boelt, B., Buus, M., Gylling, M., Holm, P. B., Kjellsson, G., Pedersen, S., Østergård, H., & Mikkelsen, S. A. (2003). Report from the Danish Working Group on the Co-existence of Genetically Modified Crops with Conventional and Organic Crops. In *Report from the*

Danish Working Group on the Co-existence of Genetically Modified Crops with Conventional and Organic Crops [Report]. Danish Institute of Agricultural Sciences.

Trigo, E., Chavarria, H., Pray, C., Smyth, S. J., Torroba, A., Wesseler, J., Zilberman, D., & Martinez, J. F. (2023). The Bioeconomy and Food System Transformation. In J. Von Braun, K. Afsana, L. O. Fresco, & M. H. A. Hassan (Eds.), *Science and Innovations for Food Systems Transformation* (pp. 849–868). Springer International Publishing. https://doi.org/10.1007/978-3-031-15703-5_45

USDA. (n.d.). *Rapeseed Meal*. Retrieved October 31, 2024, from https://fas.usda.gov/data/production/commodity/0813600

USDA. (2018, December 21). *National Bioengineered Food Disclosure Standard*. Federal Register. https://www.federalregister.gov/documents/2018/12/21/2018-27283/national-bioengineered-food-disclosure-standard

Venus, T. J., Drabik, D., & Wesseler, J. (2018). The role of a German multi-stakeholder standard for livestock products derived from non-GMO feed. *Food Policy*, *78*, 58–67. https://doi.org/10.1016/j.foodpol.2018.02.009

Weisenfeld, U., Hauerwaas, A., Elshiewy, O., Halder, P., Wesseler, J., Cingiz, K., & Broer, I. (2023). Beyond plastic – Consumers prefer food packaging derived from genetically modified plants. *Research Policy*, *52*(10), 104883. https://doi.org/10.1016/j.respol.2023.104883

Wesseler, J., & Kalaitzandonakes, N. (2019). Present and Future EU GMO Policy. In L. Dries, W. Heijman, R. Jongeneel, K. Purnhagen, & J. Wesseler (Eds.), *EU Bioeconomy Economics and Policies: Volume II* (pp. 245–256). Springer International Publishing. https://doi.org/10.1007/978-3-030-28642-2_13

Wesseler, J., Politiek, H., & Zilberman, D. (2019). The Economics of Regulating New Plant Breeding Technologies—Implications for the Bioeconomy Illustrated by a Survey Among Dutch Plant Breeders. *Frontiers in Plant Science*, *10*, 1597. https://doi.org/10.3389/fpls.2019.01597

Wesseler, J., & Zilberman, D. (2014). The economic power of the Golden Rice opposition. *Environment and Development Economics*, *19*(6), 724–742. https://doi.org/10.1017/S1355770X1300065X

Westerman, L. (2017). Digging Up the Dirt: China's Exploitation of Transgenic Seed Approvals. *University of Colorado Law Review*, *88*(3), 765–805.

Wohlgenant, M. K. (2011). Consumer Demand and Welfare in Equilibrium Displacement Models. In J. L. Lusk, J. Roosen, & J. F. Shogren (Eds.), *The Oxford Handbook of the Economics of Food Consumption and Policy* (pp. 291–318). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199569441.013.0012

A) Appendix

A.1) Data sources

The following sections show figures of the development of the cultivated area, harvested products, and yields of maize, oilseed rape, wheat, potato, and tomato from 2000 to 2023 downloaded from Eurostat (2024b). The data for the figures on imports and exports is downloaded from the Comext database by Eurostat (2024a).

A.2) Statistics on maize production and trade in the EU

Eurostat classifies two major maize products:

- Grain maize and corn-cob-mix,
- Green maize.

We will follow this classification throughout the analysis. Note that we have the following subsections:

- Harvested production,
- Yield.

A.2.1) Grain maize and corn-cob-mix:

The harvested production in the EU was 62.1 million tons in 2023. The total harvested production fluctuates between 50 to 70 million tons throughout the years. The top 5 major

Figure 11: Grain maize and corn-cob-mix area EU 2000-2023 (1000 ha).

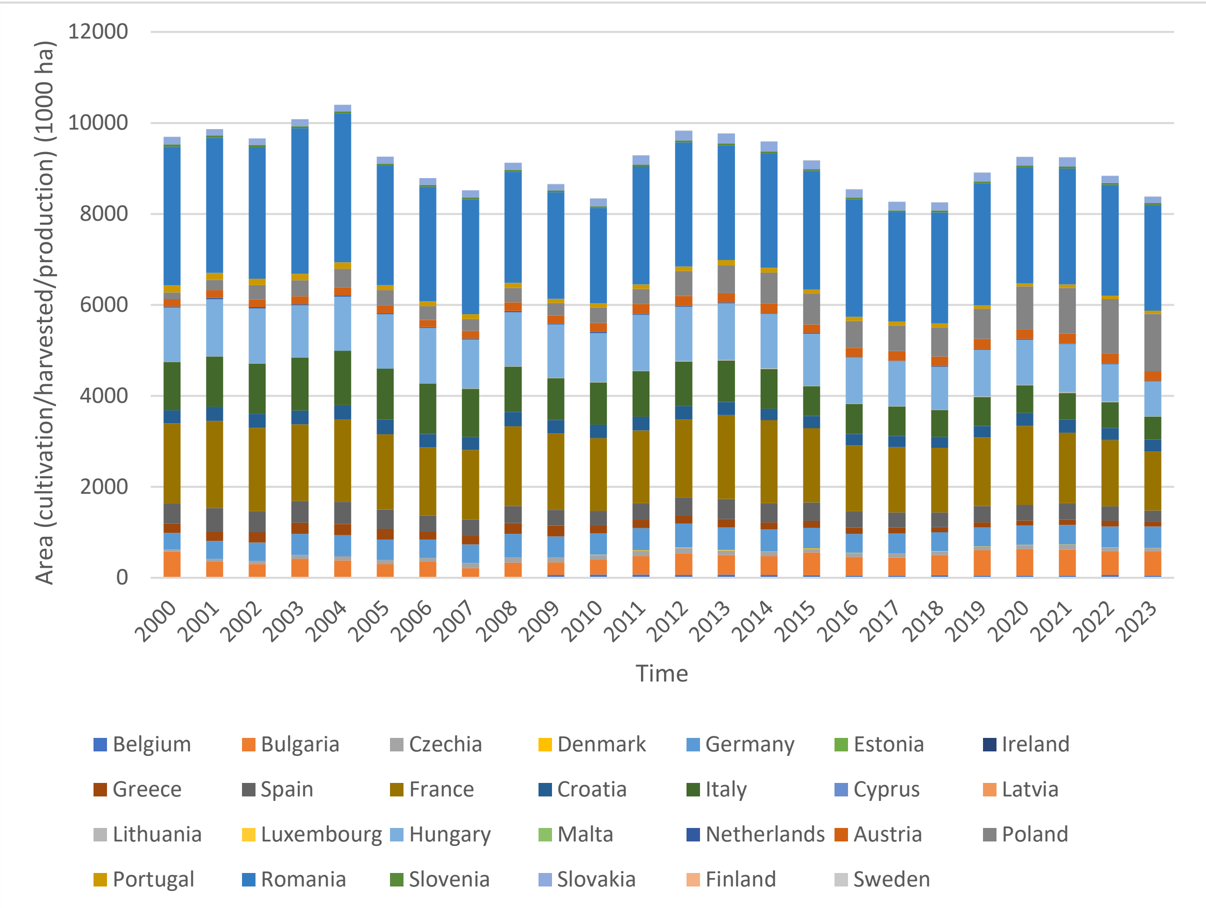
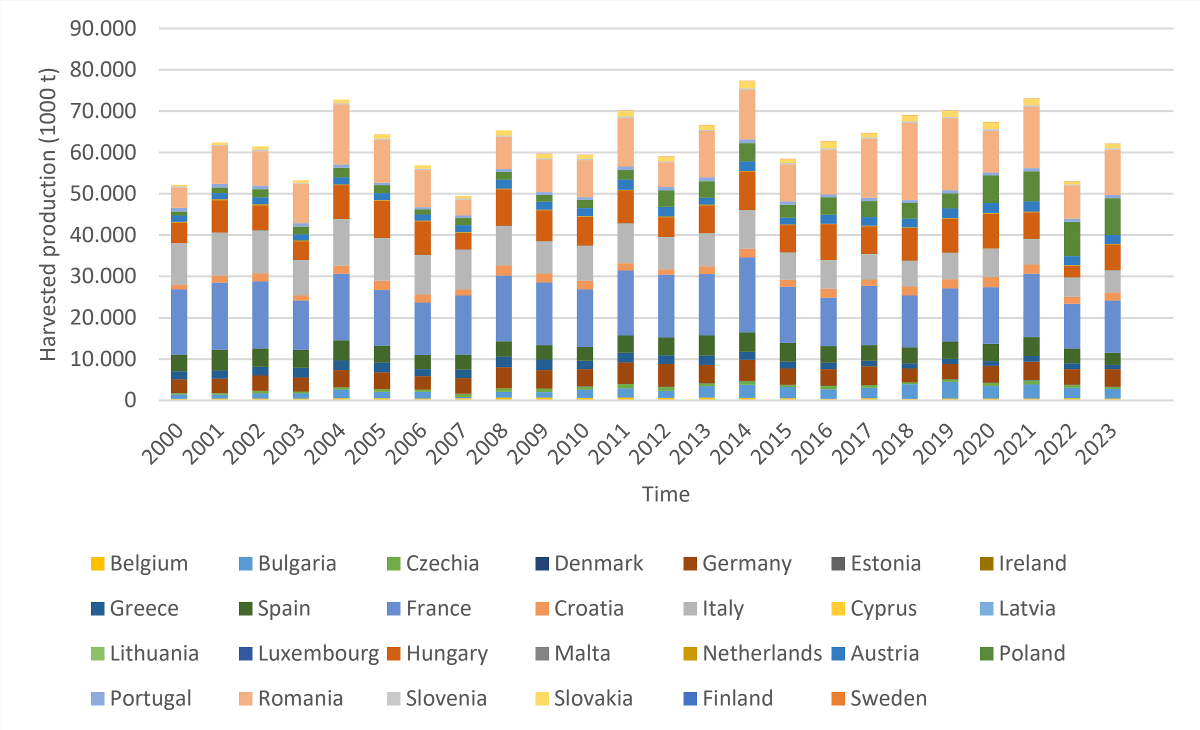


Figure 12: Grain maize and corn-cob-mix harvested production in the EU from 2000 to 2023.



producers are France, Romania, Italy, Hungary, and Germany, which represent 63 percent of the production and together constitute 39.4 million tons of the harvested production of Grain maize and corn-cob-mix in 2023. The harvested production peaked at 77.3 million (EU 27) in 2014, and the lowest production boundary was in 2015 at 58.4 million tons (EU 27).

Since there is missing data before 2010 for most of the countries, we cannot make an analysis over that period of time. After 2010, we have the following observations regarding the yield. Grain maize and corn-cob-mix yield in the EU was, on average, 6.4 tons per ha in 2023 for EU27. The yield values fluctuate between 5 to 7 tons per hectare throughout the years. The top 5 major producers are Spain, Greece, Austria, Italy, and Germany, which represent 35% of the yield and together constitute 60.8 tons per hectare of the yield of grain maize and corn-cob-mix in 2023. The yield values peaked at 182.9 tons/ha (EU 27) in 2021, and the lowest production boundary was in the year 2013 at 150.1 tons/ha (EU 27).

Figure 13: Grain maize and corn-cob-mix yield in the EU from 2000 to 2023.

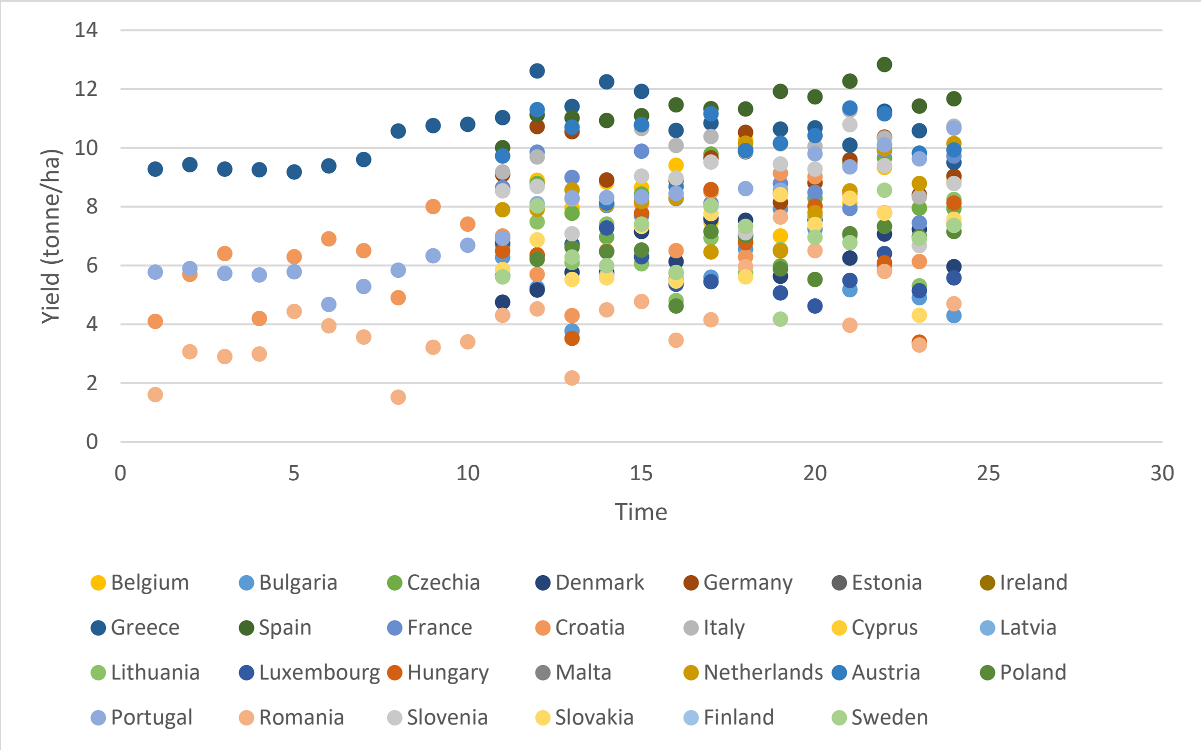
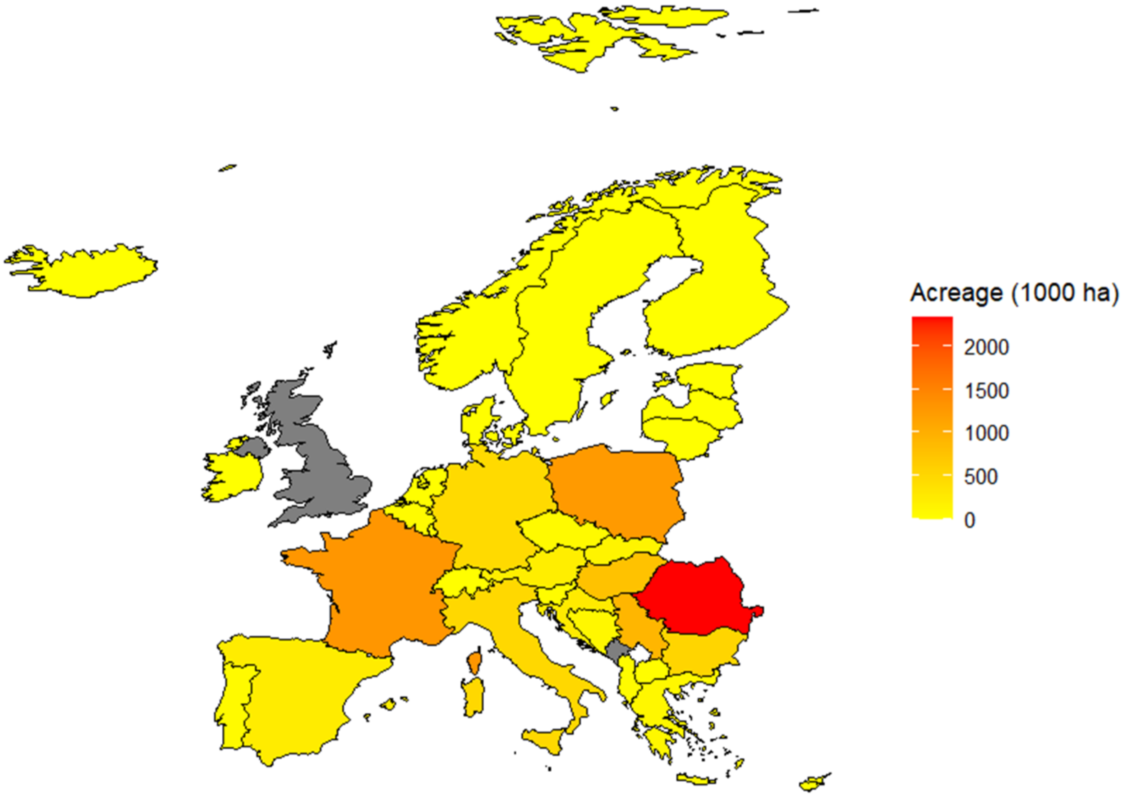
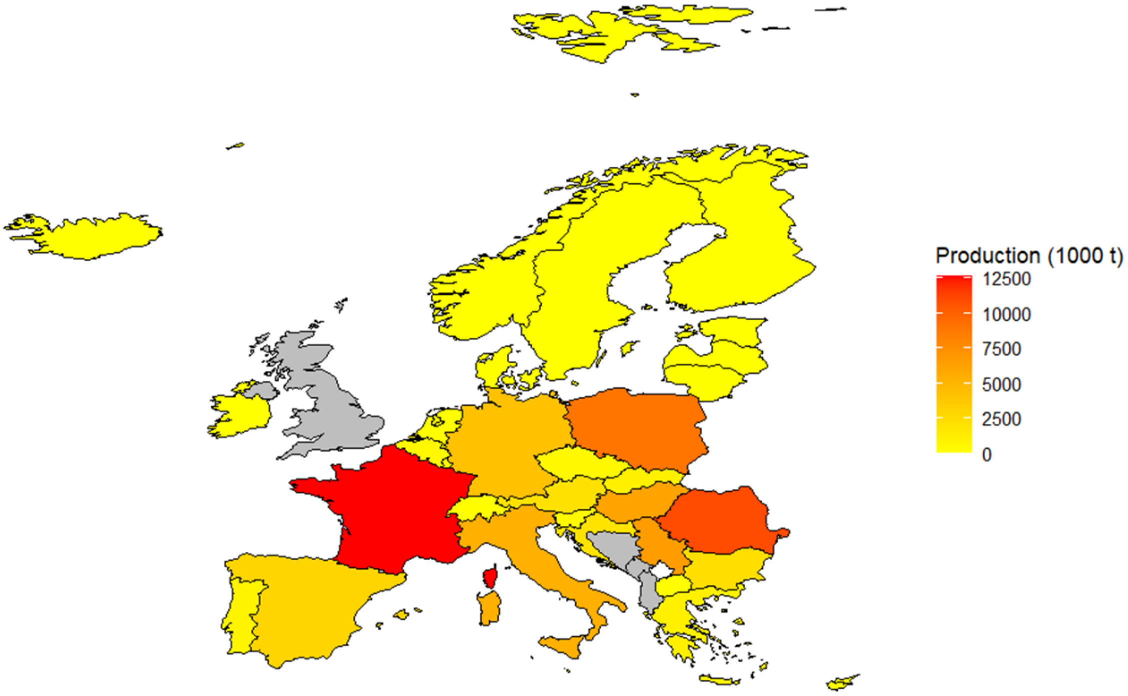
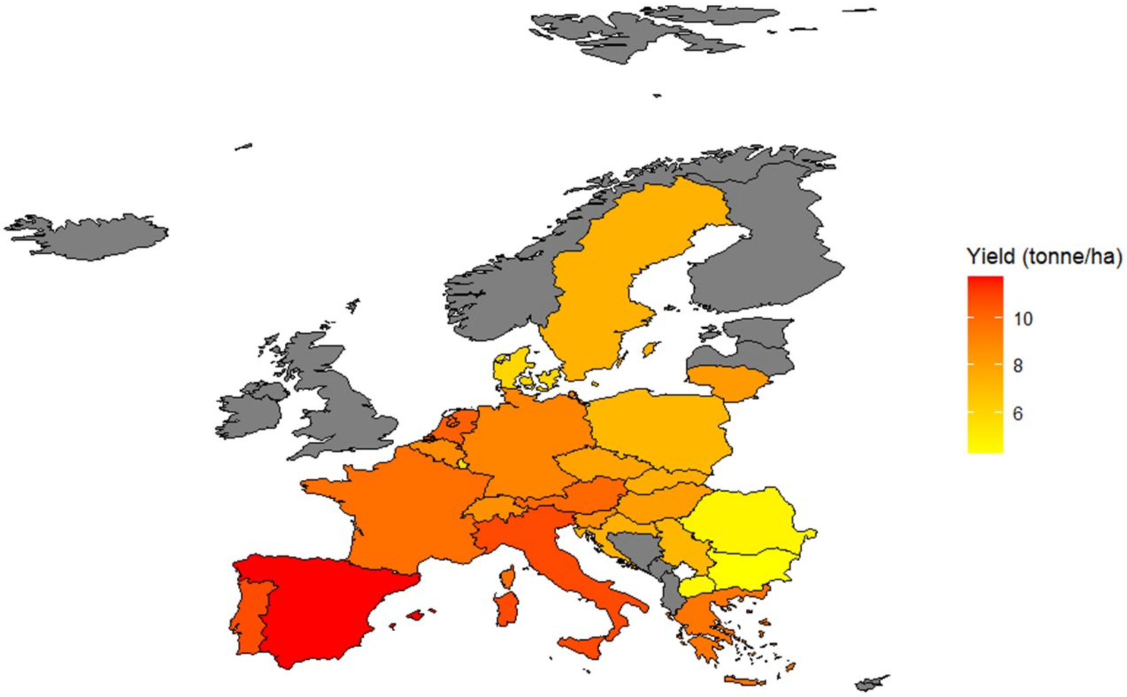


Figure 14: Acreage, production, and yield of grain ,aize in EU-27 in 2023.







