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Long-term challenges in cereal and oilseed markets – case studies analyzed with model systems

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Summary

Cereals and oilseeds are important agricultural crops which are globally produced, traded and consumed. They are the most important crops in terms of area used and output quantity in the agricultural crop sector. Therefore, this dissertation analyzes cereal and oilseed markets and the factors impacting them in the past, present, and possibly future. Consequently, three research questions are addressed:

1) What are the main factors that have impacted and might still impact cereal and oilseed markets?
2) How did cereal and oilseed markets develop in the past and which factors caused the development?
3) How will cereal and oilseed markets be impacted by the different long-term factors in the future?

Answering the first two research questions introduces the topic, provides background information, and motivates the third research question. The latter is the main focus of the dissertation.

In answer to Research Question 1, the main long-term factors impacting cereal and oilseed markets are identified as either being 'persistent underlying factors', such as, population growth, income, productivity, and land availability, or 'strongly market-interfering', such as, policies in the domain of agriculture, trade, climate change mitigation and biofuels. Other long-term 'potential market-interfering factors' are, e.g., water and nutrient availability, food loss and waste, climate change, environmental protection policies, changing preferences or diets, developments in the livestock and other downstream sectors, as well as implementations of new standards and certifications. However, a noticeable impact on cereals and oilseeds would only occur if these factors change their observed long-term trend which is less likely to happen than changes in the 'strong market-interfering factors'.

Research Question 2 is answered as follows. Cereal and oilseed markets have been growing and concentrating on few crops, namely corn, wheat, barley, soybeans, rapeseed, and sunflower seed. Considering the period from 2004/05 to 2018/19 in detail, this has continued for corn and oilseeds by increasing yields and expanding area. However, growth in the wheat market has slowed down and has only been realized by yield growth, while barley markets have not grown. Demand has increased mainly driven by population and income growth. Especially the shift in China towards more meat-based diets resulted in higher demand for cereals and oilseeds as feed. Additionally, several countries have increased demand for cereals and oilseeds by introducing biofuel policies.

Trade has been growing constantly with a few countries dominating the export market, while the import market is less concentrated. Of the large exporters, the United States, the European Union, and Argentina have not expanded production as fast as other countries and have lost shares in exports of cereals and oilseeds, while Brazil, Ukraine, and Russia have strongly increased production and have become important exporters.

Depending on the development of the 'persistent underlying factors' and the 'strongly market-interfering factors', cereals and oilseed markets will deviate from their historically observed trends. To address Research Question 3, the dissertation selects four factors to be analyzed in dedicated case studies to *ex ante* project different developments in cereal

and oilseed markets until 2030 given a change in these factors. These are productivity increases by closing yield gaps (1), trade policies (2), land availability (3), and biofuel policies (4).

For the analysis, economic equilibrium models in combination with bio-physical or land use change models are used to quantify the impact of specific changes in the four factors on cereal and oilseed markets via scenario analysis. Therefore, two model systems have been developed which consist of already existing large-scale models. One model system consists of GLOBIOM, MAGNET, and AGMEMOD and is developed as a one-way link from GLOBIOM over MAGNET to AGMEMOD. The other is a two-way iterative linkage of MAGNET and LandSHIFT.

The model system of GLOBIOM, MAGNET, and AGMEMOD is used to analyze closing yield gaps, changing trade policies, and land use changes until 2030. As study regions, Ukraine and Russia are selected because other studies state their high potential to increase yields and reuse land formerly used for agricultural production that is currently abandoned. Further, trade policies have changed in the two countries and in the future might change to more liberalization or revert back to higher protection levels.

Both countries have shown a strong production increase in cereal and oilseed markets over the last years and have become major exporters, especially, for corn, wheat, and sunflower oil. These strong dynamics require a carefully developed baseline until 2030 as a reference to which the scenarios can be compared (Case Study 1). The baseline projections show that oilseed production in Ukraine will not increase as fast as historically observed, while cereal expansion, especially corn, is continuing at similar levels. In contrast, projections for Russia indicate a continuation of strong oilseed production expansion as historically observed, while projections for cereal expansion continue at a slower pace compared to historically observed trends.

One of the conducted scenarios has been yields increased by intensification and productivity growth (Case Study 2). As a prerequisite a more stable and economic-friendly institutional environment would be necessary to achieve these elevated yields. Results show that both countries will increase their cereal and oilseed production in such a situation without using more land even though theoretically abandoned land is still large, at least in Russia. Oilseed production would increase more than cereal production in terms of percentage in both countries. In cereals, Russia would further concentrate on producing more wheat, while Ukraine would shift away from wheat production to barley and corn.

General trade strategies have been analyzed for the two countries ranging from reducing tariffs and non-tariff measures to increasing tariffs between the Eurasian Economic Union and third countries (Case Study 3). Therefore, three scenarios have been set up of which all show only small impacts on cereal and oilseed markets. However, cereal and oilseed markets regularly face ad hoc policy interference in the form of temporary export taxes, export quotas, and even export bans in Ukraine and Russia. These policies are often a reaction to high world market prices and domestic harvest shortfalls and should stabilize domestic prices.

The model system of MAGNET and LandSHIFT is used to simulate changes in global biofuel policies as well as changes in land use policies until 2030 (Case Study 4). Therefore, a baseline and three scenarios are set up which simulate a) increases in biofuel demand as proclaimed by governments, b) conservation of forest, wetlands, and peatlands, and c) a

combination of both. Results show that several regions will face production constraints in the future if they cannot expand agricultural areas and simultaneously keep their biofuel targets. This double burden is most prominent in South & East Asia, namely Indonesia and China. Parts of Africa also face production constraints which are caused by the simulated area protection policies.

The dissertation focuses on analyzing *ex ante* impacts of long-term factors on cereal and oilseed markets. Consequently, short-term factors, such as weather, ad hoc policies, or an outbreak of war, have not been considered in the case studies. Nevertheless, their importance for the markets has been presented and discussed. Often, these short-term factors impact the market more strongly than the long-term factors. However, they can only be assessed in an *ex post* analysis and require different economic methods and approaches. This is beyond the scope of the dissertation.

In conclusion, the dissertation gives an overview of the historical development of cereal and oilseed markets, highlighting the main factors impacting the markets, and contributing to a better understanding of the long-term development of cereal and oilseed markets under certain assumptions. For the latter, new model systems have been developed and applied in the case studies. The main conclusions of the dissertation are as follows. Cereal and oilseed markets would continue growing even faster than historically observed trends if yield gaps are reduced. Additional growth in demand could be met without requiring large increases in yields and only accompanied by small increases in prices. Further, policies in the fields of trade, domestic agriculture, climate change, and environmental protection often restrict the development of cereal and oilseed markets. This could continue in the future if trade barriers increase or specific areas are protected. Consequently, the various positive and negative effects resulting from a policy should be carefully assessed before a policy is being implemented.

Zusammenfassung

Getreide und Ölsaaten sind wichtige pflanzliche Agrarprodukte, die global produziert, gehandelt und verbraucht werden. Von allen pflanzlichen Agrarprodukten haben sie den größten Anteil gemessen an der genutzten landwirtschaftlichen Fläche sowie der produzierten Menge. Aus diesem Grund analysiert diese Dissertation Getreide- und Ölsaatenmärke und die Faktoren, die diese Märket in der Vergangenheit beeinflusst haben, es in der Gegenwart tun und höchst wahrscheinlich auch in der Zukunft eine zentrale Rolle spielen werden. Hierzu werden drei Forschungsfragen, die aufeinander aufbauen, adressiert:

1. Welche Faktoren haben Getreide- und Ölsaatenmärkte hauptsächlich beeinflusst und werden dies voraussichtlich weiter tun?
2. Wie haben sich die Getreide- und Ölsaatenmärkte in der Vergangenheit entwickelt und welche Faktoren waren dafür verantwortlich?
3. Wie könnten Getreide- und Ölsaatenmärkte in Zukunft durch verschiedene langfristig wirkende Faktoren beeinflusst werden?

Die Beantwortungen der ersten beiden Forschungsfragen leiten in das Thema ein, geben Hintergrundinformationen, und sind Grundlage zur Beantwortung der dritten Forschungsfrage. Forschungsfrage 3 stellt den Kern der Arbeit dar.

Zur Beantwortung der ersten Forschungsfrage, werden die unterschiedlichen Faktoren zunächst klassifiziert. Dabei werden die hauptsächlichen Faktoren, die langfristig auf Getreide- und Ölsaatenmärkte wirken in zwei Kategorien unterteilt: a) dauerhaft und kontinuierlich wirkende Faktoren wie Bevölkerungswachstum, Einkommensentwicklung, Produktivitätsänderungen und Verfügbarkeit von Land sowie b) stark den Markt beeinflussende Faktoren wie Agrar-, Handels-, Klimaschutz- und Biokraftstoffpolitiken. Andere langfristig wirkende Faktoren, die potentiell Getreide- und Ölsaatenmärkte beeinflussen können, sind zum Beispiel die Verfügbarkeit von Wasser und Nährstoffen, Nahrungsmittelverluste und -verschwendung, Klimawandel, Umweltschutzpolitiken, Präferenzänderungen, Änderungen im Ernährungsverhalten, Entwicklungen in tierischen und anderen nachgelagerten Sektoren, sowie die Einführung von Standards und Zertifizierungssystemen. Ein nennenswerter Einfluss auf Getreide- und Ölsaatenmärkte ist bei diesen Faktoren jedoch nur zu erwarten, wenn sie stark von ihren historisch beobachteten Entwicklungen abweichen. Dies wird jedoch als weniger wahrscheinlich beurteilt als Änderungen in den Faktoren, die den Markt stark beeinflussen.

Forschungsfrage 2 lässt sich wie folgt beantworten. Getreide- und Ölsaatenmärkte sind in der Vergangenheit stetig gewachsen und werden durch wenige Kulturen (Mais, Weizen, Gerste, Sojabohnen, Raps und Sonnenblumen) dominiert. Im näher betrachteten Zeitraum von 2004/05 bis 2018/19, hat sich dies für Mais und Ölsaaten fortgesetzt indem sowohl Erträge als auch Anbauflächen gestiegen sind. Im Weizenmarkt hat sich das Wachstum allerdings verlangsamt und wurde überwiegend durch Ertragszuwächse realisiert. Der Gerstenmarkt hingegen stagniert. Die Nachfrage nach Getreide und Ölsaaten ist hauptsächlich aufgrund von Bevölkerungs- und Einkommenswachstum angestiegen. Insbesondere die Entwicklung in China hin zu einem höheren Konsum tierischer Produkte, hat die Nachfrage nach Getreide und Ölsaaten als Futtermittel stark erhöht. Zusätzlich

haben die Biokraftstoffpolitiken in mehreren Ländern zu einer erhöhten Nachfrage nach Getreide und Ölsaaten geführt.

Die Handelsmengen haben sich ebenfalls kontinuierlich erhöht. Dabei dominieren einige wenige Länder die Exportseite, wohingegen die Importseite weit weniger konzentriert ist. Von den großen Exporteuren haben die Vereinigten Staaten von Amerika, die Europäische Union und Argentinien ihre Produktion weniger stark erhöht als andere Länder und daher Anteile bei den Getreide- und Ölsaatenexporten an Brasilien, die Ukraine und Russland verloren, die ihre Produktion stark erhöht haben und zu wichtigen Exporteuren wurden.

Abhängig von der Entwicklung der dauerhaft und kontinuierlich wirkenden Faktoren sowie der stark den Markt beeinflussenden Faktoren könnten sich die Getreide- und Ölsaatenmärkte anders entwickeln als der historische Trend es suggerieren würde. Um Forschungsfrage 3 zu adressieren, wurden in dieser Dissertation vier Faktoren gewählt, deren Wirkungen auf Getreide- und Ölsaatenmärkte mit Hilfe von Fallstudien analysiert wurden. Dabei wurden ex ante Projektionen in Abhängigkeit der untersuchten Faktoren durchgeführt, die Änderungen auf den Getreide- und Ölsaatenmärkten bis 2030 quantifizieren. Die gewählten Faktoren sind Produktivitätssteigerung durch Schließen von Ertragslücken (1), Handelspolitiken (2), Verfügbarkeit von Land (3) und Biokraftstoffpolitiken (4).

Mit Hilfe von ökonomischen Gleichgewichtsmodellen in Kombination mit bio-physikalischen oder Landnutzungsmodellen wird der Einfluss von Änderungen in den vier Faktoren auf Getreide- und Ölsaatenmärkten durch Szenarioanalysen quantifiziert. Dazu wurden zwei Modellsysteme entwickelt, die auf schon bestehenden großen Modellen beruhen. Das erste Modellsystem besteht aus den Modellen GLOBIOM, MAGNET und AGMEMOD und wurde als eine unidirektionale Verknüpfung von GLOBIOM über MAGNET zu AGEMEMOD entwickelt. Im anderen Modellsystem wurden MAGNET und LandSHIFT iterativ miteinander verknüpft.

Das Modellsystem aus GLOBIOM, MAGNET und AGEMOD wird genutzt um die Schließung von Ertragslücken, Änderungen in Handelspolitiken sowie Landnutzungsänderungen bis 2030 zu analysieren. Die Ukraine und Russland wurden hier als zu untersuchende Regionen gewählt, weil andere Studien ein hohes Potential in Bezug auf mögliche Ertragssteigerungen und Wiedernutzung von aktuell nicht mehr genutzten Agrarflächen in beiden Ländern ausweisen. Zudem haben sich die Handelspolitiken der beiden Länder in der Vergangenheit stark verändert und könnten sich in der Zukunft weiter ändern hin zu einer stärkeren Liberalisierung oder aber hin zu höherem Protektionismus.

Beide Länder haben ihre Produktion von Getreide und Ölsaaten über die letzten Jahre stark gesteigert und wurden so zu wichtigen Exporteuren insbesondere von Mais, Weizen und Sonnenblumenöl. Diese sehr dynamischen Entwicklungen erfordern eine sorgfältig entwickelte Baseline bis 2030, die als Referenzszenario für den Vergleich mit den entwickelten Szenarien dient (Fallstudie 1). Die Projektionen der Baseline zeigen, dass die Ölsaatenproduktion in der Ukraine weniger stark steigt als historisch beobachtet, wohingegen die Getreideproduktion, insbesondere Mais, weiter ähnlich stark ausgedehnt wird. Im Gegensatz dazu zeigen die Projektionen für Russland, dass die Ölsaatenproduktion weiter stark ausgedehnt wird, wohingegen die Getreideproduktion langsamer wächst als historisch beobachtet.

Ertragsteigerungen durch Intensivierung und Produktivitätssteigerungen ist eines der durchgeführten Szenarien (Fallstudie 2). Diese höheren Erträge haben als Voraussetzung ein stabiles und wirtschaftsfreundliches institutionelles Umfeld. Die Ergebnisse zeigen, dass beide Länder ihre Getreide und Ölsaatenproduktion unter diesen Umständen erhöhen, ohne jedoch mehr Flächen dafür zu nutzen, obwohl die theoretische Menge an ungenutzten Flächen zumindest in Russland noch hoch ist. Dabei steigt in beiden Ländern die Ölsaatenproduktion prozentual stärker als die Getreideproduktion. Zudem dehnt Russland insbesondere die Weizenproduktion aus, wohingegen die Ukraine ihre Getreideproduktion hin zu mehr Gerste und Mais ausrichtet.

In Fallstudie 3 wurden verschiedene Handelsstrategien der beiden Länder analysiert, die von einem Abbau von Zöllen und nicht-tarifären Handelshemmnissen bis hin zu einer Erhöhung der Zölle zwischen der Eurasischen Union und Drittländern reichen. Dazu wurden drei Szenarien durchgeführt, die jedoch alle nur geringe Auswirkungen auf Getreide- und Ölsaatenmärkte zeigen. In der Ukraine und Russland werden jedoch häufig kurzfristige zeitlich begrenzte Handelsbeschränkungen in Form von Exportsteuern, Exportquoten oder auch Exportverboten für Getreide und Ölsaaten eingeführt. Diese Politiken sind oft eine Reaktion auf hohe Weltmarktpreise und niedrige inländische Ernten und sollen dazu dienen das heimische Preisniveau zu stabilisieren.

Das Modellsystem mit MAGNET und LandSHIFT wird genutzt um weltweite Änderungen von Biokraftstoffpolitiken und Landnutzungspolitiken bis 2030 zu simulieren (Fallstudie 4). Hierzu wurde eine Baseline sowie drei Szenarien entwickelt, die a) eine Erhöhung der Nachfrage nach Biokraftstoffen wie durch Regierungen angekündet, b) einen Erhalt von Wäldern, Feuchtgebieten und Torfmooren und c) die Kombination aus beiden simulieren. Die Ergebnisse zeigen, dass einige Region an Produktionsgrenzen kommen werden, wenn sie ihre landwirtschaftliche Nutzfläche nicht ausdehnen können und gleichzeitig ihre Biokraftstoffziele beibehalten. Diese doppelte Belastung ist in Süd- und Ostasien, konkret in Indonesien und China, am ausgeprägtesten. Durch die simulierten politisch induzierten Schutzgebiete sind Produktionseinschränkungen auch in Teilen von Afrika zu beobachten.

Diese Dissertation legt ihren Fokus auf die ex ante Analyse von Auswirkungen langfristiger Faktoren auf Getreide- und Ölsaatenmärkte. Demzufolge wurden kurzfristige Faktoren wie beispielsweise Wettereinflüsse, ad hoc Politiken oder auch ein Kriegsausbruch nicht in den Fallstudien berücksichtigt. Diese kurzfristigen Faktoren beeinflussen die Märkte jedoch häufig stärker als die langfristigen Faktoren und daher wurden sie ebenfalls aufgezeigt und diskutiert. Die Analyse dieser Faktoren ist jedoch oft nur ex post möglich und benötigt andere ökonomische Methoden und Ansätze, was weit über den Umfang in dieser Dissertation hinaus gehen würde.

Insgesamt gibt die Dissertation einen Überblick über die historische Entwicklung von Getreide- und Ölsaatenmärkten, zeigt die Hauptfaktoren auf, die einen Einfluss auf die Märkte haben und trägt zu einem besseren Verständnis der langfristigen Entwicklungen von Getreide und Ölsaaten unter festgelegten Annahmen bei. Um Letzterem gerecht zu werden, wurden neue Modellsysteme entwickelt und in Fallstudien angewandt. Die folgenden Schlussfolgerungen können aus der Dissertation gezogen werden. Getreide- und Ölsaatenmärkte können stärker wachsen als historisch beobachtet, wenn Ertragslücken geschlossen werden. Zusätzliche Nachfrage kann bedient werden ohne dass starke Ertragszuwächse nötig sind und Preise dabei nur leicht ansteigen. Weiter wird die Entwicklung von Getreide und Ölsaatenmärkten oft von Handels-, Agar- Klimaschutz- und

Umweltschutzpolitiken beschränkt. Wie durch die Analysen in den Fallbeispielen aufgezeigt könnte dies in Zukunft fortgeführt werden, wenn Handelsbeschränkungen steigen oder Schutzgebiete ausgeweitet werden. Daher sollten die positiven und negativen Effekte einer Politik sorgfältig gegeneinander abgewogen werden bevor eine Politik eingeführt wird.

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Table of Content

List of Figures

List of Tables

List of Abbreviations

AGMEMOD	Agricultural Member State Modelling
CAP	Common Agricultural Policy
CCI	Climate Change Initiative
CDE	constant difference of elasticities
CES	constant elasticity of substitution
CET	constant elasticity of transformation
CGE	computable general equilibrium
CIF	cost, insurance, and freight
CIS	Commonwealth of Independent States
CO_2	carbon dioxide
CPI	Corruption Perception Index
DCFTA	Deep and Comprehensive Free Trade Area
DDGS	dried distillers grains with solubles
EAEU	Eurasian Economic Union
EFTA	European Free Trade Association
EPIC	Environmental Policy Integrated Climate Model
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
fob	free on board
FTA	free trade agreement
G4M	Global Forestry Model
GATT	General Agreement on Tariffs and Trade
GDP	gross domestic product
GFR	gross farm receipts
GHG	greenhouse gas
GLOBIOM	Global Biomass Optimization Model
GMO	genetically modified organisms
GTAP	Global Trade Analysis Project
I$	international dollar
IER	Institute for Economic Research and Policy Consulting
IGC	International Grains Council
IIASA	International Institute for Applied Systems Analysis
IKAR	Institute for Agricultural Market Studies
ISTA	International STatistical Agricultural Information Mielke GmbH
JRC	Joint Research Centre of the European Commission
LandSHIFT	Land Simulation to Harmonize and Integrate Freshwater Availability and the Terrestrial Environment
LPJmL	Lund-Potsdam-Jena managed Land
MAGNET	Modular Applied GeNeral Equilibrium Tool
MFN	most favored nation
MOJITO	Model Junction Linkage Tool
NTM	non-tariff measure
OECD	Organization for Economic Co-operation and Development
PE	partial equilibrium
PSD	Production, Supply and Distribution

PSE	producer support estimate
REDD+	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
RUB	Russian ruble
SDGs	Sustainability Development Goals
UAH	Ukrainian hryvnia
UN	United Nations
US	United States
USD	dollar of the United States
USDA	United States Department of Agriculture
WEcR	Wageningen Economic Research
WTO	World Trade Organization

1 Introduction

Approximately 37 % of the global land area or 4.8 billion hectares are used for agricultural production in 2018 of which 33 % or 1.6 billion hectares are cropland (FAO, 2020e). The use of cropland is dominated by the production of cereals and oilseeds. In 2018, cereals and oilseeds[1] account for 51 % and 22 % of the total area harvested, respectively (FAO, 2020a). While several types of cereals and oilseeds exist, only a few dominate the sectors. Globally, over 91 % of the cereal area is planted either with wheat, corn, rice, barley, or sorghum accounting for 97 % of the cereal production (FAO, 2020a). Similarly, the five main oilseeds are soybeans, rapeseed, seed cotton, groundnuts and sunflower seed accounting for 80 % of the total oilseeds area harvested (FAO, 2020a). These figures on the supply side demonstrate the large share of cereals and oilseeds using land which is a finite natural resource as well as the high share of only a few varieties on these markets.

On the demand side, cereals and oilseeds including their processed products are used as food, feed, seed, energy source and ingredients to industrial products. These uses often compete for the feedstock and, hence, land, but they can also complement each other. For example, rapeseed is crushed into oil and meal of which meal is used for feed, complementing the production of oil. However, the oil can be used either as food, energy source, or ingredient to industrial products which are then competing uses. While the uses are manifold, two uses dominate, i.e., food and feed use. In the cereal sector, food and feed use respectively account for 46 % and 33 % of the total global use in 2018 (FAO, 2021b). Oilseeds are mostly crushed, resulting in vegetable oils and oilseed meals. While oilseed meals are used as feed, vegetable oils are used mostly as food, energy source and ingredient to industrial products. Cereals and oilseeds are important food supply products. While cereals provide 45 % of the overall caloric intake worldwide in 2018, oilseeds provide 43 % of the overall fat intake (FAO, 2021b). Cereal and oilseed demand for biofuel production increased, especially since the beginning of the 21st century.

A large share of cereals and oilseeds are traded and, hence, changes in local consumption and production have global impact. In 2018, cereal and oilseed exports (including processed products) have a share of respectively 19 % and 25 % of global production (FAO, 2021b). Often, the export side is dominated by a few main exporting countries, while the import side is less concentrated.

Having stressed the importance of cereals and oilseeds and their concentration on a few main cereal and oilseed types, this dissertation aims to give an overall picture of the most important aspects of these markets and identifies the most important challenging factors impacting the markets. These factors can be distinguished by short-term factors, e.g., weather and stock levels, and long-term factors, e.g., population growth and production productivity development. Further, agricultural, trade, environmental and climate policies play an important role in these markets. While main drivers in the market exist for a long time, e.g. productivity, population and income growth, new factors and challenges, e.g., climate change mitigation policies, arose and continue to arise. Therefore, this dissertation

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[1] Cereals include barley, buckwheat, canary seed, cereals nes, fonio, grain mixed, maize, millet, oats, quinoa, rice paddy, rye, sorghum, triticale, and wheat and oilseeds is here equivalent to the aggregate oilcrops in FAO (2020a) and include castor oil seed, coconuts, groundnuts with shell, hempseed, jojoba seed, karite nuts (sheanuts), linseed, melonseed, mustard seed, oilseeds nes, olives, poppy seed, rapeseed, safflower seed, sesame seed, soybeans, sunflower seed, tung nuts, seed cotton, and oil palm fruit as defined in FAO (2020a).

identifies and classifies impacts on cereal and oilseed markets by answering the following research questions:

1) What are main factors that have impacted and might still impact cereal and oilseed markets?
2) How did cereal and oilseed markets develop in the past and which factors caused the development?
3) How will cereal and oilseed markets be impacted by the different long-term factors in the future?

Derived from a general overview which answers the Research Question 1 and 2, Research Question 3 is approached by analyzing specific aspects which have and will have an influence on cereal and oilseed markets with the help of different case studies. Therefore, this dissertation focuses on analyzing selected long-term factors, i.e., biofuel demand and productivity increase, and different policies, i.e., land use policies and trade policies.

For the analysis a suitable method is selected which quantifies the specific aspects and includes the other most important factors. This method is the application of different economic equilibrium simulation models linked to bio-physical and land use change simulation models for jointly running simulations. These simulations consist of various scenarios for long-term projections given specific varying assumptions. For each case study, the most appropriate model combination is selected.

The first case study analyses the Ukrainian and Russian cereal and oilseed markets which have dynamically grown in recent years. Especially production and exports have increased tremendously[2]. Is it likely that this growth will continue? To answer this question, a baseline scenario for Ukrainian and Russian cereal and oilseed markets is developed and three models are used jointly to show a possible development until 2030. The results are compared with other baselines and their robustness is tested through selected sensitivity analysis.

Building upon the first case study, a further production increase is simulated for Ukraine and Russia. The potential for increased production depends largely on the possibility and economic feasibility of intensifying production, increasing productivity, and expanding agricultural land. In both countries, these potentials are not yet fully utilized. Hence, a scenario is constructed simulating the partial closing of yield gaps in both countries. From this, potential production and exports of Ukrainian and Russian cereal and oilseed markets till 2030 and their impact on domestic markets is analyzed.

While the first two case studies focus on the possibilities for Ukraine and Russia to expand their production, the third case study analyzes different trade strategies of the two countries. Scenarios of market liberalization and increased border protection are simulated to analyze their impact on Ukrainian and Russian cereal and oilseed markets.

As demonstrated in the first case studies, domestic markets are affected by various country specific factors and can influence the global market. Hence, challenges and developments on a global scale can change overall cereal and oilseed markets. Climate change and the

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[2] The work in this dissertation has been started long before the Russian invasion of Ukraine. Hence, this new development is not considered in the conducted analysis. However, implications to the cereal and oilseed markets as well as the results of this dissertation are elaborated on in Chapter 6 and 7.

protection of the environment are such broad challenges with various aspects. The last case study combines and analyses two aspects of climate change and the protection of the environment at global level. These are a) the ambition to preserve land with high capacities of carbon sequestration, namely forests, wetlands, and peatlands, in its current state and, hence, to restrict the expansion of land for agricultural purposes and b) the aim to increase biofuel production to substitute fossil fuel use and, therefore, reduce greenhouse gas emissions.

While each case study can be seen as an individual analysis, together they demonstrate the wide range of possible future developments in cereal and oilseed markets. Major drivers in the markets and their impacts are included and quantified. However, these case studies do not cover all relevant aspects and, hence, have no claim to completeness. Additionally, the applied method has its limits and boundaries which have to be considered when interpreting the results. Nevertheless, this dissertation contributes to increase the understanding of cereal and oilseed markets with a focus on long-term challenges by giving a complete overview of these challenges as well as some in depth analysis targeting specific challenges.