A.2.2) Green Maize

The harvested production in the EU was 237 million tons in 2023. The total harvested production fluctuates between 150 mil-270 mil throughout the years. The top 5 major producers are Germany, France, Poland, Italy, and the Netherlands, which represent 78% of the production with together constitute 185 million tons of the harvested production of Green maize in 2023. The harvested production peaked at 269.2 million (EU 27) in 2021, and the lowest production boundary was in the year 2022, with 218.2 million tons (EU 27).

Since there is missing data before 2010 for most of the countries, we cannot make an analysis over that period of time. After 2010, we have the following observations regarding the yield. Green maize yield in the EU was 1041,1 tons per ha in 2023 for EU27. The yield values fluctuate between 700 to 1000 tons/ha throughout the years. The top 5 major producers are Cyprus, Denmark, Ireland, Netherlands, and Slovenia, which represent 31% of the yield and together constitute 322.5 tons per hectare of the yield of Green maize in 2023. The yield values peaked at 1041.1 ton/ha (EU 27) in 2023, and the lowest production boundary was in the year 2013 at 747.4 ton/ha (EU 27).

Figure 15: Green maize area EU 2000-2024 (1000 ha).

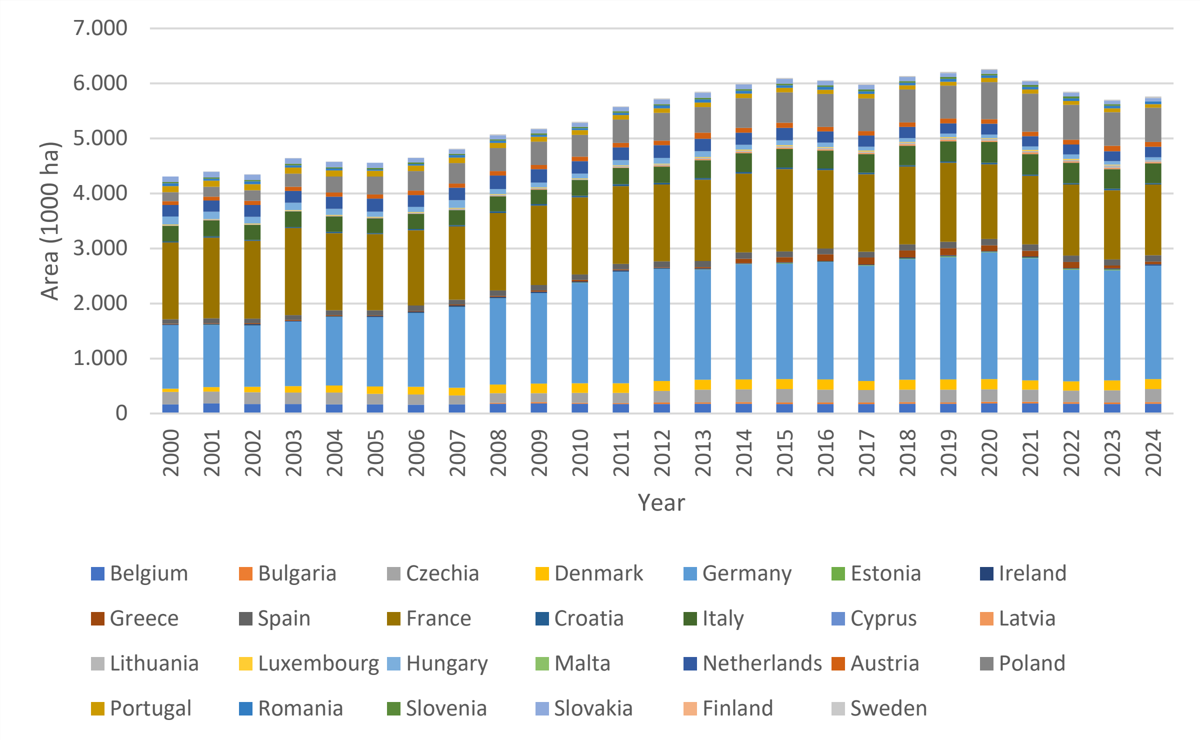


Figure 16: Green maize harvested production 2000-2023.

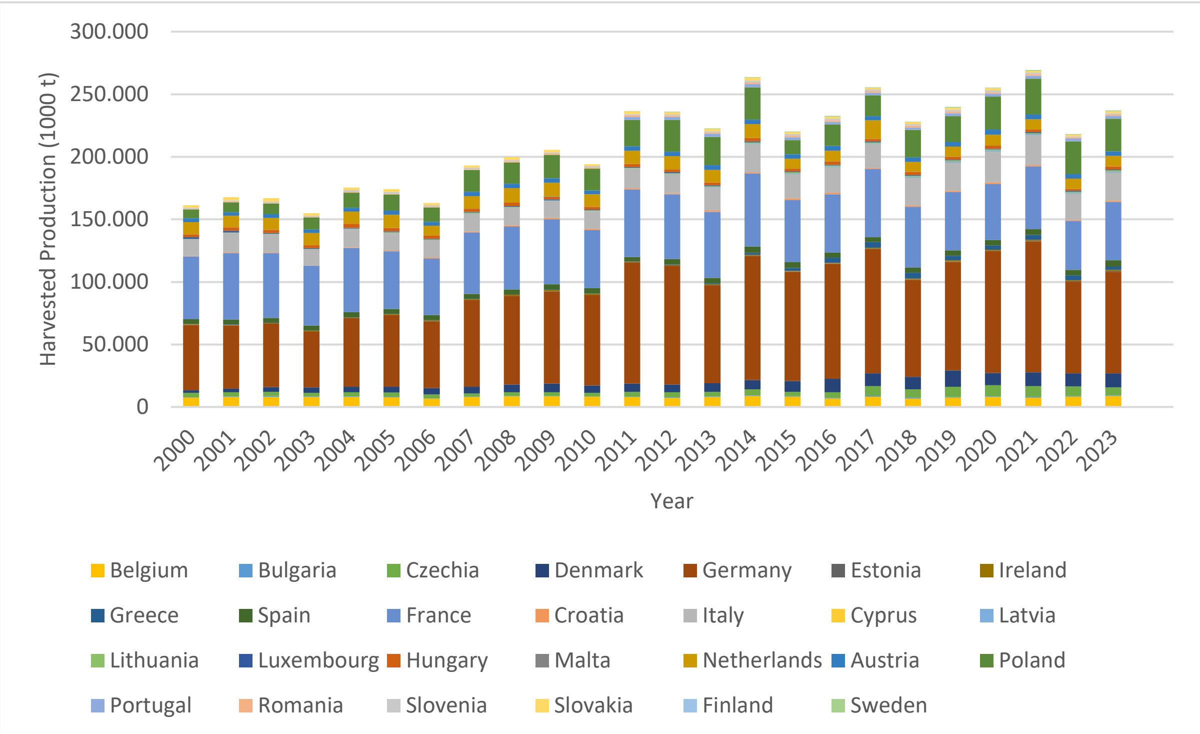
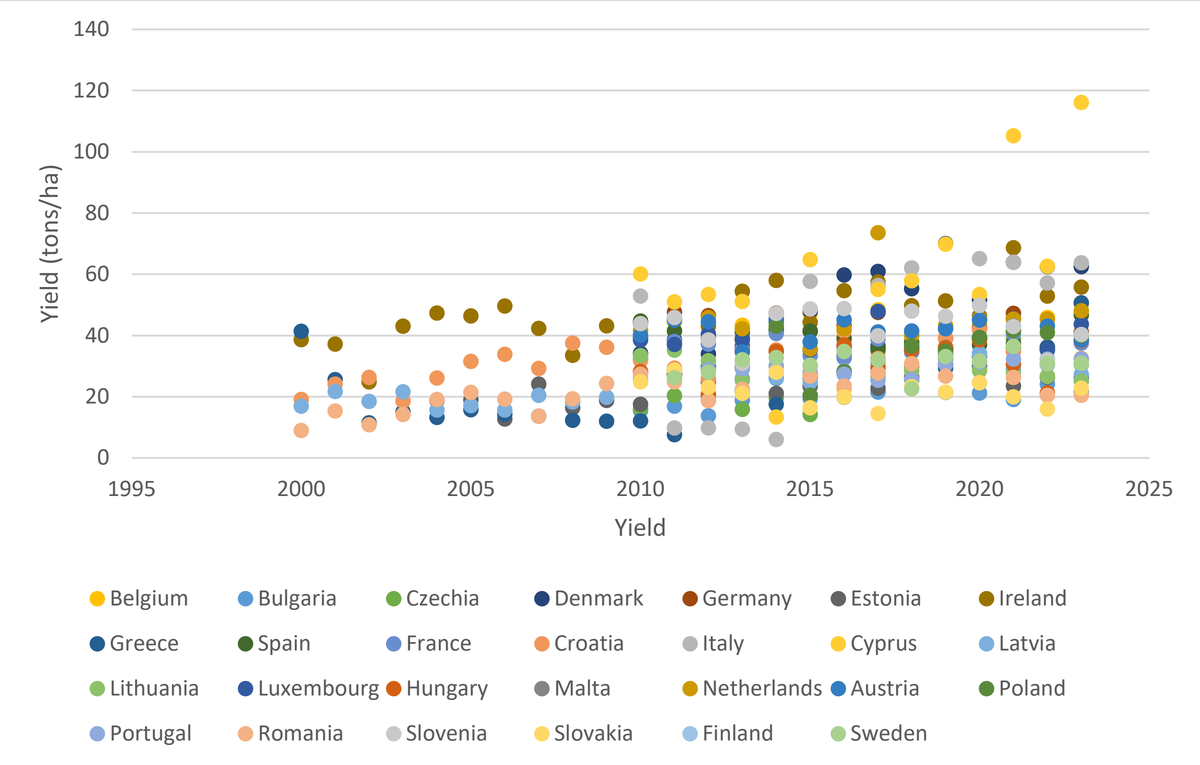
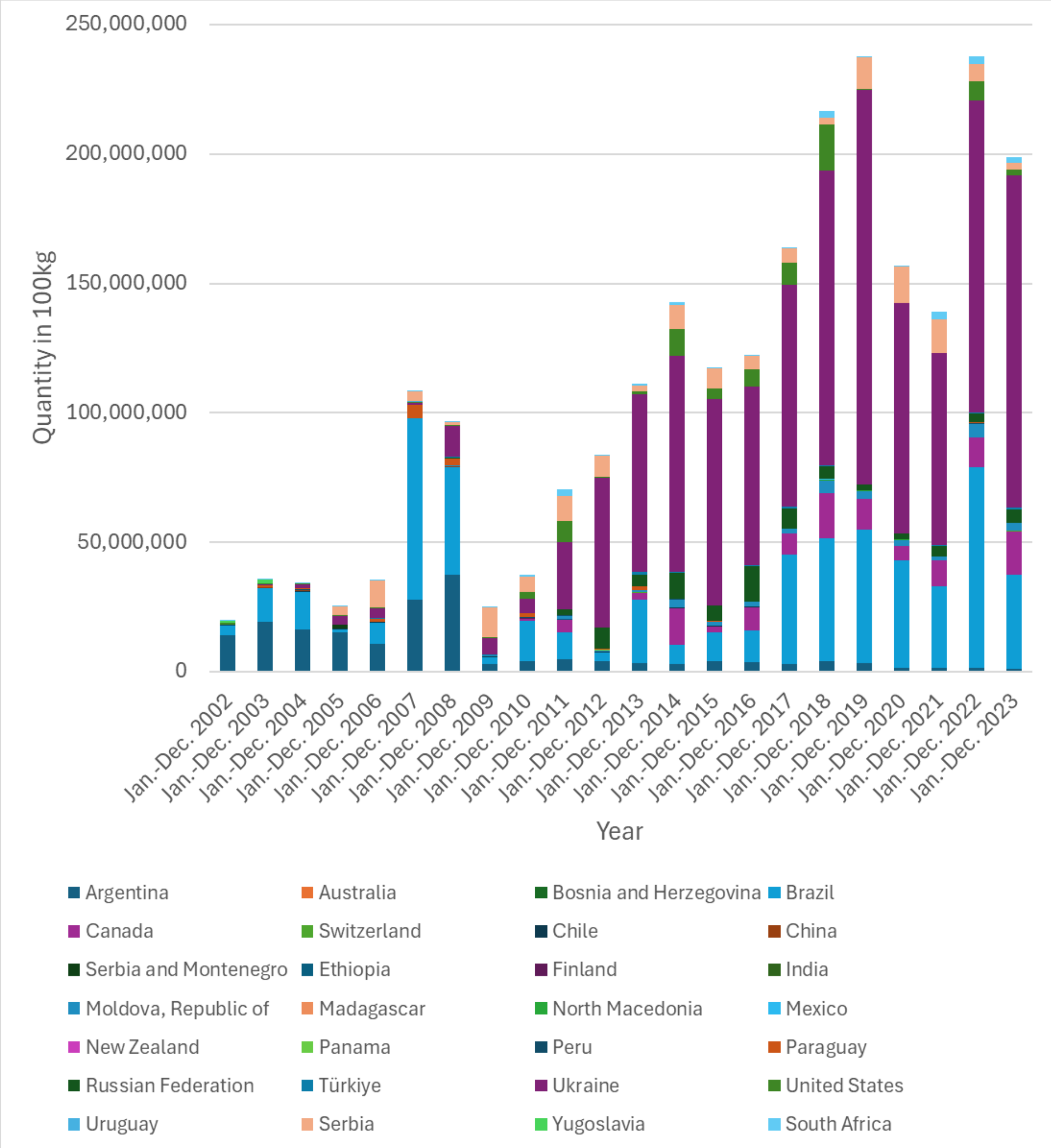


Figure 17: Green maize yield in the EU from 2000 to 2023.



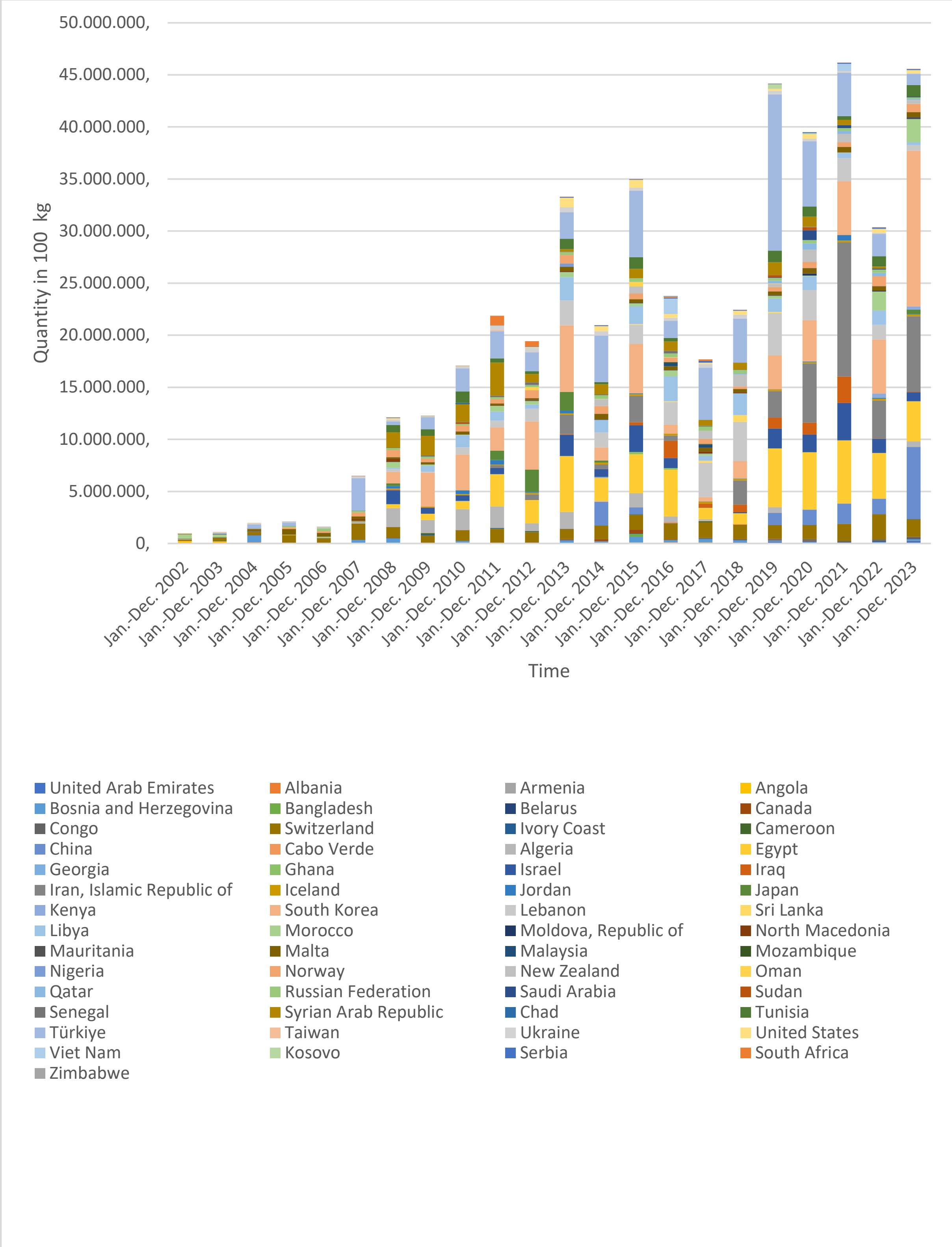
In 2023, the EU has imported 20 million tons of maize from the rest of the world. This is 3.9 million tons of maize less than in 2022 when the EU imported 23.9 million tons of maize, and 18 million tons more than in 2002 when the EU imported 2 million tons of maize. On the other hand, the EU exported 4.5 million tons of maize in 2023, which is 1.5 million tons more than in 2022 and 44 million tons more than they exported in 2000, which was 0.09 million tons of maize.

Figure 18: Import of Maize by the EU from 2002 to 2023.



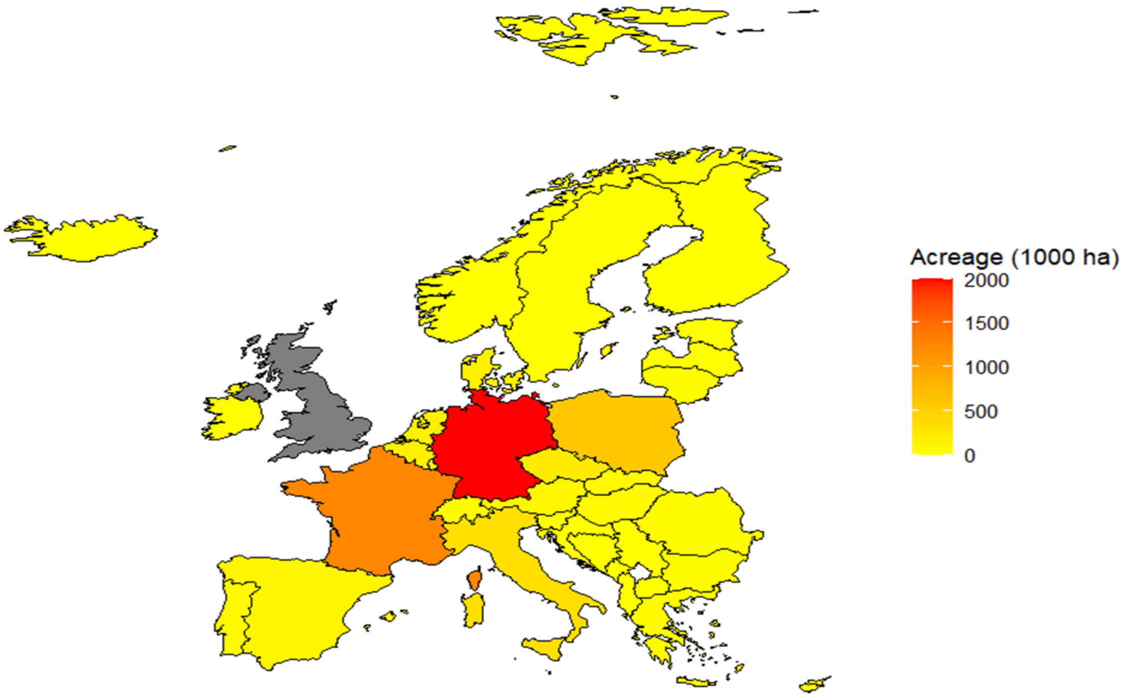
Note: This graph only includes countries with more than 10000 tons in total.

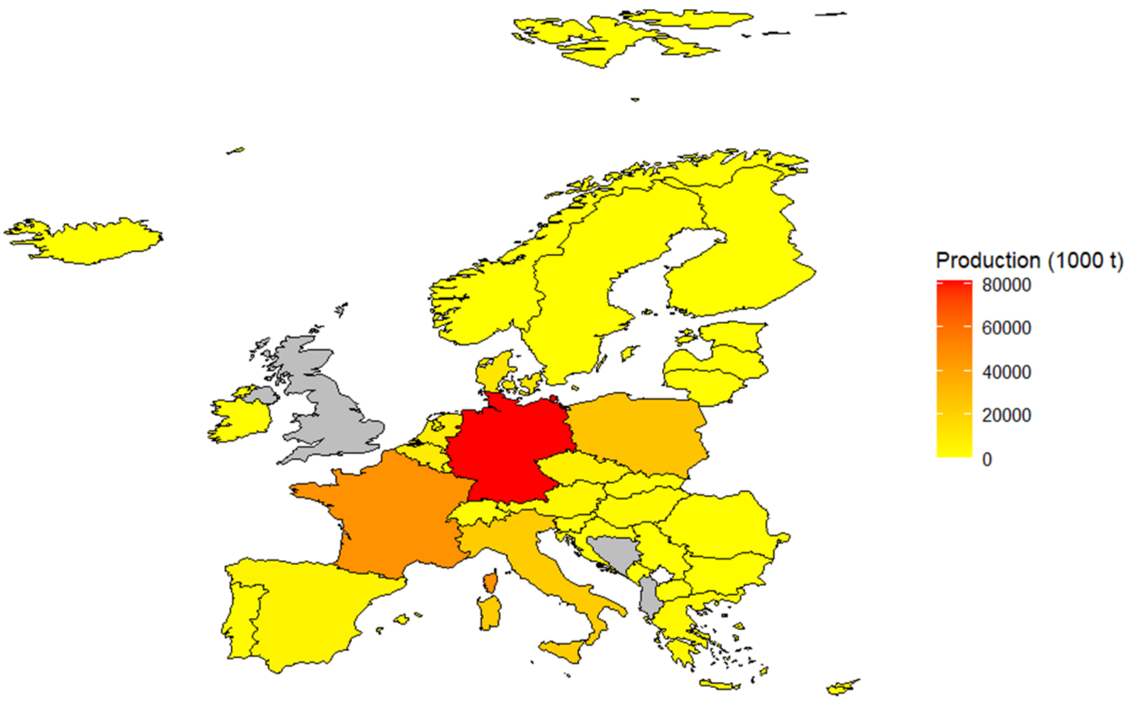
Figure 19: Export of maize by the EU from 2002 to 2023.

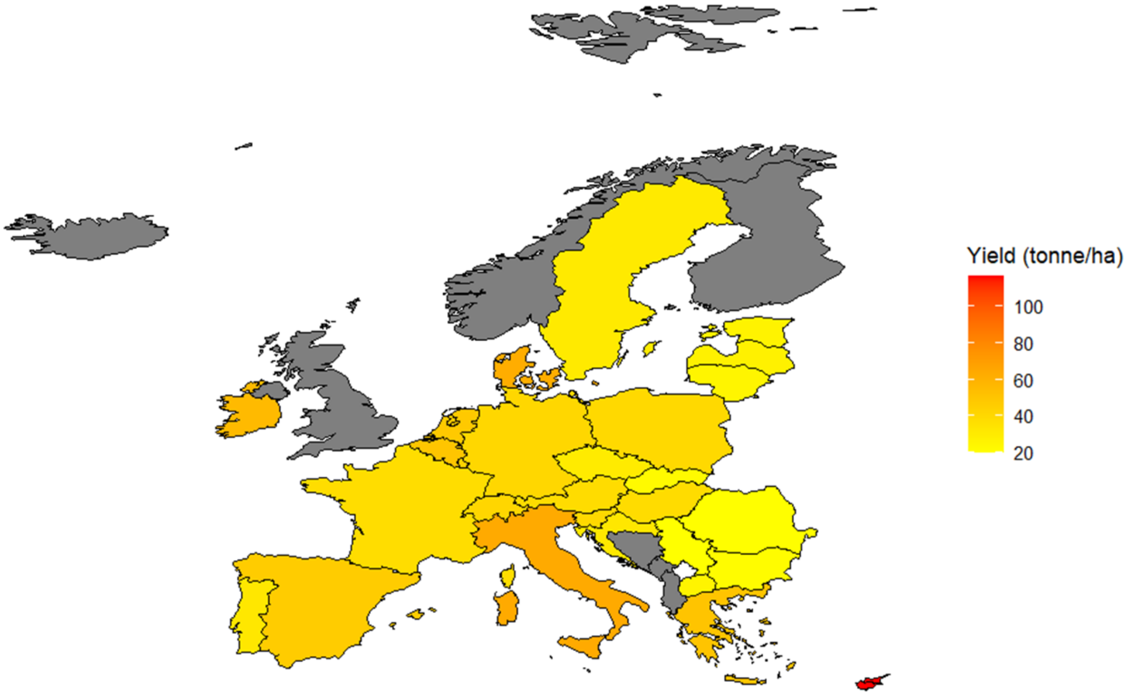


Note: This graph only includes countries with more than 10000 tons in total .

Figure 20: Acreage, production, and yield of green maize in EU-27 in 2023.






Yield (tonne/ha)
100
80
60
40
20

A.3) Statistics on Oilseed Rape Production and Trade in the EU

The harvested product in the European Union was 19.7 million tons in 2023. This is about 9.5 billion tons more than in the year 2000 when production was 10.2 million tons. The increase mostly happened from 2000 to 2009, and afterward, the level of production is fluctuating.

Figure 22: Rape and turnip rape seeds harvested production in EU (1000 t).

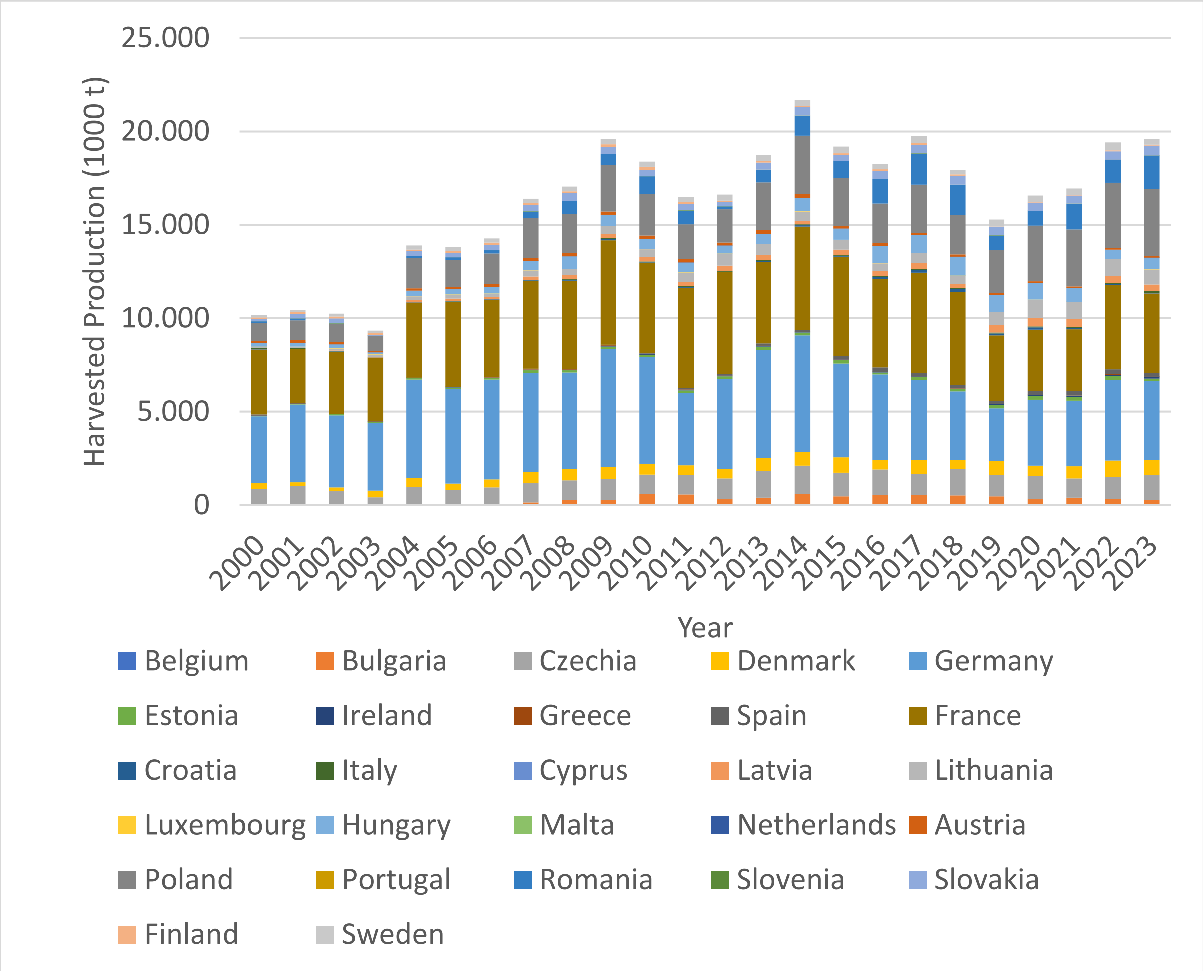
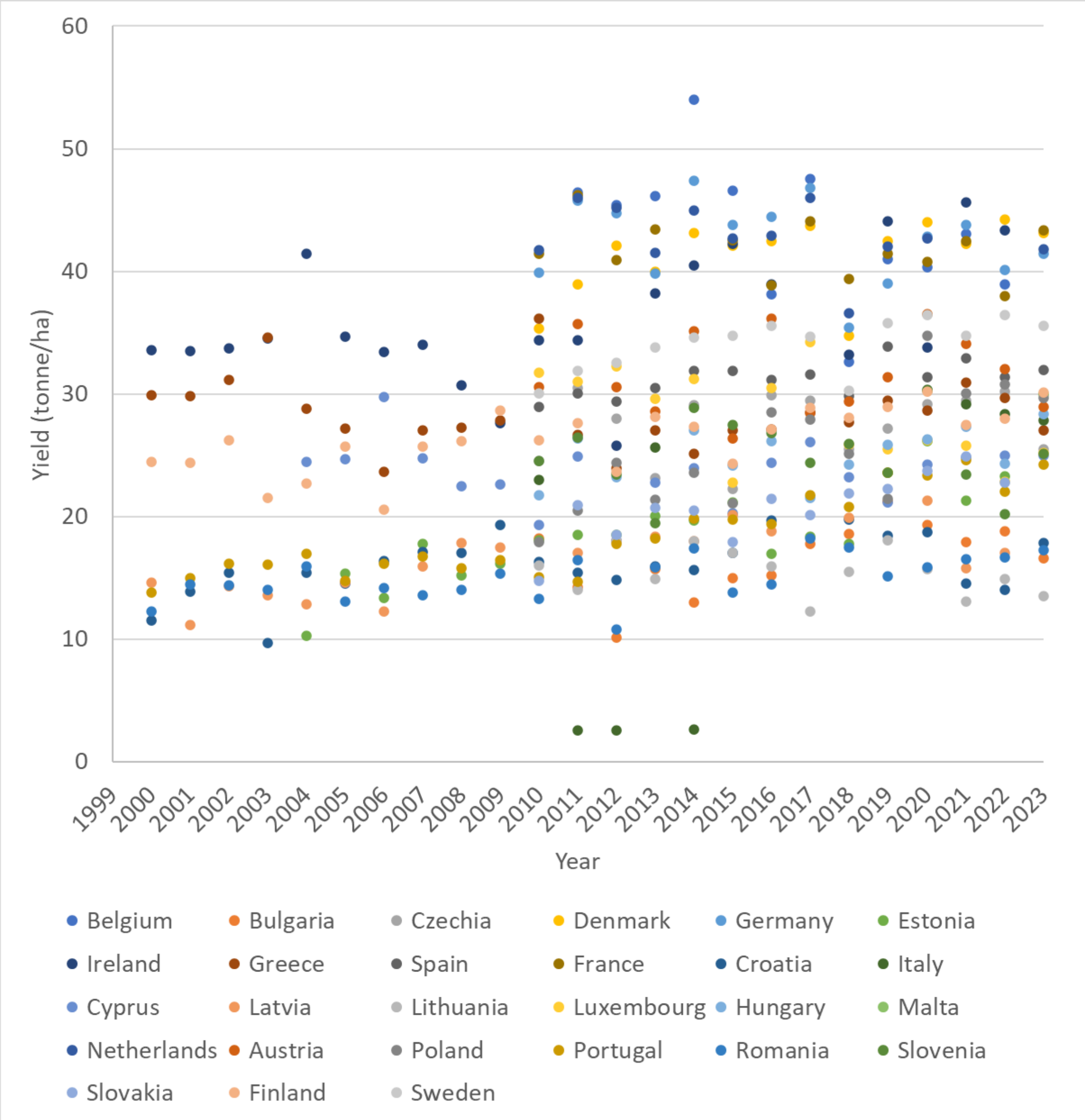


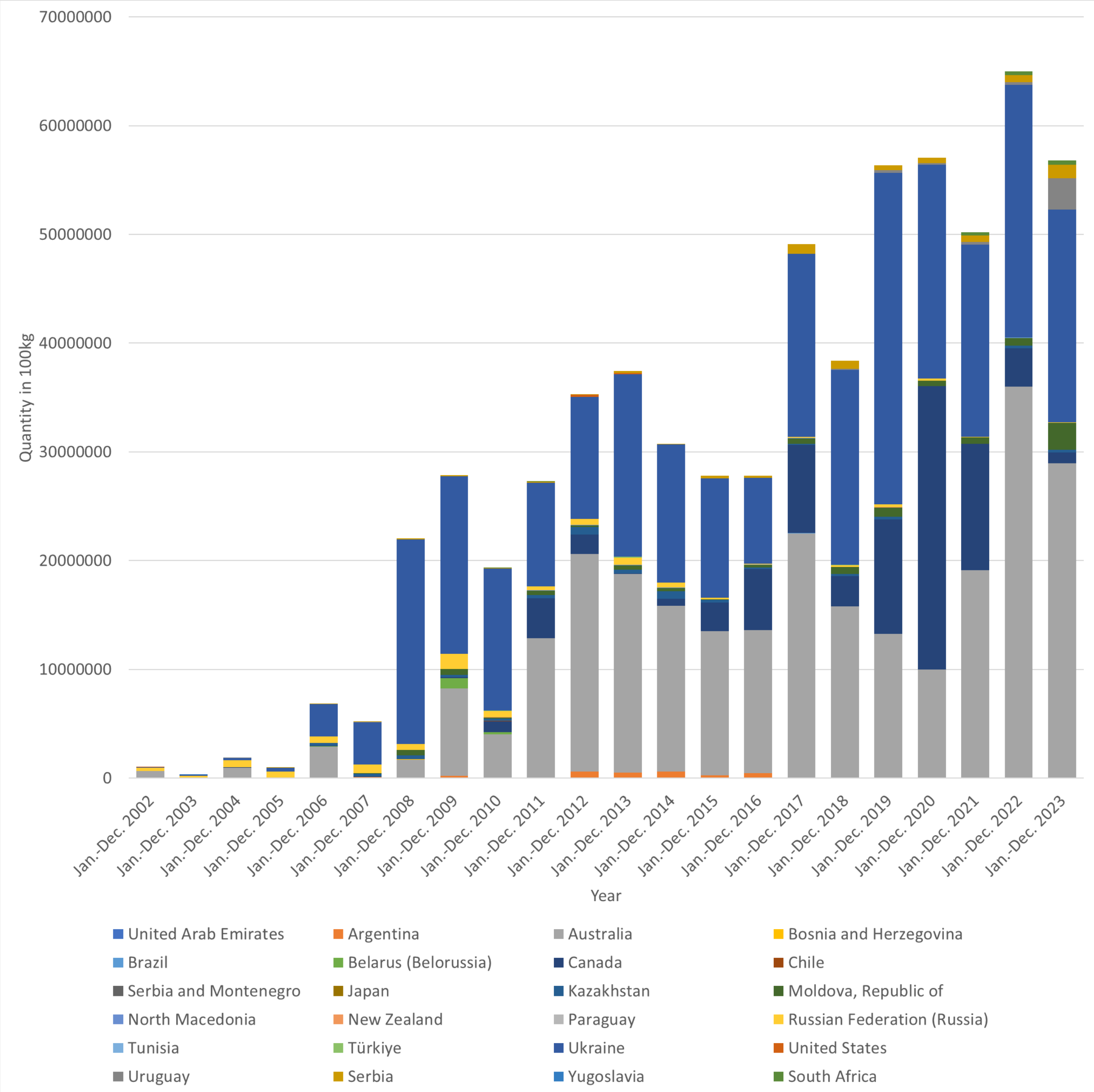
Figure 23: Rape and turnip rape seeds yield in EU (tons/ha).



The production area in the European Union was 6.2 million tons in 2023. This is about 9.5 billion tons more than in the year 2000 when the production area was 4.1 billion tons. The increase mostly happened from 2000 to 2010, and afterward, the level of production is fluctuating.

The main producers of oilseed rape in the EU are France, Germany and Poland. In 2023, these three countries accounted for 58% of soya production in the EU. France has the highest oilseed rape production in the EU, with 1.3 million tons of oilseed rape produced in 2023.

Figure 24: Import of rape or colza seeds by the EU from 2002 to 2023.

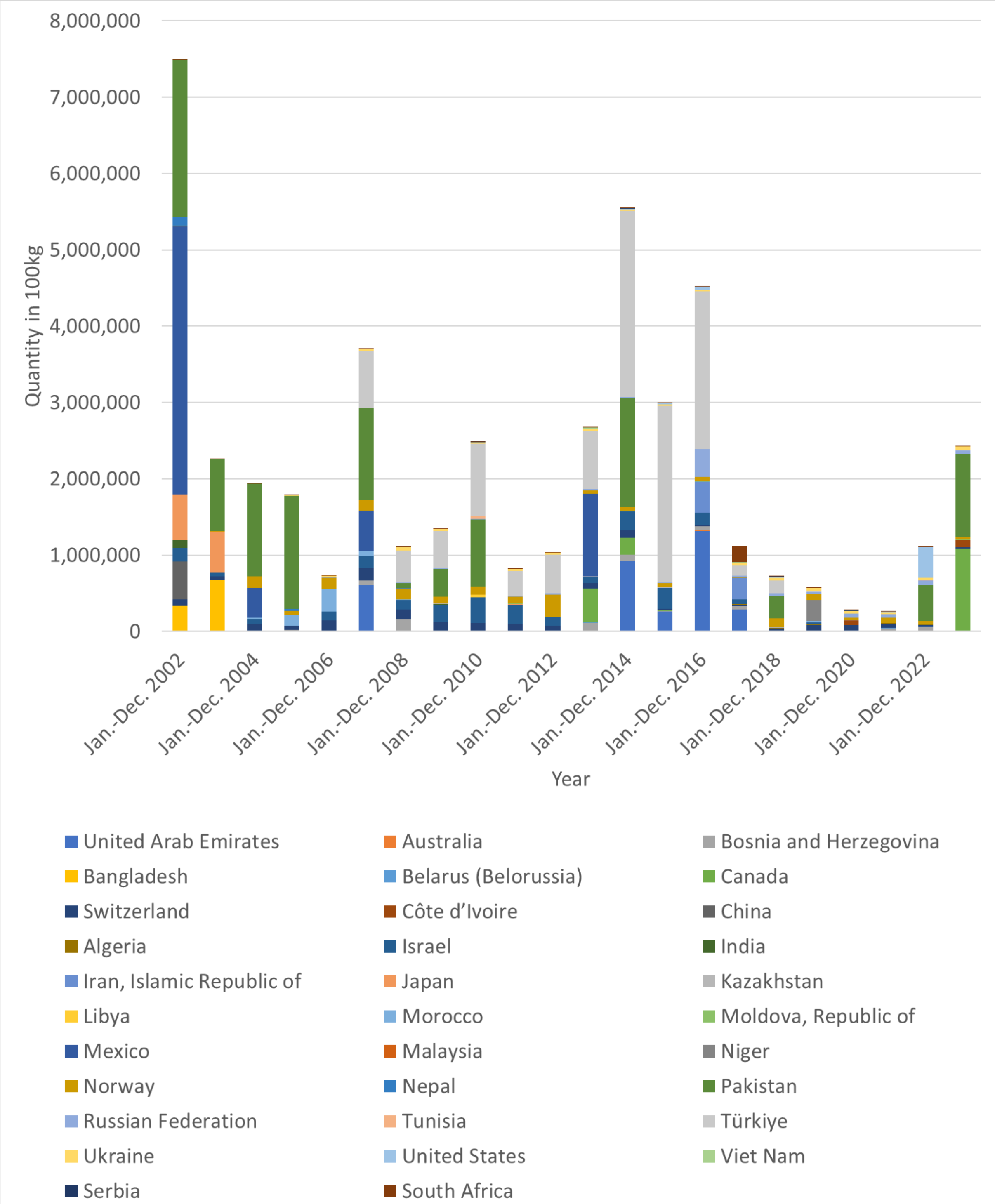


Note: This graph only includes countries with more than 1000 tons in total.

In 2023 the EU has imported 5.7 million tons of oilseed rape from the rest of the world. This is 0.8 million tons of potatoes less than in 2022, when the EU imported 6.5 million tons of potatoes. On the other hand, the EU exported 0.2 million tons of oilseed rape in 2023, which is 0.1 million tons more than in 2022.