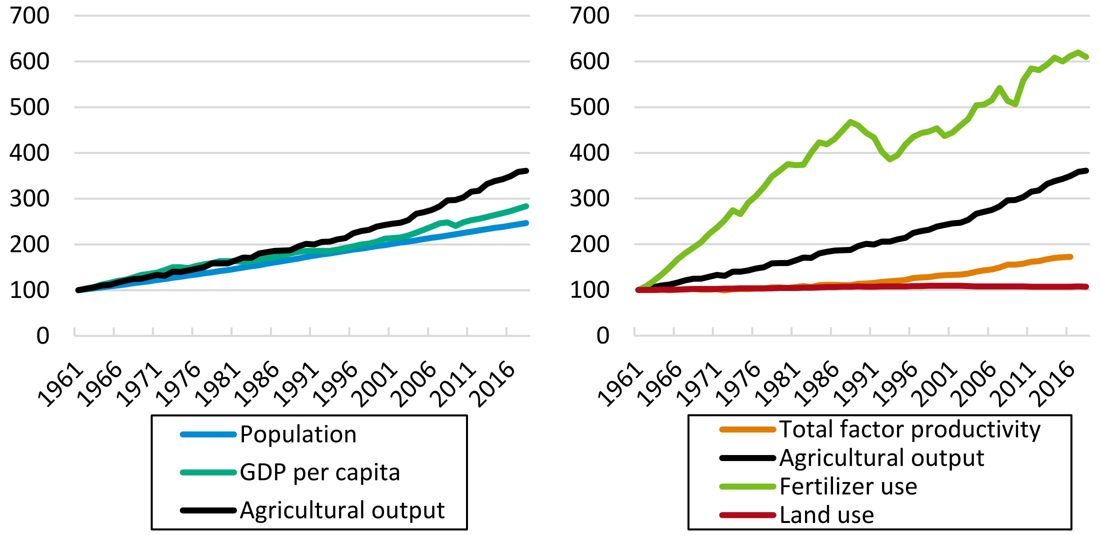
The remainder of the dissertation is structured as follows. The next chapter presents fundamental factors and the historical development of cereal and oilseed markets. The focus lies on historical and likely changing future developments of the most important factors and their impact on cereal and oilseed markets. Chapter 3 addresses the method selected for the analysis of the case studies, i.e., the combined use of different large-scale models. First, a literature review on economic models and the linkage of economic models with each other and other models is given. The used models are then briefly described before the developed linkages are presented. Chapter 4 consists of the four case studies and a concluding section discussing the implications for cereal and oilseed markets based on the case studies. Chapter 5 discusses the applied methodological approach, while Chapter 6 discusses the developments and future challenges of cereals and oilseeds. Chapter 7 summarizes the main findings, points to areas for further research and concludes with policy recommendations.

2 Fundamental factors and historical development of cereal and oilseed markets

The understanding of agricultural markets including the ones of cereal and oilseed starts with analyzing past developments of these markets and identifying the drivers behind these developments. The past reveals that agricultural markets are in the long term strongly driven by the development of population and income on the demand side as well as by productivity levels and input use on the supply side as commonly known in agricultural economics (Koester, 2016) and acknowledged by numerous researchers (Valin *et al.*, 2014). Many different aspects stand behind these long-term drivers. For example, income is a measure of the overall economic performance, and productivity depends on inventions and their implementation.

Furthermore, the long-term drivers of agricultural markets are also influenced by agricultural markets. So, the relationship is not unidirectional. For example, an increase in population is only possible if sufficient food is available and the agricultural sector contributes to the overall economic performance. Historically, these drivers have increased along with production increases. Figure 1 illustrates these joined developments by showing selected indices for estimated global developments. From 1961 to 2018, agricultural output nearly tripled to satisfy the increased demand by a growing and wealthier population. This output growth was realized by increased factor inputs, e.g., fertilizer, and in more recent years by strong productivity gains, i.e., producing more with constant inputs. The contribution of area expansion to this growth is low as it grew by less than 10 % over the whole period and is even declining since 2001.

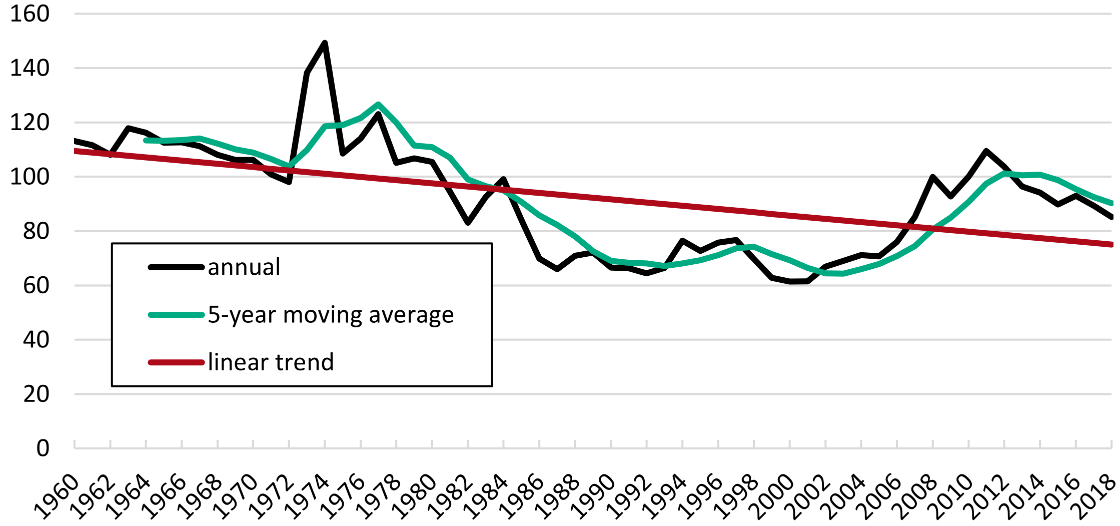
Figure 1 Development of agricultural output and main factors on the demand side (left graph) and supply side (right graph), 1961 to 2018, as index with 1961=100



Notes: Indices converted from original sources as follows population = world population according to UN (2019b); GDP per capita = GDP (constant 2010 USD) based on World Bank (2021b) divided by world population according to (UN, 2019b); agricultural output = world agriculture gross production value (constant 2014-2016 thousand international dollar (I$) according to FAO (2021c); total factor productivity = world agricultural total factor productivity index with 2005=100 according to USDA (2021a) and based on the methodology by Fuglie (2015); fertilizer use = sum of world agricultural use of nutrients nitrogen, phosphate and potash in tons according to FAO (2021a); land use = world agricultural land in 1000 ha according to (FAO, 2020e). All data from 1961 to 2018 except total factor productivity from 1961 to 2016.
Source: own calculations based on different data sources as stated in notes

Real prices decrease in years where supply factors outweigh demand factors and increase in years where demand factors outweigh supply factors. Besides the already mentioned long-term drivers, short-term drivers especially on the supply side, e.g., weather conditions, and unforeseeable events, e.g., an economic crisis, play an important role and cause volatility in prices. Historically, real agricultural prices have declined over time (Figure 2). This implies that productivity growth in the whole supply chain outweighed the increase in demand. However, increases in prices and sidewise fluctuations can also be observed (Figure 2). Especially price spikes such as around 1973 and 2007 are due to several short-term coinciding factors which were a sudden surge of global demand resulting in increased trade, economic crises, depreciation of the dollar of the United States (USD), increased input prices especially for oil and fertilizer, low harvest in successive years due to unfavorable weather conditions in main producing regions and low stock levels for cereals (Peters, Langley and Westcott, 2009). Agricultural and trade policies added to these price increases (Anderson, 2013). These price spikes were followed by periods of decreasing prices due to increases in productivity and production which outweighed demand growth.

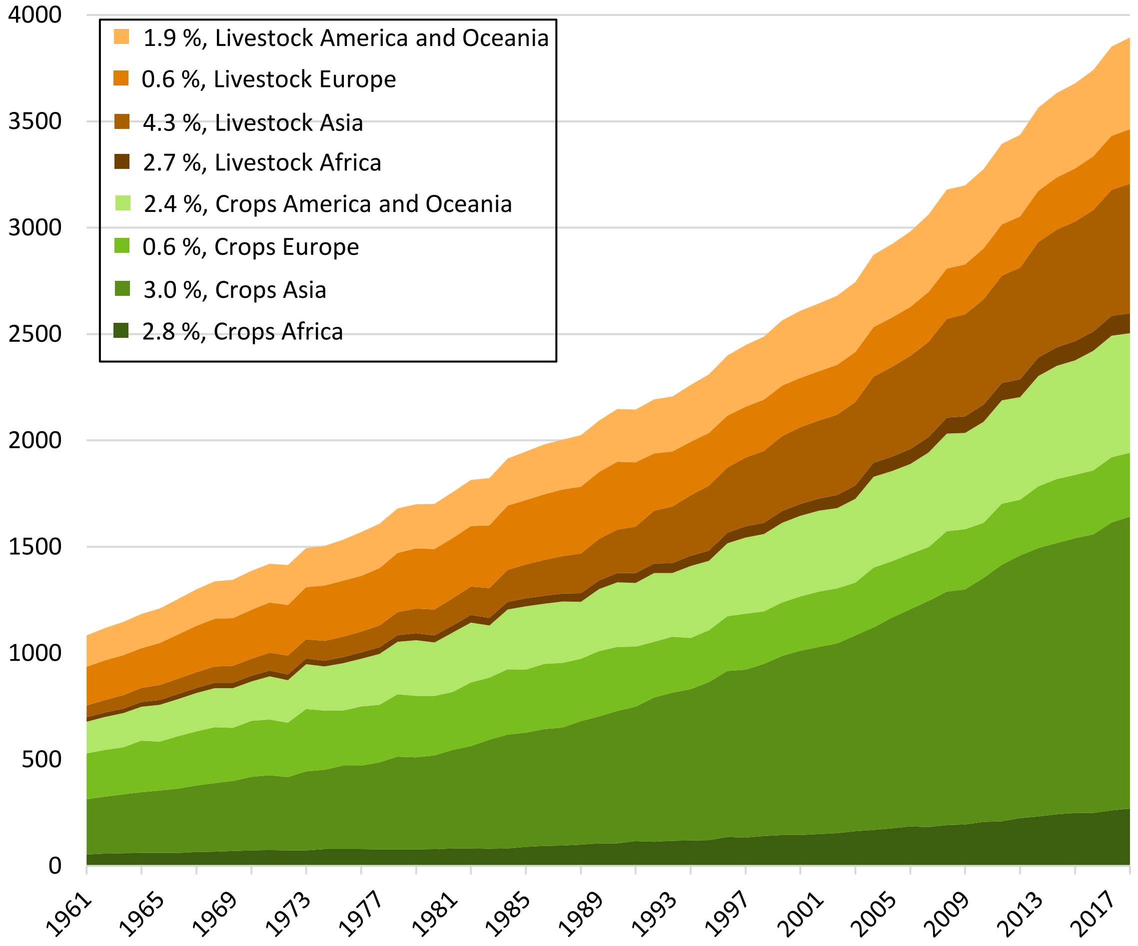
Figure 2 Real annual price index of agriculture, 1960 to 2018, index 2010=100, its 5-year moving average and linear trend



Notes: Index based on weighted annual prices for 28 different agricultural products in real 2010 USD according to World Bank (2021a)
Source: own calculations based on World Bank (2021a)

This general overview stresses the most important long-term drivers in agricultural markets but conceals different regional and product specific developments. The value of agricultural production can be broadly classified in crop production accounting for almost two third of agricultural output and livestock production accounting for the remaining part of agricultural output in the period 1961 to 2018 (FAO, 2021c). Agricultural output has been growing strongly over the years with main production increases in livestock and crops in Asia (Figure 3). The development in Asia is dominated by the strong growth in China. In percentage terms, Africa shows the second largest growth rates, however, total output value is the lowest. After the collapse of the Soviet Union, agricultural output sharply declined in Europe (including Russia) before increasing again, however, at lower levels than in other regions.

Figure 3 Global gross production value of crops and livestock grouped into four regions, 2016 to 2018, in billion constant 2014-16 international dollars and global annual average growth rates from 2016 to 2018

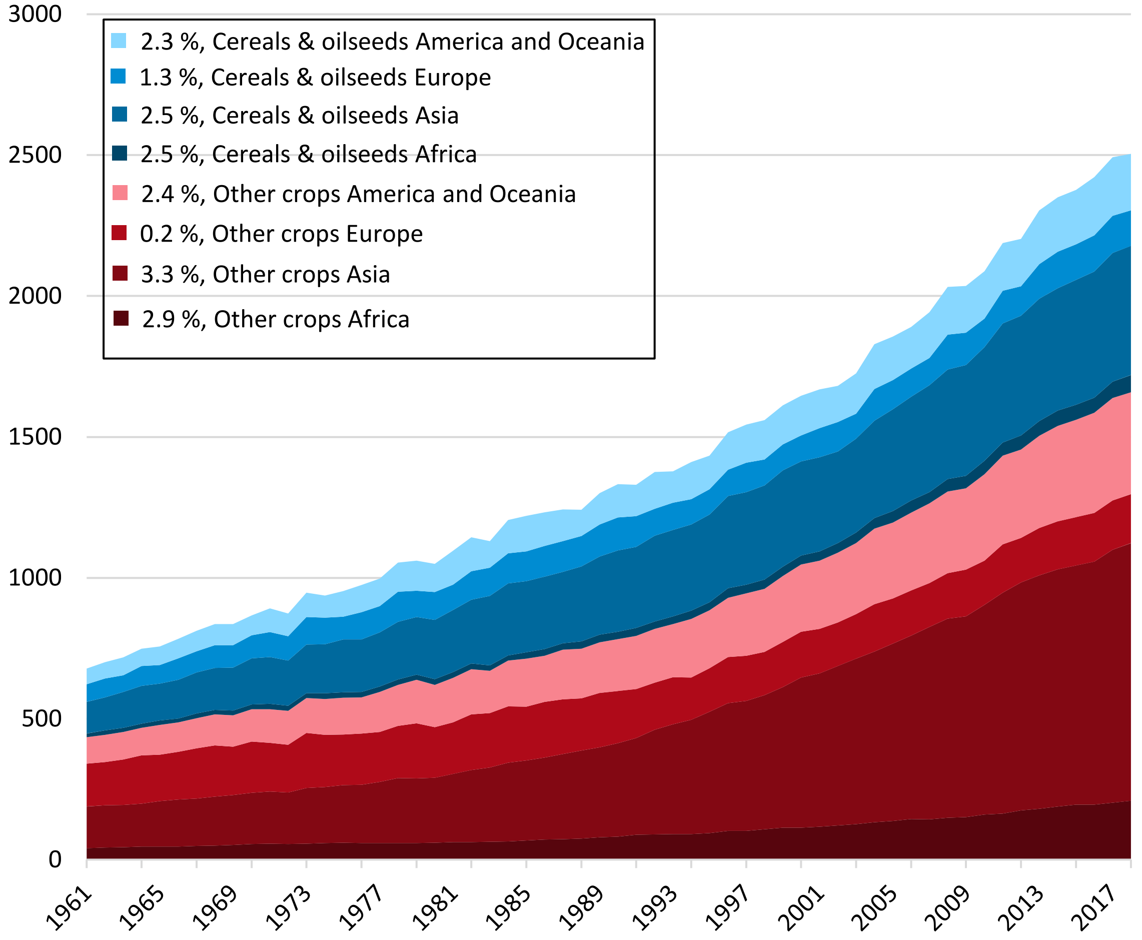


Notes: Crops = aggregate Agriculture minus aggregate Livestock from FAO (2021c), originally all in gross production value (constant 2014-2016 thousand I$)
Source: own representation based on FAO (2021c)

In terms of agricultural output, cereals and oilseeds account for a bit more than a third of crop output (FAO, 2021c). The increase in output of other crops, e.g., fruits and vegetables, has contributed more to crop output increase than cereal and oilseed output, except for Europe (Figure 4). Cereal and oilseed output globally grew by 2.2 % per year (average 1961-63 to 2016-18) with similar growth rates across the globe, again except for Europe. This growth contributed to satisfy the food demand of a growing population and the feed demand for a growing livestock sector.

Oilseeds grew much faster than cereals not only in value but also in area and quantity but starting from lower original levels. As stated in Chapter 1, cereals and oilseeds are bulk commodities with a few varieties dominating the markets. They are produced annually, or semiannually in some regions, around the globe and the quantity and quality produced strongly depend on the local weather conditions. International trade and stocks compensate for varying production levels in a region and ensure a more or less constant supply at market level within the year and between years.

Figure 4 Global gross production value of cereals & oilseeds and other crops grouped into four regions, 2016 to 2018, in billion constant 2014-16 international dollars and global annual average growth rates from 2016 to 2018



Notes: cereals & oilseeds = cereal, total plus oilcrops, oil equivalent; other crops = agriculture minus livestock minus cereal, total minus oilcrops, oil equivalent, originally all in gross production value (constant 2014-2016 thousand I$)
Source: own representation based on FAO (2021c)

In every region, at least one cereal is a staple crop and poor households rely on its availability and affordability to satisfy their caloric intake. This circumstance led and leads to policy intervention such as production subsidies, price settings, strategic reserves, tariffs and other trade restrictions to ensure their availability and affordability for their own population. In contrast, oilseeds are not seen as staple crops as they provide a) vegetable oils which contribute to a more balanced diet and are used in the industrial and energy sector as well as b) oilseed meal which is a pure feedstock. This circumstance led and leads to policy interventions such as tariffs and taxation. For the same reasons, most regions produce large amounts of their domestically demanded cereals, while they are more open to satisfy their demand for oilseeds, vegetable oil and oilseed meals from international markets.

International trade has increased strongly over the years due to trade liberalization, a reduction in domestic policies distorting the markets especially in developed countries, and increases in efficiency along the whole supply chain including means of transport. Furthermore, trade patterns easily adjust as cereals and oilseeds are relatively homogenous goods and, hence, the origin of the crop is less important. Nevertheless, countries which are close to each other trade more intensively than countries needing to overcome long distances due to increased transportation costs especially if ships cannot be used.

This general overview puts cereal and oilseed markets in relation to the overall agricultural market before analyzing these markets in detail. The purpose of this dissertation is a) to present the factors which drive cereal and oilseed markets, b) to show past developments of cereal and oilseed markets, c) to demonstrate the impact of the factors on the market development in the past and d) to quantify their possible future developments and impacts on cereal and oilseed markets. Hence, the next section presents and categorizes these factors in detail. Section 2.2 presents a detailed historical overview of cereal and oilseed markets focusing on more recent developments by covering the period of 2004 to 2018 and highlights years, regions or crops where specific factors dominated the market development. Section 2.3 discusses possible future development of the different factors and identifies the most important future factors which will affect cereal and oilseed markets. Finally, Section 2.4 concludes and lays the foundation for the specific analysis in the remainder of this dissertation quantifying the impact of changes in important factors on cereal and oilseed markets.

2.1 Fundamental factors affecting cereal and oilseed markets

The factors affecting cereal and oilseed markets can be classified in four broad categories serving the purpose of the dissertation. First, factors which are important, long-standing, underlying and persistent such as the factors mentioned before. Second, factors which were, are and will change in the long run and, hence, are likely to change cereal and oilseed markets significantly in the future, depending on their different developments. Third, factors which might change in the future or gain importance and, hence, will change cereal and oilseed markets if they change. Fourth, other factors which have only slight influences on cereal and oilseed markets or have a very uncertain development or minor influence. The factors are listed in Table 1 and further discussed in the following sections. These various factors have different properties which are important when analyzing their impact on cereal and oilseed markets. First, each factor affects the market from a different angle. These can be a direct impact on demand, supply, trade or prices. Furthermore, the influence of the factors can be classified in short- and long-term of which the latter is the focus of this dissertation. Additionally, some factors have a global influence on cereal and oilseed markets, while other factors are restricted to specific regions which helps to narrow down the appropriate regional coverage when analyzing the factors.

Table 1 Factors affecting cereal and oilseed markets

	Primary impact on				Time span		Coverage	
Factor	demand	supply	trade	prices	short	long	regional	global
Important persistent underlying factors								
Population growth	x					x	x	x
Income	x					x	x	x
Productivity		x				x	x	x
Resource Land		x			x	x	x	x
Weather		x			x		x	
Input markets		x		x	x	x	x	x
Stock holding				x	x		x	x
Exchange rate			x	x	x		x	
Strong market-interfering factors								
Domestic policies		x		x	x	x	x	x
Trade policies			x		x	x	x	x
Climate change mitigation policies	x	x				x	x	x
Biofuel sector	x					x	x	x
Potential market-interfering factors								
Resources (Water, Nutrients)		x				x	x	
Food losses		x				x	x	x
Food waste	x					x	x	x
Climate change		x				x		x
Environmental protection		x			x	x	x	x
Changing diets	x					x	x	
Changing preferences	x					x	x	
Standards and certification	x	x	x	x		x	x	x
Livestock sector	x				x	x		x
Other downstream sectors	x					x	x	
Other underlying factors								
Institutional environment		x			x	x	x	
Infrastructure	x	x	x	x		x	x	
Population migration	x	x				x	x	
Structural change	x	x				x	x	
Conflicts, war, crisis	x	x	x	x	x		x	
Unexpected events				x	x		x	x
Natural catastrophes		x			x		x	

Source: own compilation

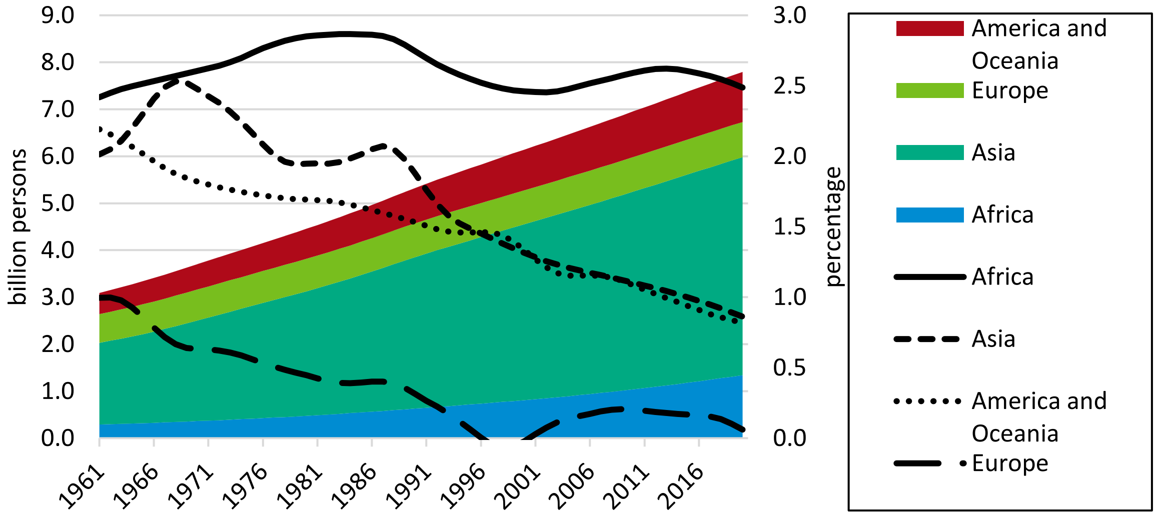
2.1.1 Important persistent underlying factors

On the demand side, the development of population and income are the most important long-term factors which have a strong positive correlation respectively with food and feed demand. On the supply side, productivity in the form of technical progress, intensification and an increase in efficiency dominate long-term developments as well as the use of land. Short-term factors change rapidly within or between years and cause fluctuations in cereal and oilseed markets. The most important and persistent factors are weather, stock levels, exchange rates as well as sudden changes in input markets and the overall economy.

Long-term factors on the demand side

A growing population, as historically observed, requires more food. From 1961 to 2020, the world population grew by 4.7 billion people, i.e., 150 % or an annual growth rate of 1.6 % (UN, 2019b). Since 1968, global annual growth rates were declining from 2.1 % to 1.1 % in 2020 (UN, 2019b). At regional levels, a more differentiated picture presents itself (Figure 5). The majority of people live in Asia but growth rates have started to decline as observed in other regions. Growth rates are lowest in Europe and highest in Africa. In recent years, the world population has grown by more than 80 million persons per year, i.e., approximately the population of Germany. This requires additional production of food for more than 80 million persons each year.

Figure 5 Global population (left axis) and annual average growth rates (right axis) grouped into four regions, 1961 to 2020

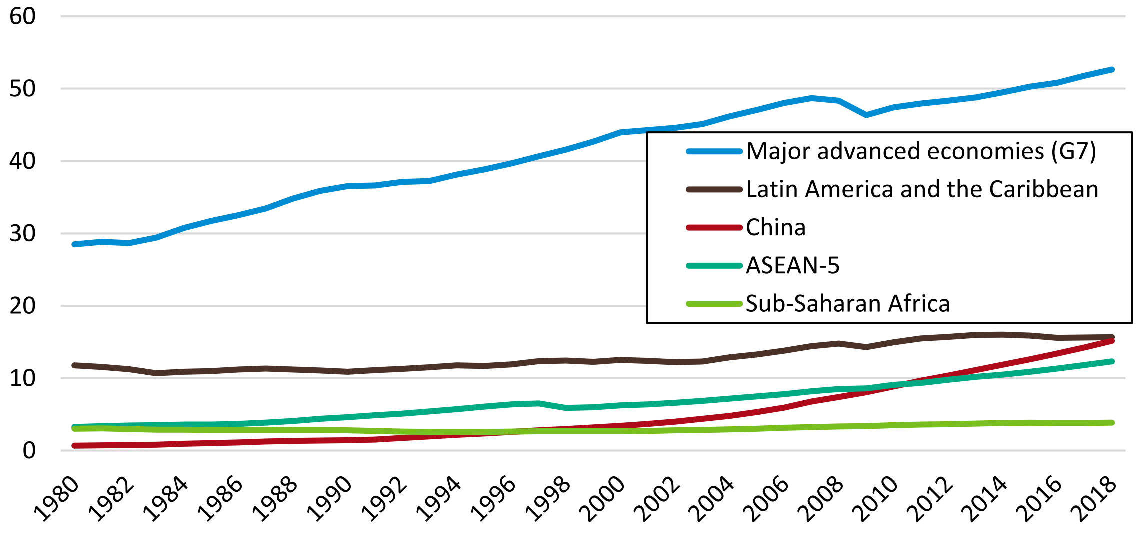


Source: own calculations based on UN (2019b)

Increases in income, as observed in the past, cause a further increase in food and changes in diets. First, with rising income, expenditures on food increases less strongly and, hence, the share of income spend on food declines (Engel's law). Second, food consumption shifts away from staple foods, i.e., cereals, to high value foods, i.e., livestock products (Bennett's law). This development has been widely observed in several regions and translates into income demand elasticities ranging between 0 and 1 and being smaller for staple foods and high-income countries than for high value foods and low-income countries. Country specific estimations of income demand elasticities for food and food subcategories support these observations and even confirm a saturation in the demand for cereals in high income countries (Muhammad *et al.*, 2013). Parallel, as the demand for livestock products increase, the demand for feed, i.e., cereals and oilseed meals, increases.

Income is often approximated by gross domestic product (GDP) per capita. Global annual percentage growth rates of GDP per capita declined in the past, i.e., incomes are growing but at slower rates. Economic crises, such as the financial crisis in 2009, caused GDP to decline sharply and recover in successive years. Regional differences in income vary considerably and have increased over time as the main advanced economies have grown stronger than less advanced economies, e.g., Sub-Saharan Africa (Figure 6). China is the most remarkable exception with strong increases in recent years. This growth is directly related to shifts in Chinese diets towards more meat consumption. This in turn is one of the main reasons for an observed increase in feed demand from global cereal and oilseed markets in recent years (Fukase and Martin, 2016; Westhoff and Thompson, 2017).