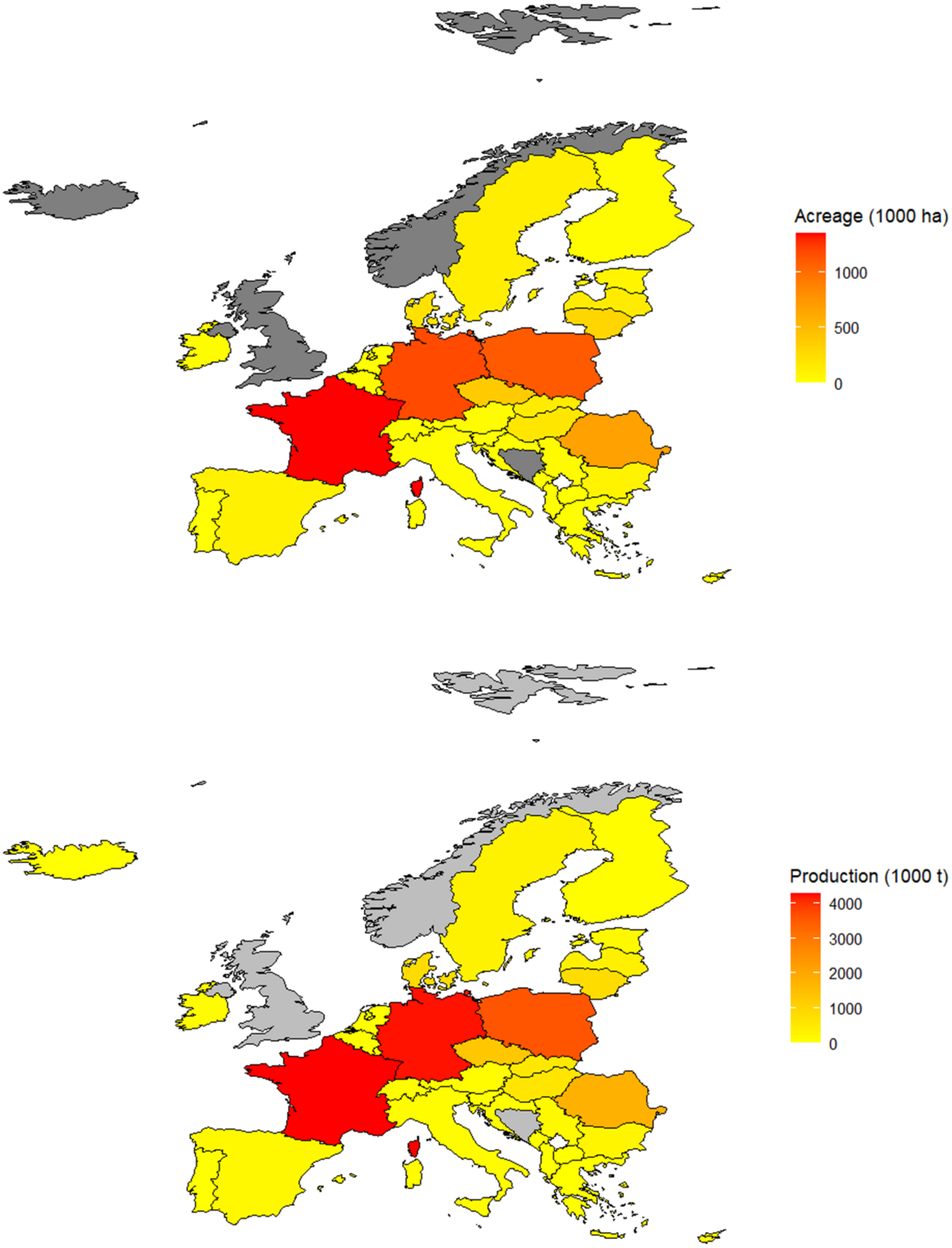
The EU's main Imports come from Australia, from which it imported 2.9 million tons of oilseed rape in 2023, and Ukraine, from which it imported 1.9 million tons of oilseed rape in 2023. Its main exports go to Canada and Pakistan, each producing 0.1 million tons.

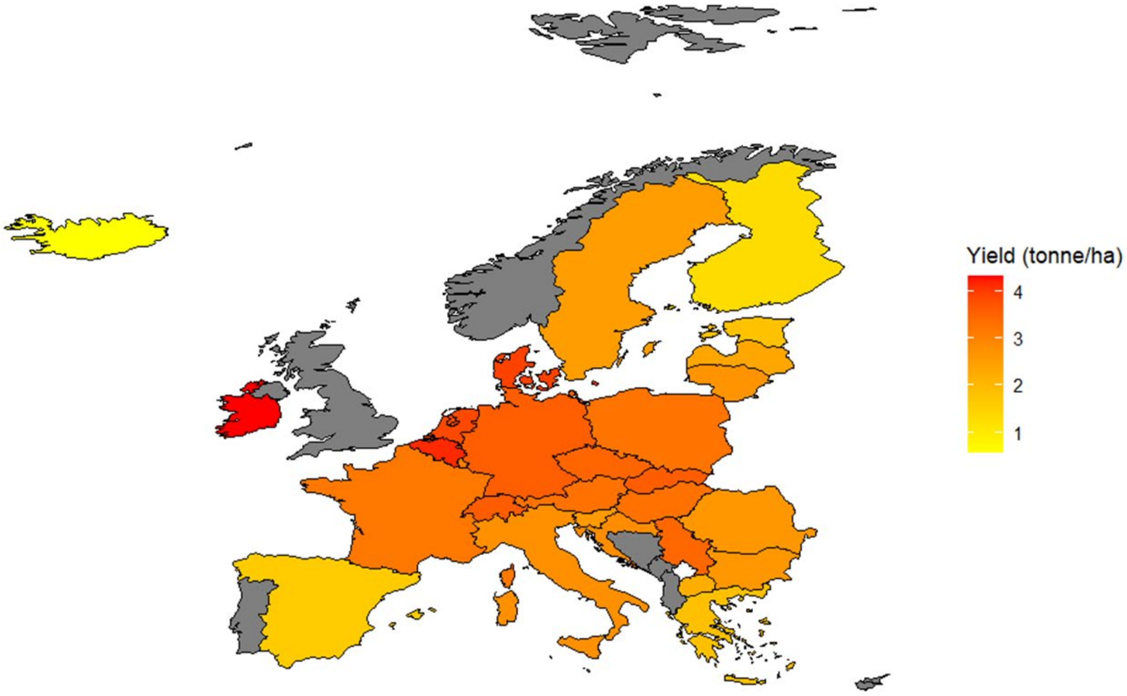
Figure 25: Export of rape or colza seeds by the EU from 2002 to 2023.



Note: This graph only includes countries with more than 1000 tons in total.

Figure 26: Acreage, production, and yield of oilseed rape in EU-27 in 2023



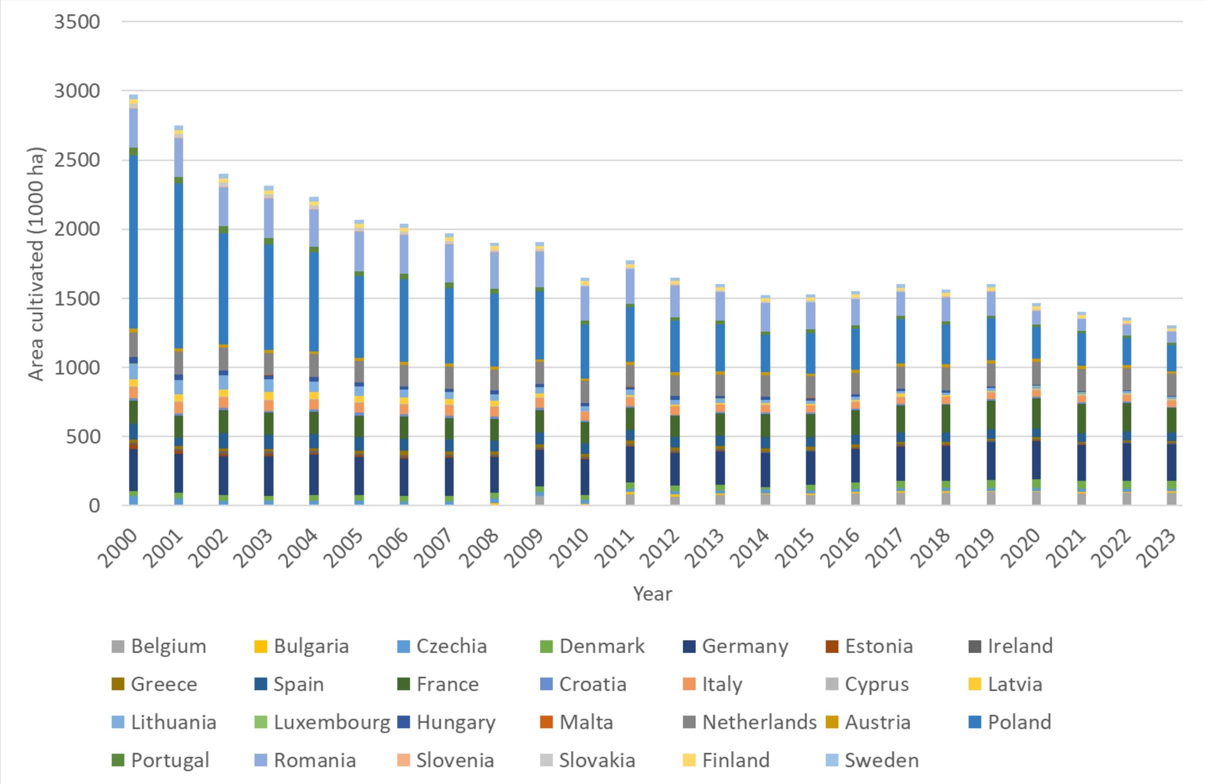


A.4) Statistics on Potato Production and Trade in the EU

The harvested production in the European Union was 46.2 million tons in 2020. This is about 30 million tons less than in the year 2000 when production was 76.2 million tons. The production of potatoes has been declining throughout the years and has reached its lowest point in 2023, with 46.2 million tons of potatoes produced.

The potato area in the EU has been in a long-term decline. The area cultivated to produce potatoes more than halved between 2000 (3 million hectares) and 2023 (1.3 million hectares). Especially in Poland, the area cultivated has dramatically decreased from 1.25 million hectares in 2000 to 186 thousand hectares in 2023, decreasing by more than 1 million hectares.

Figure 27: Area cultivated with potatoes in the EU from 2000 to 2023.

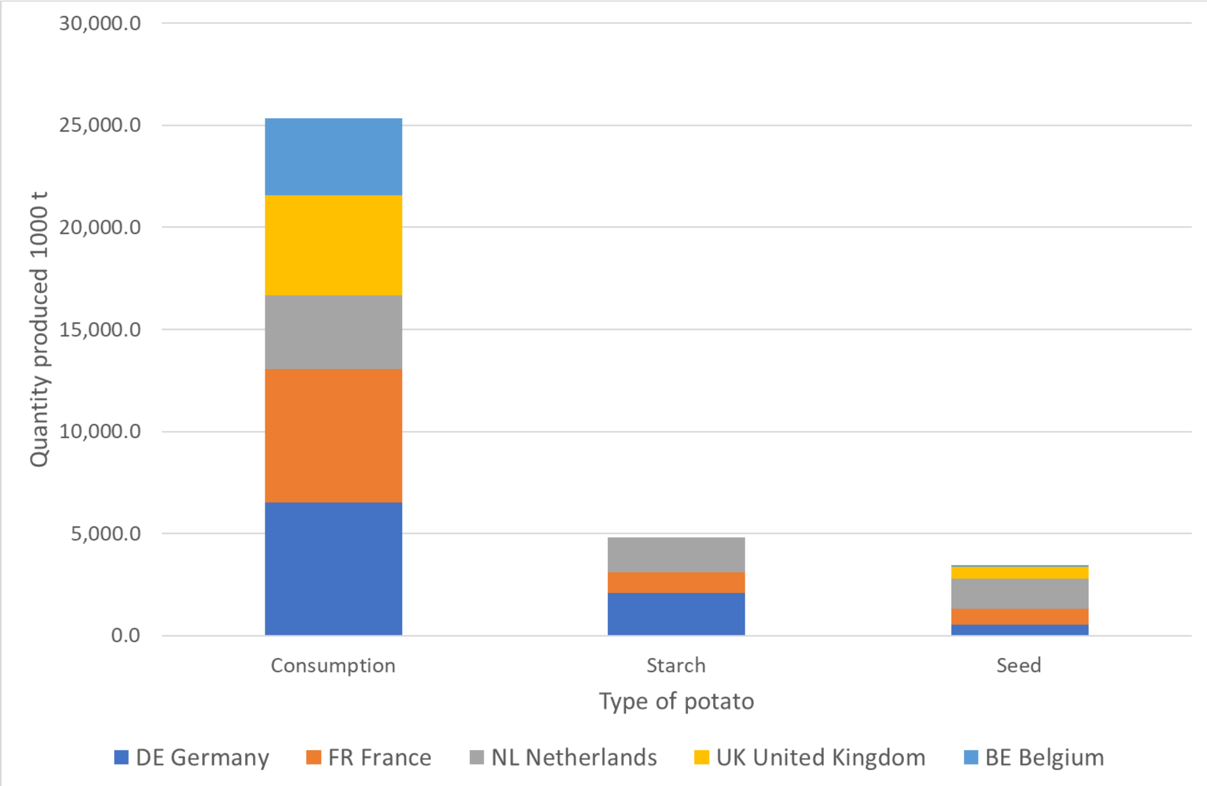


However, the potato yield has increased in the EU with time from 31.9 tons per hectare in 2011 to 35.5 tons per hectare in 2023. The yield is highest in France and Denmark, with 43.36 tons per hectare and 43.1 tons per hectare in 2023. The smallest yield in the EU is in Lithuania, with 13.5 tons per hectare, and in Bulgaria, with 16.6 tons per hectare in 2023.

The main producers of potatoes in the EU are Germany, Poland, France, and the Netherlands. In 2023, these four countries accounted for 66 % of potato production in the EU. Germany has the highest potato production in the EU, with 10.9 million potatoes produced in 2023. Poland used to have the highest potato production, with over 24 million potatoes produced in 2000, but production reduced to 5.5 million potatoes in 2023. The countries with the lowest potato production in the EU are Malta, with 7.5 thousand potatoes produced in 2023, and Luxembourg, with 14.1 thousand potatoes produced in 2023.

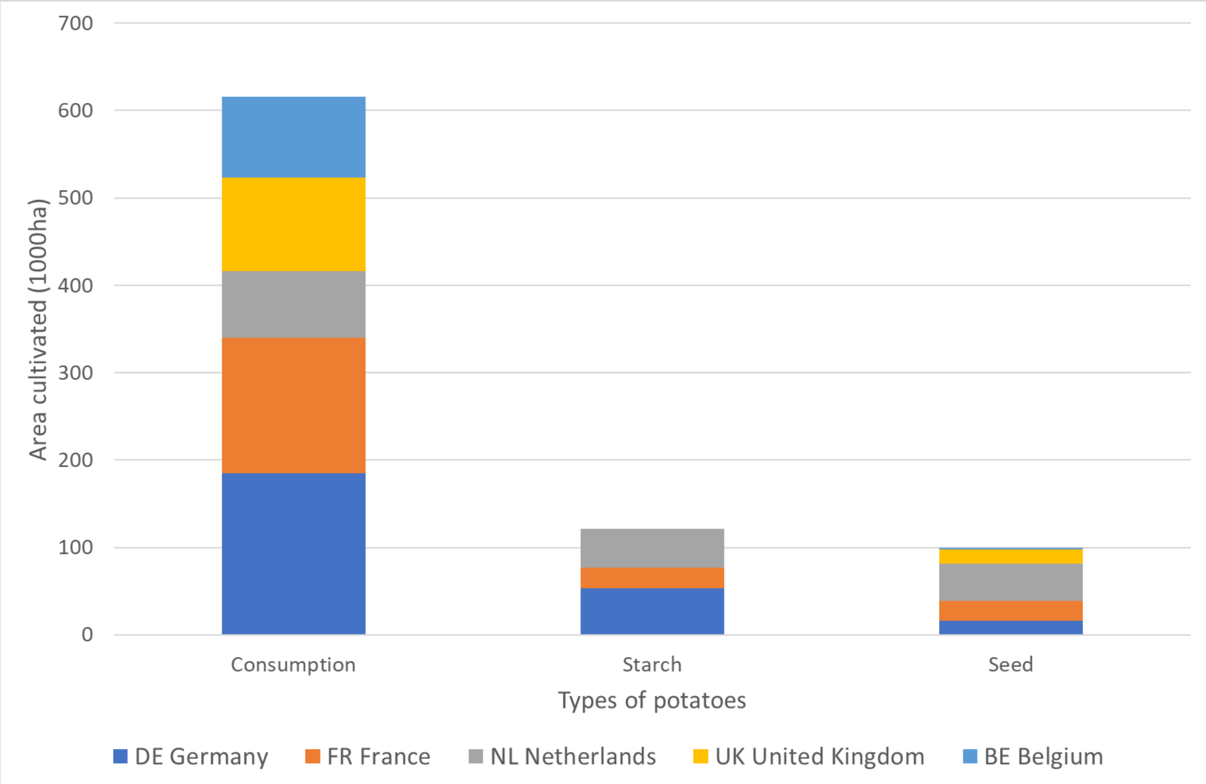
In the period from 2017 to 2019, the consumption of potatoes makes up more than 75% of the annual average potato production in the five main North-western European countries (NWEC-05). Germany is the main producer of starch potatoes, accounting for 43.3 % of starch potatoes produced in the NWEC-05. The main producers of potato consumption are France and Germany, which produced 25.8% of the potato consumption and 25.7% of the potato consumption in the NWEC-05.

Figure 28: Potato production for consumption, starch and seed in the five main countries.



Source: (Goffart et al., 2022).

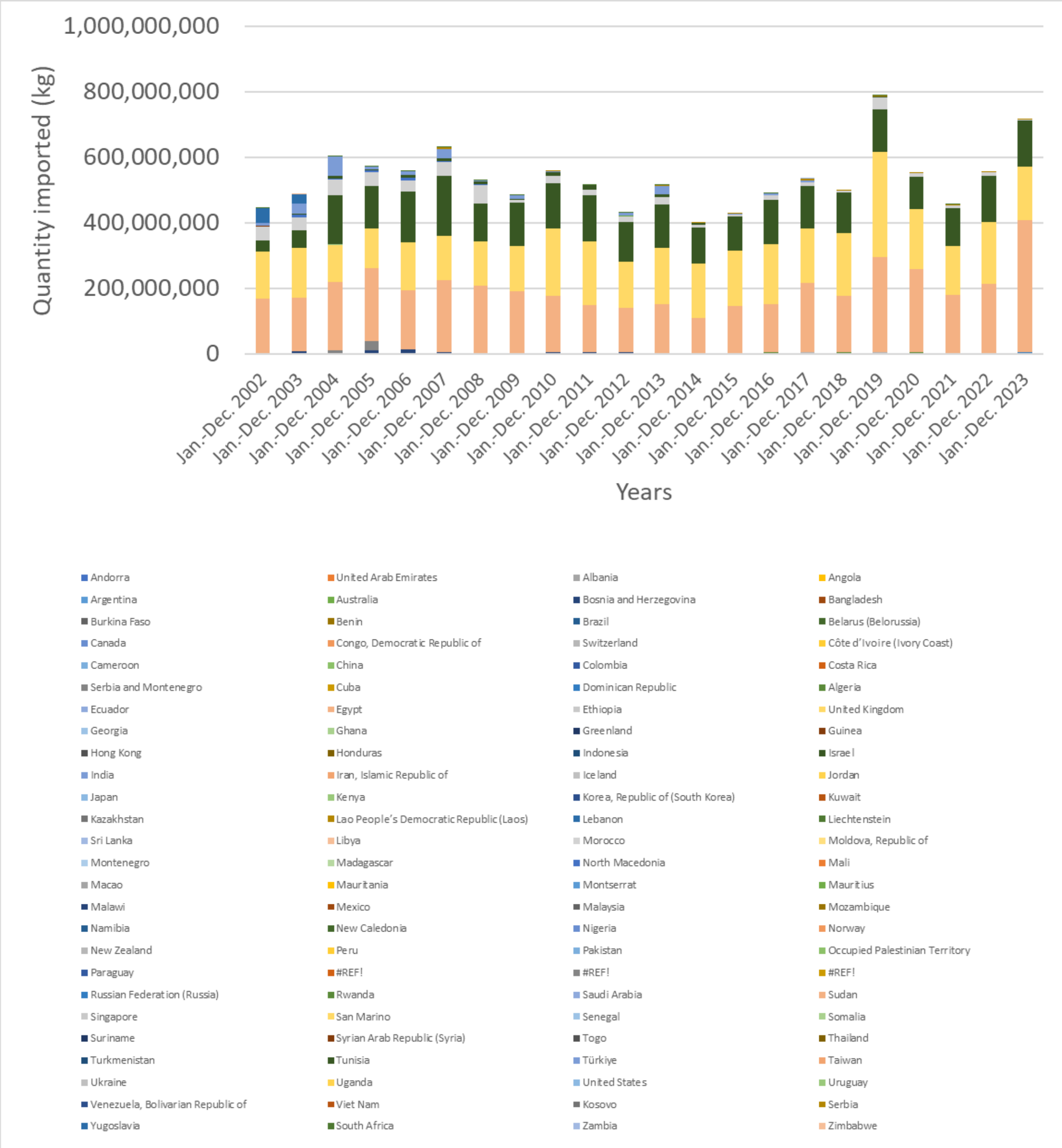
Figure 29: Area cultivated for the different types of potatoes in NWEC-05 annual average 2017-2019.



Source: (Goffart et al., 2022).

In 2023, the EU imported 715.4 million tons of potatoes, excluding seed potatoes from the rest of the world. This is 160 million tons of potatoes more than in 2022 when the EU imported 555.2 million tons of potatoes, and 270 million tons more than in 2002 when the EU imported 445.6 million tons of potatoes. On the other hand, the EU exported 588 million tons of potatoes in 2023, 107 million tons less than in 2022 and 205 million tons less than they exported in 2000, which was 792.7 million tons of potatoes.

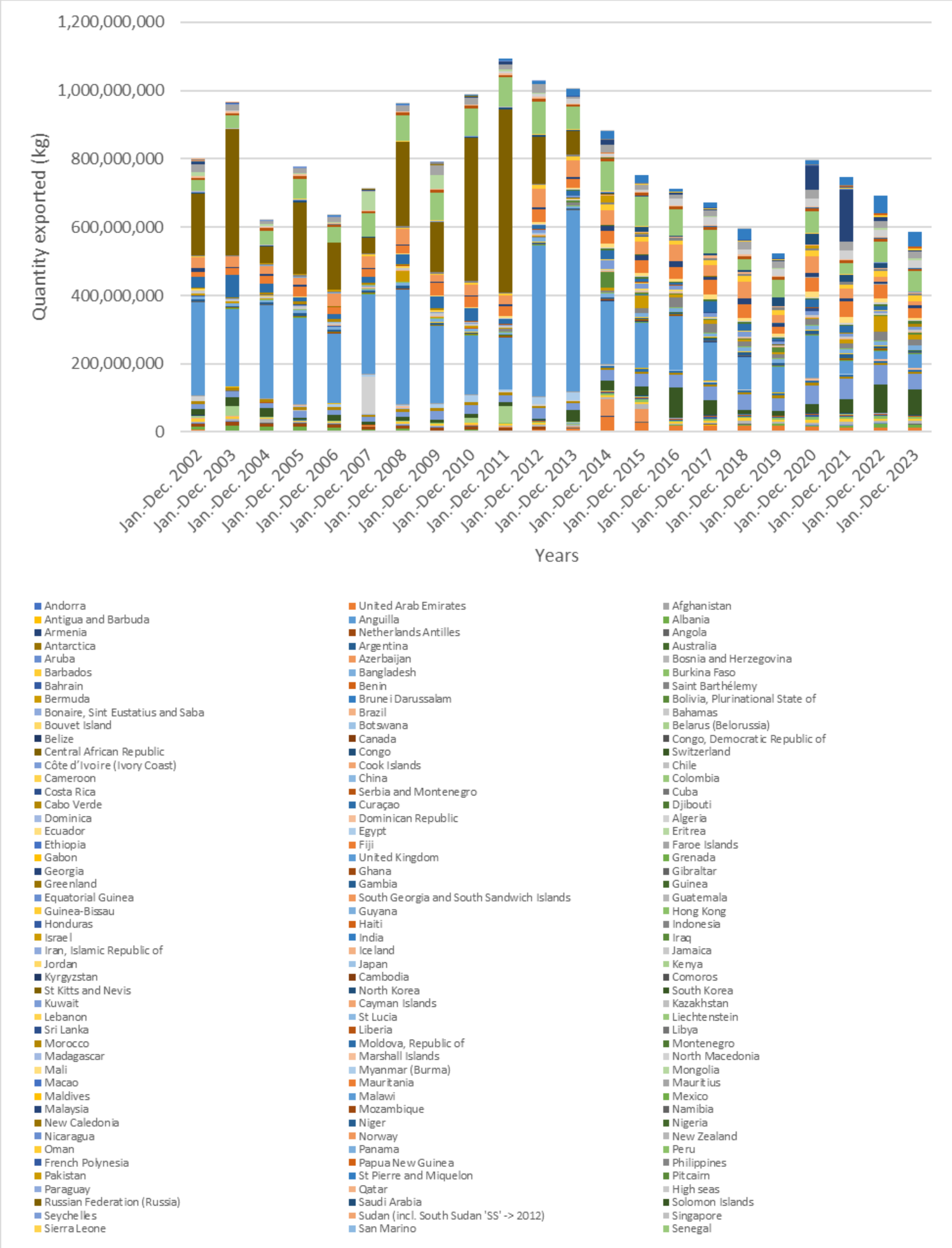
Figure 30: Import of fresh or chilled potatoes excluding seed potatoes by the EU from 2002 to 2023.



Source: (Eurostat, 2024a).

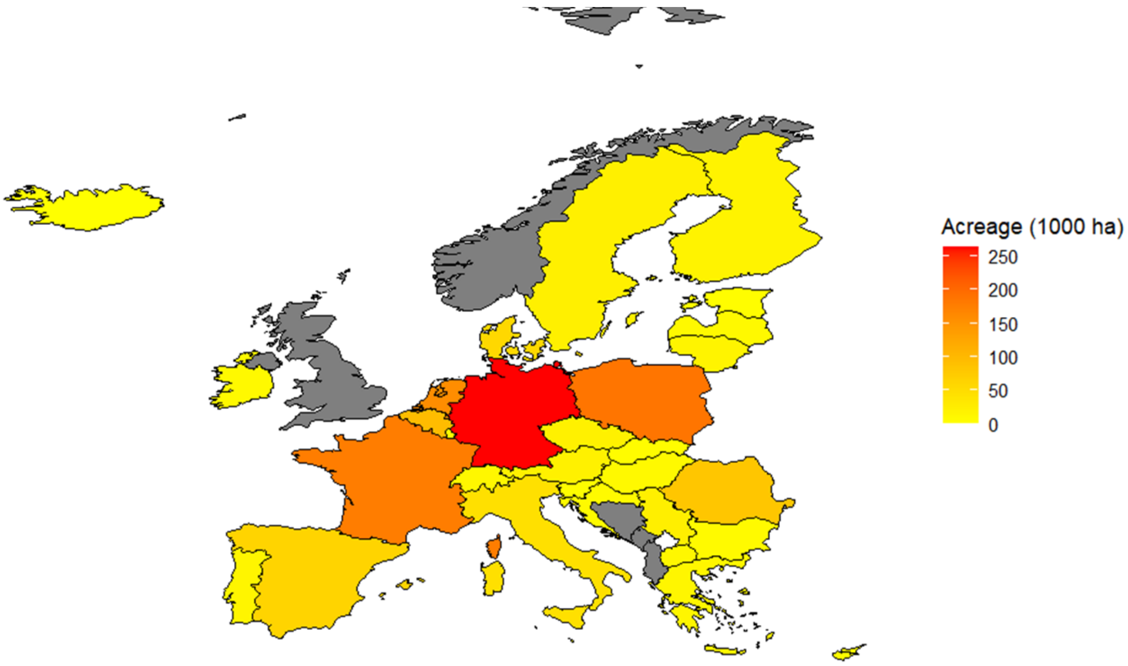
The EU's main imports come from Egypt, from which it imported 403.1 million tons of potatoes in 2023, and UK, from which it imported 163.8 million tons of potatoes in 2023. Its main exports go to Switzerland, to which it imported 76.5 million tons of potatoes in 2023, and to Senegal, to which it imported 58.7 million tons of potatoes in 2023.

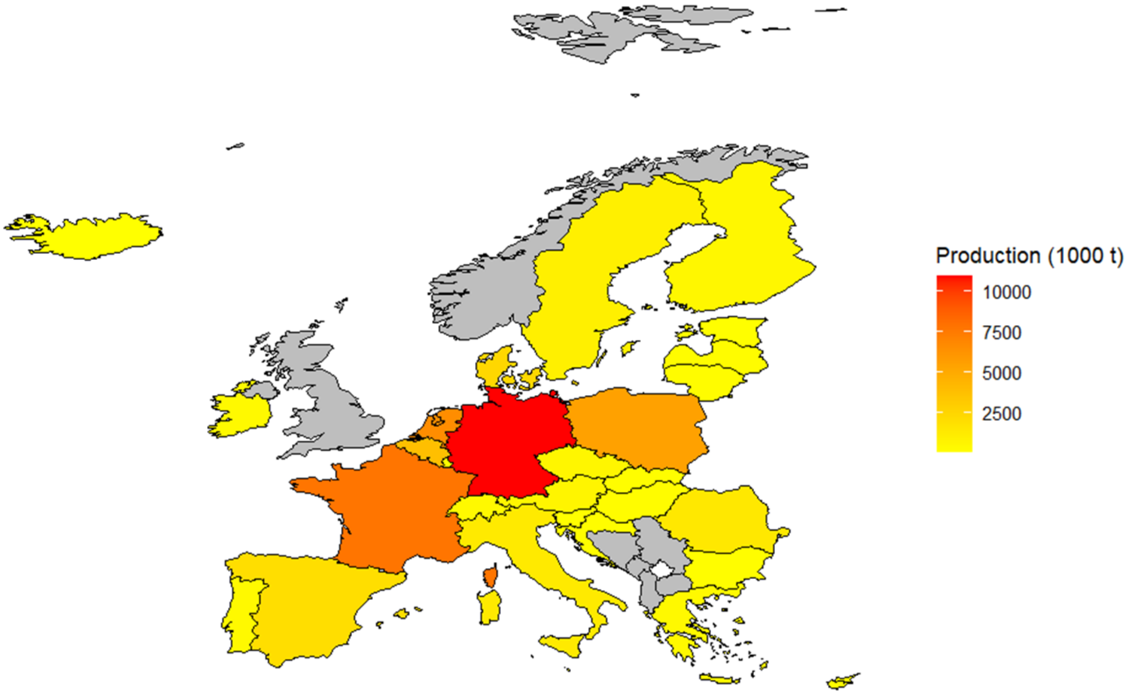
Figure 31: Export of fresh or chilled potatoes excluding seed potatoes by the EU from 2002 to 2023.

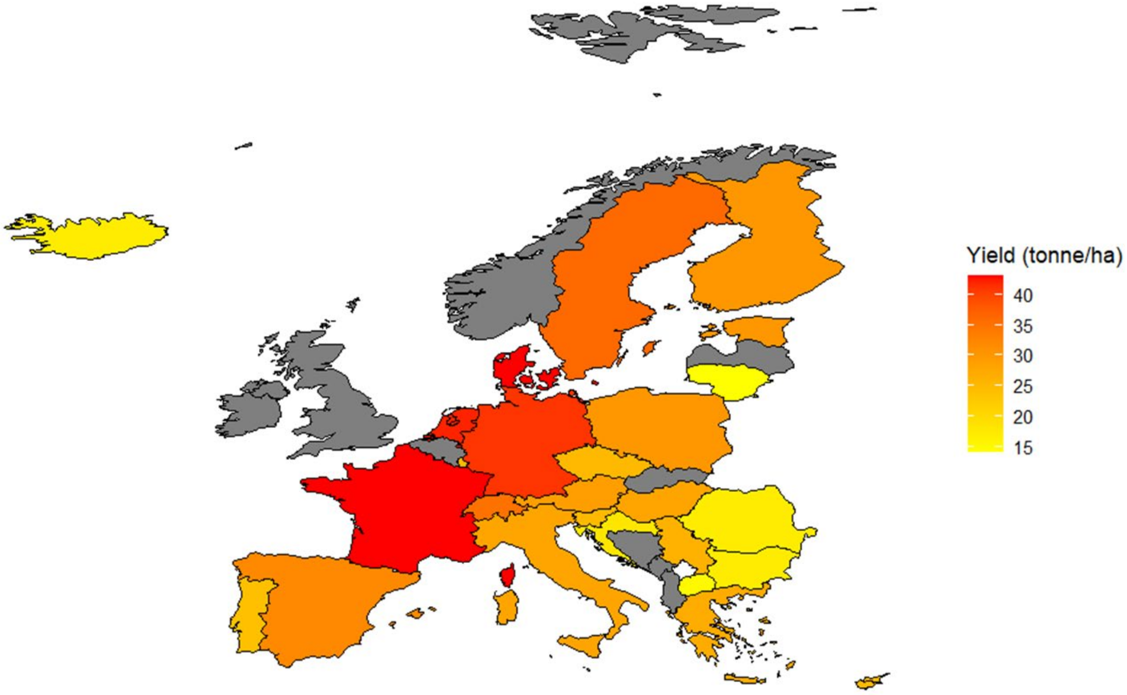


.

Figure 32: Acreage, production, and yield of green maize in EU-27 in 2023.







Yield (tonne/ha)
40
35
30
25
20
15

A.5) Statistics on Tomato production and trade in the EU

The harvested production in the EU was 15.4 million tons in 2022. The total harvested production was between 15 million and 18 million throughout the years. The top 5 major producers are Italy, Spain, Greece, Portugal, France, and the Netherlands, for the 5th place, which represents 87% of the production together and constitutes 13.4 million tons of the harvested production of tomatoes in 2022. The tomato harvested production peaked at 18.3 million (EU27) in 2016, and the lowest production boundary was in year 2013 by 15 million tons (EU27).

In 2023, the EU imported 0,8 million tons of tomatoes, fresh or chilled, from the rest of the world. This value is 0,1 million tons higher than the import amount in 2022 and 0,6 million tons more than in 2002 when the EU imported 0,2 million tons of tomatoes. On the other hand, the EU exported 0,09 million tons of tomatoes in 2023, which is 0,01 million tons less than in 2022 and 0,03 million tons less than they exported in 2000, which was 0,12 million tons of tomatoes.

Figure 33: Tomato production from 2000 to 2023 in the EU.

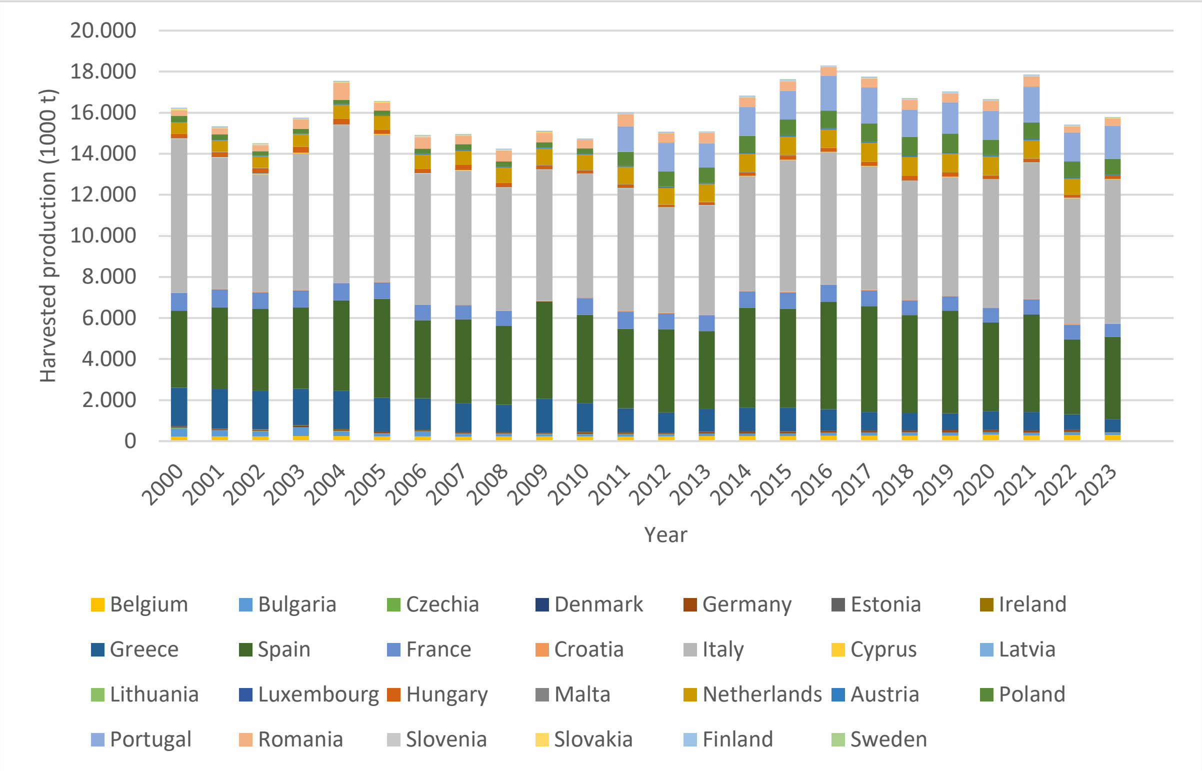


Figure 34: Area cultivated with tomatoes in the EU from 2000 to 2023.