Figure 6 Gross domestic product per capita, 1980 to 2018, in constant prices purchasing power parity thousand international dollars (2017)

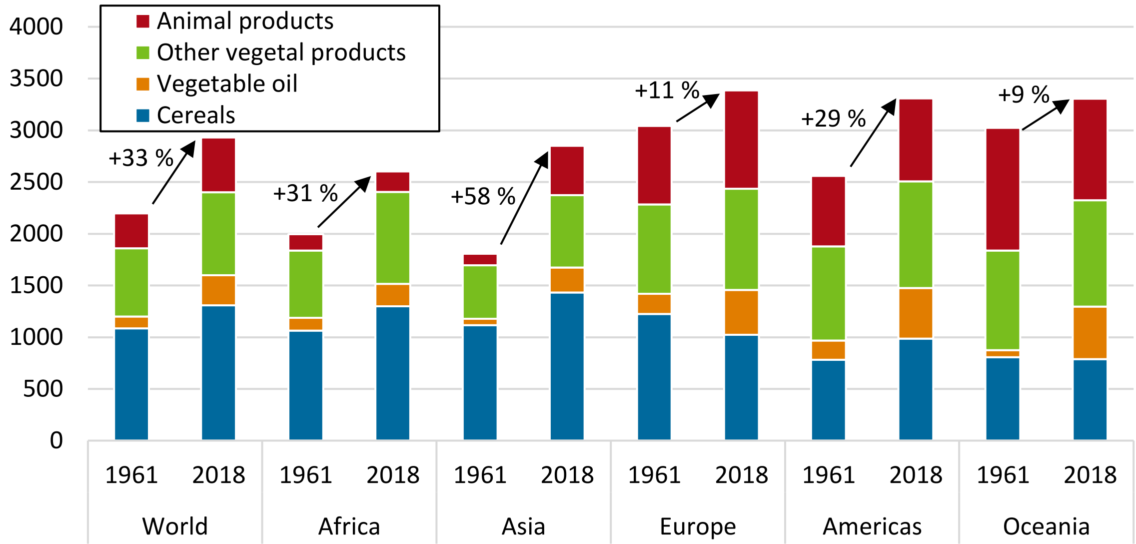


Notes: Country aggregation according to IMF (2020) with Major advanced economies (G7) = Canada, France, Germany, Italy, Japan, United Kingdom, United States and ASEAN-5 = Indonesia, Malaysia, Philippines, Thailand, Vietnam

Source: own representation based on data from IMF (2020)

Per capita food consumption confirms this relationship as high-income regions have larger caloric food intake than lower-income regions. While per capita food consumption grew in all regions, it grew most in regions with lower per capita food intake. Nevertheless, per capita food intake in 2018 in Africa and Asia are still below the levels of, e.g., Europe in 1961 (Figure 7). Caloric intake from cereals have increased the least and even declined in Europe and Oceania (Figure 7). In contrast, caloric food intake from vegetable oils increased everywhere. Furthermore, caloric food intake from animal products increased everywhere with the exception of Oceania.

Figure 7 Daily caloric intake per food category for different regions, 1961 and 2018, kcal per capita per day



Source: own representation based on data from FAO (2017a) for 1961 and FAO (2021b) for 2018

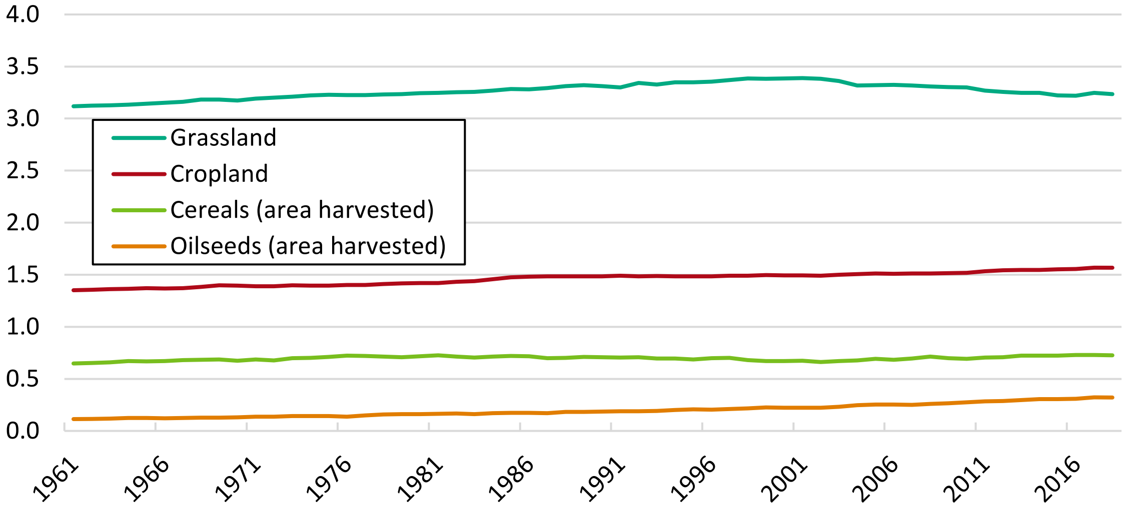
Long-term factors on the supply side

The dominating, long-term, global fundamental factors influencing the supply side of cereals and oilseeds are limited land availability as well as productivity growth. Cereal and oilseed production increased due to four factors: land expansion, yield increase due to technical progress, yield increase due to intensification, and applying double cropping systems, i.e., planting and harvesting more than once a year from the same area. The latter is rare and most areas with cereals and oilseeds are harvested once per year. Double cropping systems are only possible in regions with long vegetation periods. They are, for example, applied in China for rice cultivation and in Brazil for cultivation of corn after soybean.

In the short-term, producers chose between expanding area or increasing yields through intensification if the demand for the produced products is high enough, i.e., prices make it profitable to use more land or to intensify. Costs involved in expanding area depend on the former use of the converted area. Cropland is easily used for different crops, while converting grassland or even non-agricultural area to cropland incurs higher costs.

Additionally, land is multifunctional and used for many purposes, such as forestry, agriculture, environmental protection, settlements and infrastructure. These uses are complements and, hence, agricultural area expansion towards other areas is limited. This statement is supported by Figure 8 showing that agricultural area has only slightly grown until 2002 and then globally even declined slightly. However, cropland has been constantly increasing and in recent years predominantly at the expense of grassland (Figure 8). Agricultural area amounts to 4.8 billion hectare in 2018 or 37 % of total area of which 1.6 billion hectares or 33 % are cropland (FAO, 2020e). Cereal area harvested only slightly increased, while oilseed area harvested nearly tripled from 1961 to 2018 (Figure 8).

Figure 8 Area of grassland and cropland as well as area harvested for cereals and oilseeds, 1961 to 2018, billion hectares



Notes: Grassland = land under perm. meadows and pastures, cropland = cropland based on FAO (2020e); cereals = cereals, total, oilseeds = oilcrops based on FAO (2020a)
Source: own representation based on FAO (2020e) and FAO (2020a)

This global picture conceals regional developments which are very heterogenous. In some areas land is degraded or lies idle and, hence, is not used for agricultural production anymore. In others, non-agricultural areas, e.g., forest and other natural habitats, are converted to agricultural area. The expansion of agricultural area is restricted by the availability of suitable land with respect to bio-physical properties, e.g., low-productive or marginal lands, as well as competing uses, e.g., forestry or nature reserves.

Productivity growth includes all changes which result in a reduced amount of inputs to achieve the same output or in other words which result in the same amount of inputs to achieve a higher output (Alston, Babcock and Pardey, 2010). Hence, efficiency gains or technical progress in the use of an input results in productivity growth. Classical inputs in cereal and oilseed production are, e.g., land, labor, and capital as well as water, fertilizer, and crop protection products.

In agriculture, more capital inputs result in higher mechanization, automatization and digitalization. Historically, cereal and oilseed production systems have changed from being labor intensive to capital intensive in the most advanced production systems. These two inputs have been substituted against each other and increased the output per worker. Land is less substitutable as each additional hectare allows to apply the chosen production system and, so, generates additional output. However, land is also the major constraint in expanding agriculture as demonstrated above. Hence, productivity is often related to output per unit of land, i.e., yields.

Yield increases are twofold and have many causes such as use of seed variety, machinery, irrigation, fertilizer, and crop protection. They can be achieved by increasing potential yields and closing yield gaps. Potential yields are the maximum achievable yields given observed weather conditions when nutrients and water (in case of irrigated production) are no limiting factors and management practices are optimal, e.g., sowing date and planting density (van Ittersum *et al.*, 2013). The potential yields vary from area to area and depend on multiple bio-physical factors such as solar radiation, temperature, and atmospheric carbon dioxide (CO_2) (van Ittersum *et al.*, 2013). Under rainfed conditions, precipitation and soil properties are additional important bio-physical factors affecting potential yields (van Ittersum *et al.*, 2013).

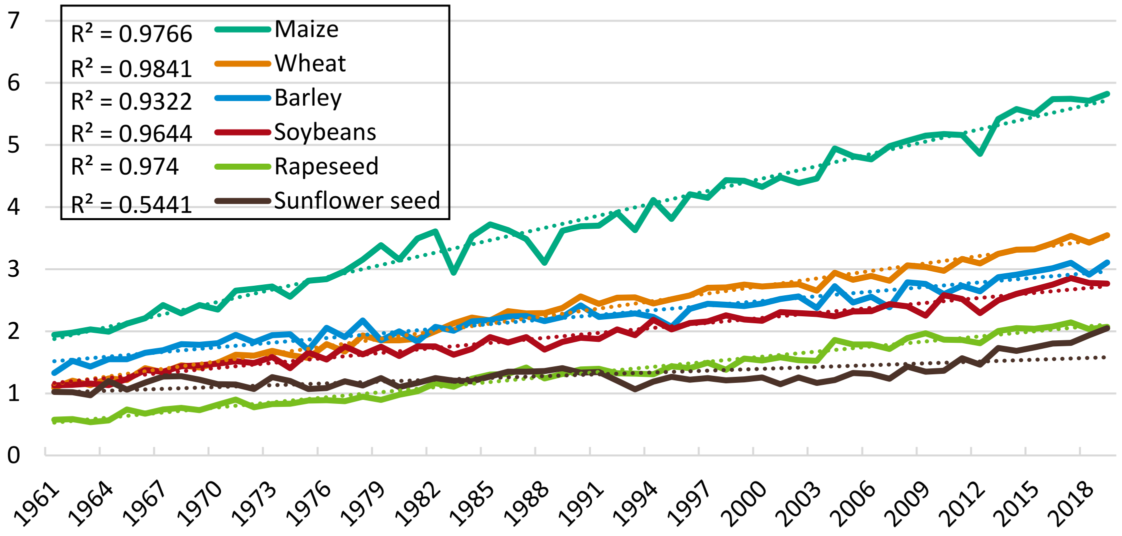
Potential yields can be increased by research and development. Improvements, new techniques and new products in these areas are constantly being developed and make crop production more efficient in terms of yield increase or reduced inputs to achieve similar yields. In the area of breeding, new breeding techniques are currently applied and promise to develop new seed varieties in a shorter time, e.g., genome editing. Precision farming is another promising development which reduces input use through optimal allocation, e.g., remote sensing methods for regulating fertilizer application. Research on fertilizer, e.g., to improve absorption and reduce leakages, and crop protection, e.g., to overcome resistances and to protect against new pests and diseases, is improving these products and their effects on crop yields. These techniques were and are increasing potential yields over time.

These potential yields might be achievable in field experiments but are not yet observed in reality. The difference between these potential yields and actual realized yields is termed the yield gap (van Ittersum *et al.*, 2013). For other definitions and a discussion of potential yields and yield gaps see Lobell, Cassman and Field (2009). In practice, yields in high input production systems reach a maximum of around 80 % of potential yields as higher yields are associated with higher costs and, hence, are not maximizing profits (van Ittersum *et al.*, 2013; Lobell, Cassman and Field, 2009). In this dissertation, closing of yield gaps is defined as reaching 80 % of potential yields which in the remainder of the text is termed 'maximal economic feasible yield'.

This closing of yield gaps is achieved through intensification and adaptation. Yield gaps can be large as the techniques of achieving highest yields are not applied globally due to lack of knowledge, inability to implement these techniques because of capital, social and other constraints, and tradeoffs with other aims, e.g., environmental protection. Increases of yields across the globe are achievable through knowledge transfer, availability and affordability of inputs, access to markets and a secure environment for investments. These factors are closing existing yield gaps but can also widen yield gaps if they are not present or secured. Additionally, the 'maximal economic feasible yield' might not be the economical optimal yield in specific circumstances, e.g., if weather varies strongly and the risk of crop failures with this are high.

Historically, yields have increased constantly with several authors finding a linear trend over time most fitting for main crops (Hafner, 2003; Jaggard, Qi and Ober, 2010; Ewert *et al.*, 2005). Figure 9 illustrates these findings for the main cereals and oilseeds at global level. Except for sunflower seeds, a linear trend over time fits the development well. As sunflower seeds are mainly grown in Russia and Ukraine, the collapse of the Soviet Union caused the global drop of sunflower seeds between 1991 to 1993 from which a recovery and acceleration started. The presented yields (Figure 9) grew on average between 1.2 % and 2.2 % per year from 1961 to 2019. Partially confirming the cited studies, Arata, Fabrizi and Sckokai (2020) found increasing, no or decreasing trends when analyzing per crop and per country data but with increasing trends dominating. Hence, developments between crops as well as regional developments vary strongly.

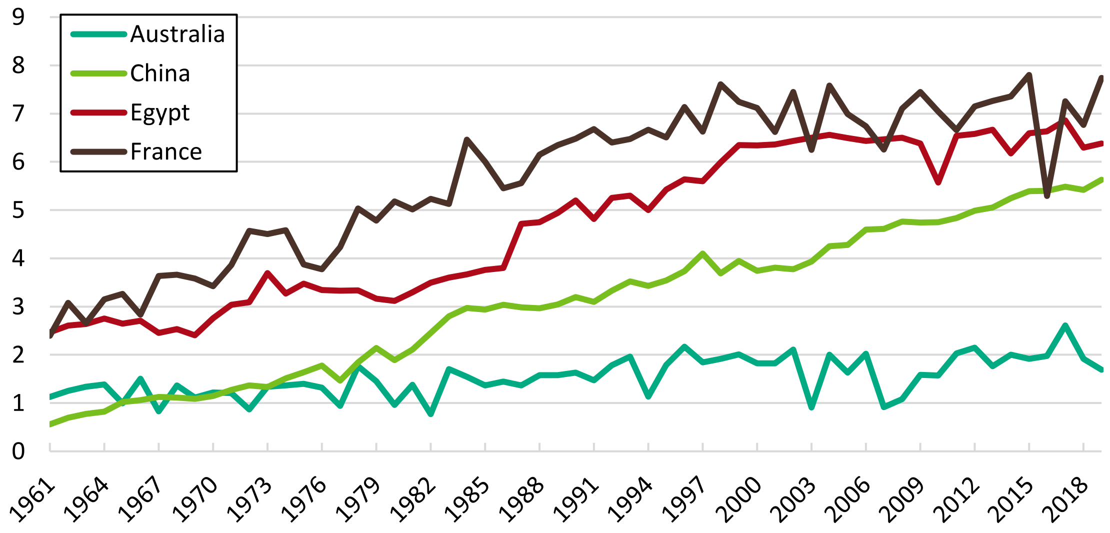
Figure 9 Global yields and their linear trend of main cereals and oilseeds, 1961 to 2019, t/ha



Source: own representation based on data from FAO (2020a)

As stated, potential yields depend on bio-physical properties which differ between regions. Realized yields depend on potential yields in combination with the chosen production system and management practices which are defined and affected by the above-mentioned factors. For example, wheat yields differ strongly between France and Australia, as potential yields and the intensification level in France are much higher than in Australia (Figure 10). Countries with intensive production systems, i.e., France and Egypt, have shown a reduced increase in wheat yields in recent years as their realized yields are close to potential yields and growth can come from increasing potential yields but not so much from intensification. In contrast, Chinese wheat yields have been growing strongly starting with the green revolution in the 1960s through seeding new varieties and applying more fertilizer and crop protection as well as increasing mechanization.

Figure 10 Wheat yields for Australia, China, Egypt, and France, 1961 to 2019, t/ha



Source: own representation based on data from FAO (2020a)

From an economic point of view, intensive production systems are not always optimal. For example, large variations in weather increase the risk of crop failures, and, hence, more extensive productions systems are economically optimal as costs are minimized. Additionally, yields can be negatively affected by regulations and policies, e.g., restrictions on fertilizer application and prohibition of planting genetically modified crop varieties. The aim of these policies is not to reduce yields, but to achieve other goals, e.g., environmental protection. Hence, reduced yields are a mere side effect.

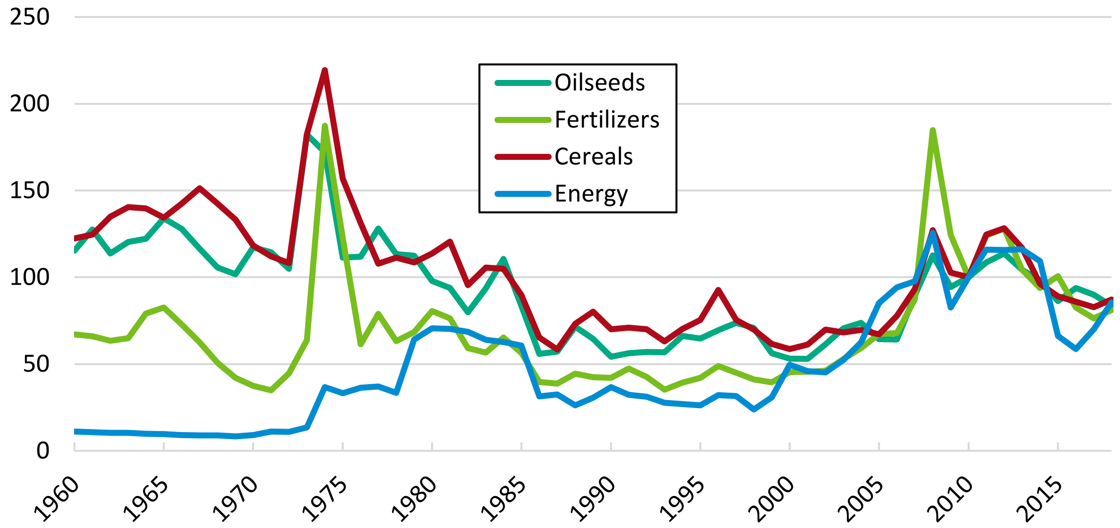
Persistent short-term factors

Short-term factors cause deviations from the presented long-term developments and their impact on cereal and oilseed markets often outweighs the long-term factors, especially when focusing on shorter periods. Cereal and oilseed markets mostly react to these factors by changes in prices. The most important and persistent factors are the weather during the growing season, price increases for inputs, stock levels, exchange rates and the overall economic situation.

Weather is the main cause for the yield variations shown in Figure 9 and Figure 10 and, hence, variations in production levels. Favorable weather conditions, i.e., the right temperature and precipitation at the right time, cause record yields. Unfavorable weather conditions can severely reduce yields, e.g., too much or too little precipitation or extreme temperatures. Extreme weather events, e.g., hurricanes and tsunamis, can destroy local harvests completely. Irrigated production systems, such as wheat in Egypt, show a lower variation in yields as they do not rely on rainfall (Figure 10). Due to different local weather conditions, yields vary more on a local level than on global levels. Furthermore, the influence of weather is of a short-term nature and rarely persists into the next growing season.

Expected prices of the crop planted and input costs are other factors for varying yields. High input prices reduce the economically optimal amount of inputs resulting in lower yields, while high expected crop prices increase the economically optimal amount of inputs resulting in higher yields. The development of related markets, especially input markets such as the fertilizer market or the oil market, is another factor to be considered when analyzing cereal and oilseed markets. Changes in input markets affect supply and prices. To some extent, prices of related markets positively correlate with crop prices as Figure 11 shows. For the oil market this relationship has strengthened in recent years due to the developments of biofuels, i.e., the crude oil market is not only linked to cereal and oilseed markets by the input side but also by the demand side. In the long run, high prices foster an increase in productivity through higher incentives to intensify and improve efficiency, which in turn leads to declining prices and a more or less cyclical trend of price variations.

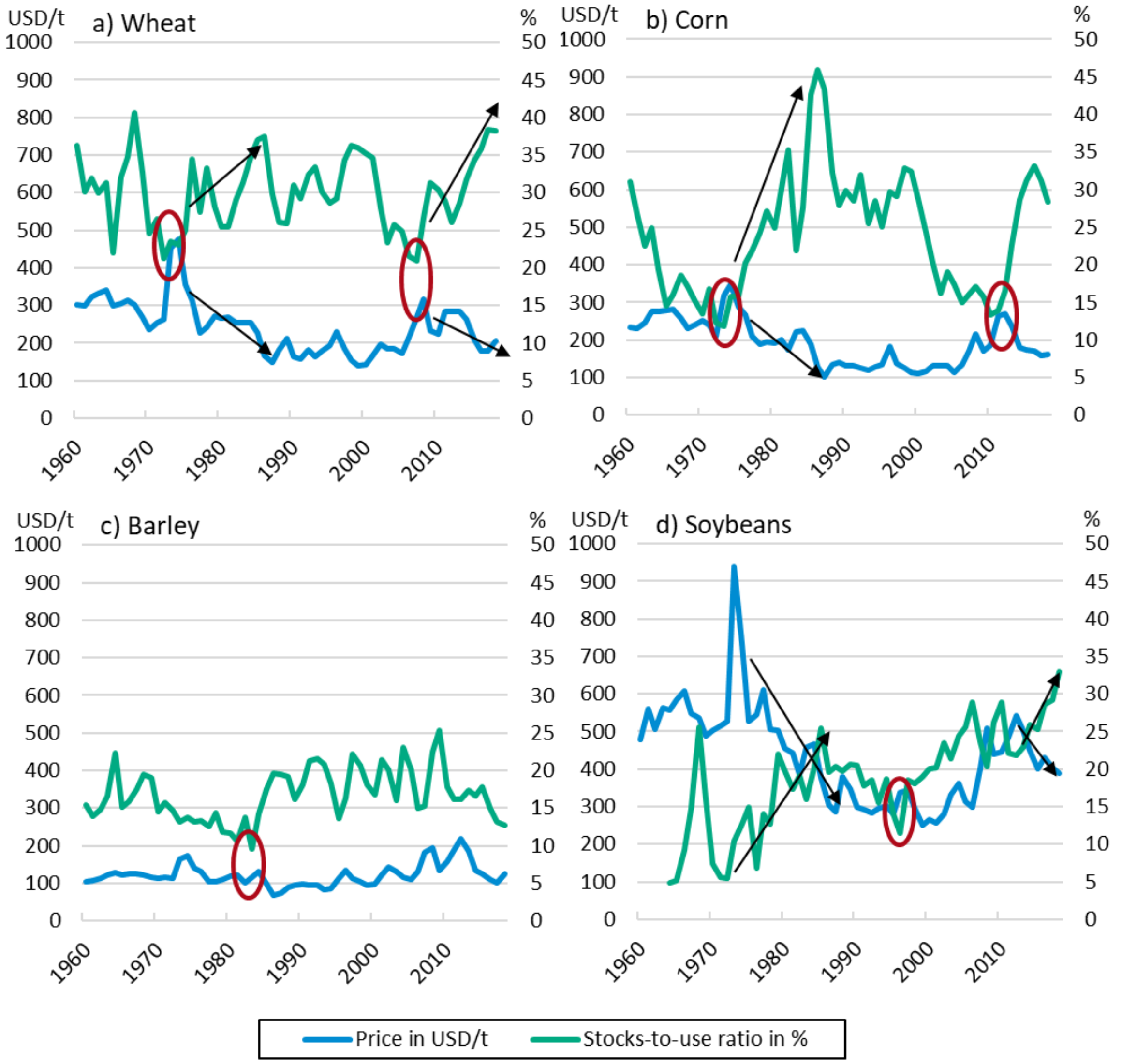
Figure 11 Real annual price index of cereals, oilseeds, fertilizer and energy, 1960 to 2018, index 2010=100



Notes: Index based on weighted annual prices in real 2010 US dollars for selected products in the different categories according to World Bank (2021a): Oilseeds = soybeans, soybean Oil, soybean meal, palm oil, coconut oil, groundnut oil; Cereals = rice, wheat, maize, barley; Fertilizers = natural phosphate rock, phosphate, potassium, nitrogenous; Energy = coal, crude oil, natural gas
Source: own representation based on World Bank (2021a)

Variation in prices leads to a balance between supply and demand at the market level, i.e., prices are the result of the interplay of supply and demand. In the case of cereal and oilseed markets the stocks-to-use ratio is an important indicator for the tightness of the market. High stock levels indicate that supply outweighs demand and result in low prices especially if accumulating over the years, while low stock levels indicate that demand outweighs supply and can result in high prices and price spikes. Figure 12 demonstrates both occurrences for selected cereals and oilseeds. The relationship is not perfect as observed price spikes have many causes and the situation on substituting markets also play a role. It is observable that wheat despite having the highest stocks-to-use ratio shows the closest relationship as it is a staple crop in many countries and not as easily substitutable as, e.g., feed cereals.

Figure 12 Real prices in constant 2010 USD per ton (left axis) and stocks-to-use ratio as percentage (right axis) for selected crops, 1960 to 2018



Notes: Real annual prices in real 2010 USD according to World Bank (2021a) with wheat = Wheat (U.S.), no. 1, hard red winter, ordinary protein, export price delivered at the US Gulf port for prompt or 30 days shipment; corn = Maize (U.S.), no. 2, yellow, f.o.b. US Gulf ports; barley = Barley (U.S.) feed, No. 2, spot, 20 days To-Arrive, delivered Minneapolis from May 2012 onwards; during 1980 - 2012 April Canadian, feed, Western No. 1, Winnipeg Commodity Exchange, spot, wholesale farmers' price; soybeans = Soybeans, U.S. No. 2 yellow soybean, CIF Rotterdam; US origin, nearest forward.; Stocks-to-use ratio = ending stocks divided by domestic consumption based on USDA (2020a)

Source: own calculations based on World Bank (2021a) and USDA (2020a)

Prices displayed so far were indices or representative world market prices. Regional prices correlate with these representative prices, especially when the regional market is connected to the international market and market distorting policies are absent. They differ from these representative world market prices due to transportation costs, local currency exchange rate, and further regional market conditions.

Cereals and oilseeds are intensively traded in USD on the international market. Hence, the exchange rate of the local currency to the USD influences the competitiveness of an exporting region on the world market. If the currency is depreciating, exports become cheaper and more competitive and imports more expensive as you get less USD per local currency. With increased exports, the local currency appreciates. Hence, exchange rates fluctuate and to some degree reflect the economic situation within a country. Effects of exchange rates are short-term and regional as the markets adjust relatively quickly.

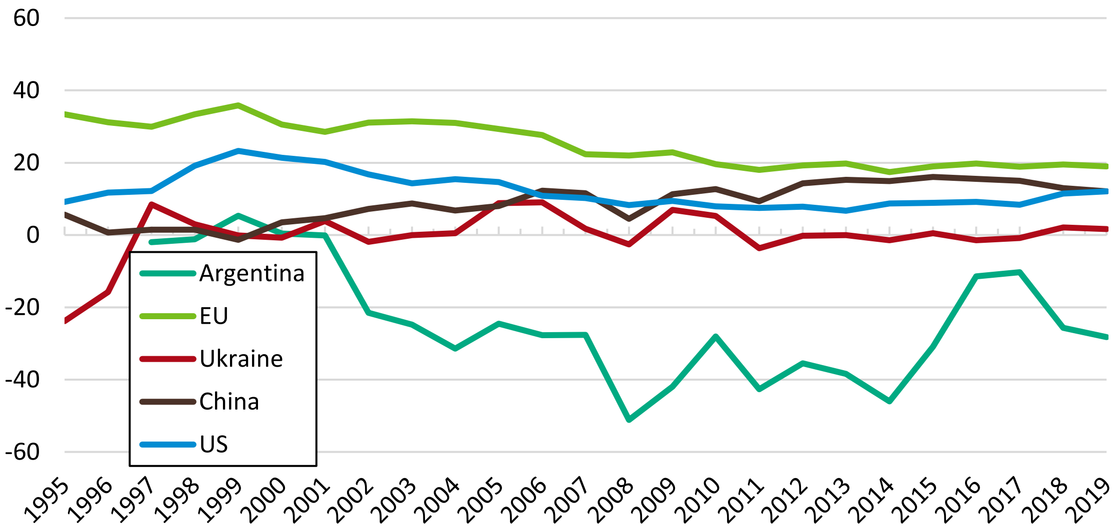
2.1.2 Strong market-interfering factors

The already presented factors played and will play a role in explaining cereal and oilseed markets without any interference in the market. However, several directly market-interfering factors have short-term as well as long-term effects on markets depending on their definition and implementation, namely policies. This includes not only agricultural and trade policies which are primarily implemented for reasons of food security and safety but also policies from other disciplines such as biofuels and other climate change mitigation policies. Policies adjust or change regularly, which requires a careful assessment of their impact on markets.