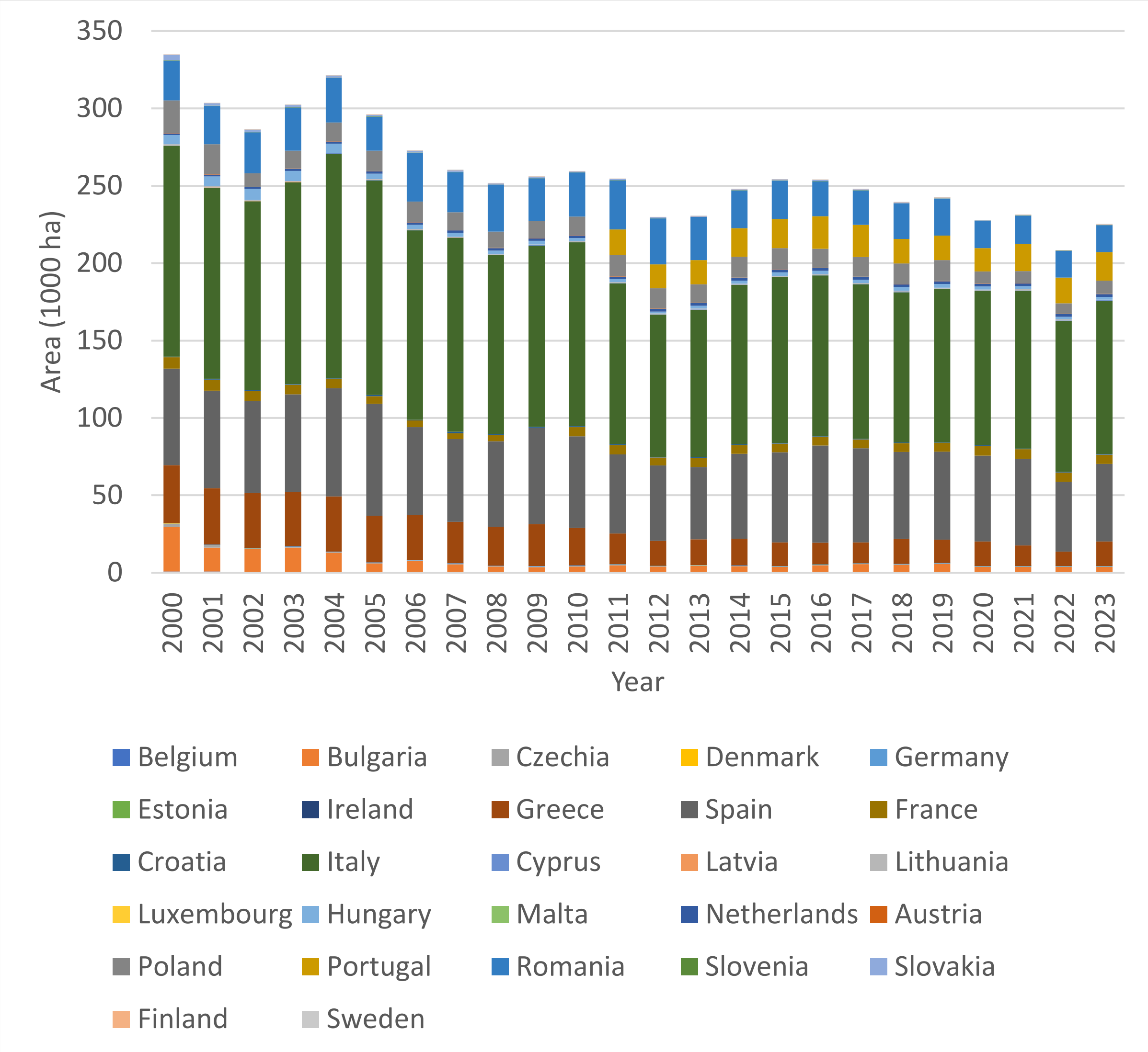
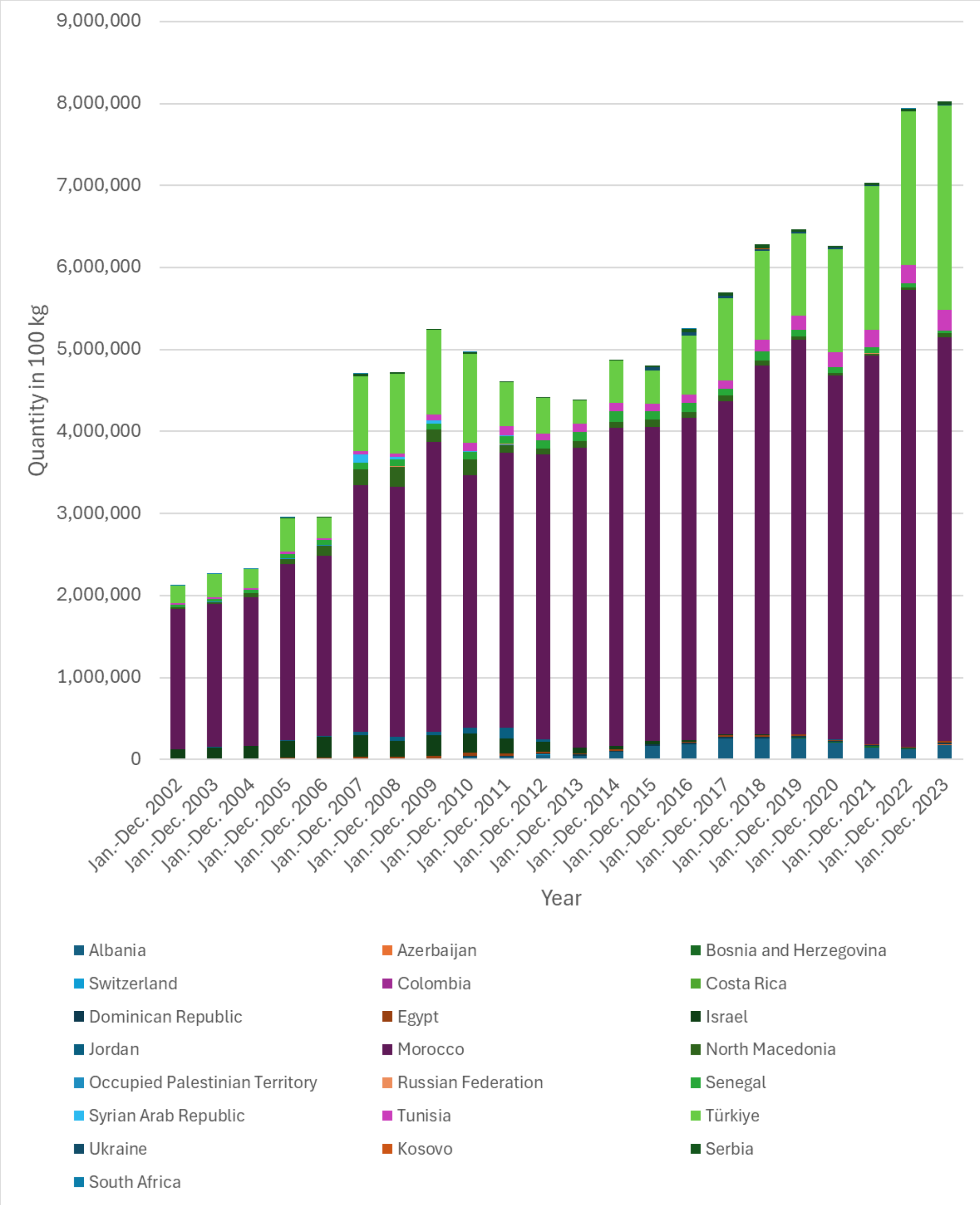
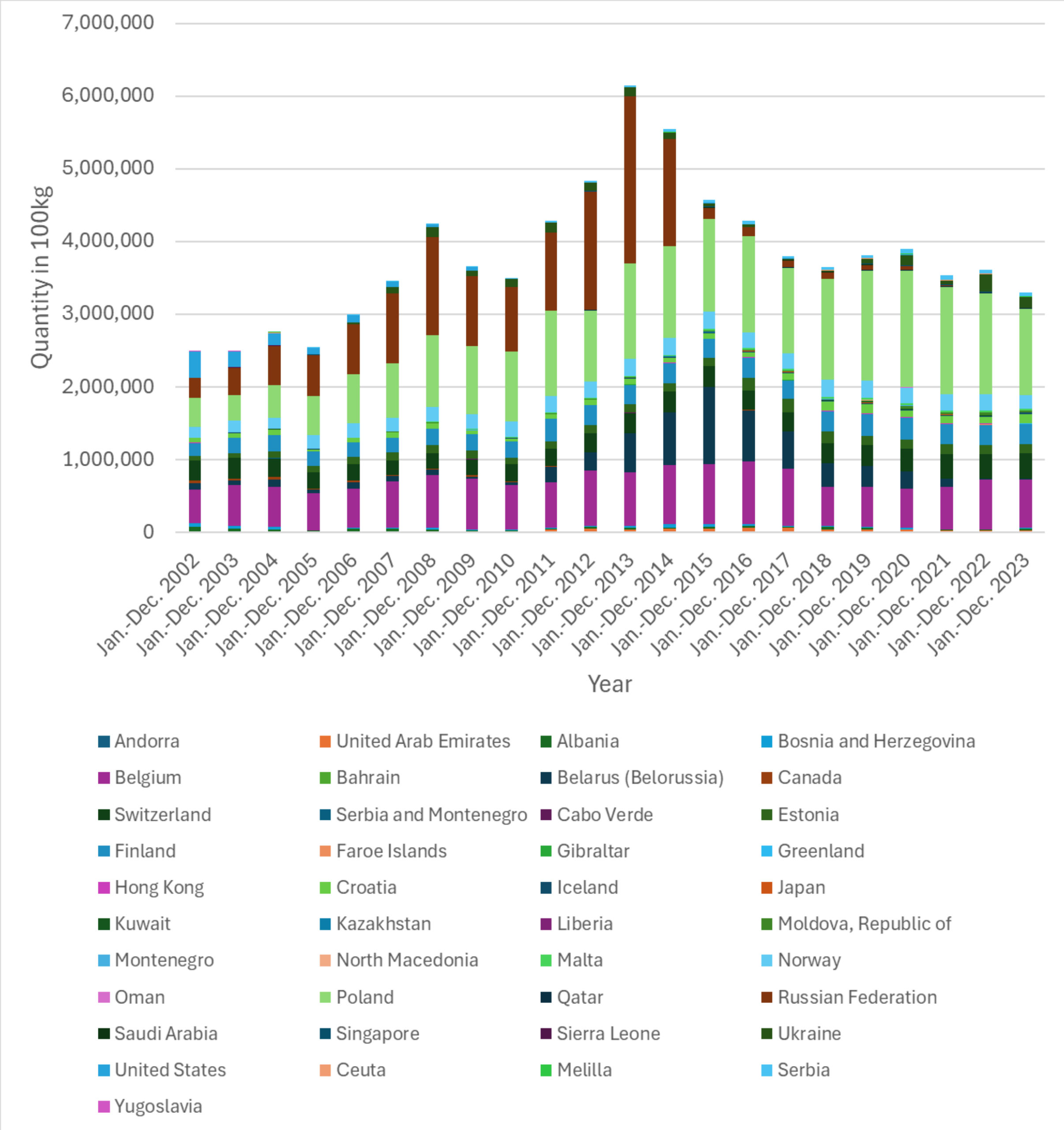


Figure 35: Import of fresh or chilled tomatoes by the EU from 2002 to 2023.



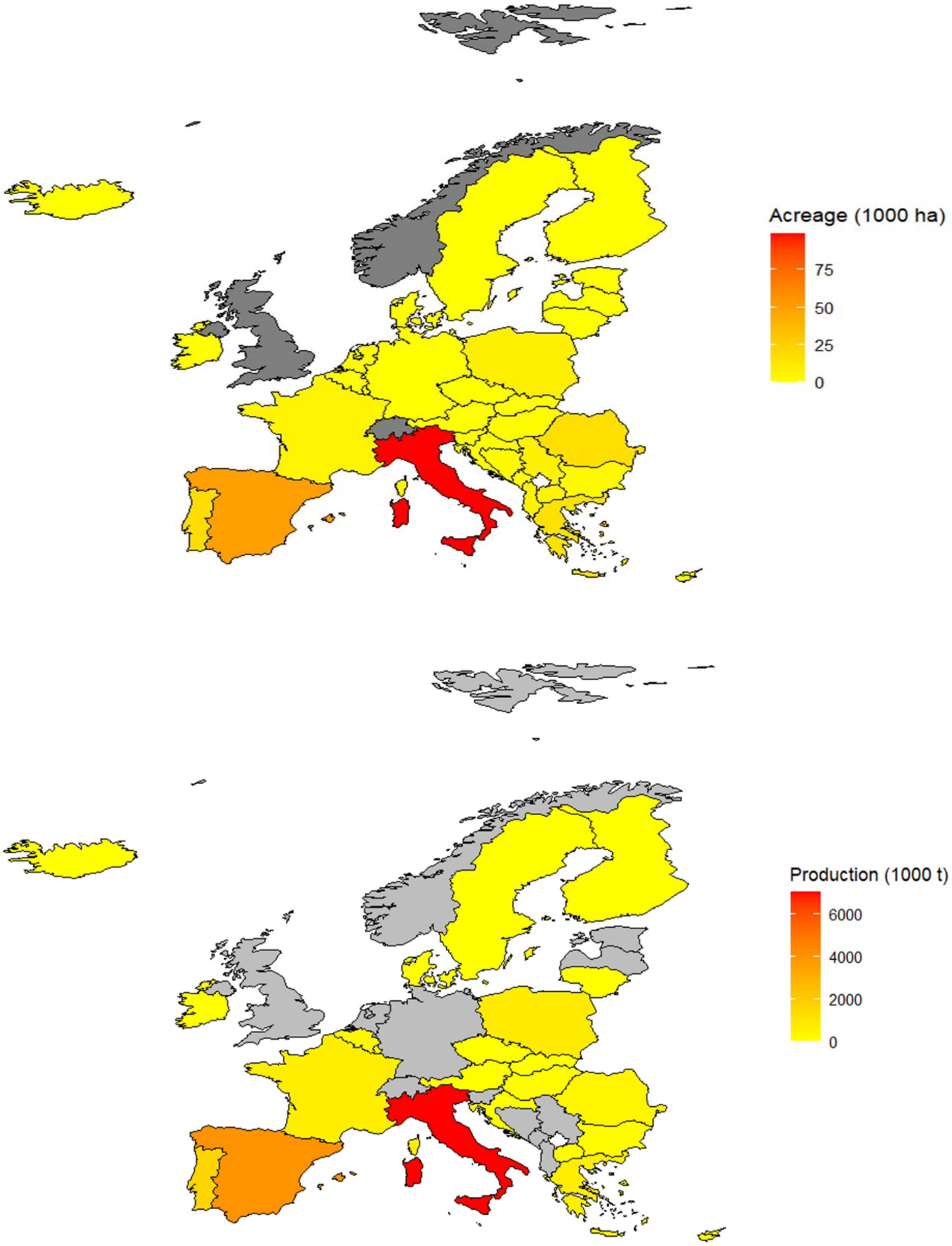
Note: This graph only includes countries with more than 1000 tons of total imports.

Figure 36: Export of fresh or chilled tomatoes by the EU from 2002 to 2023.



Note: This graph only includes countries with more than 1000 tons of total exports.

Figure 37: Acreage and production of tomatoes in EU-27 in 2023



A.6) Statistics on Wheat production and trade in the EU

Eurostat classifies wheat as “wheat and spelt” and we will follow this classification throughout the analysis. Note that we have the following subsections:

- Area (cultivation/harvested/production) (1000 ha),
- Harvested production in EU standard humidity (1000 t),
- Yield in EU standard humidity (tonne/ha)

Comext dataset classifies wheat as “wheat and meslin”.

The area cultivated in the EU was 23.9 million hectares in 2023. The total cultivated area fluctuates between 20 to 25 million hectares throughout the years. The top 5 major producers are France, Germany, Poland, Romania, and Spain, which represent 60% of the production, which together constitute 14.5 million hectares of area cultivated of wheat and spelt in 2023. The area cultivated has peaked to 25.2 million (EU 27) in 2016.

Figure 38: Area cultivated with wheat in the EU from 2000 to 2023.

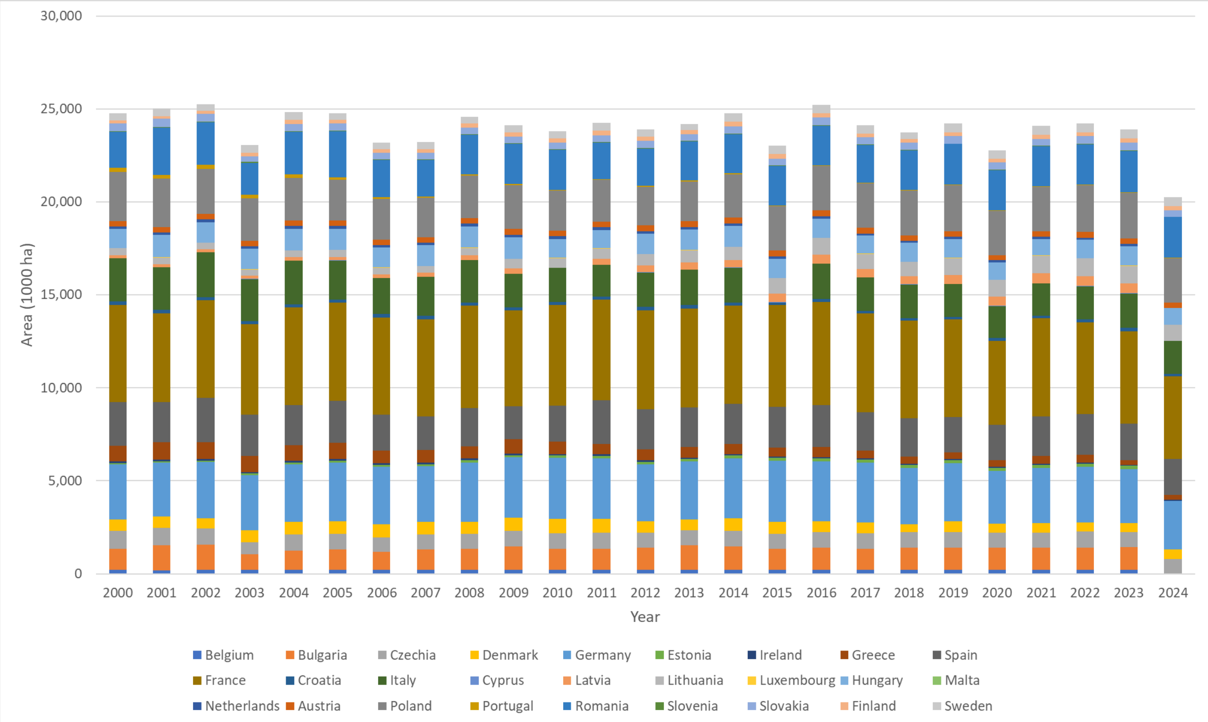
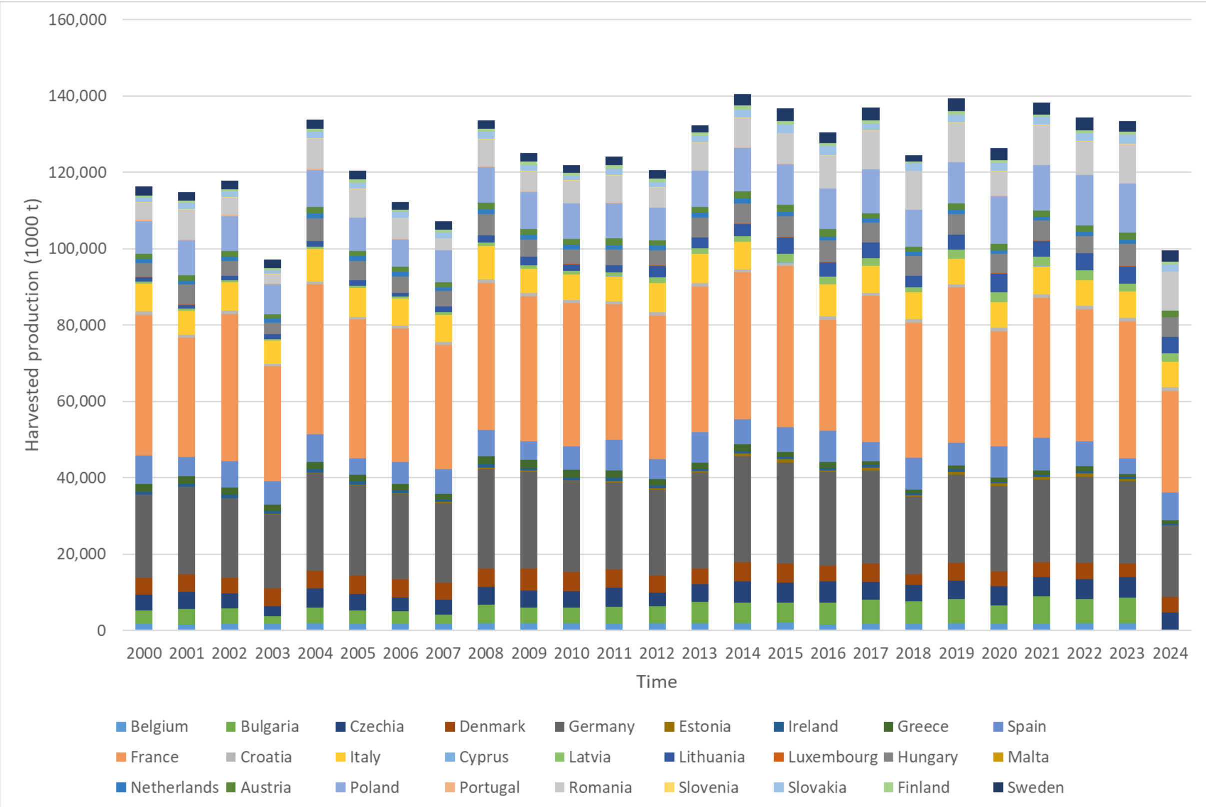


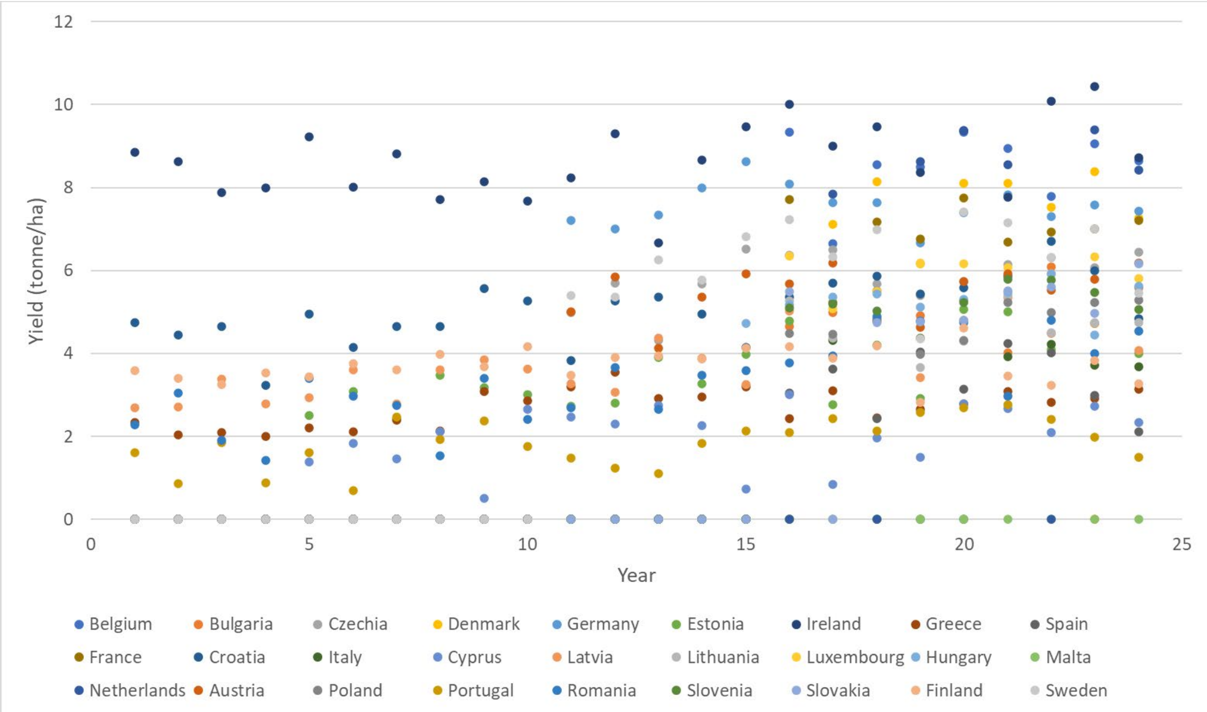
Figure 39: Wheat production from 2000 to 2023 in the EU.



The harvested production in the EU was 133,4 million tons in 2023. The total harvested production was between 90 mil-160 mil throughout the years. The top 5 major producers are France, Germany, Romania, Italy, and Spain, which represent 58.9% of the production, together constituting 78.6 million tons of the harvested production of wheat and spelt in 2023. The wheat and spelt harvested production peaked at 140.5 million (EU27) in 2014.