Domestic agricultural and trade policies

Traditionally, the agricultural sector is a sector with high policy interferences. The OECD monitors and evaluates agricultural policies and calculates comparable indicators, e.g., the producer support estimate (PSE), of agricultural support between countries (OECD, 2016). Figure 13 demonstrates the range and development of possible support or taxation in agriculture with selected examples.

Figure 13 Policy support to agriculture, 1995 to 2019, PSE as a share of GFR in %



Notes: PSE (=Producer Support Estimate) as a share of GFR (=gross farm receipts) in %. PSE=The annual monetary value of gross transfers from consumers and taxpayers to agricultural producers, measured at the farm gate level, arising from policies that support agriculture, regardless of their nature, objectives or impacts on farm production or income; GFR=value of production (at farm gate) plus aggregated budgetary and other transfers to producers from policies (OECD, 2016).
Source: own representation based on OECD (2020)

Generally, the support for domestic production ensuring farmers income or achieving food security by high levels of self-sufficiency dominates in the sector. However, several countries also regularly tax agricultural products to earn state revenues, e.g., Argentina applies export taxes. Over time, some high-income countries, e.g., the United States (US), have reduced their support for agricultural production coming from high levels, while some middle-income countries, e.g. China, increased it. Ukraine normally taxes the crop sector, i.e., products they export, and supports the livestock sector, i.e., products in which the country is not self-sufficient (Schmitz and Meyers, 2015). This explains why the support to agriculture varies around zero.

These policies range from being highly market distorting, e.g., price regulations, subsidies, taxation, quotas, and tariffs, to barely market distorting, e.g., crop insurance, uncoupled area payments, and public stockholding for food security reasons. In several regions some policies have changed from directly market distorting policies to less market distorting policies but still support domestic agriculture on a high level. In the European Union (EU) for example, production subsidies were replaced by area payments, intervention prices lowered, production quotas and export subsidies abolished and trade liberalized due to import tariff reductions and import quota increases.

Historically, international trade has been liberalized starting with the General Agreement on Tariffs and Trade (GATT) in 1948. The agricultural sector was and is often exempt from the general rules and only in 1995 the Agreement on Agriculture negotiated during the Uruguay round came into force. Countries committed themselves to reduce market distorting policies in the agricultural sector (GATT, 1994). Agricultural trade has been liberalized further through new negotiations within the World Trade Organization (WTO) and multiple bilateral trade agreements which liberalize trade between regions beyond international requirements under the WTO. Two examples are the Deep and Comprehensive Free Trade Area (DCFTA) between the EU and Ukraine applied as of 2016 and the formation of the Eurasian Economic Union (EAEU) between Russia, Belarus, Kazakhstan, Armenia, and Kyrgyzstan in 2015.

Nevertheless, the agricultural sector is still a sensitive topic in trade negotiations and often subject to higher protection levels than other sectors and to special exemptions from the general agreements (Josling *et al.*, 2010; Anderson, 2010). This results in various bilateral tariffs and quotas without tariffs or reduced tariffs.

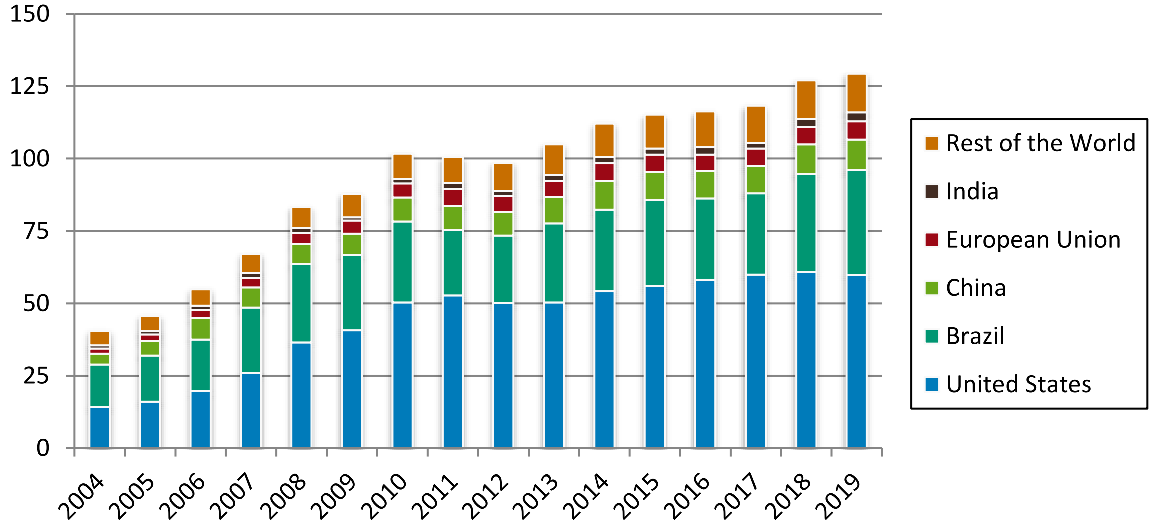
Trade policies are used for short-term policy interferences in markets as well. For example, export bans or taxes on staple cereals such as rice and wheat have been implemented by several exporting countries during periods of high world market prices to stabilize prices in the domestic market and to ensure their own food security. These export restrictions contributed to a further increase in global prices (Martin and Anderson, 2012). In recent years, increased tariffs and bans have been observed globally due to disputes between countries, e.g., an import ban on several agricultural products to Russia from the EU and other countries not agreeing with their invasion of the Ukrainian peninsula Crimea in 2014 or import tariffs of China on US soybeans in 2018.

Climate change mitigation policies

Besides domestic agricultural and trade policies, cereal and oilseed markets are affected by climate change mitigation policies. Their effects ranges from restricting agricultural production, e.g., on certain land cover types, to increasing demand for agricultural products, e.g., for biofuel production. The primary aim of climate change mitigation policies is to reduce greenhouse gas (GHG) emissions (UN, 2015) and various commitments or policies are in place to achieve these, e.g., biofuel policies, land use policies, carbon certificates, and carbon taxes. Carbon certificates and taxes are widely discussed and implemented in some regions but the agricultural sector is currently exempt from these measures (Banse and Sturm, 2019). While biofuel policies increase the demand for cereals and oilseeds, land use policies restrict the conversion of land and, hence, constrain the use.

In most countries, biofuel policies are justified with the aim to reduce GHG emissions and oil dependency as well as supporting the local industry and feedstock producers (Sorda, Banse and Kemfert, 2010). The implemented policies differ across countries but most have linked the demand of biofuels to total transport fuel consumption via blending mandates or targets, i.e., a certain share of transport fuel should be biofuels (Sorda, Banse and Kemfert, 2010). This policy-driven demand for biofuels has directly increased the demand for cereals and oilseeds. Even though food and feed stay the main uses for cereals and oilseeds, the demand from the biofuel industry has evolved strongly in recent years. Cereals are used for ethanol production and oilseeds for biodiesel production. The historical production of ethanol had a steep increase until 2010 followed by a slowdown with annual average growth rates of 3 % from 2010 to 2019 (Figure 14). The largest producers of ethanol are the US and Brazil which respectively mainly use corn and sugarcane as feedstock (OECD and FAO, 2020a). In 2019, 80 % of all corn for biofuel production was used in the US.

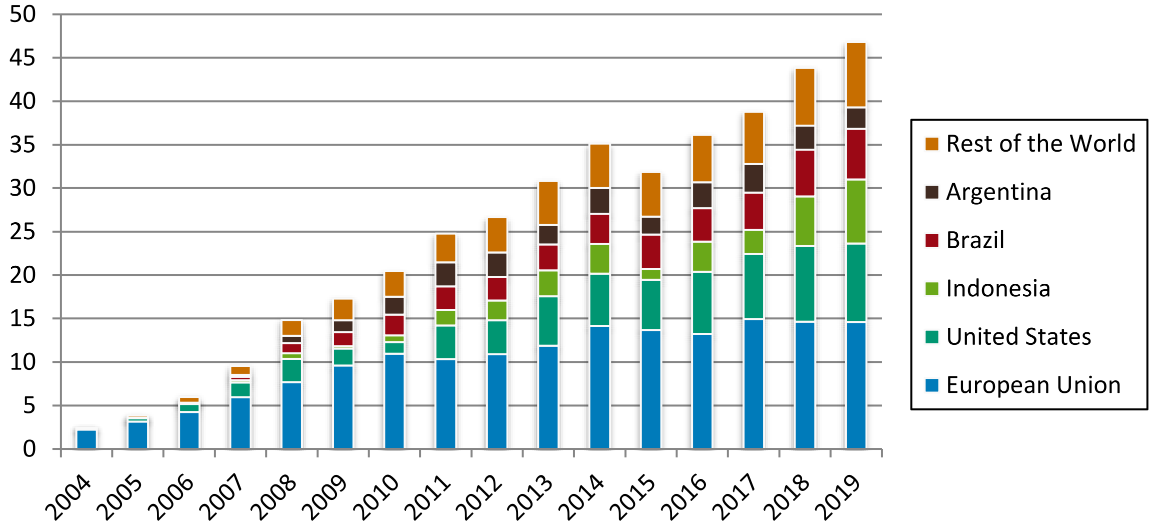
Figure 14 Global ethanol production differentiated by major producing countries, 2004 to 2019, billion liters



Source: own representation based on data from OECD and FAO (2020a)

Biodiesel production is much smaller but shows a continued strong increase over time, i.e., annual growth rates of 22 % from 2004-2019, with a slight drop in 2015 (Figure 15). The largest producers of biodiesel are the EU using predominantly rapeseed oil and used cooking oil as feedstock followed by the US, Brazil and Argentina which use soybean oil as feedstock and Indonesia which uses palm oil (OECD and FAO, 2020b). Protein rich feedstuff emerges from the production of biofuels as by-products such as dried distillers grains with solubles (DDGS) and vegetable meals which have changed local animal feed rations.

Figure 15 Global biodiesel production differentiated by major producing countries, 2004 to 2019, billion litres



Source: own representation based on data from (OECD and FAO, 2020a)

The use of crop-based feedstocks has led to the food vs. fuel as well as the indirect land use change debate (Muscat *et al.*, 2020). Furthermore, the sustainability of biofuel production as well as the contribution of biofuels towards climate change mitigation has been challenged (Oliveira, McKay and Plank, 2017). Hence, while biofuel consumption is still a political goal in many countries, several countries limit or restrict the use of crop-based biofuels or directly link the production to saving of GHG emissions.

Another climate change mitigation policy is protection of areas with high potentials to sequester CO_2 (IPCC, 2014a). Forest, especially tropical forest, and peatlands have a large potential to sequester CO_2 and, hence, contribute to reducing GHG emissions (IPCC, 2014a). These areas are often rich in biodiversity and, hence, their protection saves GHG and simultaneously contributes to reduce biodiversity losses. Therefore, several initiatives, programs, commitments and policies around the globe aim at protecting and conserving forest, e.g., the Amazon Soy Moratorium, the Convention on Biological Diversity, the program Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+), and the European Forest Strategy. This restricts the possibility to convert forest area to agricultural area.

2.1.3 Potential market-interfering factors

The previously discussed factors changed cereal and oilseed markets in the past and will continue to affect them in the future. Cereal and oilseed markets depend on the following additional factors, which, however, have only played minor roles in changing the markets in the past or are partly covered by the above factors. If these factors do not deviate from their long-term trend, their impact will stay minor. On the supply side, these factors are additional resource constraints such as water and nutrients, climate change, environmental protection and reducing food losses. On the demand side, these factors are changes in food waste, diets, preferences, and crop demanding sectors. Furthermore, standards and certification schemes can also affect cereal and oilseed markets.

Resource constraints

The main resource constraints for cereal and oilseed production are the availability of land as presented above as well as water and nutrients. These resources are limited and agricultural production competes with other uses and services for these resources.

Approximately a quarter of arable land is currently equipped for irrigation (FAO, 2020e) but less is actively irrigated. Irrigation compared to rainfed agriculture is costly and is mainly used in intensive production systems, areas with insufficient precipitation or for crops with high values. Hence, most cereals and oilseeds are not irrigated. Crops which are irrigated have higher and less volatile yields than rainfed crops. However, water is another limited resource where agriculture competes directly with human demand and other uses. Hence, even if it was economically profitable, expansion of irrigation would be limited. Depletion of fresh water resources have occurred and are still occurring mainly due to agricultural irrigation, already increasing the pressure on global fresh water resources (FAO, 2017b). Furthermore, reduced soil quality due to irrigation in the form of salinity buildup, degraded soil structure, or accumulation of toxic material in the soil is another problem reducing the long-term effectiveness of irrigation (Assouline *et al.*, 2015).

The application of fertilizer contributed to a large share of historically observed yield increases. The three most important nutrients are nitrogen, phosphorus, and potassium. The production of nitrogen fertilizers requires natural gas as a feedstock and is energy intensive. The feedstock for phosphate fertilizers is phosphate rock. The source of potassium for plant production is potash. Hence, all fertilizers depend on natural resources that are mined. Additionally, recycling and circular use of the nutrients are possible sources. Currently, scarcity of resource is not imminent.

However, economic and social scarcity exist as farmers cannot afford to buy fertilizers or lack the knowledge or technologies to apply fertilizers. Hence, they realize low yields and contribute to deplete their soils. For example, Nedelciu *et al.* (2020) identifies South Asia, Latin America and Sub-Saharan Africa as main regions which can increase the use of phosphate fertilizer to increase agricultural production.

Climate change

Climate change is another factor which influences the supply of cereal and oilseeds. Especially, the effect of climate change on yields is of high research interest as it can increase or decrease yields depending on the crop and region and increases variability of yields. Historically, most studies find negative yield impacts due to climate change for wheat, rice and corn of up to a 5 % decrease in yields per decade, while soybean yields are less affected (IPCC, 2014b). Additional negative effects of climate change are an increase in extreme weather events and a spread of pests and diseases towards new regions increasing yield volatility. Transferred to cereal and oilseed markets, direct climate change in the form of slightly reduced and more volatile yields influenced the markets less than indirect impacts of climate change through mitigation policies as presented above.

Environmental protection

Negative environmental effects associated with agricultural production systems and implemented policies to reduce these effects are factors affecting cereal and oilseed markets. The application of yield increasing techniques, i.e., fertilizer, crop protection, irrigation, and large machineries, are often related to negative environmental effects such as increased GHG emissions, biodiversity loss, deforestation, degradation of soil and reduced water quality. However, the review of Clark and Tilman (2017) shows that intensification related to nitrogen fertilization yields lowest environmental impacts per calorie food produced on all analyzed environmental indicators (GHG emissions, energy use, land use, acidification potential, and eutrophication potential). Clark and Tilman (2017) conclude that negative environmental effects can best be tackled by increasing efficiency, especially in regions with low efficiencies, however, they also point to the economic cost associated with it.

In several regions, e.g., the EU, organic farming is promoted as an environmentally friendly and sustainable way to produce agricultural products. Their environmental advantages compared to conventional farming on the regional level are supported by multiple studies (Sanders and Heß, 2019). For example, organic farming compared to conventional farming reduces biodiversity loss and increases soil quality on the land being farmed (Sanders and Heß, 2019). However, as yields tend to be lower than with conventional farming more land is required to produce similar amounts. If this additional land is converted from natural vegetation, biodiversity and soil quality might be reduced.

Plant production and especially cereal production have the lowest environmental impacts per calorie of food produced compared to other food categories (Clark and Tilman, 2017). Yet several environmental policies and political aims exist which potentially influence the production of cereals and oilseeds negatively. For example, the Nitrate-Directive of the EU restricts the use of nitrogen fertilizer due to high levels of nitrate in groundwater (European Parliament and Council of the European Union, 1991). This impacts cereal production, especially high-quality wheat which requires large amounts of nitrogen to achieve desired protein levels. Also, several crop protection products including neonicotinoids were banned in several countries due to their negative effect on bees and other pollinators. This results in reduced crop yields when pest infestation is high. However, several crops, e.g., rapeseed, profit from insect pollination and if these are reduced, yields also decline. Hence, rapeseed is negatively and positively affected by the ban of neonicotinoids and the research community is inconclusive about which factor outweighs the other (Lundin *et al.*, 2020).

Food losses and waste

Food waste occurring on the consumption side, food losses occurring on the supply side and the recent attention they get by policies, researchers and the wider public is another factor which might affect agricultural markets and, hence, cereal and oilseed markets. One of the targets of the Sustainability Development Goals (SDGs) adopted by 193 countries, i.e., target 12.3, is the reduction of food losses and waste per capita by 50 % until 2030 (UN, 2021b). Main food losses occur in developing regions, while main food waste occurs in developed regions (FAO, 2011). FAO (2011) stated that up to one third of all food might be lost or wasted which led to a wide debate about reducing food losses and waste including an increased research interest. Food losses are estimated between 20 % to 35 % depending on the region for cereals and 15 % to 30 % for oilseeds and pulses (FAO, 2011).

These figures seem to leave much room for reducing food losses and waste with the benefit that the producer is *ceteris paribus* able to sell more of its produced food, as less is lost, and the consumer is *ceteris paribus* able to consume the same at lower cost, as less is wasted. Resulting price effects might reduce these benefits, e.g., if increased production costs increase prices and lower production or decreased prices lead to relatively more waste (Rutten, 2013). Further, definitions about food loss and waste, accounting methods, and quantifying the forgone value are numerous, lack observed data, and seem to overstate the amount of food losses and waste (Rutten, 2013; Bellemare *et al.*, 2017; Leverenz *et al.*, 2021). Also, the cost of reducing food loss and waste is often not considered (Rutten, 2013; Koester, 2014).

For example, Leverenz *et al.* (2021) built a database on food waste in Germany for 2015 including all waste after harvest which amounts to a total of 11.9 (± 2.4) million tons of which 6.2 (± 1.3) million tons are avoidable waste. They stress the challenges they faced because of insufficient data, having to rely on coefficients from case studies, using non-representative data, and combining different data sources. Of the avoidable waste, 2.4 (±0.8) million tons can be attributed to product categories of which 0.6 (±0.1) million tons are cereals and cereal products. In comparison, Germany used 43 million tons of cereals in 2015 (BMEL, 2020). Hence, a reduction in food waste might have only small, if any, effects on the German cereal markets. As another example, Fine *et al.* (2015) found that an amount equivalent to approximately 10 % of total vegetable oil consumed in France is lost, i.e., below the range of FAO (2011). They state that through technical innovation, e.g., breeding and improved harvesting techniques, these can be efficiently reduced. However, they do not distinguish between avoidable and non-avoidable losses and, hence, do neither quantify by how much losses might be reduced nor at what costs.

Up to now, the market effects of reducing food losses and waste are unclear and depend on many uncertainties. However, the two examples illustrate that effects of food loss and waste reduction on cereal and oilseed markets might be of small magnitude. Only a fraction of the reported value might be reduced especially when considering costs involved and concentrating on actual avoidable food waste.

Changing diets and preferences

Besides undernourishment and nutrient deficient diets, overweight and obesity as a result of overconsumption of food has become a main concern affecting people’s health (FAO, 2017b). Changes in diets are not only linked to a changing population structure and changes in income as presented above but also to changes in consumer preferences. Shifts in consumer preferences are based on taste, availability, prices, expectations, beliefs, and knowledge and influenced by policies and advertisement. Observed negative trends are an increase in consumption of processed foods and sweetened beverages adding to this problem. Several policies exist to influence consumer choices by promoting healthy foods and discouraging the use of unhealthy foods, e.g., distribution of fruits and vegetables in schools and implementation of sugar taxes.

Furthermore, products with specific properties, such as being regional, fair trade, organic or free of genetically modified organisms (GMO), gain popularity among some consumer groups especially in the EU. Separate supply chains are developed for these products parallel to the existing ones and labeling and certification schemes help to distinguish them. One example is the increasing shift from GMO soybean meal to GMO-free soybean meal and alternative non-GMO protein feedstuffs in Germany, especially in the dairy and poultry industry (European Commission, 2019a).

On the supply side, the standards to be applied and certifications required, increase production costs. Adding to this, supply chains need to be separated between certified and non-certified products, resulting in additional cost. On the demand side, consumers can better inform themselves and make informed buying decisions. For example, multiple labels and standards exist for organic products. Definitions on what is organic differ between countries and various standards exist even within countries differentiating between different organic farming practices. Also, certifications for sustainable and deforest-free palm oil and soybeans are established by external private companies, within large trading companies, and through public sources (Hinkes, 2021). However, Hinkes (2021) found that the supply of deforest-free certified palm oil exceeds the demand in the EU. Consequently, certified products are partly sold without a premium and the attractiveness of certification is reduced (Hinkes, 2021).

Specific standards or minimum quality requirements exist for each product to ensure food safety or animal and plant health through setting sanitary and phytosanitary standards, e.g., the maximum level of mycotoxin allowed in wheat. These vary between countries and act as barriers to trade because they are applied within the country and at the border. They belong to the group of non-tariff measures (NTMs) which increase trade costs. With the Agreement on the Application of Sanitary and Phytosanitary Measures as a result of the Uruguay Round, a multi-lateral framework for their applications has been established, leaving room for country individual specifications.

Livestock and other downstream sectors

Besides the general, increased demand for livestock products closely related to income growth, a change in livestock production systems and shifting demand between different livestock types also changes demand for feed, e.g., cereals and oilseeds. Historically, livestock production has intensified. One contributing factor to this is the increased use of energy rich foods in feed rations, e.g., cereals and oilseed meals. Furthermore, feed rations vary between the different animal types and these markets show different developments. In the EU for example, beef production is declining, while poultry production is increasing. Hence, changes within the livestock sector affects cereal and oilseed markets. Short-term shocks in the livestock sector can also translate in short-term shock in the cereals and oilseed markets. The outbreak of African Swine Fever in China in 2018 caused a sharp decline in Chinese pork production followed by a rapid recovery of pork production accompanied by high imports of cereals and oilseeds to cover the increased feed demand (OECD and FAO, 2021b).

Demand for cereals and oilseeds also come from other sectors such as the starch and pharmaceutical industry. Currently, these have a relatively low share in total demand.

2.1.4 Other underlying factors

The factors described here correspond to the last category in Table 1 (page 9) and deserve mentioning but have either a very general, low, uncertain or short-term impact on cereal and oilseed markets. In general, they all contribute to the overall economic development of a country or region and, hence, are already covered to some extent by the factors presented above.

The state of the institutional environment is one of the factors fostering or hindering economic development. A safe and supporting institutional environment also ensures supply or more efficient supply in cereal and oilseed production. A safe institutional environment constitutes of a stable country in social, economic and political terms and ensures property rights especially for land and water. A supporting institutional environment includes public provision of infrastructure through improved transportation options and investments in research and development. This allows long-term planning and investments of private stakeholders which results in more efficient and sustainable production systems, e.g., through improved soil management. Contrary to this, conflicts, wars and any social or economic crisis hinder long-term investments and, hence, sustainable cereal and oilseed production. Changes of territory connections and political systems, e.g., the collapse of the Soviet Union, the German reunification, the formation of the EU, or the division of the Sudan, have altered the economy and institutional environment in the respective regions.

Infrastructure is of importance especially for traded commodities. International trade with cereals and oilseeds happens mostly by ship. Port capacities as well as available and useable water ways can be a limiting factor for growth expansions. As vessels have become larger over the years, the infrastructure needs to keep pace, otherwise a region becomes disconnected from the world market through increased transport costs resulting in increased domestic consumer prices and decreased domestic producer prices.

Structural change and migration away from agriculture and rural areas towards the manufacturing and service sectors and urban areas is a general trend historically observed in nearly every region. However, regional differences are considerable: agriculture contributes least to GDP in high income countries, while it contributes most in low-income countries. However, the agricultural sector share of GDP has been declining everywhere. Employment in agriculture, too, declined everywhere over the years. People moving to cities change their demand for food products as more processed foods and less raw materials are consumed. Often, migration across borders to work in more prosperous countries and sending the money back home to increase the families living standards is a common phenomenon. Additionally, life expectancy increased and the human population is aging with old people requiring less food.

Natural disasters such as earthquakes, volcano eruptions or plagues of locusts can destroy a harvest completely on a local scale. If these events are not repeated, they are of short-term nature. Other short-term and unexpected local events, such as the announcement of the Brexit, influenced markets through an exchange rate turmoil. However, the markets recovered fast with a devaluation of the pound.

2.2 Historical development of international cereal and oilseed markets[3]

In the previous sections historical long-term developments of the agricultural sector and the underlying factors with the focus on cereal and oilseed markets have been discussed. This section presents a more detailed presentation of recent historical developments, i.e., 2004/05 to 2018/19, in the main cereal and oilseed markets.

In general, increases in population, income, intensification, and productivity led to an increase in agricultural output at global level. However, focusing on more recent

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[3] This chapter is based on own work by the author published as Wolf and Haß (2017) and represents an update of cereal markets as well as the extension to oilseed markets

developments, there is some evidence that this growth slows down as some factors on the demand and supply side are developing less dynamically. Table 2 shows the global annual average growth rates of the mentioned factors for a more recent period (average 2004-06 to 2016-18, called ‘second period’ in the following text) and the period before (average 1961-63 to 2004-06, called ‘first period’ in the following text). On the demand side, the growth of population, GDP and the livestock sector showed lower growth rates in the second period but nevertheless absolute growth was immense. Biofuel demand only started in the second period with high growth rates. This required additional production of cereals and oilseeds. On the supply side, productivity has increased strongly in the second period, while the use of fertilizer is slowing down. Cropland expansion is not slowing down either, while total agricultural area declined in the second period.

Table 2 Development of selected factors driving cereals and oilseed markets with absolute and annual percentage changes

Factors	Absolute change			Annual average change		
	Unit	1961-63 to 2004-06	2004-06 to 2016-18	Unit	1961-63 to 2004-06	2004-06 to 2016-18
Population	billion persons	3.4	1	%	1.7	1.2
GDP	constant 2010 billion USD	45,744	22,196	%	3.6	2.7
Biofuel demand	billion liters	-	109	%	-	10.0
Livestock sector	constant 2014-2016 billion I$	650	288	%	2.2	2.0
Productivity	Index 2005 =100	30	21$^{1)}$	%	0.8	1.8$^{1)}$
Agricultural area	million hectares	350	-33	%	0.18	-0.06
Crop area	million hectares	153	55	%	0.25	0.3
Fertilizer use	million tons	123	33	%	3.6	1.6

Notes: period 1961-63 to 2004-06 corresponds to 43 years, period 2004-06 to 2016-18 corresponds to 12 years; population = world population according to UN (2019b); GDP = based on GDP (constant 2010 USD) of World Bank (2021b); biofuel demand = sum of biodiesel and ethanol production based on OECD and FAO (2020a); livestock sector = world livestock gross production value (constant 2014-2016 thousand I$) according to FAO (2021c); total factor productivity = world agricultural total factor productivity index with 2005=100 according to USDA (2021a) with $^{1)}$= only including 2016 as latest year data is available; agricultural area = world agricultural land according to (FAO, 2020e); crop area = world cropland according to (FAO, 2020e); fertilizer input = sum of world agricultural use of nutrients nitrogen N, phosphate P2O5 and potash K2O according to FAO (2021a)

Source: own calculations based on different data sources as stated in notes

The presentation of long-term developments conceals several driving factors such as policies and policy changes which contributed to several developments by supporting or restricting them. Additionally, the cereal and oilseed markets of today are hardly comparable with the cereal and oilseed markets in the 1960s or even in the 1990s. The world has changed tremendously with changes in the institutional environment, technological advances, and more and more integrated international markets.

Hence, focusing on more recent developments in more detail is the next step to understanding current and future cereal and oilseed markets. A historical overview is given for cereals and oilseed markets separately with a focus on the main countries in terms of production, consumption, and trade in each market to develop a better understanding of the specific markets. For this overview, data from USDA (2020a) is used, if not stated otherwise.

Several institutions exist which provide data for global cereal and oilseed market developments, e.g., the United States Department of Agriculture (USDA), the Food and Agriculture Organization of the United Nations (FAO), the Organization for Economic Co-operation and Development (OECD), the International Grains Council (IGC), and the International STatistical Agricultural Information Mielke GmbH (ISTA). These global datasets have the advantage of consistent definitions across countries, their own approach to collect and harmonize the data, and are provided in English. However, data quality might be less accurate than using regional or national statistics as well as data quantity where national statistics can provide more detail. Each database has its own coverage, definitions, and boundaries which results in different values for similar or even seemingly identical data points. For a global overview, the advantages of using one data source outweighs possible disadvantages as the comparability between regions and products is most crucial. For the current overview the 'Production, Supply and Distribution' (PSD) database of the USDA (USDA, 2020a) is chosen as primary source because it is the most up-to-date database with a sufficient level of detail. While some databases publish data with a lack of several years, the PSD database is updated monthly and includes forecasts for the next crop year. This forecast and the previous year are intentionally not included in this overview as the data is preliminary and subject to change. The USDA data is complemented by data from the other sources if the required detail is not given.

Before analyzing cereal and oilseed markets in more detail, several general observations can be summarized. Production and consumption have been growing over time with production varying more than consumption due to different weather conditions from year to year. At the same time, trade has increased more than production. Mostly, a few countries dominate the export markets while importers are more numerous. This increase was possible because of improvements in transport and storage as well as trade liberalization. Exports of a country vary between the years depending on production levels but also on prices and trade policies.

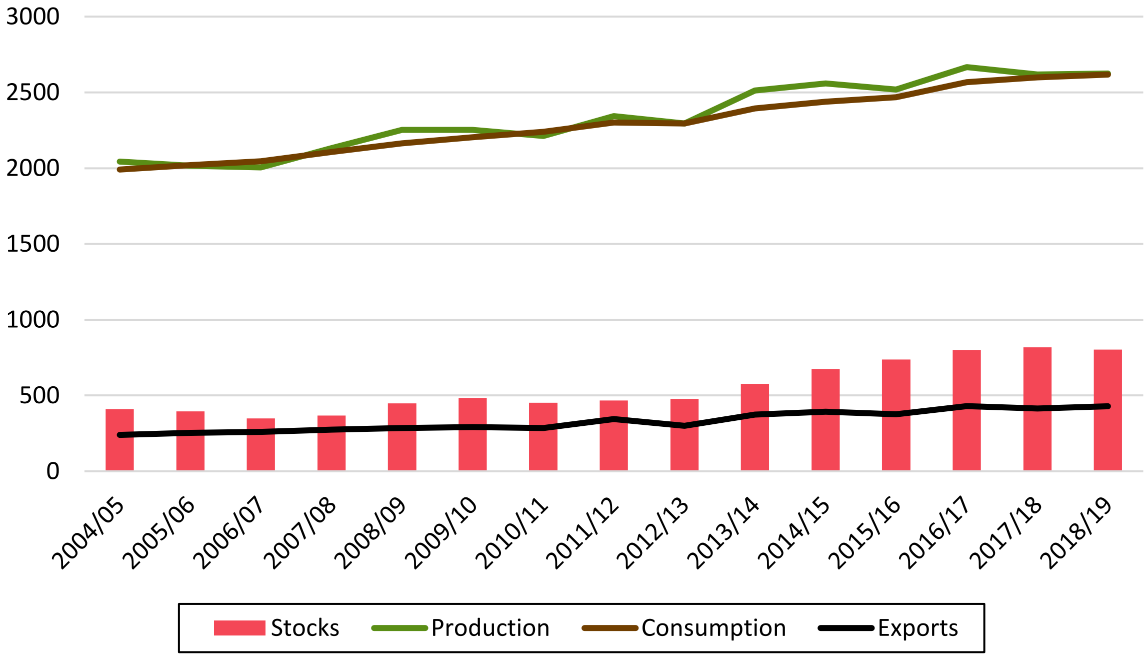
In the long-run, prices reflect the interplay between supply and demand and follow a decreasing trend in real prices over time by adjusted behavior of market actors. In the short-run, prices vary around this trend and can influence producers or consumers negatively. If prices are low, producers might not be able to cover production cost. If prices are high, consumers – especially the poor – might not be able to satisfy their daily food requirements given their limited income.

Different annual developments in production and consumption lead to changes in stocks and prices. If production surpasses consumptions, stocks grow and prices are likely to decrease. Similarly, if consumption surpasses production, stocks decline and prices are likely to increase. The magnitude of price changes depends on stock levels, i.e., with low stocks prices can increase more than with high stocks as observed in the marketing year 2007/08. Hence, in several markets the stocks-to-use ratio is a good indicator for the tightness of the market.

2.2.1 Cereal markets[4]

Global cereal production has reached nearly 2,636 million tons (average of 2016-18). This is an increase of 30 % compared to the average of 2004-06 and was due to increases in average yields by 22 %, i.e., 1.6 % per year, and area expansion by 6 %. While a general upward trend of cereal production is observable, it varies between years mostly due to variations in weather conditions (Figure 16). For example, unfavorable weather conditions in the form of dry and hot summers in the US and the EU led to a modest cereal production in 2012/13. In contrast to production, global cereal consumption has followed a smoother upward trend during the last years increasing on average by 1.9 % per year and reaching 2,595 million tons (average 2016-18) (Figure 16). This increased demand is primarily driven by population growth as well as feedstock demand from the livestock sector and in some regions from the biofuel sector. Stocks accumulate if production surpasses consumption as observable in the years 2011/12 to 2017/18. Overall trade strongly increased and exports reached 425 million tons (average of 2016-18), i.e., 16 % of total cereal production, compared to 252 million tons (average of 2004-06), i.e., 12 % of total cereal production.

Figure 16 Global cereal markets overview, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

Corn, wheat, and barley account for 2 billion tons (average of 2016-18), i.e., 76 % of global cereal production. These three cereals are highly substitutable on the production side with corn requiring slightly warmer weather than wheat or barley and are also highly substitutable on the consumption side, especially in the feed sector. Rice as a fourth important cereal accounted for 19 % of global production (average of 2016-18) but is not analyzed in more depth here because it a) has different production requirements and systems, b) is predominantly consumed as food, c) is traded less on international markets, and d) its main production is located in Asia (excluding Russia) which is not a focus of the current analysis. Other cereals, e.g., sorghum, millet, oats, rye, and triticale, play important

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[4] In the database USDA (2020a), cereals include barley, corn, millet, mixed cereal, oats, rice (milled), rye, sorghum, and wheat and the EU is treated as one entity

roles in only a few regions. Hence, global market developments for corn, wheat and barley are presented in more depth here.

The main growth in total cereal output was realized through increases in the corn market (Table 3). While yield growth is similar between the different cereals, the varying production increases are mainly due to changes in area ranging from decline for barley over stagnation in wheat to increase in corn. Trade intensity, measured as exports divided by production, has increased for all cereals with wheat showing highest export shares of production.

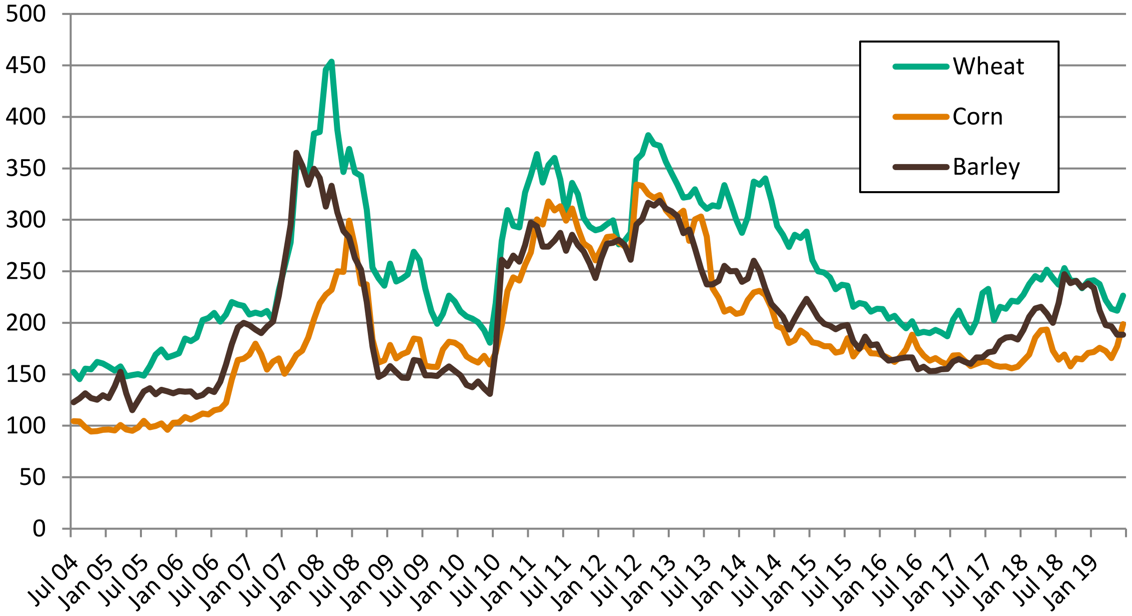
Table 3 Supply side developments of cereals in annual growth rates (average 2004-06 to 2016-18) and export shares of production for average 2004-06 and 2016-18, %

	Annual growth rates			Export shares of production	
	Production	Yield	Area	2004-06	2016-18
Total cereals	2.2	1.7	0.5	12	16
Corn	3.8	1.4	2.3	12	15
Wheat	1.7	1.5	0.1	18	24
Barley	0.1	1.3	-1.2	11	19

Notes: exports exclude intra-EU trade as the EU is reported as one entity
Source: own representation based on data from USDA (2020a)

Figure 17 shows the monthly development of export prices for corn, wheat, and barley on important, selected ports. These are often regarded as world market prices and reflect the global market situation of a cereal. Generally, the prices show roughly similar developments over time and deviations are explainable when looking into a specific market in more detail as follows below. In recent years, the sharpest increase of cereal prices was observed in 2007/08 when stocks for major cereals were low, small harvests were expected, and oil prices were high. From 2013 to 2017, cereal prices declined because of successively very good global harvests replenishing stocks. Nevertheless, the price levels stayed above the level previous to the price spike in 2007/08.

Figure 17 Monthly representative export prices for wheat, corn and barley, July 2004 to June 2019, USD/t fob



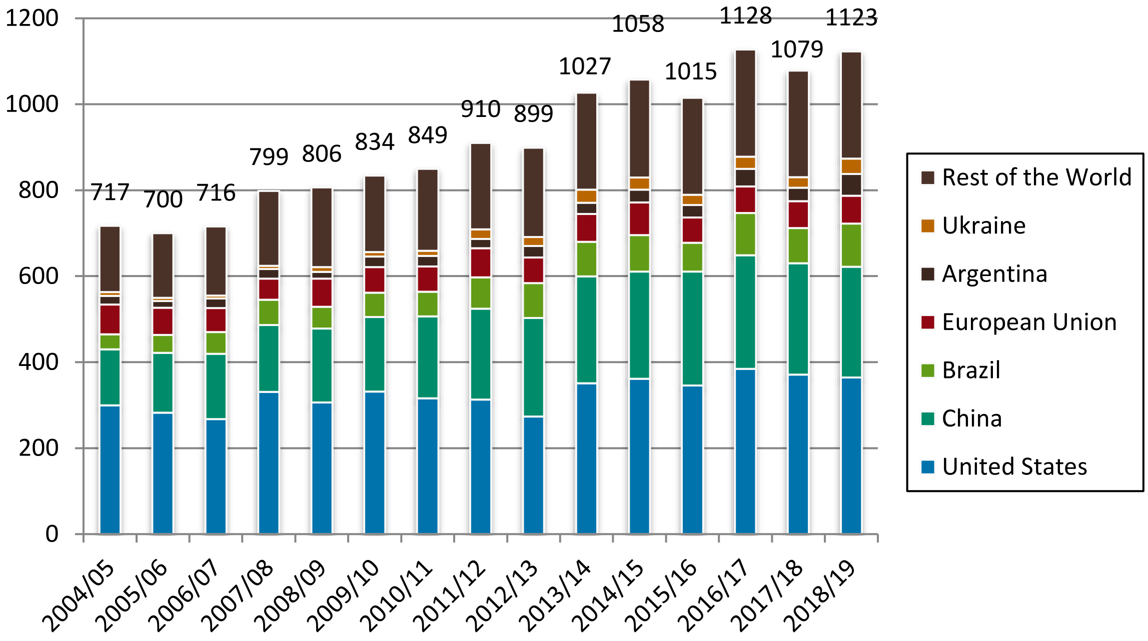
Note: monthly averages of export quotations net of export refunds/ taxes in USD/t fob for wheat = US hard red winter wheat Gulf, corn = US 3 grade yellow corn Gulf, barley = France feed barley Rouen
Source: own representation based on data from IGC (2019)

The following sections discuss the three globally important cereal markets in detail highlighting the most important countries with respect to production, consumption, and trade. Dominating underlying drivers resulting in exceptional market developments are highlighted for selected times and products.

2.2.1.1 **Corn market**

Corn production has grown steadily over the past years at a rate of 3.8 % per year (average of 2016-18 to 2004-06), i.e., a total increase of over 56 % in 13 years. Annual fluctuations are mainly due to favorable or unfavorable weather conditions in the main producing regions in the different marketing years. For example, the globally low production in 2015/16 was mainly due to wet conditions during planting in the US which reduced corn area, and dry conditions in Brazil during growing which reduced corn yields. In the next marketing year, a record harvest was realized mainly due to favorable weather conditions in nearly all main producing regions. The six largest producers, as depicted in Figure 18, harvested 78 % of total global production in 2018/19. Of these countries, Ukraine nearly tripled production, Brazil, and Argentina more than doubled production while the US increased production by only 32 % and the EU even stayed at the level of 2004-06. While global demand for corn increased in general and, hence, stimulated production, specific demand increases added to this, e.g., the expansion of corn-based ethanol production in the US.

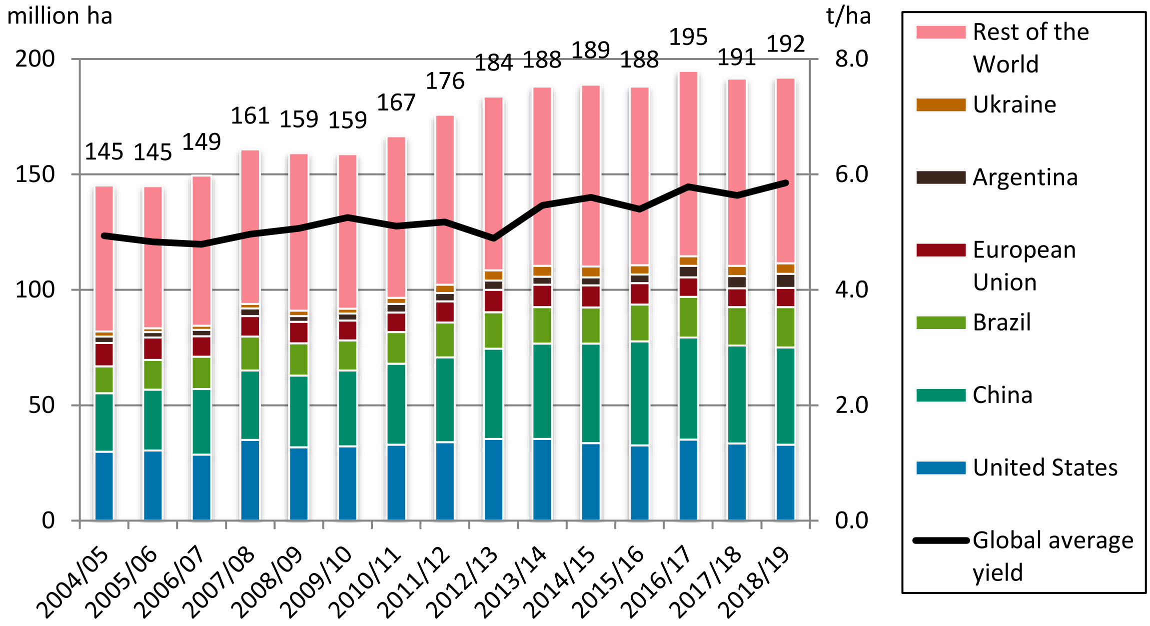
Figure 18 Global corn production and major producing countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

Global corn production increased through area expansion and yield growth. Area expansion contributed slightly more to this increase than yield expansion. Area harvested of corn increased at a rate of 2.3 % per year (average of 2016-18 to 2004-06). However, as depicted in Figure 19, area expansion has been slowing down since 2013/14. China increased area harvested in absolute terms the most, i.e., by over 16 million hectares (average of 2016-18 to 2004-06), while Argentina and Ukraine increased area harvested in relative terms the most, i.e., both more than doubled their area harvested. In contrast, the corn area harvested decreased in the EU by 12 % over the same period. In Brazil, corn can be cultivated in a double cropping system with soybeans. In terms of area harvested, this production system has increased constantly, while the system of growing corn as a first crop decreased. Since May 2012, the area harvested of corn as second crop surpassed the area harvested of corn as a first crop and had a share of 70 % on total corn area harvested in 2018/19 (IBGE, 2021).

Figure 19 Global corn area and major producing countries in million ha (left axis) and global average yield in t/ha (right axis), 2004/05 to 2018/19

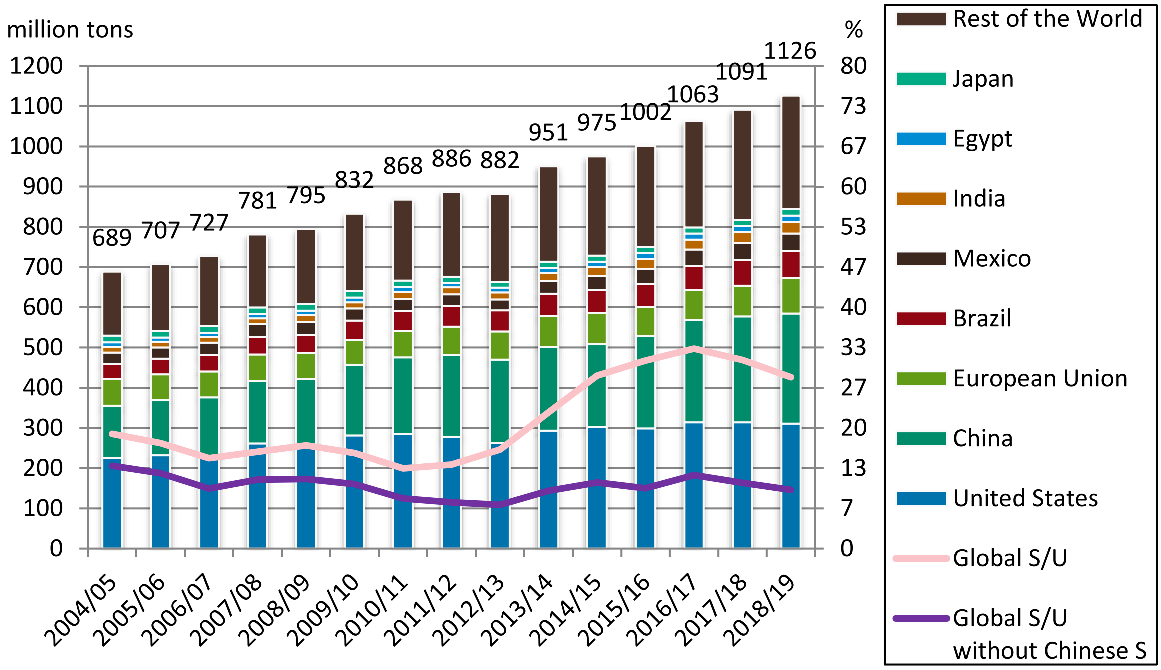


Source: own representation based on data from USDA (2020a)

Global corn yields have increased at a rate of 1.4 % per year (average of 2016-18 to 2004-06) and reached an average of 5.8 t/ha for the period 2016-18 (Figure 19). Brazil and Ukraine increased their yields strongly with average annual growth rates of 4.2 % and 4.6 %, respectively. Of the largest producers, Argentina’s corn yields increased the least with an average annual growth rate of 0.4 %. Corn yields vary widely across the world with the US achieving high average yields of 11 t/ha (average of 2016-18) and India, the seventh largest producer, achieving low average yield of 2.9 t/ha (average of 2016-18). Some smaller corn producing countries, mostly located in Africa, do not even reach yields of 1 t/ha.

Global corn consumption grew steadily by 3.7 % per year (average of 2016-18 to 2004-06) with only slight fluctuations. The four main corn producers, producing 70 % of global corn, are also the four main corn consumers, consuming 65 % of global corn in 2018/19 (compare Figure 18 and Figure 20) with the US and China being by far the largest. Corn is used primarily as food in most African countries, for ethanol production in the US, and animal feed in most other regions. In the US, corn markets became more interlinked with the oil market, i.e., price correlations between corn and oil prices increased, through the use of corn as ethanol feedstock (de Gorter, Drabik and Just, 2015). The strong increase in Chinas corn consumption is a result of increased livestock production, especially pork, to satisfy the increased demand for meat in Chinese diets as their income grew. Corn is a preferred feedstuff compared to other cereals due to its high energy content and its share in feed rations has globally increased over time. Beside the general upward trend in consumption, corn consumption depends on prices. If prices are high or relatively high compared to other cereals, consumption declines if used as animal feed because compound feed producers and livestock owners partially substitute corn with cheaper alternatives in their feed rations.

Figure 20 Global corn consumption and major consuming countries in million tons (left axis) and global stocks-to-use ratio in percentage with and without Chinese stocks (right axis), 2004/05 to 2018/19



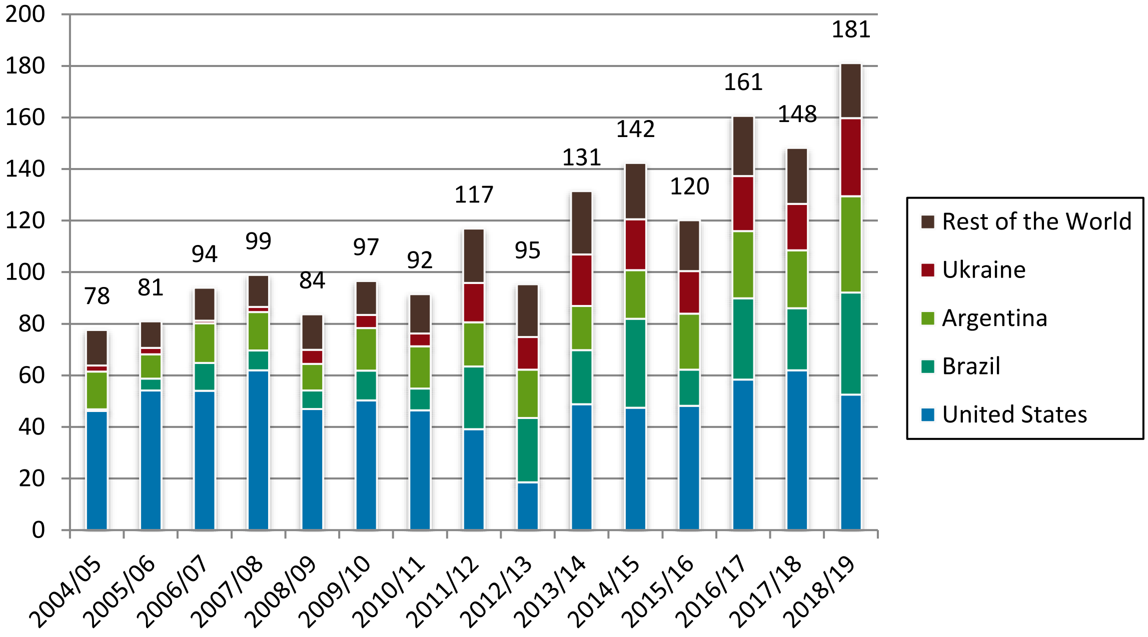
Note: S/U = Stocks-to-use ratio, S=Stocks

Source: own representation based on data from USDA (2020a)

As the stocks-to-use ratio is a measure of the tightness of a market, it is observable that prices generally go in opposite directions. However, the magnitude is not certain and prices tend to change more sensitively when stocks are low. The stocks-to-use ratio excluding Chinese stocks shows this relationship more precisely in the corn market. Several reasons exist for this: a) data on Chinese stocks are very uncertain as no reliable official statistics exist, b) the USDA has revised Chinese corn market data backwards in November 2018 based on new published production data from China's National Bureau of Statistics resulting in new larger stock data from 2012 onwards (USDA, 2018), c) China's corn stocks are not available for the world market due to the implemented policies aiming to ensure national food security.

Corn trade has nearly doubled from the average of 2004-06 to 2016-18 resulting in an export share of total production of 15 % (average of 2016-18) compared to 12 % (average of 2004-06). Of the large producers, the EU and China are net importers, while the other four large producers, namely the US, Brazil, Argentina, and Ukraine, are large net exporters dominating the export market. They account for nearly 90 % of all exports in 2018/19 (Figure 21). The US exports, while varying considerably due to production levels, have stayed on a relatively constant level over the years due to higher domestic demand coming from the production of ethanol. In contrast, Ukraine's additional corn production is solely targeted towards exports, i.e., Ukraine exported 80 % of its production (average of 2016-18).

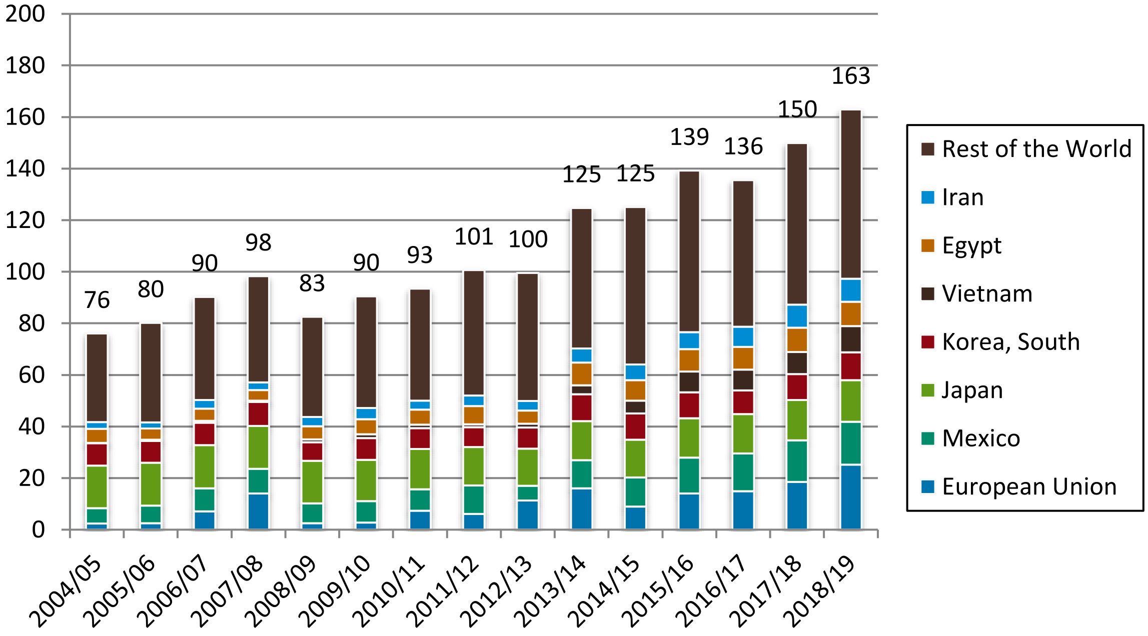
Figure 21 Global corn exports and major exporting countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

The largest seven importers imported less than 60 % of all imports in 2018/19 showing that imports are less concentrated than exports. Before 2017/18, Japan was the largest corn importer and was then surpassed by the EU and Mexico (Figure 22). Japan has nearly no own production and, hence, imports all the corn it consumes. Import levels did not change much between the years as Japan's livestock production is slightly declining. In contrast, the EU imports fluctuate as imports depend to a large extent on its own corn production.