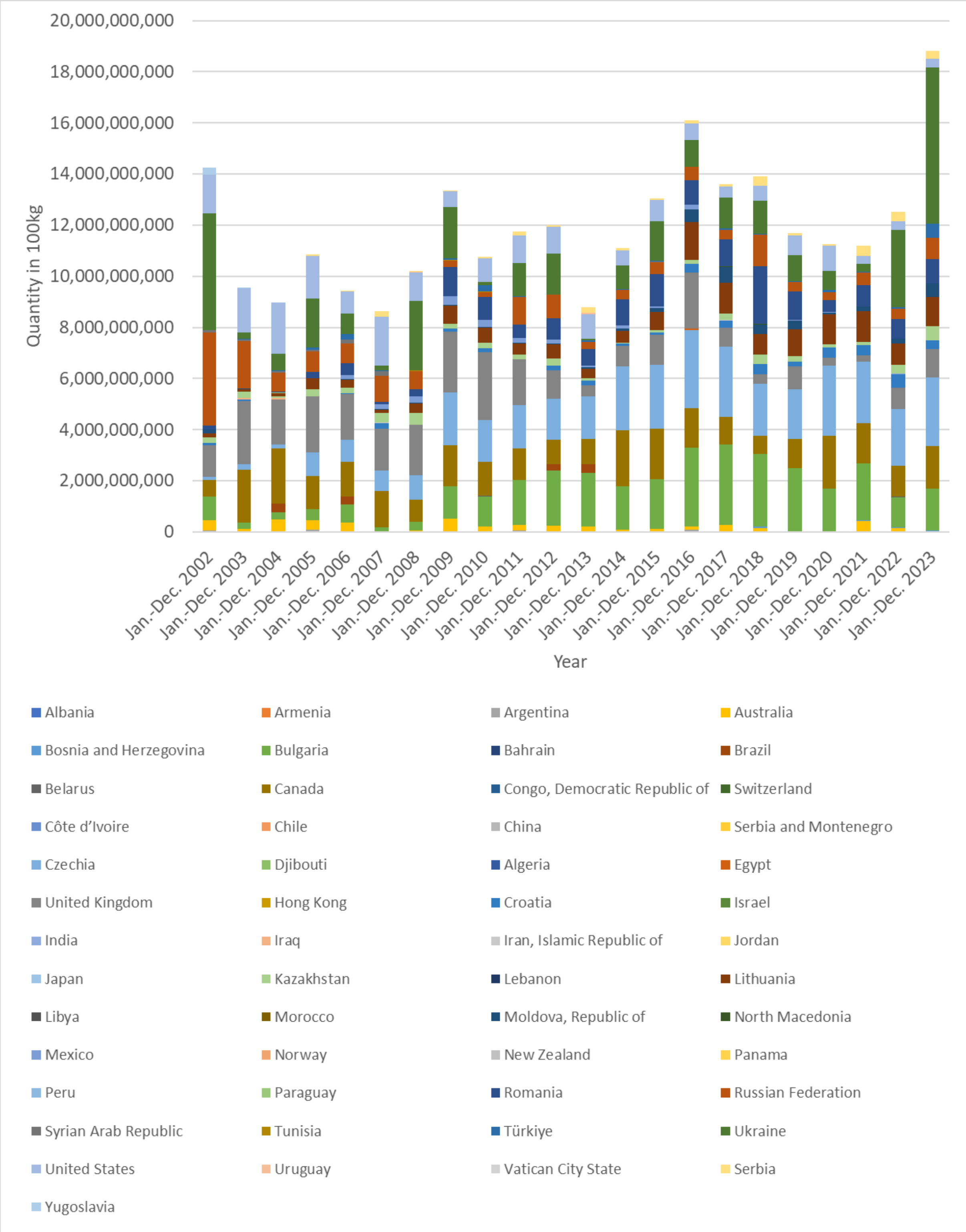
Most countries had missing data before 2010, so we could not make an analysis over that period of time. After 2010, yield in the EU, on average, was 5.1 tons per ha in 2023 for EU27. The yield values fluctuate between 1.5 tons to 5.5 tons per hectare throughout the years. The top 5 yields per ha producers are Ireland, Croatia, Finland, Latvia, Sweden, and Czechia for the 5th position. The yield values peaked at 5.3 tonne/ha (EU 27) in 2020.

Figure 40: Wheat Yield in EU (tons/ha).



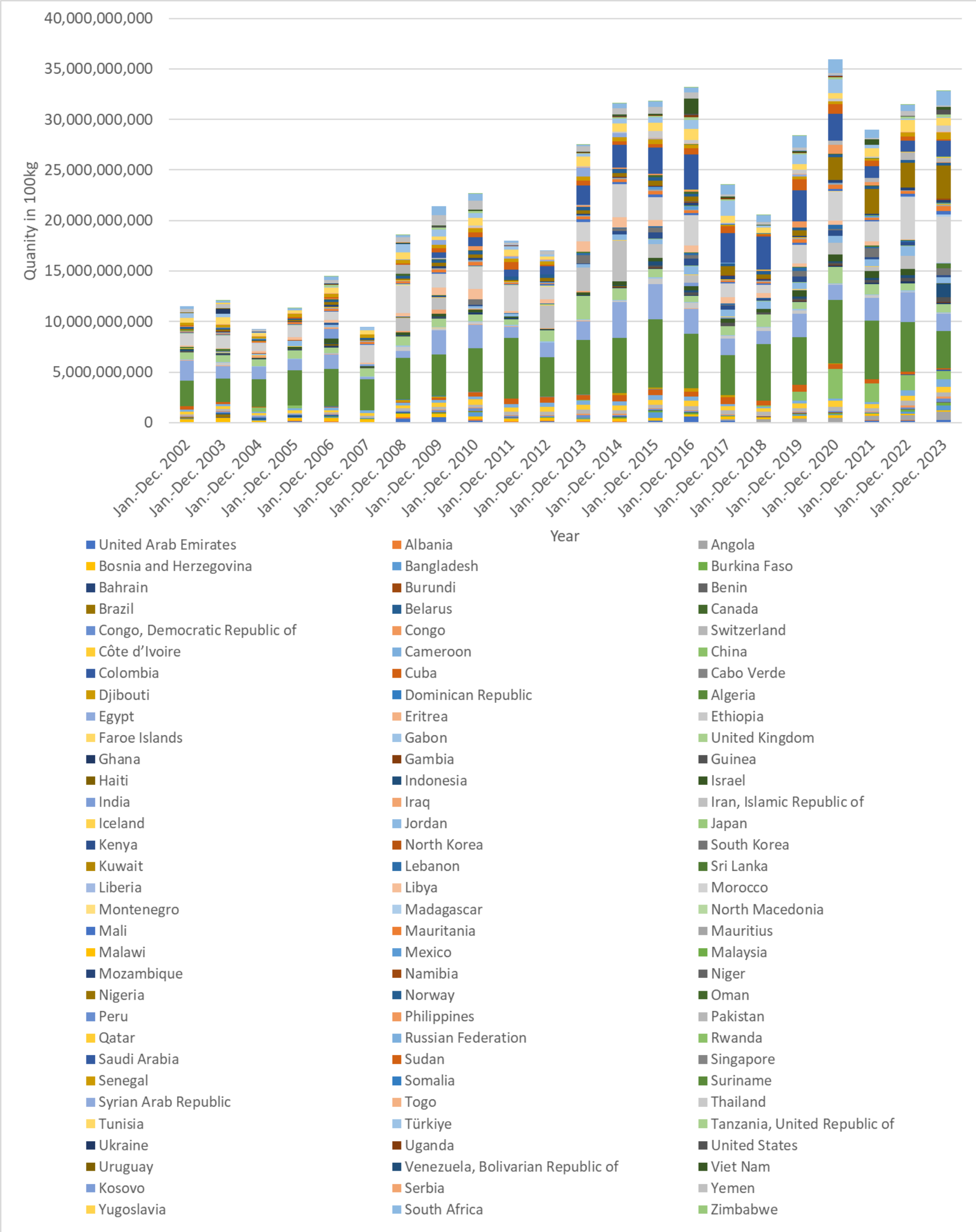
In 2023, the EU has imported 12 million tons of wheat and meslin from the rest of the world. This is 5.1 million tons of wheat and meslin less than in 2022, where the EU imported 6.9 million tons of wheat and meslin. On the other hand, the EU exported 32.8 million tons in 2023, which is 1.4 million tons more than in 2022 and 21.2 million tons more than they exported in 2000, which was 11.6 million tons of maize.

Figure 41: Import of wheat by the EU from 2002 to 2023.



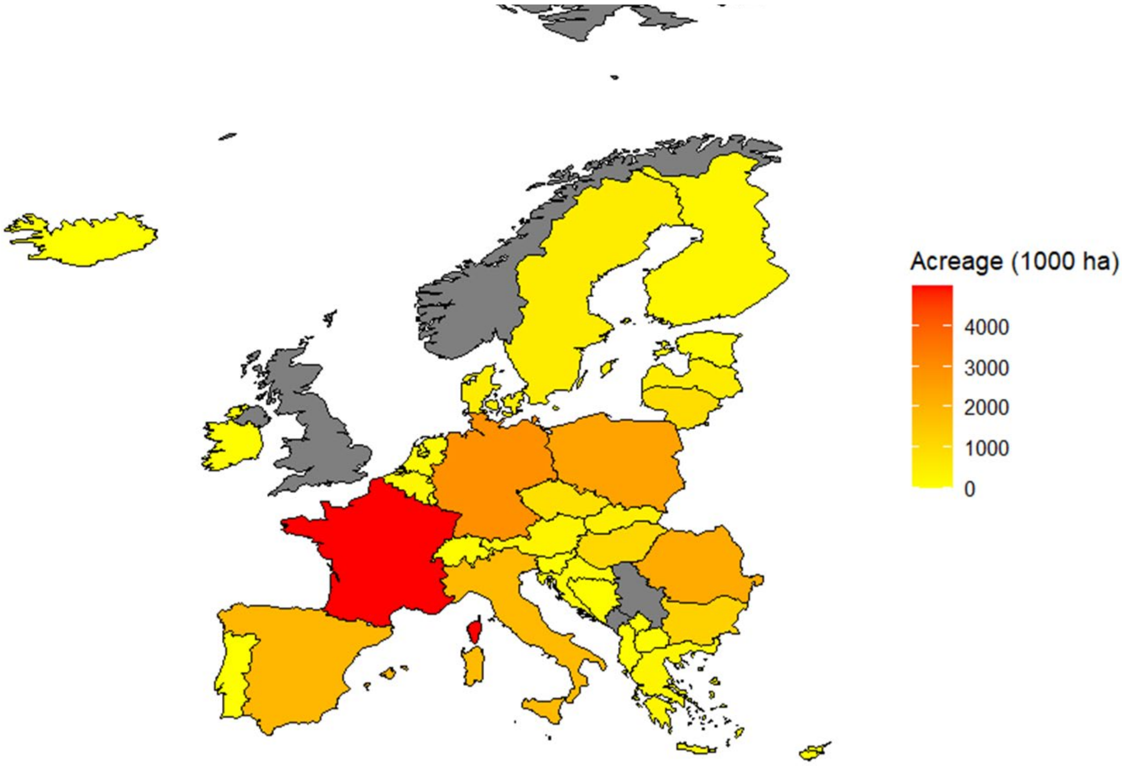
Note: This graph only includes countries with more than 10,000 tons of total imports.

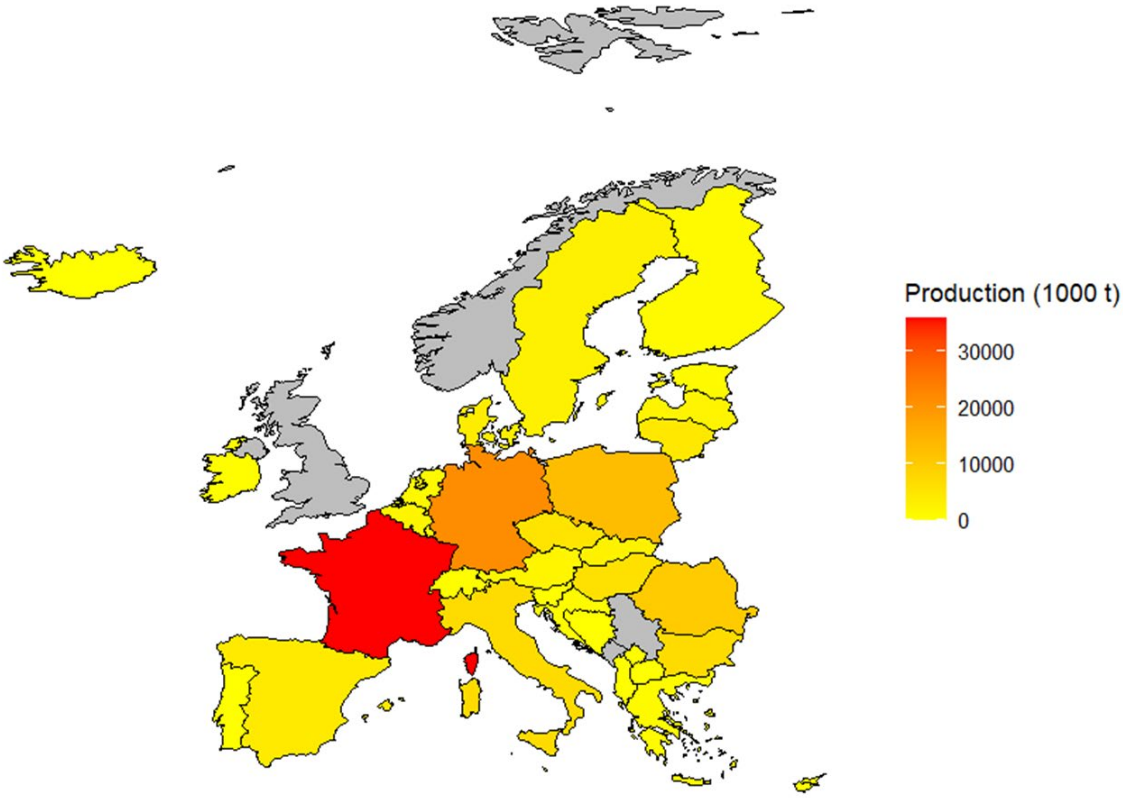
Figure 42: Export of wheat by the EU from 2002 to 2023.

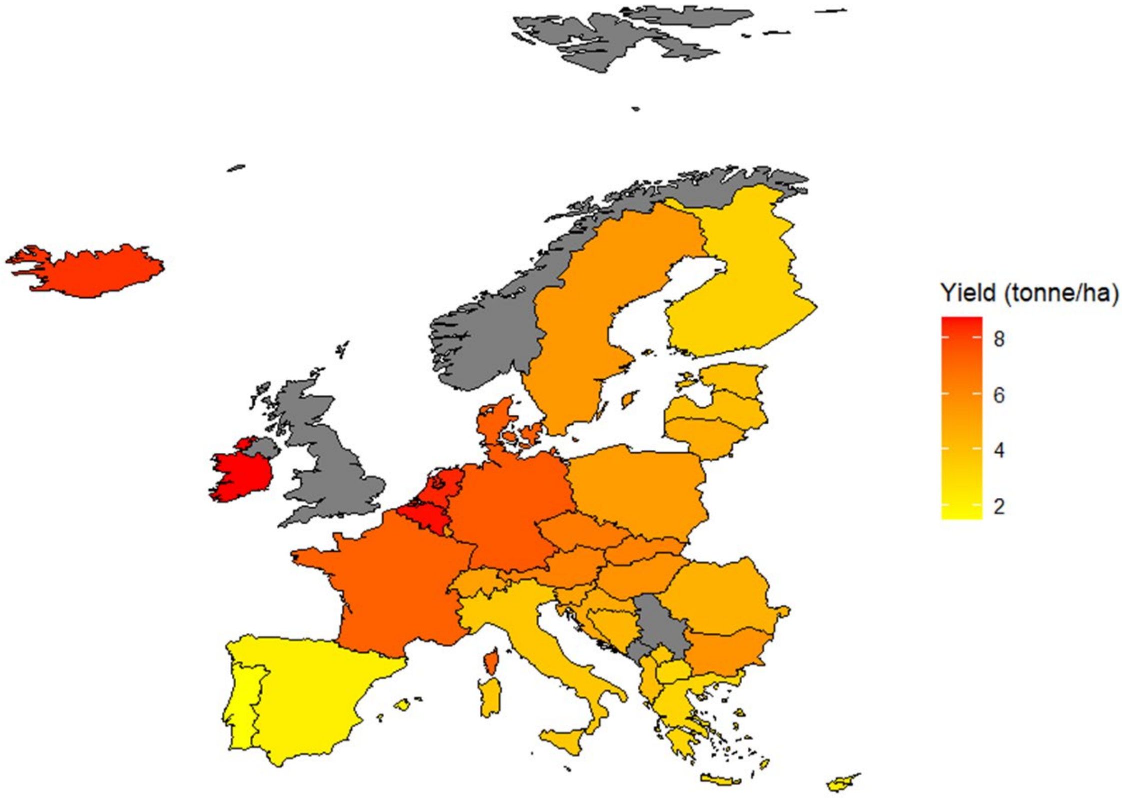


Note: This graph only includes countries with more than 5,000,000 tons of total imports.

Figure 43: Acreage, production, and yield of wheat in EU-27 in 2023.






Yield (tonne/ha)
8
6
4
2

A.7) Data used for the baseline scenario

The data for the baseline scenario is presented in Table 22.

Table 22: EU-wide initial prices and quantities as three-year averages for the period 2021 to 2023.

	Maize	Oilseed rape	Wheat	Tomato	Potato
Production (Tons)					
Unprocessed	305,583,900	18,677,937	135,297,130	6,425,160	48,725,770
Processed		23,233,333		9,910,687	
Imports (Tons)					
Unprocessed	19,380,589	5,775,355	77,394	767,956	5,881
Processed	515,704	443,877	2,872	408,022	610
% GM of Imports	22.5	5 - 10			
Exports (Tons)					
Unprocessed	4,890,834	500,132	311,006	360,477	12,263
Processed	672,264	620,745	9,815	1,397,642	36,493
Prices (€/Ton)					
Unprocessed	245	561.1	273.7	1185.5	407.5
Processed	-	348.1	815.9	1192.5	885.6
GM	-	-	-	-	-
Non-GM	-	-	-	-	-

Sources: ENGA (2024)*, Eurostat* (2024a, 2024b, 2024c)*, USDA* (n.d.)

A.8) EU Maize Supply Chain

The following are the short-term outcomes of the endogenous variables (listed in Table 23) over the years 2021, 2022, 2023 due to the introduction of the shocks (exogenous variables listed in Table 24).

Model Outcomes	
	% of change
$Q^1_{EU,D}$	0,019873878
$Q^2_{EU,D}$	-0,00051889
$Q^3_{EU,D}$	0
$Q^1_{EU,pd}$	-0,016050436
$Q^1_{FI,p}$	0,030303518
$Q^2_{EU,pd}$	-0,000644253
$Q^2_{FI,p}$	-8,70833E-05
$Q^1_{FE,p}$	0,016023508
$Q^2_{FE,p}$	0
$Q^1_{EU,p}$	-0,04295168
$Q^2_{EU,p}$	-0,000644898
$Q^1_{EU,up}$	0,179584335
$Q^2_{EU,up}$	0,008992293
$Q^1_{FI,up}$	-0,10755891
$Q^2_{FI,up}$	-0,033839666
x^1_1	-0,04295168
x^2_1	-0,000644898
x_2	-0,021798289
x_3	-0,000644898
$Q^1_{EU,S}$	1,783538955
$Q^2_{EU,S}$	0,009001294
$Q^1_{FE,up}$	-0,001231671
$Q^2_{FE,up}$	0
P^1_p	-0,04861744
P^2_p	0,000147011
w^1_1	-0,04861744
w^2_1	-0,016094848
w_2	-0,021179663
w_3	0,006494861

A.9) EU Oilseed Rape Supply Chain

The following are the short-term outcomes of the endogenous variables (listed in Table 23) over the years 2021, 2022, and 2023 due to the introduction of the shocks (exogenous variables listed in Table 24).

Model Outcomes	
	% of change
$Q^1_{EU,D}$	-0,705543551
$Q^2_{EU,D}$	-0,002662823
$Q^3_{EU,D}$	-0,002662823
$Q^1_{EU,pd}$	-3,277736424
$Q^1_{FI,p}$	-0,570164979
$Q^2_{EU,pd}$	0,029869522
$Q^2_{FI,p}$	-0,620777373
$Q^1_{FE,p}$	3,281623012
$Q^2_{FE,p}$	0
$Q^1_{EU,p}$	0,604964836
$Q^2_{EU,p}$	0,029899421
$Q^1_{EU,up}$	1,468382331
$Q^2_{EU,up}$	0,02965742
$Q^1_{FI,up}$	0,55952181
$Q^2_{FI,up}$	0,034497451
x^1_1	0,604964836
x^2_1	0,029899421
x_2	0,317432129
x_3	0,029899421
$Q^1_{EU,S}$	2,737008161
$Q^2_{EU,S}$	0,029687107
$Q^1_{FE,up}$	1,269895725
$Q^2_{FE,up}$	0
P^1_p	0,812053676
P^2_p	0,930326066
w^1_1	0,812053676
w^2_1	0,052682919
w_2	-1,124762662
w_3	0,369198427

A.10) EU Potato Supply Chain

The following are the short-term outcomes of the endogenous variables (listed in Table 23) over the years 2021, 2022, and 2023 due to the introduction of the shocks (exogenous variables listed in Table 24).

Model Outcomes	
	% of change
$Q^1_{EU,D}$	0,129535557
$Q^2_{EU,D}$	0
$Q^3_{EU,D}$	0,030316373
$Q^1_{EU,pd}$	-0,131780168
$Q^1_{FI,p}$	0,129535559
$Q^2_{EU,pd}$	3,16213E-24
$Q^2_{FI,p}$	0
$Q^1_{FE,p}$	0,131955247
$Q^2_{FE,p}$	0
$Q^1_{EU,p}$	0,043124307
$Q^2_{EU,p}$	3,1653E-24
$Q^1_{EU,up}$	-0,3235290003
$Q^2_{EU,up}$	3,1653E-24
$Q^1_{FI,up}$	0,366653312
$Q^2_{FI,up}$	0
x^1_1	0,043124307
x^2_1	3,1653E-24
x_2	0,043124307
x_3	3,1653E-24
$Q^1_{EU,S}$	-0,32352900101
$Q^2_{EU,S}$	3,16847E-24
$Q^1_{FE,up}$	-0,072142028
$Q^2_{FE,up}$	0
P^1_p	0,349530248
P^2_p	0,044494248
w^1_1	0,349530248
w^2_1	0,01425523
w_2	0,044494248
w_3	-0,005626356

A.11) EU Tomato Supply Chain

The following are the short-term outcomes of the endogenous variables (listed in Table 23) over the years 2021, 2022, and 2023 due to the introduction of the shocks (exogenous variables listed in Table 24).