Figure 22 Global corn imports and major importing countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

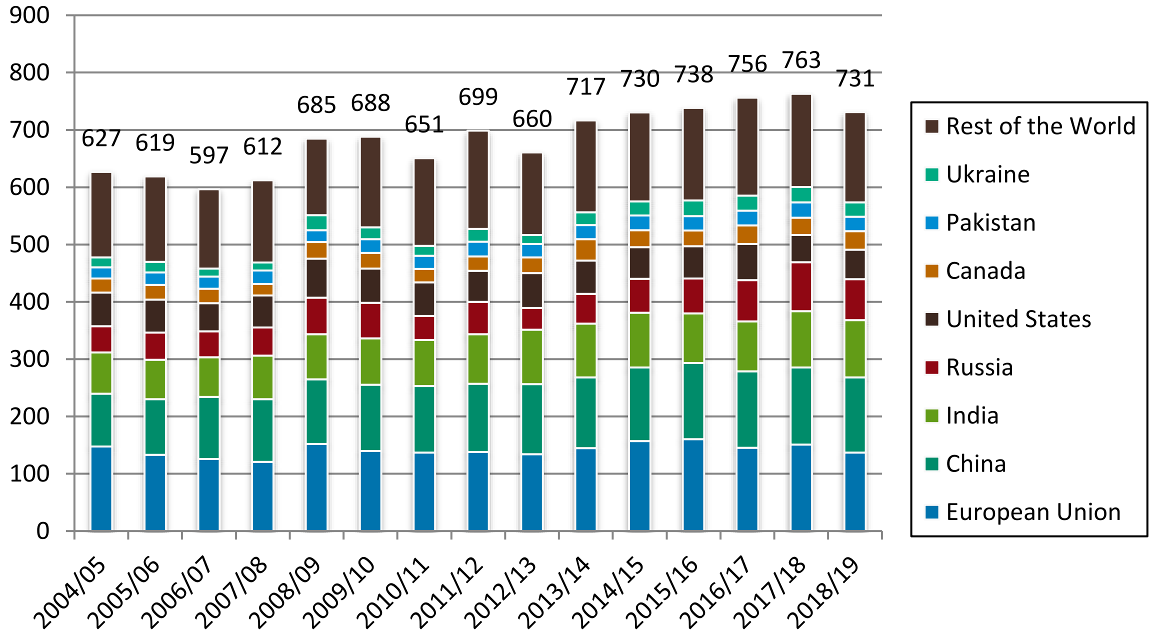
Bilateral trade flows as reported by FAO (2020d), show that trade flows change over time. For example, Ukraine became the main source of corn for the EU as of 2011 and corn imports from Argentina to the EU even decreased despite the overall growth. Brazil is another country having increased exports to all large importing countries, with Iran being the main importer, over the whole period from 2005 to 2019. Corn imports of Japan and Mexico originate mainly from the US with the US having lost some import shares to Brazil over time.

Concluding, the corn market is dominated by the US and China as the two largest producers and consumers. Further, it has been a fast-growing market over the last few years with production increases especially in Ukraine and Brazil which both became large exporters.

2.2.1.2 **Wheat market**

Global wheat production grew less than corn with a rate of 1.7 % per year (average of 2016-18 to 2004-06), i.e., a total increase of 22 % in 13 years. The years 2013/14 to 2017/18 were five years in a row with record harvests due to favorable weather conditions resulting in slowly declining prices over this period. The eight largest producers harvested approximately 79 % of all wheat in 2018/19 (Figure 23). Of these, the largest growth is observed in Russia and Ukraine with increases of 66 % and 57 % (average of 2016-18 to 2004-06), i.e., growth rates of 4.3 % and 3.8 % per year, respectively, while wheat production in the US slightly declined.

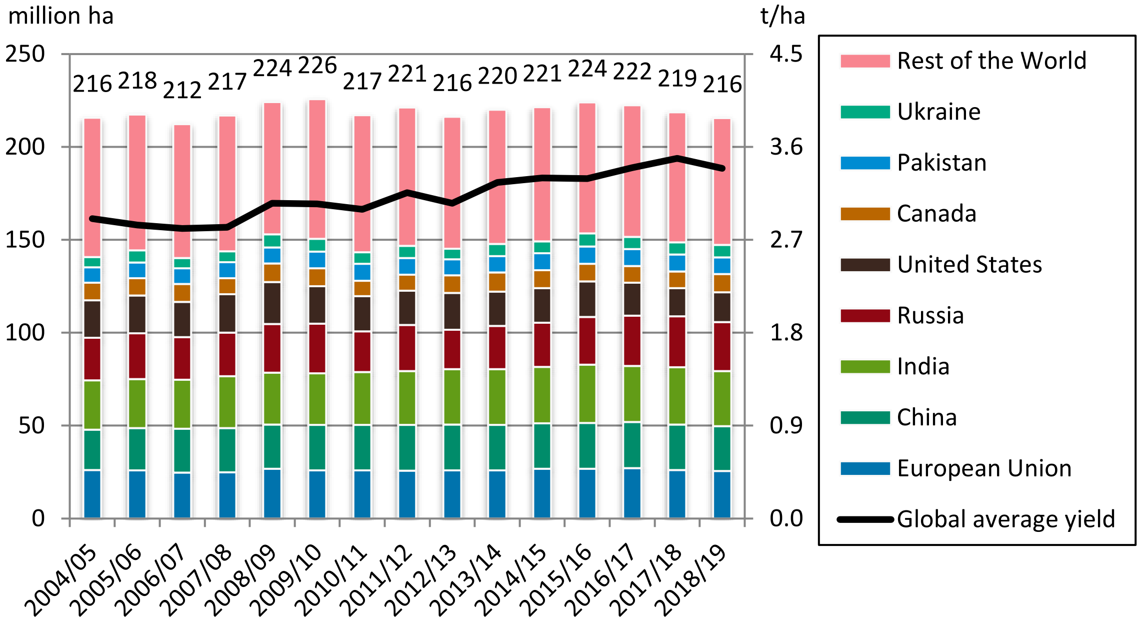
Figure 23 Global wheat production and major producing countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

The overall production increase is primarily due to increases in yields. Global area harvested stayed approximately constant over the last 15 years but shifted considerably at the regional level (Figure 24). India, Russia, and Ukraine expanded their wheat area together by nearly 8 million hectares (average of 2016-18 to 2004-06), i.e., increases between 12 % and 15 %, while the US decreased it by nearly 3.5 million hectares, i.e., more than 17 %.

Figure 24 Global wheat area and major producing countries in million ha (left axis) and global average yield in t/ha (right axis), 2004/05 to 2018/19

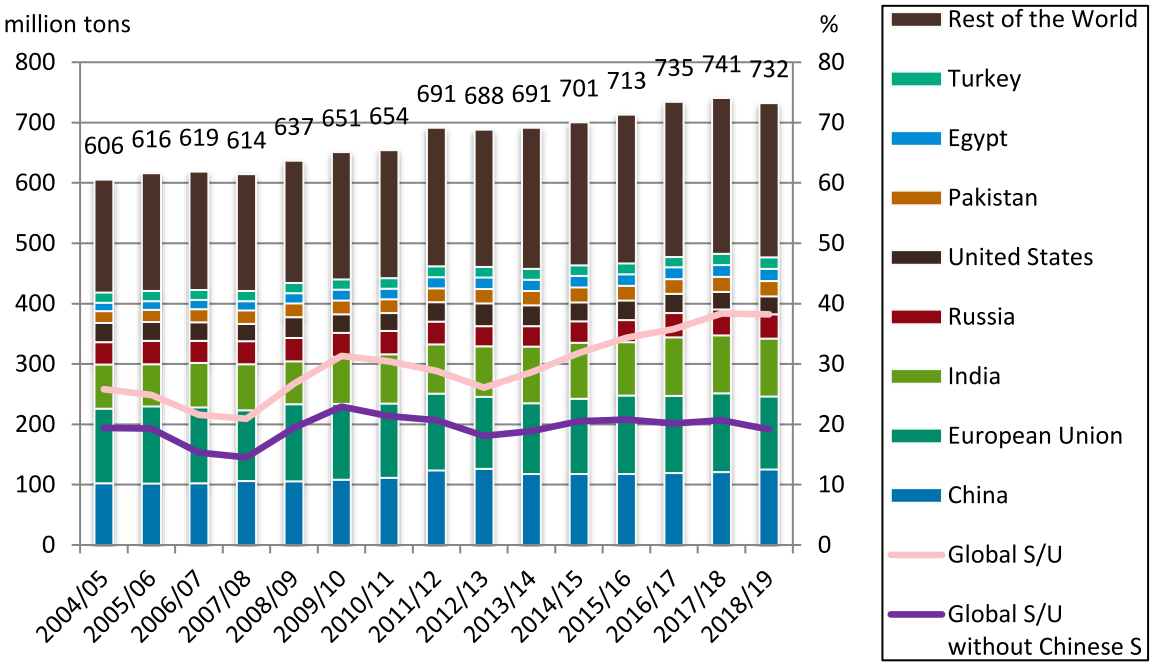


Source: own representation based on data from USDA (2020a)

Global wheat yields increased by 1.5 % per year (average of 2016-18 to 2004-06) and reached an average of 3.4 t/ha for the period 2016-18 (Figure 24).Highest yield increases are observed in Russia and Ukraine which increased wheat yields by 3.1 % and 2.8 % per year (average of 2016-18 to 2004-06) and resulted in total yields of 2.8 t/ha and 4.0 t/ha (average of 2016-18), respectively. In the EU, wheat yields were highest with 5.5 t/ha (average of 2016-18) but growth rates were lowest with only 0.3 % per year between 2004-06 to 2016-18. The large yields in the EU, which can be above 10 t/ha in some parts, are due to favorable climatic conditions and intensive production systems. In contrast, Russia faces less favorable climatic conditions in several wheat growing regions and produces less intensively. Yield variations are larger in regions depending on rainfall and facing extreme weather events such as droughts or floods than regions using irrigation and facing less variation in weather conditions. For example, Australia, a large wheat exporting country, faced a drought in 2006/07 with yields of only 0.9 t/ha and achieved a record yield of 2.6 t/ha in 2016/17, i.e., a difference of nearly 200 %. Egypt, a large importing country, is irrigating its wheat production and achieves yields around 6.4 t/ha with highest variations of 15 % between 2004/05 to 2018/19.

Global wheat consumption grew by 1.5 % per year (average of 2016-18 to 2004-06). The five main producers, producing 67 % of global wheat, are also the five main consumers, using 56 % of global wheat in 2018/19 (compare Figure 23 and Figure 25). Globally, wheat is primarily used as food, i.e., 70 % of all wheat consumed in 2018 (FAO, 2021b). Some countries in the EU, Australia, Thailand and Belarus also use wheat to a larger extent as feed with feed shares above 50 % in 2018 (FAO, 2021b). Wheat is a staple food in most counties and, hence, has been growing most in countries with a large growth in population, i.e., in the regions Africa, South East Asia, and the Middle East. Of the large consumers, India and Egypt increased wheat consumption the most, i.e., more than 30 % from the average of 2004-06 to 2016-18, while consumption in the EU and the US stayed nearly constant over that period.

Figure 25 Global wheat consumption and major consuming countries in million tons (left axis) and global stocks-to-use ratio in percentage (right axis), 2004/05 to 2018/19

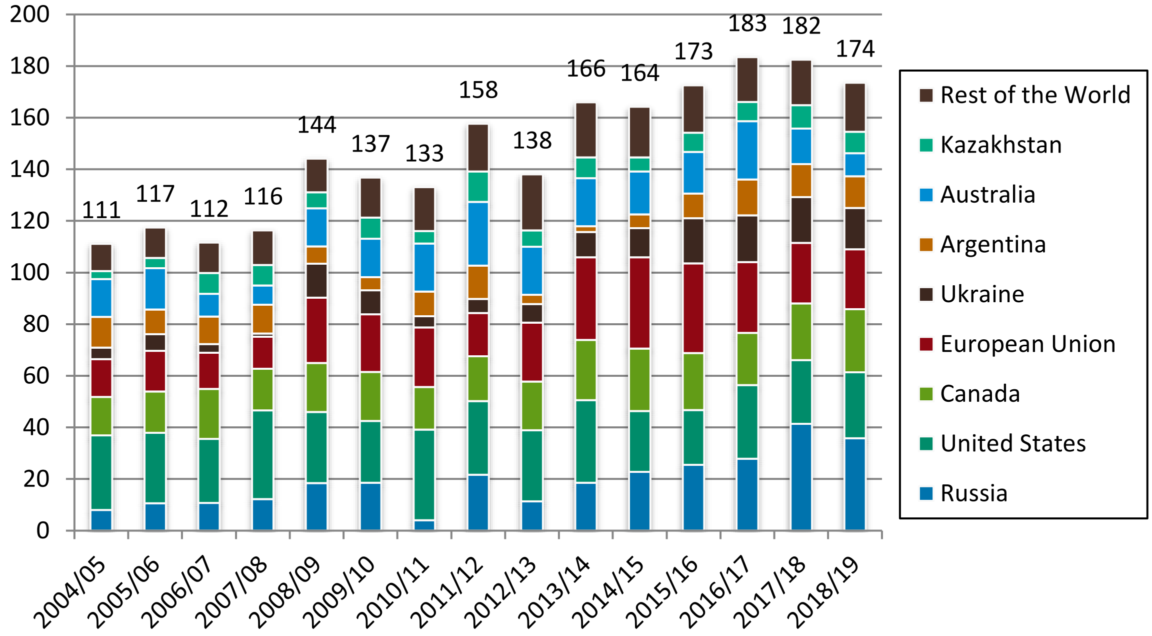


Source: own representation based on data from USDA (2020a)

Because wheat is an important staple crop in many countries, the global stocks-to-use ratio is generally higher than for corn as several countries store wheat to ensure food security, e.g., China, Saudi Arabia and Lebanon. Further prices tend to react stronger when stocks deplete, e.g., the sharp price increase in 2007/08 after several years of declining stocks as well as the price increases in 2010/11 and 2012/13. The global stocks-to-use ratio without Chinese stocks fluctuated since 2012/13 between 19 % and 21 % and correlates to the price developments better than with the inclusion of Chinese stocks which are – as in the case of corn – uncertain. China, India, and Pakistan aim for high self-sufficiency ratios in wheat to ensure food security. Even though their policies vary and have changed, all three countries set minimum price levels and procure wheat for stocks. Depending on their production, they can either be wheat net importers or wheat net exporters in a marketing year.

The other large wheat producers are net exporters. Additionally, Argentina, Australia, and Kazakhstan export large amounts of their wheat production. Together these eight countries, as depicted in Figure 26, accounted for 90 % of wheat exports in 2018/19. The total export share of production has increased from 18 % (average of 2004-06) to 24 % (average of 2016-18). Russia and Ukraine contributed most to this increase with exporting an additional 25.2 million tons and 12.6 million tons (average of 2016-18 to 2004-06), respectively. Russia even became the main wheat exporter as of 2016/17. Canada, Ukraine, Argentina, and Australia depend strongly on the consumption of other countries as their export shares of production are above 60 % (average of 2016-18). Competitiveness of an exporting region depends on production costs, transport costs, the exchange rate of the national currency to the USD, and policies, e.g., tariffs or national production policies, as well as wheat quality. For example, the Argentinian wheat export market is subject to strongly varying trade policies resulting in considerable changes in wheat exports and production levels. Export taxes of up to 22 % were applied until 2016 as well as export quotas from 2007-2011 (OECD, 2019). From 2016 export taxes on wheat were eliminated, considerably increasing wheat exports as shown in Figure 26. However, economic turmoil and a strong national currency devaluation resulted in new export taxes in September 2018 to improve the government's fiscal situation (USDA FAS, 2018).

Figure 26 Global wheat exports and major exporting countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

Wheat is imported by many countries with 42 countries importing more than 1 million tons (average of 2016-18). The five main importers, namely Egypt, Indonesia, Algeria, Brazil, and the Philippines, accounted for just 25 % of all imports (average of 2016-18). More than 60 countries mainly located in Asia, Africa and South America, import all or nearly all of the wheat they consume.

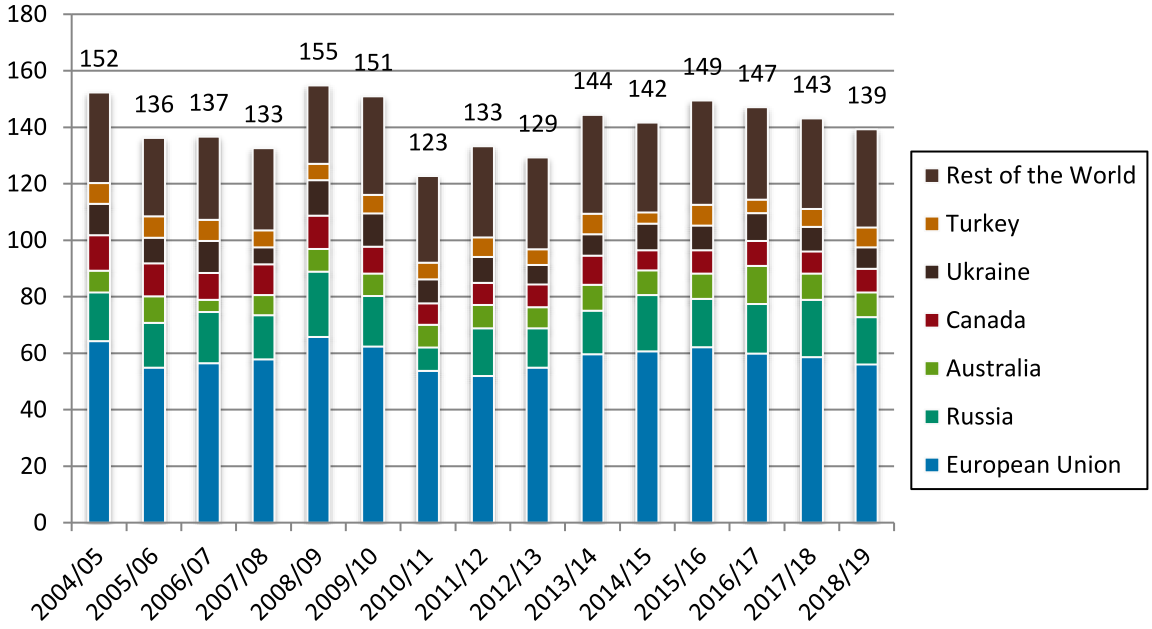
Many trade flows between countries exist and, if qualities are sufficient, the cheapest origin is bought first by importers. For example, the Egyptian government imports wheat from the cheapest trader complying with their tender specifications which include quantity, time for delivery and specific quality requirements often lying above the countries standard requirements (FAO, 2015). Due to transport costs, proximity between importer and exporter plays an important role as well. For example, most Argentinian wheat goes to Brazil, most European wheat to the Middle East and North Africa, most Kazakh wheat to former Soviet Union countries and Afghanistan, and most Australian wheat to Asia. With Russia and Ukraine entering export markets, trade flows have changed. In the Egyptian wheat market, the US has lost wheat import shares, while Russia and Ukraine gained shares. Wheat trade flows are very flexible as, for example, Australian wheat exports to Indonesia shrank in 2018 and 2019 (FAO, 2020d) due to the Australian production being impacted by drought in both years and were filled by Ukraine, Canada, Argentina, and Russia.

Summarizing, wheat is a staple crop in many countries and, hence, food security issues lead to supporting domestic production as well as keeping national storages in several countries. Over the presented period, Russia and Ukraine expanded wheat production, hence, becoming major players in the export market, while the US reduced both production and exports.

2.2.1.3 **Barley market**

The barley market is much smaller than the corn and wheat market and has not grown over the observed period. There is malted barley grown for beer production and feed barley for animal feed. For malted barley compared to feed barley, a price premium is paid as it requires certain qualities, e.g., a low protein content. If quality requirements are not met, malted barley is used as animal feed. As feed, barley, corn and wheat can substitute each other. However, barley has the lowest energy and highest fiber content of the three, making it less attractive compared to corn and wheat as cereals are mainly included in animal rations due to its energy content. Additionally, barley is often the least profitable as yields are lower. Hence, it is often grown in regions where corn production is not feasible due to climatic conditions, because barley requires a shorter vegetation period and lower temperatures. Barley production fluctuated around 141 million tons (average of 2004-2018) with deviations of at most 18 million tons. The largest barley producer is, by far, the EU (Figure 27). Of the large producers, only Australia expanded barley production strongly, i.e., 47 % from the average of 2004-06 to 2016-18, while Canada, Ukraine, and Turkey even decreased production.

Figure 27 Global barley production and major producing countries, 2004/05 to 2018/19, million tons



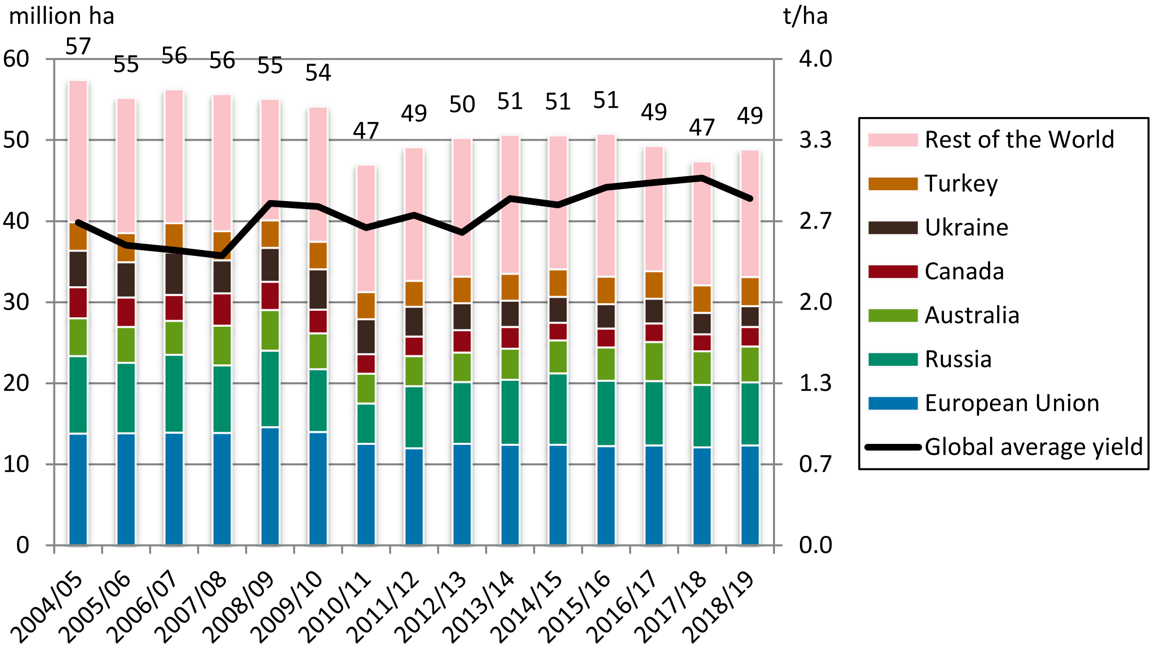
Source: own representation based on data from USDA (2020a)

Globally, area harvested decreased by 14 % (average of 2016-18 to 2004-06), and of the large producers, only Australia and Turkey kept area harvested approximately constant (Figure 28). Area harvested of the other four large producers decreased by more than 1 million hectares (average of 2016-18 to 2004-06) in each region with the main drop occurring between 2009/10 and 2010/11 after two years of low barley prices (compare Figure 17) and record stocks of 37 million tons in 2009/10.

Global barley yields increased at a rate of 1.3 % per year (average of 2016-18 to 2004-06) and reached an average of 3 t/ha for the period 2016-18, i.e., lower than yields for corn and wheat. Largest yield increases were realized in Australia and Ukraine with an annual rate of 3.2 % and 3 %, respectively. In contrast, yields in Turkey declined and only reached

1.7 t/ha (average of 2016-18). Highest average barley yields are realized in the EU with 4.8 t/ha (average of 2016-18).

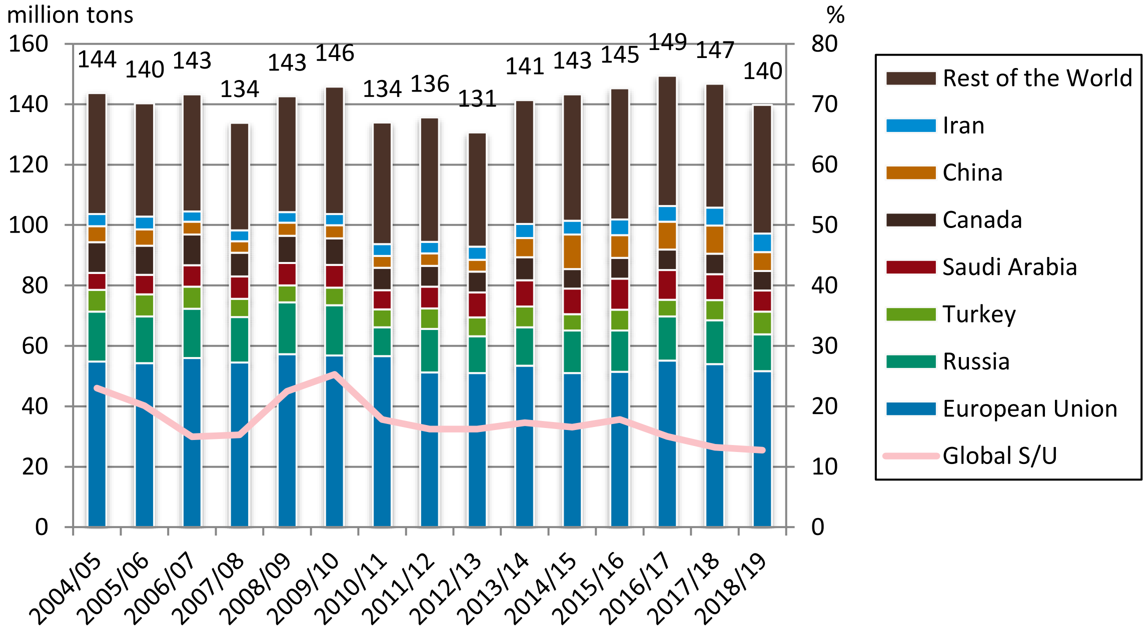
Figure 28 Global barley area and major producing countries in million ha (left axis) and global average yield in t/ha (right axis), 2004/05 to 2018/19



Source: own representation based on data from USDA (2020a)

Barley consumption, just as production, was relatively constant from 2004 to 2018 and fluctuated less than production, i.e., by maximal 7 million tons (Figure 29). Four of the large producers are also main consumers of barley, namely the EU, Russia, Turkey, and Canada. Together they produced 63 % of global barely and consumed 56 % in 2018/19.

Figure 29 Global barley consumption and major consuming countries in million tons (left axis) and global stocks-to-use ratio in percentage (right axis), 2004/05 to 2018/19



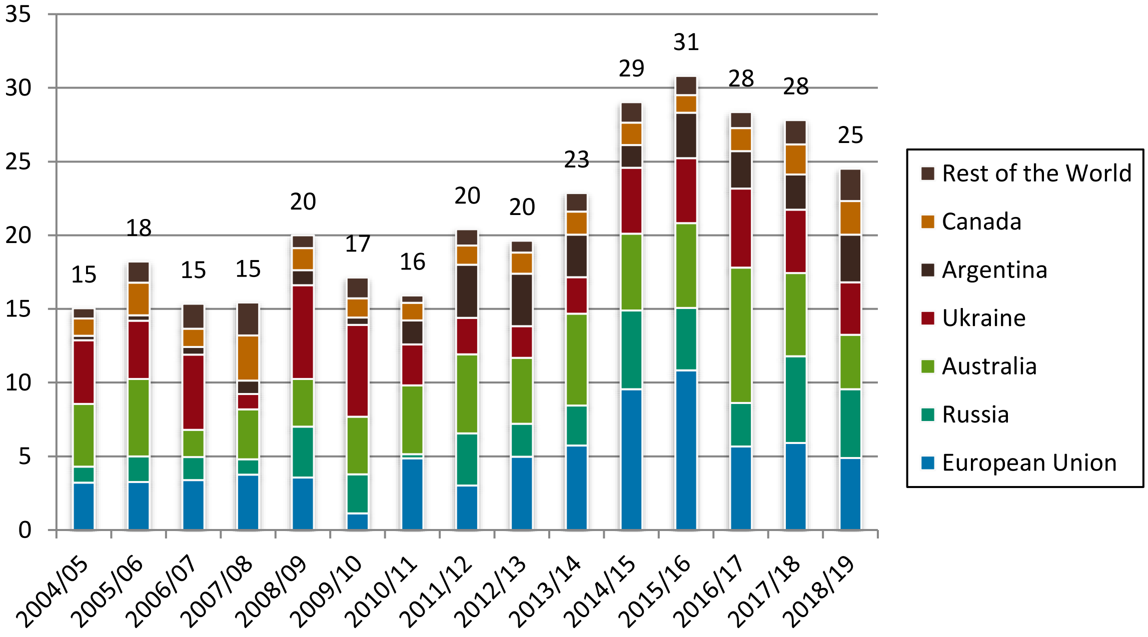
Source: own representation based on data from USDA (2020a)

Growth in global beer production has slowed down and has even stagnated around 190 million tons since 2012 (FAO, 2020b), while feed consumption fluctuates with available production. In 2018, approximately 60 % of barely where used as feed and nearly 25 % as beer (FAO, 2021b). Of the large consumers, Saudi Arabia, Iran, and Turkey consumed barley nearly exclusively as feed, while the other large consumers use it as feed and for beer production. Barley consumption in Saudi Arabia and Iran grew the most, i.e., 2.4 % and 3.4 % per year (average of 2016-18 to 2004-06), respectively.

Barley is not subject to food security policies as it is not a staple crop and, hence, stocks-to-use ratios are generally below those of corn or wheat. From 2012/13 to 2015/16, prices for barley declined similar to wheat prices even though the stocks-to-use ratio was relatively stable as a result of the substitution possibilities in feed rations. In the last three marketing years, the global stocks-to-use ratio has declined the most for barley resulting in price increases neither observed for wheat nor corn.

Of the large producers Turkey is self-sufficient in barley, while the others are large exporters. As in the case of wheat and corn, the export market is dominated by a few countries, i.e., the six largest exporters shipped more than 90 % of barley in 2018/19 (Figure 30). Export shares of production have increased from 11 % (average of 2004-06) to 19 % (average of 2016-18). The EU is the largest exporter of barley. However, this varies and depends on regional price differences as well as production surplus, e.g., Australia was the largest exporter in 2016/17 because of their record harvest. Argentina depends most strongly on global markets followed by Australia and Ukraine as they all exported more than 50 % of their production (average of 2016-18).

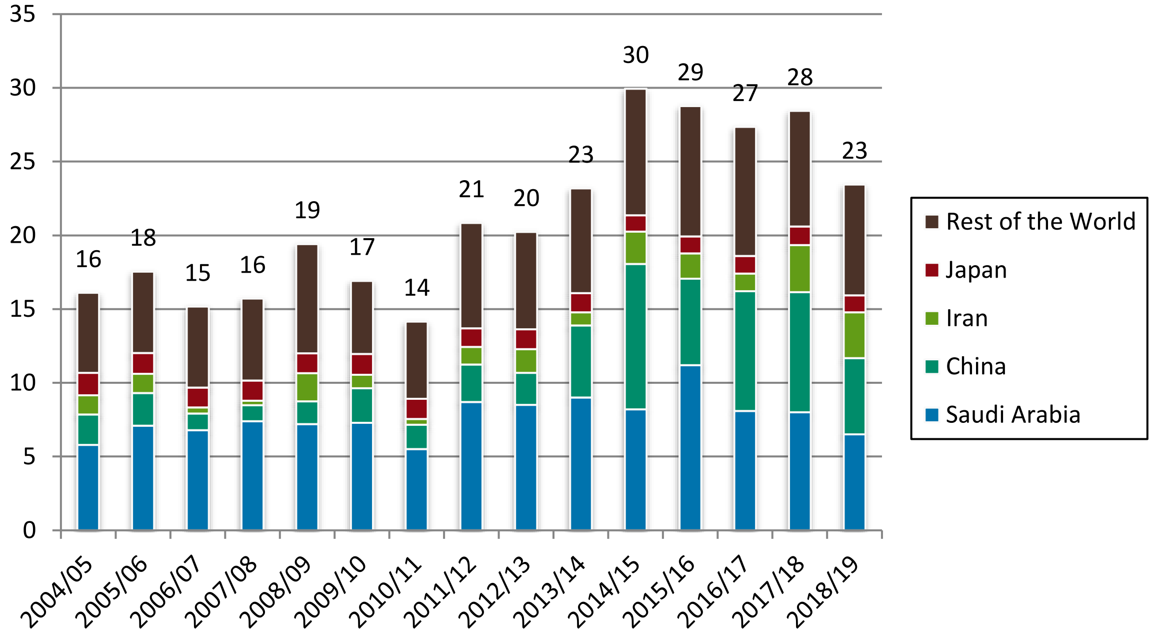
Figure 30 Global barley exports and major exporting countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

The barley import market is more concentrated than wheat and corn as the four main importers accounted for 68 % of all trade in 2018/19 (Figure 31). The import market has been dominated by Saudi Arabia which imports all its consumed barley. Barley is preferred over other feed cereals by Bedouin herders because of its traditional use despite the government advocating for more efficient compound feed (USDA FAS, 2020b). Since 2013/14, China's imports have strongly increased. Chinese non-feed use of barley was nearly constant with approximately 3.8 million tons. Consequently, the increase and variation of barley imports can be attributed to feed barley which depends on prices and availability of corn and sorghum.

Figure 31 Global barley imports and major importing countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

Changing trade flows can also be observed in the barley market. Saudi Arabia imports barley from all large exporting countries with main imports coming from the EU, Ukraine and Russia (average of 2017-19) (FAO, 2020d). Since 2013, Australia has lost import shares in Saudi Arabia, while Russia and Argentina have gained import shares. From then on, Australian barley was primarily shipped to China and Japan. China only allows cereal imports from countries which have a Bilateral Phytosanitary Protocol with them (USDA FAS, 2020a). From 2012 to 2020 the list of countries eligible for barley exports to China increased from five to 12 (USDA FAS, 2012, 2020a). However, several large exporters from the EU are not yet allowed to export to China, e.g., Germany.

Concluding, the barley market has not been growing over the presented period. The EU is the main barley producer, consumer, and exporter. While barley is losing attractiveness in traditional consuming counties, China poses new opportunities for exports.

2.2.2 Oilseed market[5]

In general, oilseeds are grown to produce vegetable oil and oilseed meal, the accompanying by-product when extracting the oil. While vegetable oil is used as food, energy source or ingredient to industrial products, meal is used in the animal sector as a protein rich

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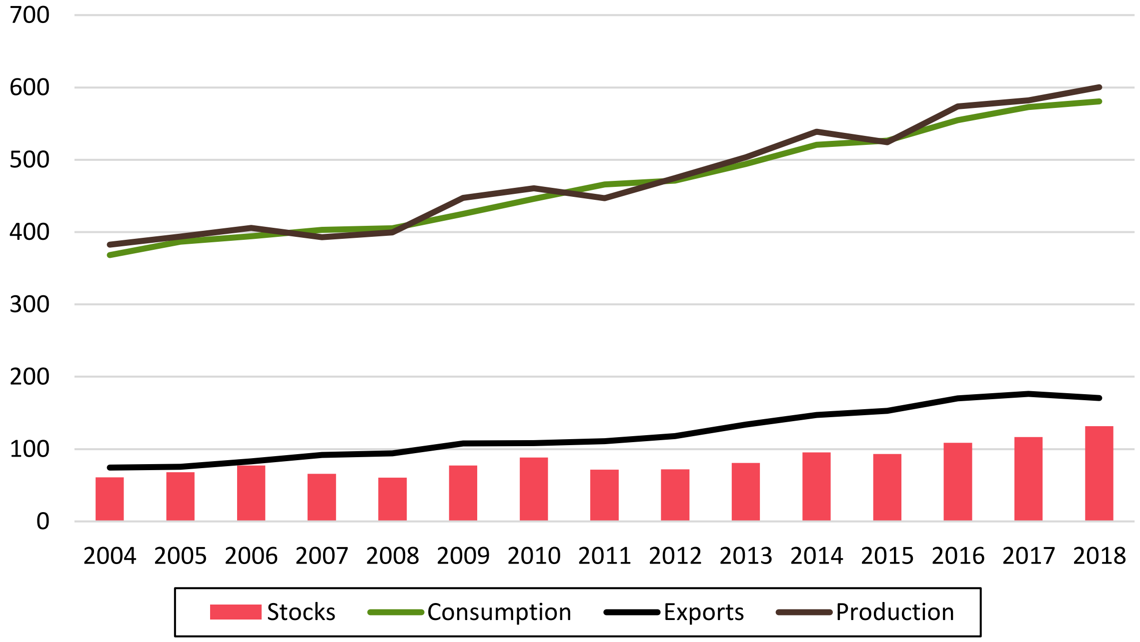
[5] In the database, oilseeds include copra, cottonseed, palm kernel, peanut (groundnut), rapeseed (including canola), soybean, and sunflower and the EU is treated as one entity USDA (2020a).

feedstuff. Demand for vegetable oil and animal feed has been growing and, hence, oilseed production has been expanded. This increased demand is primarily driven by population growth and higher food demand due to raises in income as well as feedstock demand from the biofuel sector in some regions. In the case of soybeans, the demand from the livestock sector played a dominant role as well.

Global oilseed production increased by 49 % (average of 2016-18 to 2004-06), i.e., an average annual increase of 3.1 %, and reached 585 million tons (average of 2016-18). As in the case of cereals, consumption follows a smoother increase than production resulting in higher or lower levels than production which are balanced by varying stocks (Figure 32). Trade increased at a rate of 6.3 % per year and exports reached 172 million tons (average 2016-18), i.e., 29 % of total oilseed production, compared to 78 million tons (average of 2004-06), i.e., 20 % of total oilseed production. Compared to cereals, more oilseeds are traded and the market is internationally more interlinked. Additionally, oil and meal from crushing oilseeds are again intensively traded across borders.

Figure 32 Global oilseed markets overview, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

The oilseed market is dominated by soybean, rapeseed, and sunflower which together account for 470 million tons (average of 2016-18), i.e., more than 80 % of all oilseeds. All three oilseeds are crushed into oil and meal. In the vegetable oil market, they account for more than 50 % of total vegetable oil after palm oil with a share of 36 %. In the meal market, their share is 88 % (average of 2016-18). The three oilseeds are substitutes of each other on the production as well as on the consumption side. Other oilseeds or oil crops have larger differences in production systems, e.g., oil palm is a perennial crop located in tropical areas, or play only local or minor roles in the oilseed, meal or oil markets such as copra, cottonseed and groundnut.

Oilseed production grew faster than cereal production with increases in area as well as yields for the three main oilseeds (Table 4). Sunflower yield increased most, while soybean area was expanded the most. From 2004-06 to 2016-18, trade in soybeans has increased for the raw material while meal and oil trade intensity declined. This is predominantly due to the increase of Chinese soybean imports. China crushes them domestically and also consume the oil and meal domestically. For rapeseed, trade intensified for the raw product as well as oil and meal. The relatively small export shares of production should not be overinterpreted because rapeseed is a main oilseed in Europe but trade within the EU is excluded here. For sunflower, trade in the raw material is relatively low but has strongly increased for oil and meal as the main producers, i.e., Russia and Ukraine, increased production mainly to export their processed products.

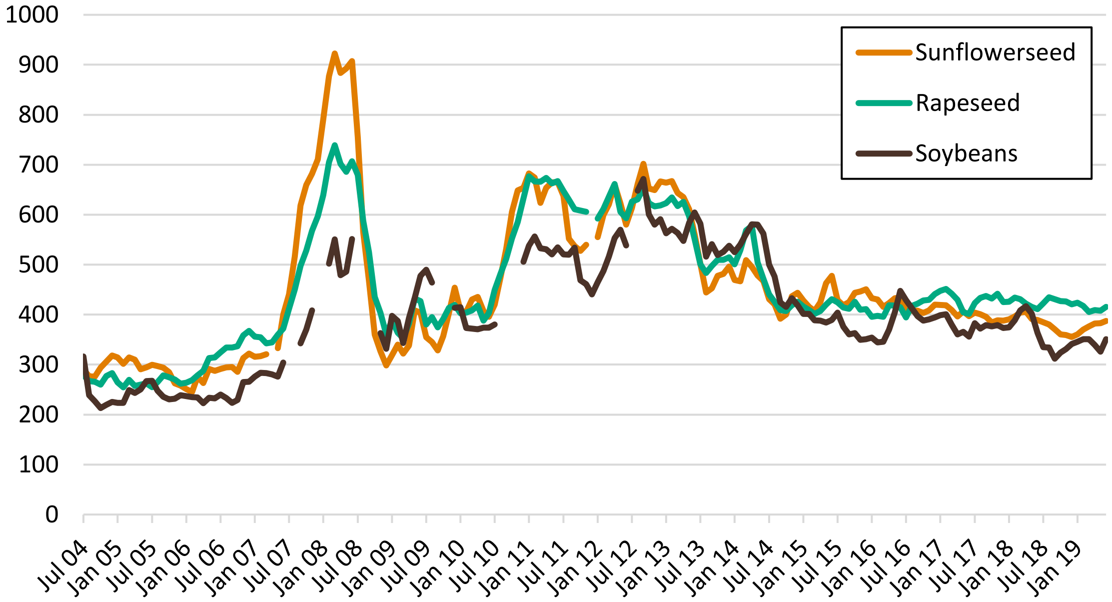
Table 4 Supply side developments of main oilseeds in annual growth rates (average 2004-06 to 2016-18) and export shares of production for main oilseeds and processed products for average 2004-06 and 2016-18, %

	Annual growth rates average 2004-06 to 2016-18			Export shares of production					
				2004-06			2016-18		
	Production	Yield	Area	raw	oil	meal	raw	oil	meal
Soybeans	3.8	1.5	2.3	30	28	36	43	20	28
Rapeseed	3.7	1.3	2.3	13	10	11	21	17	16
Sunflower	4.6	3.3	1.3	5	35	29	5	56	37

Notes: exports exclude intra-EU trade as the EU is reported as one entity
Source: own representation based on data from USDA (2020a)

Figure 33 shows the monthly development of export prices for sunflower, rapeseed and soybean, which roughly follow a similar development. Variations depend on the market situation in the respective market or the downstream oil or meal markets as elaborated below. Similar to cereals a price spike occurred in 2007 to 2008. Since July 2014, oilseed prices declined due to production surpassing consumption and the continuous build-up of stocks. The oilseed prices are not only dependent on each other but also on the development of meal and oil prices (see as an example in Figure 34).

Figure 33 Monthly representative export prices for sunflower seed, rapeseed, and soybeans, July 2004 to June 2019, USD/t fob



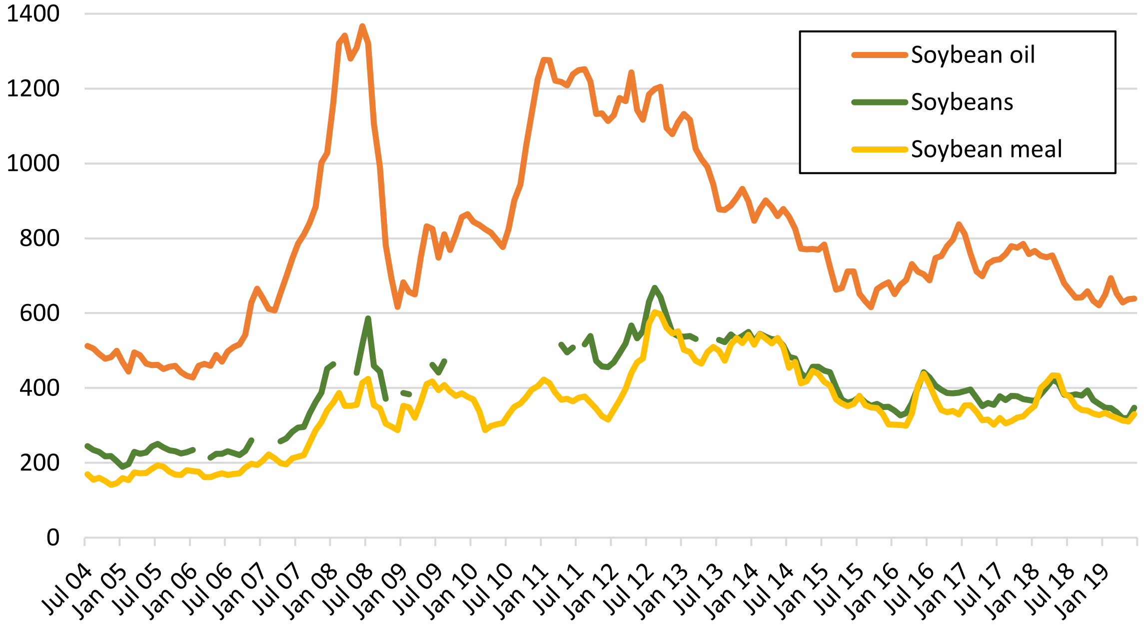
Note: Sunflower seed = sunflowerseed export price - EU (France) (Bordeaux), rapeseed = rapeseed export price - EU (France) (Moselle), soybeans = soyabeans export price - US 2Y (Gulf), missing data points = no trade in the respective month and port
Source: own representation based on data from IGC (2021)

In the following sections, the focus is laid on the presentation of soybean, rapeseed, and sunflower markets. The oil and meal markets are presented where appropriate as well because they strongly influence the oilseed market. As in the case of cereal markets, details of drivers are only briefly touched upon as they are analyzed in Section 2.1.

2.2.2.1 **Soybean market**

The soybean market has been growing strongly driven primarily by the increased demand for soybean meal as animal feed and less by the increased demand for soybean oil. This circumstance is also reflected in the development of prices for the respective products. For example, the differences between export prices of Argentinian soybeans and its downstream products have narrowed (Figure 34). The ratio of soybean meal price to soybeans has increased from 0.75 (average of 2004-06) to 0.92 (average of 2016-18), while the ratio of soybean oil to soybeans has decreased from 2.18 to 1.92.

Figure 34 Monthly representative export prices for Argentinian soybeans, soybean meal and soybean oil, July 2004 to June 2019, USD/t fob

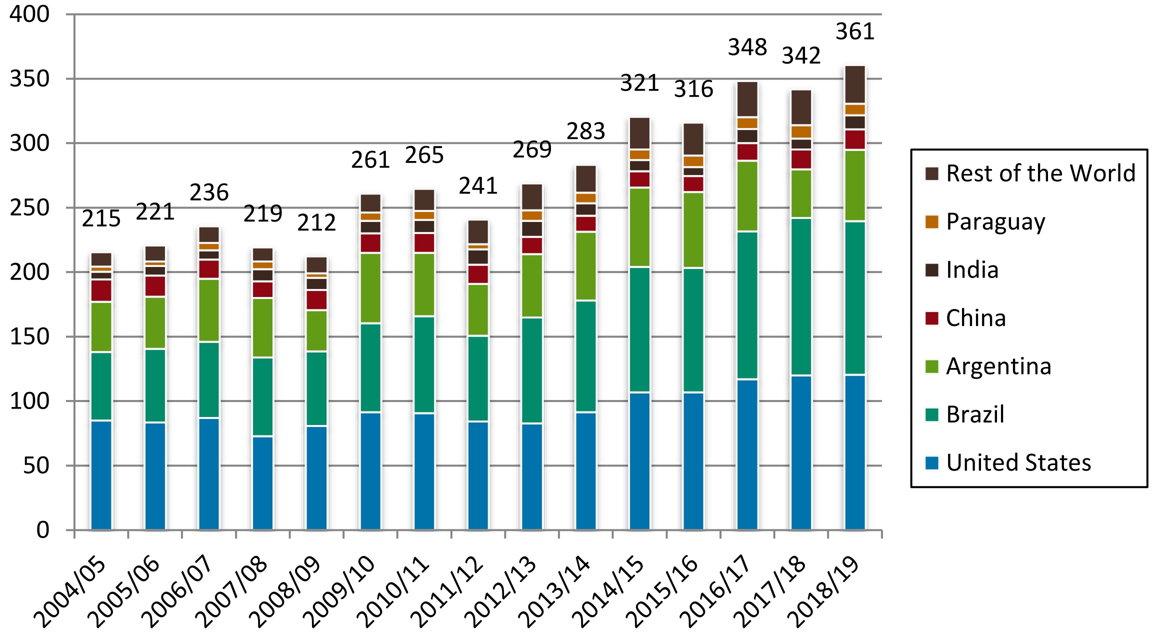


Note: Soybeans = soyabeans export price - Argentina (up river), soybean meal= soyameal export price - Argentina (up river), soybean oil= soyaoil export price - Argentina (up river) from IGC (2021), missing data points = no trade in the respective month and port

Source: own representation based on data from IGC (2021)

Soybean production grew as fast as corn production, i.e., at a rate of 3.8 % per year (average of 2016-18 to 2004-06), reaching 350 million tons (average of 2016-18). Figure 35 shows the six largest producers which account for more than 90 % of global soybean production in 2018/19. Of these, the US and Brazil each accounted for one third of the production (average of 2016-18). The production in Brazil grew with an annual average rate of 6.4 % and therefore, much stronger than the production of the US with an annual average rate of 2.8 %. Chinese production even declined in the same period.

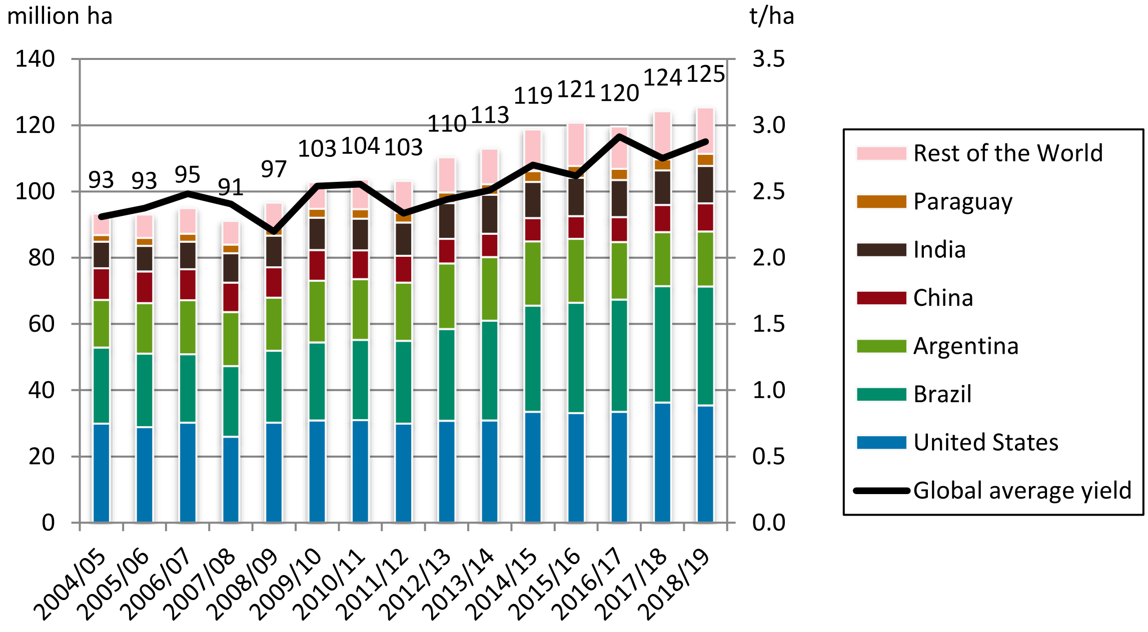
Figure 35 Global soybean production and major producing countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

The global production growth was realized through area expansion of 2.3 % per year and yield increase of 1.5 % per year (average of 2016-18 to 2004-06). Of the main producers, only China reduced area (Figure 36). In Brazil area harvested grew the most, i.e., at an average rate of 4 % per year, and resulted in 13 million hectares of additional soybean area (average of 2016-18 to 2004-06).

Figure 36 Global soybean area and major producing countries in million ha (left axis) and global average yield in t/ha (right axis), 2004/05 to 2018/19



Source: own representation based on data from USDA (2020a)

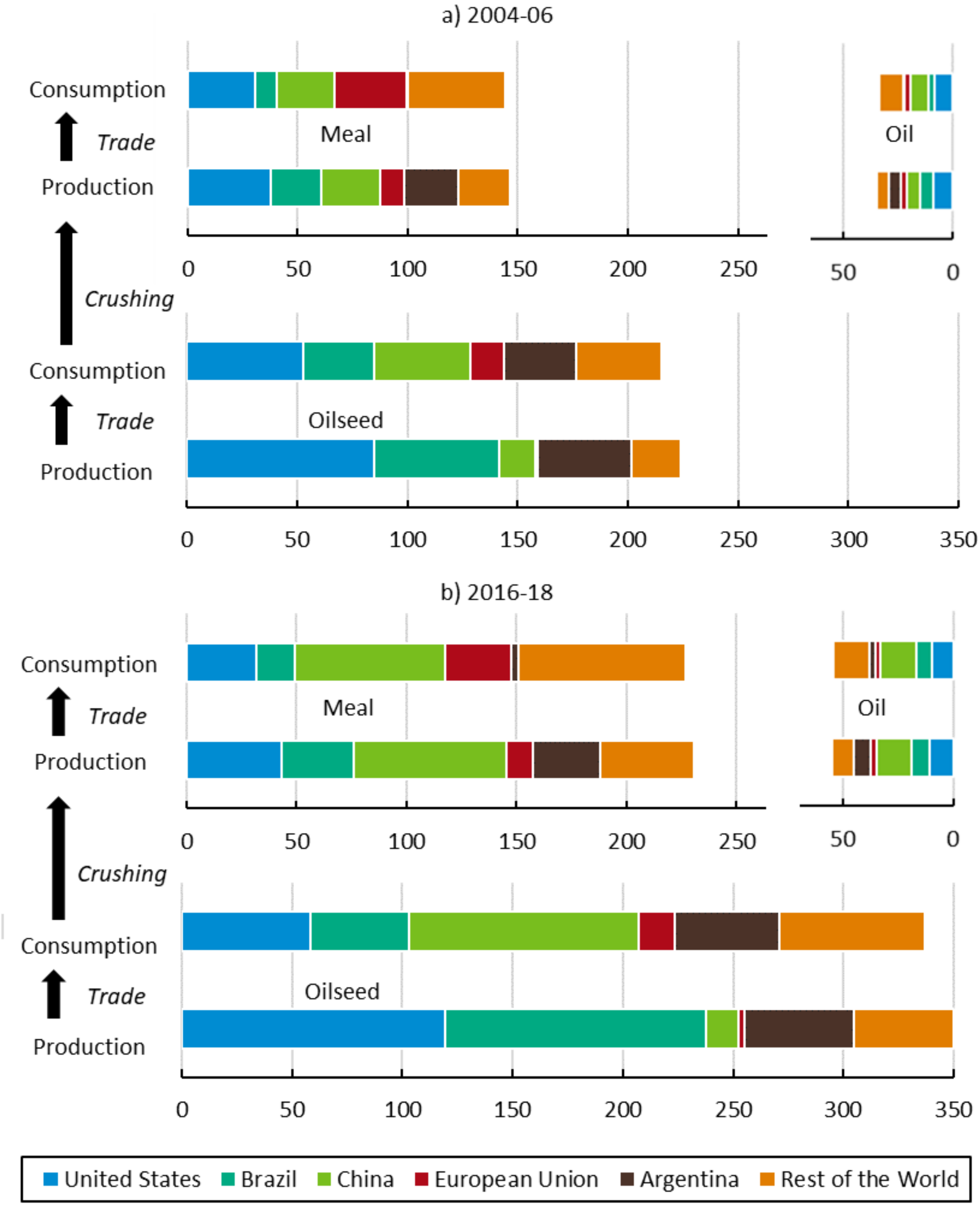
Global soybean yields reached 2.8 t/ha (average of 2016-18) (Figure 36), with highest average yields of 3.4 t/ha achieved in the US and Brazil. Strongest yield growths are observed in Brazil and Paraguay, i.e., 2.3 % and 2.9 % (annual average of 2016-18 to 2004-06), respectively, while yields grew in Argentina, China, and India around 0.5 % per year over the same period.