Model Outcomes	
	% of change
$Q^1_{EU,D}$	0,775833009
$Q^2_{EU,D}$	0
$Q^3_{EU,D}$	0,62651918
$Q^1_{EU,pd}$	-0,001431246
$Q^1_{FI,p}$	0,775833016
$Q^2_{EU,pd}$	0
$Q^2_{FI,p}$	0
$Q^1_{FE,p}$	0,002075047
$Q^2_{FE,p}$	0
$Q^1_{EU,p}$	0,64172589
$Q^2_{EU,p}$	0
$Q^1_{EU,up}$	-0,84786387
$Q^2_{EU,up}$	0
$Q^1_{FI,up}$	1,489589785
$Q^2_{FI,up}$	0
x^1_1	0,64172589
x^2_1	0
x_2	0,64172589
x_3	0
$Q^1_{EU,S}$	-0,847863881
$Q^2_{EU,S}$	0
$Q^1_{FE,up}$	-0,938793596
$Q^2_{FE,up}$	0
P^1_p	5,072027247
P^2_p	0,393975157
w^1_1	5,072027247
w^2_1	0,004414469
w_2	0,393975157
w_3	-0,001742334

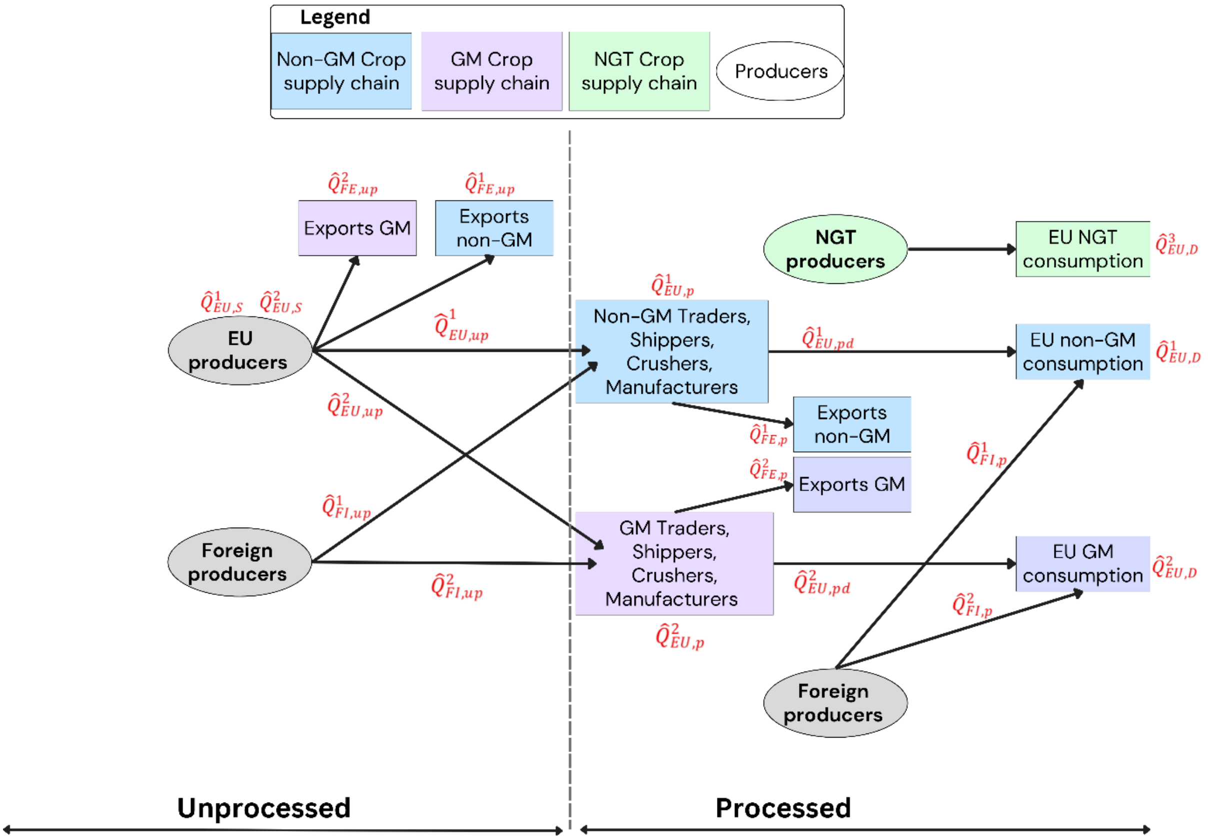
A.12) EU Wheat Supply Chain

The following are the short-term outcomes of the endogenous variables (listed in Table 23) over the years 2021, 2022, and 2023 due to the introduction of the shocks (exogenous variables listed in Table 24).

Model Outcomes	
	% of change
$Q^1_{EU,D}$	0,105452544
$Q^2_{EU,D}$	0
$Q^3_{EU,D}$	0,010549356
$Q^1_{EU,pd}$	-0,014372174
$Q^1_{FI,p}$	0,105453742
$Q^2_{EU,pd}$	0
$Q^2_{FI,p}$	0
$Q^1_{FE,p}$	0,014452199
$Q^2_{FE,p}$	0
$Q^1_{EU,p}$	0,065572443
$Q^2_{EU,p}$	0
$Q^1_{EU,up}$	-0,722872471
$Q^2_{EU,up}$	0
$Q^1_{FI,up}$	0,072796043
$Q^2_{FI,up}$	0
x^1_1	0,065572443
x^2_1	0
x_2	0,065572443
x_3	0
$Q^1_{EU,S}$	-0,72225505
$Q^2_{EU,S}$	0
$Q^1_{FE,up}$	0,029926562
$Q^2_{FE,up}$	0
P^1_p	0,092125291
P^2_p	0,024102205
w^1_1	0,092125291
w^2_1	0,002441385
w_2	0,024102205
w_3	-0,000963583

A.13) Crop Supply Chain in the EU

Figure 44: Crop supply chain in the EU.



Set of equations:

(1-3) Proportionate change in the retail demand for EU consumers

$$\hat{Q}^1_{EU,D} = \eta^{11}(\hat{P}^1_p + \delta^1) + \eta^{12}(\hat{P}^2_p + \delta^2) + \eta^{13}(\hat{P}^3_p + \delta^3)$$

$$\hat{Q}^2_{EU,D} = \eta^{21}(\hat{P}^1_p + \delta^1) + \eta^{22}(\hat{P}^2_p + \delta^2) + \eta^{23}(\hat{P}^3_p + \delta^3)$$

$$\hat{Q}^3_{EU,D} = \eta^{31}(\hat{P}^1_p + \delta^1) + \eta^{32}(\hat{P}^2_p + \delta^2) + \eta^{33}(\hat{P}^3_p + \delta^3)$$

(4-5) Proportionate change in the total quantity of EU consumption

$$\hat{Q}^1_{EU,D} = (1 - S^1_{FI,p})\hat{Q}^1_{EU,pd} \ + \ S^1_{FI,p}\hat{Q}^1_{FI,p}$$

$$\hat{Q}^2_{EU,D} = (1 - S^2_{FI,p})\hat{Q}^2_{EU,pd} \ + \ S^2_{FI,p}\hat{Q}^2_{FI,p}$$

(6-7) Proportionate change in the supply of processed imported crop

$$\hat{Q}^1_{FI,p} = \epsilon^1_{FI,p}\hat{P}^1_p$$

$$\hat{Q}^2_{FI,p} = \epsilon^2_{FI,p}\hat{P}^2_p$$

(8-9) Proportionate change in the supply of processed crop, minus exports

$$\hat{Q}^1_{EU,pd} = (1 - S^1_{FE,p})\hat{Q}^1_{EU,p} \;-\; S^1_{FE,p}Q^1_{FE,p}$$

$$\hat{Q}^2_{EU,pd} = (1 - S^2_{FE,p})\hat{Q}^2_{EU,p} \;-\; S^2_{FE,p}Q^1_{FE,p}$$

(10-11) Proportionate change in the foreign demand for EU processed crop

$$\hat{Q}^1_{FE,p} = \eta^{11}_{FE,p}(\hat{P}^1_p + \delta^1_{FE,p}) \;+\; \eta^{12}_{FE,p}(\hat{P}^2_p + \delta^2_{FE,p})$$

$$\hat{Q}^2_{FE,p} = \eta^{21}_{FE,p}(\hat{P}^1_p + \delta^1_{FE,p}) \;+\; \eta^{22}_{FE,p}(\hat{P}^2_p + \delta^2_{FE,p})$$

(12-13) Proportionate change in the supply of unprocessed crop, plus imports

$$\hat{Q}^1_{EU,p} = (1 - S^1_{FI,up})\hat{Q}^1_{EU,up} \;+\; S^1_{FI,up}\hat{Q}^1_{FI,up}$$

$$\hat{Q}^2_{EU,p} = (1 - S^2_{FI,up})\hat{Q}^2_{EU,up} \;+\; S^2_{FI,up}\hat{Q}^2_{FI,up}$$

(14-15) Proportionate change in the supply of unprocessed imported crop

$$\hat{Q}^1_{FI,up} = \epsilon^1_{FI,up}\hat{w}^1_1$$

$$\hat{Q}^2_{FI,up} = \epsilon^2_{FI,up}\hat{w}^2_1$$

(16-17) Proportionate change in the retail price

$$\hat{P}^1_p = SR^1\hat{w}^1_1 \;+\; (1 - \alpha^1 - SR^1)\hat{w}_2 + \alpha^1\hat{w}_3$$

$$\hat{P}^2_p = SR^2\hat{w}^2_1 \;+\; (1 - \alpha^2 - SR^2)\hat{w}_2 + \alpha^2\hat{w}_3$$

(18-21) Proportionate change in the quantity of inputs

$$\hat{x}^1_1 = SC^1_1\hat{Q}^1_{EU,p} + (1 - SC^1_1)\hat{Q}^2_{EU,p}$$

$$\hat{x}^2_1 = SC^2_1\hat{Q}^1_{EU,p} + (1 - SC^2_1)\hat{Q}^2_{EU,p}$$

$$\hat{x}_2 = SC_2\hat{Q}^1_{EU,p} \;+\; (1 - SC_2)\hat{Q}^2_{EU,p}$$

$$\hat{x}_3 = SC_3\hat{Q}^1_{EU,p} \;+\; (1 - SC_3)\hat{Q}^2_{EU,p}$$

(22-25) Supply curves of inputs

$$\hat{x}^1_1 = \epsilon^1_1(\hat{w}^1_1 \;+\; v^1_1)$$

$$\hat{x}^2_1 = \epsilon^2_1(\hat{w}^2_1 \;+\; v^2_1)$$

$$\hat{x}_2 = \epsilon_2(\hat{w}_2 \;+\; v_2)$$

$$\hat{x}_3 = \epsilon_3(\hat{w}_3 \;+\; v_3)$$

(26-27) Proportionate change in the supply of unprocessed crop, minus exports

$$\hat{Q}^1_{EU,up} = (1 - S^1_{FE,up})\hat{Q}^1_{EU,S} \;-\; S^1_{FE,up}Q^1_{FE,up}$$

$$\hat{Q}^2_{EU,up} = (1 - S^2_{FE,up})\hat{Q}^2_{EU,S} \;-\; S^2_{FE,up}Q^2_{FE,up}$$

(28-29) Proportionate change in the foreign demand for EU unprocessed crop

$$\hat{Q}^1_{FE,up} = \eta^{11}_{FE,up}(\hat{w}^1_1 + \delta^1_{FE,up}) \;+\; \eta^{12}_{FE,up}(\hat{w}^2_1 + \delta^2_{FE,up})$$

$$\hat{Q}^2_{FE,up} = \eta^{21}_{FE,up}(\hat{w}^1_1 + \delta^1_{FE,up}) \;+\; \eta^{22}_{FE,up}(\hat{w}^2_1 + \delta^2_{FE,up})$$

Table 23: Endogenous variables.

	Variable	Proportionate change in…
1	$\hat{Q}^1_{EU,D}$	EU consumption of non-GM crop
2	$\hat{Q}^2_{EU,D}$	EU consumption of GM crop
3	$\hat{Q}^3_{EU,D}$	EU consumption of NGT crop
4	$\hat{Q}^1_{EU,pd}$	EU supply of processed non-GM crop, minus processed exports
5	$\hat{Q}^2_{EU,pd}$	EU supply of processed GM crop, minus processed exports
6	$\hat{Q}^1_{EU,p}$	EU supply of unprocessed non-GM crop, plus unprocessed imports, which will be processed
7	$\hat{Q}^2_{EU,p}$	EU supply of unprocessed GM crop, plus unprocessed imports, which will be processed
8	$\hat{Q}^1_{EU,up}$	EU supply of unprocessed non-GM crop, minus unprocessed exports
9	$\hat{Q}^2_{EU,up}$	EU supply of unprocessed GM crop, minus unprocessed exports
10	$\hat{P}^1{}_p$	Retail price of processed non-GM crop
11	$\hat{P}^2{}_p$	Retail price of processed GM crop
12	$\widehat{Q^1}_{FE,p}$	EU foreign exports of processed non-GM crop
13	$\widehat{Q^2}_{FE,p}$	EU foreign exports of processed GM crop
14	$\widehat{Q^1}_{FE,up}$	EU foreign exports of unprocessed non-GM crop
15	$\widehat{Q^2}_{FE,up}$	EU foreign exports of unprocessed GM crop
16	$\hat{Q}^1_{FI,up}$	Quantity of unprocessed non-GM crop imported to EU
17	$\hat{Q}^2_{FI,up}$	Quantity of unprocessed GM crop imported to EU
18	$\hat{Q}^1_{FI,p}$	Quantity of processed non-GM crop imported to EU
19	$\hat{Q}^2_{FI,p}$	Quantity of processed GM crop imported to EU
20	$\hat{Q}^1_{EU,S}$	EU supply of unprocessed non-GM crop
21	$\hat{Q}^2_{EU,S}$	EU supply of unprocessed GM crop
22	$\widehat{x^1_1}$	Supply curves of unprocessed non-GM crop
23	$\widehat{x^2_1}$	Supply curves of unprocessed GM crop
24	$\hat{x}_2$	Supply curves of manufacturing/processing

25	$\hat{x}_3$	Supply curves of 3 scenarios
26	$\widehat{w_1^1}$	Price of non-GM unprocessed crop
27	$\widehat{w_1^2}$	Price of GM unprocessed crop
28	$\widehat{w}_2$	Price of manufacturing/processing
29	$\widehat{w}_3$	Price of 3 scenarios

Table 24: Exogeneous variables.

1	$\hat{P}^3$	Proportionate change in Retail price of NGT crop
2	δ^1	Willingness to pay for processed non-GM crop of EU consumers *-1
3	δ^2	Willingness to pay for processed GM crop of EU consumers *-1
4	δ^3	Willingness to pay for NGT crop of EU consumers *-1
5	$\delta^1_{FE,p}$	Willingness to pay for processed non-GM crop of foreign consumers *-1
6	$\delta^2_{FE,p}$	Willingness to pay for processed GM crop of foreign consumers *-1
7	v_1^1	Marginal cost of unprocessed non-GM crop *-1
8	v_1^2	Marginal cost of unprocessed GM crop *-1
9	v_2	Marginal cost of manufacturing/processing *-1
10	v_3	Marginal cost of 3 scenarios *-1
11	$\delta^1_{FE,up}$	Willingness to pay for unprocessed non-GM crop of foreign consumers *-1
12	$\delta^2_{FE,up}$	Willingness to pay for unprocessed GM crop of foreign consumers *-1

Table 25: Example of matrix operations in Excel.

	changes in Quantities														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Equations	$Q^1_{EU,D}$	$Q^2_{EU,D}$	$Q^3_{EU,D}$	$Q^1_{EU,pd}$	$Q^1_{FI,p}$	$Q^2_{EU,pd}$	$Q^2_{FI,p}$	$Q^1_{FE,p}$	$Q^2_{FE,p}$	$Q^1_{EU,p}$	$Q^2_{EU,p}$	$Q^1_{EU,up}$	$Q^2_{EU,up}$	$Q^1_{FI,up}$	$Q^2_{FI,up}$
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

									changes in Prices							Model Outcomes	
	16	17	18	19	20	21	22	23	24	25	26	27	28	29			
Equations	x^1_1	x^2_1	x_2	x_3	$Q^1_{EU,S}$	$Q^2_{EU,S}$	$Q^1_{FE,up}$	$Q^2_{FE,up}$	P^1_p	P^2_p	w^1_1	w^2_1	w_2	w_3	Shocks		% of change
1	0	0	0	0	0	0	0	0	0,00	0,30	0	0	0	0	0,0000	$Q^1_{EU,D}$	0
2	0	0	0	0	0	0	0	0	0,00	0,00	0	0	0	0	0,0000	$Q^2_{EU,D}$	0
3	0	0	0	0	0	0	0	0	0,00	0,00	0	0	0	0	0,0000	$Q^3_{EU,D}$	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^1_{EU,pd}$	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^1_{FI,p}$	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^2_{EU,pd}$	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^2_{FI,p}$	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^1_{FE,p}$	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^2_{FE,p}$	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^1_{EU,p}$	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^2_{EU,p}$	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^1_{EU,up}$	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^2_{EU,up}$	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^1_{FI,up}$	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^2_{FI,up}$	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	x^1_1	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	x^2_1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	x_2	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	x_3	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^1_{EU,S}$	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^2_{EU,S}$	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^1_{FE,up}$	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	$Q^2_{FE,up}$	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	P^1_p	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	P^2_p	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	w^1_1	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	w^2_1	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	w_2	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0000	w_3	0

A.14) Glossary

Term	Description	Source
Appeal Committee	The Appeal Committee functions like the other Comitology Committees (made up of EU country's representatives, chaired by the Commission, same voting rules). It is not a permanent body, but rather a procedural tool which gives the EU countries the opportunity to have a second discussion at a higher level of representation.	EC (n.d.-a)
Coexistence	The ability of farmers to make a practical choice between conventional, organic and genetically modified (GM) crop production.	EC (2006b)
Consumer surplus	The excess of the benefit a consumer gains from purchase of a good over the amount paid for the good. An individual demand curve shows the valuation put by a consumer on successive units of a good. Goods whose value to the consumer is higher than their price are bought; purchasing stops when their marginal utility is equal to their price times the marginal utility of income.	Black et al. (2017)
Demand elasticity	The ratio between proportional change in quantity demanded and proportional change in price.	Black et al. (2017)
Discount rate	The interest rate at which future receipts or payments are discounted to find their present value. If the discount rate is r per cent per annum in decimal points, the present discounted value of a payment of A due in T years' time is $V = A/(1 + r)^T$.	Black et al. (2017)
Event	An event is the insertion of a particular transgene into a specific location on a chromosome. The term "event" is often used to differentiate genetically engineered crop varieties.	(AgBiosafety, n.d.)
GMO	An organism which contains genetic material that has been deliberately altered and which does not occur naturally through breeding or selection	EFSA (n.d.)
Traceability	The ability to trace GMOs and products produced from GMOs at all stages of the placing on the market throughout the production and distribution chains facilitating quality control and also the possibility to withdraw products.	EU (2003)
Identity preservation	Identity preserved agricultural production means that the unique traits or quality characteristics of a variety are maintained from when the crop is seeded through to when the crop is harvested, transported, handled, processed and shipped.	CSGA (n.d.)
NGT1	NGT plants that could also occur naturally or by conventional breeding ('category 1 NGT plants') would be subject to a verification procedure, based on criteria set in the proposal. NGT plants that meet these criteria would be treated like conventional plants and exempted from the requirements of the GMO legislation. Information on category 1 NGT plants would be provided through the labelling of seeds, in a public database and through the relevant catalogues on plant varieties.	EC (n.d.-c)
NGT2	For all other NGT plants ('category 2 NGT plants'), the requirements of the current GMO legislation would apply. They would be subject to risk assessment and authorisation before could be put on the market. They would be traced and labelled as GMOs, with the possibility of a voluntary label to indicate the purpose of the genetic modification. The risk assessment, detection method and monitoring requirements would be adapted to different risk profiles and regulatory incentives would be	EC (n.d.-c)

	available for NGT plants featuring traits that can contribute to sustainability goals.	
Producer Surplus	Total benefit to the producer from remaining in business, given by profit plus fixed cost under fixed factor prices. The area between the price line and the supply curve.	Just et al. (2004)
SDN-1	Techniques using site-directed nucleases with the objective of generating localized random base pair changes, deletions or short random insertions (indels), as a result of error in the cell gene repair mechanism based on non-homologous end joining (NHEJ). No exogenous DNA repair template is used in these applications.	FAO (2012)
SDN-3	Techniques using site-directed nucleases with the objective of generating a localized pre-defined insertion/deletion/replacement of entire genetic elements (promoters, coding sequences, etc.), or entire genes, because of co-introducing a large DNA molecule to be inserted in the target area. DNA molecule may or may not be homologous to the targeted area, and its insertion can take place either by HR or by NHEJ.	FAO (2012)
SND-2	Techniques using site-directed nucleases with the objective of generating a localized predefined point mutation or deletion/addition, because of co-introducing a repair DNA molecule that is homologous to the targeted area and is expected to act as a repair template. Repairing is achieved by homologous recombination (HR). SDN-2 generates changes spanning few base pairs in genetic elements (promoters, coding sequences, etc.) that pre-exist in the host genome.	FAO (2012)
Social costs	The total cost of any activity. This includes private costs which fall directly on the person or firm conducting the activity, as well as external costs outside the price system which fall on other people or firms.	Black et al. (2017)
Standing Committee	Standing Committees deliver opinions that inform the Commission's work on measures that it is planning. Such measures relate to the implementation of legislation that is already adopted. The Commission consults the relevant committee depending on the policy area: food & feed safety, animal health & welfare and plant health. Committee members are national experts who represent EU governments and public authorities.	EC (n.d.-d)
Supply elasticity	The ratio of the proportional rise in the quantity of a good supplied to a proportional rise in its price.	Black et al. (2017)
Trait	One of the many characteristics that define an organism. The phenotype is a description of one or more traits.	(FAO, 2001)