The largest consumers are the four largest producers plus the EU accounting for 80 % of total soybean consumption in 2018/19. Soybean is predominantly crushed with global average extraction rates of 0.19 for soybean oil and 0.79 soybean meal. The final consumption of oil and meal is not necessarily identical with the country where the oilseed is crushed as producers and consumers crush soybeans and trade oil and meal. Figure 37 illustrates the production and consumption levels for the average of 2004-06 and 2016-18. For example, the EU with a production of 2.5 million tons of soybeans ranks only 11th largest producer but they are the 3rd largest consumer of soybean meal with 30 million tons (average of 2016-18), while Argentina with 49 million tons is the 3rd largest producer of soybeans but only ranks 14th in the consumption of soybean meal with 3 million tons (average of 2016-18). Over time, China increased its soybean crushing and its accompanying meal and oil consumption the most and has been the largest consumer since 2006 for oil, 2007 for meal and 2008 for oilseeds surpassing the US.

Soybean meal is often preferred as animal feed compared to other protein feeds not only because of the price but also because of the protein quantity and quality. Over time, all regions increased the consumption of soybean meal except the EU. The EU reduced soybean meal consumption by nearly 9 % (average of 2016-18 to 2004-06) and partially substituted it with alternative protein feeds, e.g., rapeseed meal in the dairy sector. This development is supported by preferences within the EU to reduce genetically modified feedstuff in animal rations, especially observable in Germany, and to avoid the accusation of contributing to deforestation.

Soybean oil is dominantly used for food consumption but the use for biodiesel production has increased in recent years. In China and India, soybean oil is still used only for food consumption, while the other large consumers, i.e., the US, Brazil, Argentina, and the EU, started supporting biodiesel production and, hence, the use of soybean oil. For example, Argentina used 84 % of its soybean oil as biodiesel in 2016-18 but only 9 % in 2004-06 corresponding to an increase of 2.4 million tons.

Figure 37 Production and consumption of soybeans, soybean meal and soybean oil, average 2004-06 and 2016-18, million tons



Source: own representation based on data from USDA (2020a)

Soybean stocks have been growing since 2011/12 to 113 million tons in 2018/19 resulting in a stocks-to-use ratio of nearly 33 % and declining prices which, however, have stabilized since 2014/15. Stocks are mainly located in Brazil, Argentina, the US, and China. Soybean meal and oil stocks-to-use ratios are generally lower, i.e., ranging between 4.3 % to 11.4 % and the connection to price developments are less distinct.

Trade in soybeans has more than doubled (average of 2016-18 to 2004-06) corresponding to a growth rate of 7 % per year. Export shares of production have increased from 30 % (average of 2004-06) to 43 % (average of 2016-18). Brazil and the US are the main exporters together having a share of more than 80 % of all exports in 2018/19, while China and the EU are the main importers with a share of 57 % and 10 % of all imports in 2018/19, respectively. Brazils exports have grown the most, i.e., by nearly 10 % per year (average of

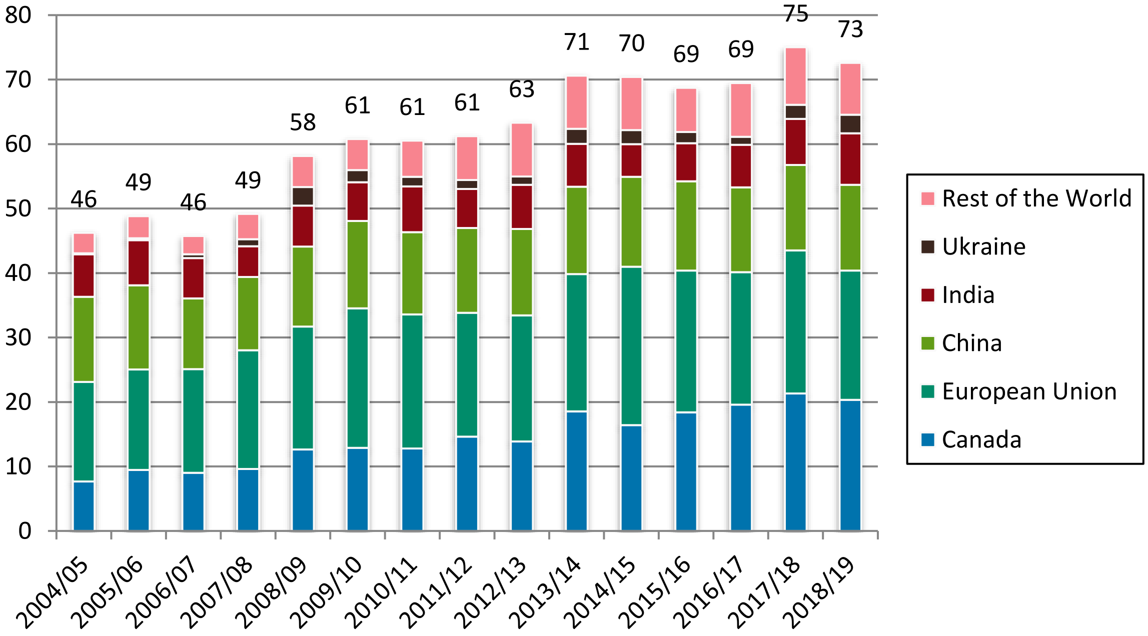
2016-18 to 2004-06), while the US exports increased by 6 %. Chinas soybean imports have grown by more than 10 % per year. This shows that international soybean markets are strongly concentrated. Trade in soybean meal is smaller and less dynamic and has grown only 1.7 % per year, resulting in declining export shares of production from 35 % to 28 %. Argentina is the largest meal exporter followed by Brazil and the US, while the EU is the largest importer followed by Vietnam and Indonesia. Trade in soybean oil is even less dynamic and the two largest exporters, i.e., Argentina and Brazil, have even reduced exports due to their local policies supporting biodiesel production. On the import side, China reduced soybean oil imports strongly. Hence, China ranked only 4th largest importer after India, Bangladesh, and Algeria which all strongly increased imports (average of 2016-18 to 2004-06).

Concluding, the soybean market has been growing strongly with Brazil and China showing the largest increases. Soybean production is concentrated in South and North America, while main consumers besides the US and Brazil are China and the EU. The EU demands primarily soybean meal, while China uses meal and oil.

2.2.2.2 **Rapeseed market**

The rapeseed market is the second largest oilseed market but its size is only a fifth of the size of the soybean market (average of 2016-18). Rapeseed production grew in relative terms nearly as fast as soybean production, i.e., at a rate of 3.7 % per year (average of 2016-18 to 2004-06), reaching 72 million tons (average of 2016-18). Nearly 90 % of rapeseed is grown in five countries in 2018/19 (Figure 38). Canada’s production has grown strongly, i.e., at a rate of 7.4 % per year (average of 2016-18 to 2004-06), while the EU’s, China’s and India’s production has stayed approximately constant since 2009/10. Ukraine’s production was negligible in 2004/05 but over the years it became the fifth largest producer of rapeseed.

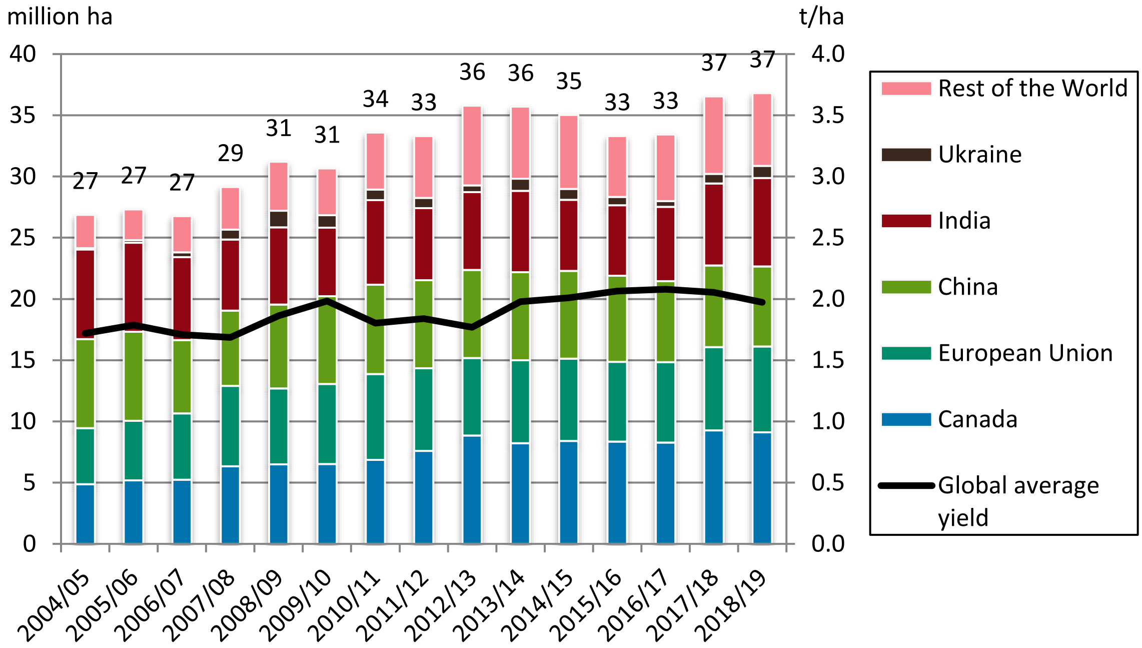
Figure 38 Global rapeseed production and major producing countries in million tons, 2004/05 to 2018/19



Source: own representation based on data from USDA (2020a)

Accompanied with production growth, area and yield grew respectively at 2.3 % and 1.3 % per year (average of 2016-18 to 2004-06). Of the large producers, China, and India slightly reduced area, while Canada and Ukraine expanded area strongly (Figure 39). Global yields increased from 1.7 t/ha (average of 2004-06) to 2 t/ha (average of 2016-18). As in the case of area, Canada and Ukraine increased yields the most, i.e., 2.5 % and 5.5 % per year (average of 2016-18 to 2004-06). In Canada, this increase was primarily due to new seed varieties, i.e., potential yields increased, while in Ukraine improvements in farming techniques and management contributed to the increase as well, i.e., the yield gap was reduced. Yields in the EU have stagnated but are the highest with 3.1 t/ha (average of 2016-18).

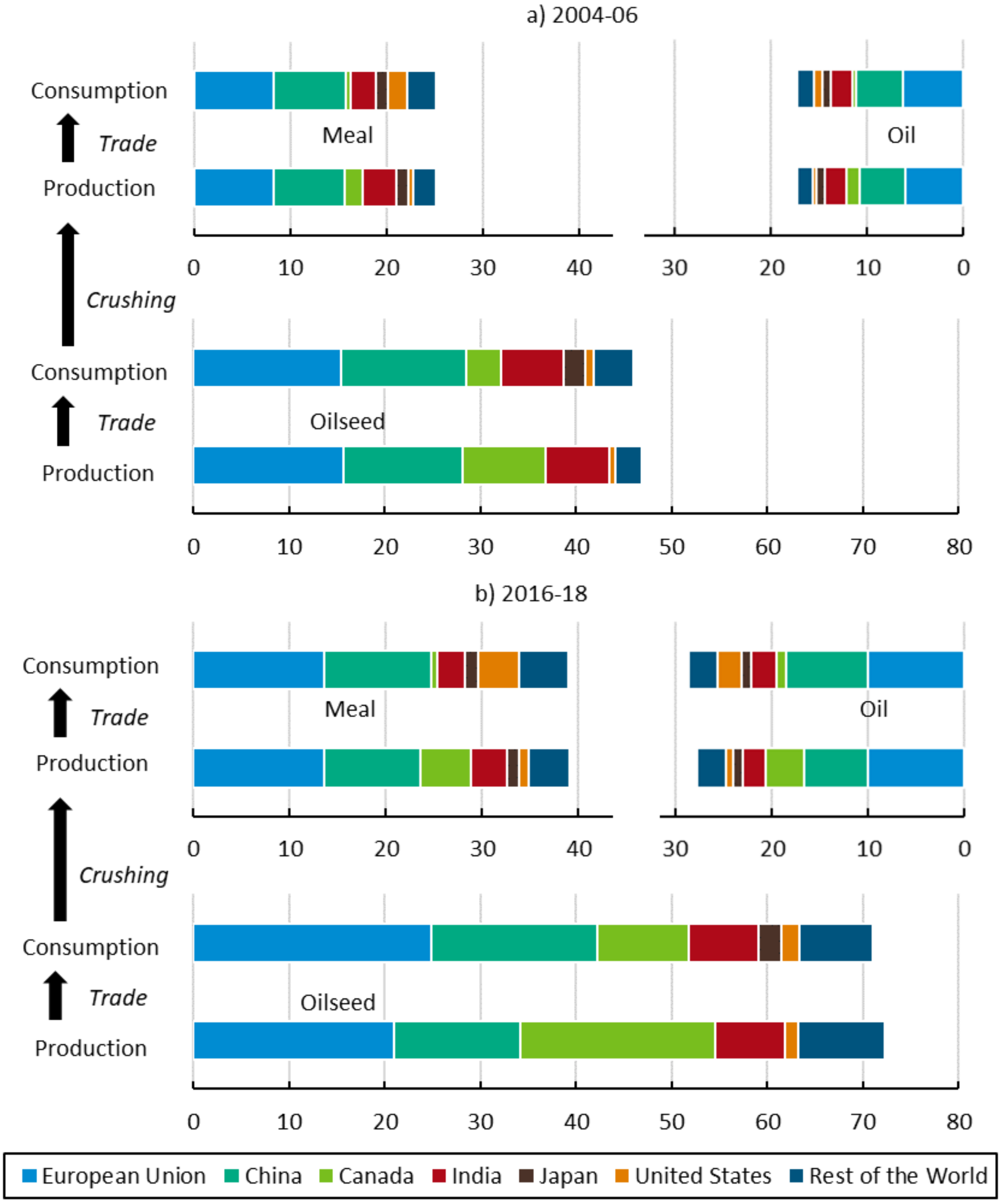
Figure 39 Global rapeseed area and major producing countries in million ha (left axis) and global average yield in t/ha (right axis), 2004/05 to 2018/19



Source: own representation based on data from USDA (2020a)

Approximately 95 % of rapeseed is crushed into meal and oil with global average extraction rates of 0.41 for oil and 0.58 for meal. Regional differences between rapeseed production and final consumption of meal and oil exist (Figure 40), but are less pronounced than for soybeans. The main consumers of rapeseed are the four largest producers plus Japan and the US accounting together for nearly 90 % of consumption in 2018/19. They are also the main oil and meal consumers except for Canada which only ranks 9th largest country in rapeseed meal consumption as it exports large amounts for dairy production to the US. Rapeseed oil is predominantly used as food. Due to its availability and promoted health properties, rapeseed oil became the main vegetable oil used as food in Canada, i.e., more than 60 % of vegetable oil food consumption is rapeseed oil, mostly replacing soybean oil. Additionally, biodiesel production has gained importance, especially in Canada and the EU, where currently 34 % and 70 % of rapeseed oil (average of 2016-18) is used for biodiesel production compared to 1 % and 60 % earlier (average of 2004-06), respectively. Contrary to Canadian developments, the demand for rapeseed meal has grown similarly to rapeseed oil in the EU by 4.2 % per year (average of 2016-18 to 2004-06). The availability and price competitiveness but also the trend of reducing genetically modified soybean meal in feed rations have supported this development.

Figure 40 Production and consumption of rapeseed, rapeseed meal and rapeseed oil, average 2004-06 and 2016-18, million tons



Source: own representation based on data from USDA (2020a)

Trade in rapeseed more than doubled (average of 2016-18 to 2004-06) corresponding to a growth rate of 6.6 % per year. Export shares of production have increased from 13 % (average of 2004-06) to 21 % (average of 2016-18). Trade in rapeseed meal and oil increased even more in relative terms, i.e., at rates of 7.4 % and 9.1 % per year (average of 2016-18 to 2004-06), reaching export shares of production of 16 % and 17 %, respectively.

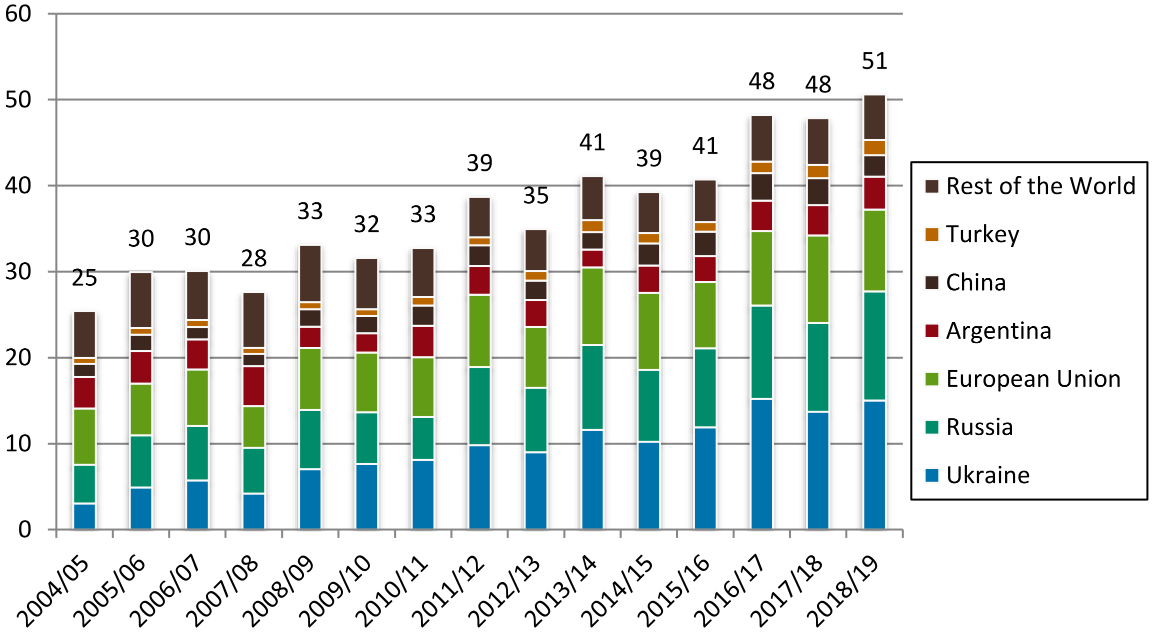
In the EU, demand for meal and oil has increased more than production over time resulting in increased imports of rapeseed which is crushed in the EU for own consumption of meal and oil. Chinese demand also increased more than their own production resulting in increased imports of rapeseed, meal, and oil. In 2018/19, China was the 2nd largest importer of rapeseed after the EU and the 2nd largest importer of meal and oil after the US. Canada produces rapeseed to a large extent for direct exports but also exports oil and meal and is the largest exporter in all three markets. While main oilseed exports from Canada went to China, Japan, and Mexico, meal and oil was shipped mostly to the US in the observed period (FAO, 2020d). Ukraine and Australia are the 2nd and 3rd largest rapeseed exporters after Canada and export respectively 90 % and 66 % of their production (average 2016-18). The 3rd and 4th largest importer of oilseeds, namely Japan and Mexico, import all the rapeseed they consume.

Concluding, the EU and China play important roles in the rapeseed market as main producers, consumers, and importers. Canada increased its production strongly over time and is the largest exporter in rapeseed, rapeseed meal and oil markets.

2.2.2.3 **Sunflower seed market**

The sunflower seed market is the 3rd largest oilseed market with 49 million tons of production (average of 2016-18). Production has been growing at a rate of 4.6 % per year, i.e., more than soybean and rapeseed production. The largest six producers account for 90 % of all production in 2018/19 (Figure 41). Of these Ukraine increased production the strongest, i.e. more than 10 % per year (average of 2016-18 to 2004-06), while Argentinian production stayed constant.

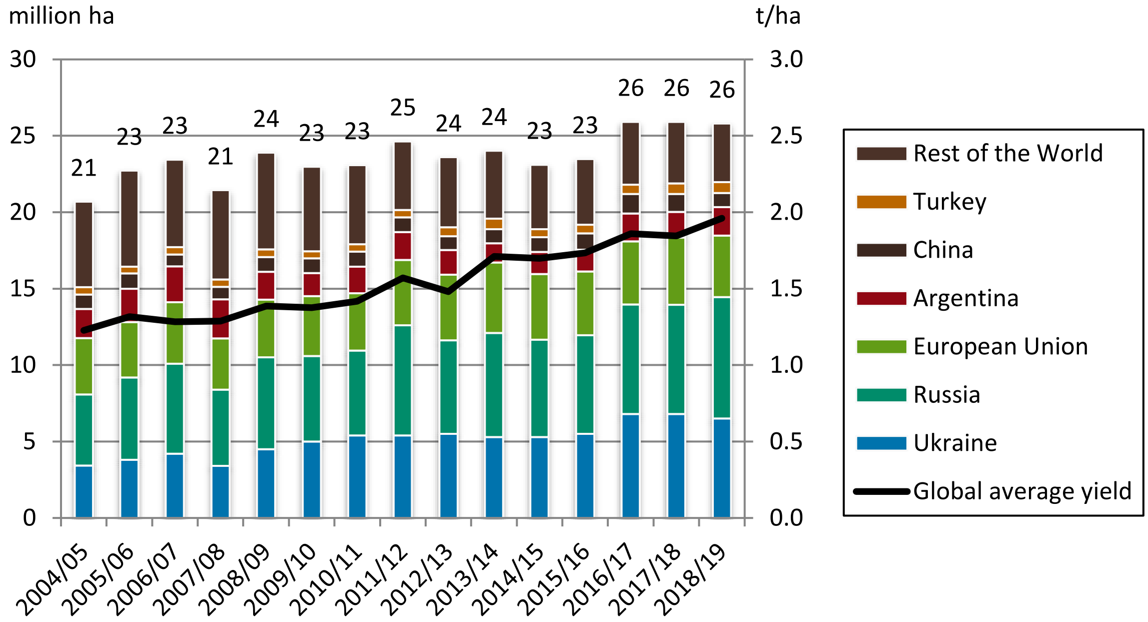
Figure 41 Global sunflower seed production and major producing countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

Growth in production was primarily due to increases in yield and only slight increases in area of 1.3 % per year (average of 2016-18 to 2004-06). As depicted in Figure 42, Ukraine and Russia increased area the most. Globally, yields grew at a remarkable rate of 3.3 % per year and reached 2 t/ha in 2018/19. In Ukraine, yields grew the most with a rate of 5.3 % per year reaching 2.2 t/ha (average of 2016-18). Even in the EU, which had slow yield growth in other crops, yields grew by 2.4 % per year and reached 2.3 t/ha (average of 2016-18).

Figure 42 Global sunflower seed area and major producing countries in million ha (left axis) and global average yield in t/ha (right axis), 2004/05 to 2018/19



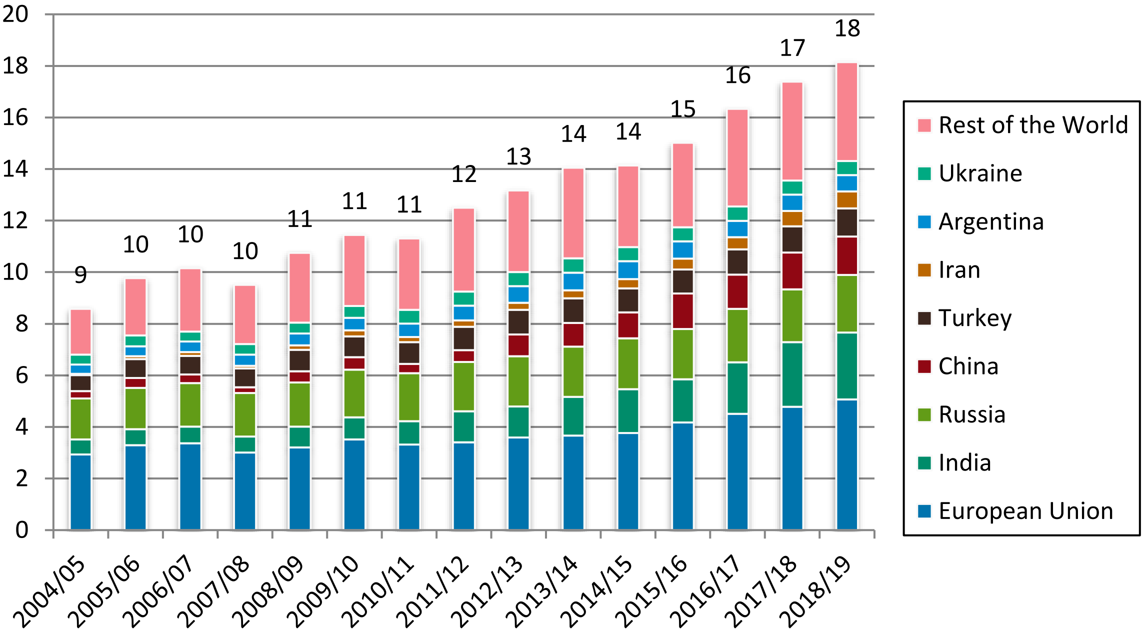
Source: own representation based on data from USDA (2020a)

Sunflower seeds are primarily grown to produce oil, i.e., around 90 % is crushed. Contrary to soybeans and rapeseed, sunflower seed is crushed predominantly in the country of production with global average extraction rates of 0.42 for sunflower oil and 0.45 for sunflower meal. Only 5 % of sunflower seed production was traded and this has remained relatively constant from 2004/05 to 2018/19.

Sunflower oil consumption was less concentrated than production, still the eight largest consumers accounted for 80 % of total consumption in 2018/19 (Figure 43). Consumption increased in all countries with India, China, and Iran increasing the most in relative terms over the observed period. Sunflower oil was used predominantly as food and only 5 % was industrial use (average of 2016-18), e.g., for soap production in Russia and for biodiesel in the EU.

Consumption of sunflower meal, a by-product of oil processing, is also consumed globally but generally traded over less distances. Sunflower meal contains less protein and more fiber than rapeseed or soybean meal and, hence, is not preferably used as feed for all livestock. The six main consumers of sunflower meal are the EU, Russia, Turkey, China, Ukraine, and Belarus and account for 85 % of total consumption. They all more than doubled consumption of sunflower meal except the EU which increased consumption by 72 % (average of 2016-18 to 2004-06).

Figure 43 Global sunflower oil consumption and major consuming countries, 2004/05 to 2018/19, million tons



Source: own representation based on data from USDA (2020a)

As a consequence, trade in sunflower oil and meal was considerable and strongly increased over time. Sunflower oil exports had a share of production of 34 % (average of 2004-06) which increased to 56 % (average of 2016-18), i.e., an increase in exports of 7 million tons. Sunflower meal export shares of production were lower and reached 37 % (average of 2016-18) corresponding to an increase in exports of 4.2 million tons (average of 2016-18 to 2004-06). This growth is attributed primarily to Ukraine followed by Russia which both strongly increased exports. Ukraine exported 93 % and 78 % of its produced sunflower oil and meal (average of 2016-18), respectively. Argentina, as the 3rd largest exporter in both markets, decreased exports in the observed period. The three countries together account for 86 % of all sunflower oil exports and 91 % of all sunflower meal exports in 2018/19 showing how concentrated these export markets are.

The five largest importers of sunflower oil, namely India, the EU, China, Iran, and Turkey, accounted for 70 % of all imports in 2018/19. While India and Iran import nearly all their consumed sunflower oil, the other countries are large sunflower seed producers as well, despite their net importing position. In the case of sunflower meal, the EU is the largest importer accounting for more than 50 % of all imports in the observed period except in 2018/19 where China imported 1.3 million tons compared to only 0.2 million tons a year before. This change can be attributed to the trade war between US and China, where China imposed additional tariffs on soybeans and, hence, had to import a larger amount of alternative meals as less soybean meal was produced domestically. For the meal market in China, these additional imports are minor, however for the small sunflower meal market, these changes are significant.

The sunflower market has shown remarkable growth rates over the observed period. It is dominated by Ukraine and Russia. Contrary to soybeans and rapeseed, sunflower seeds are mostly crushed in the country of production and trade in oil and meal is larger.

2.2.3 Conclusion and implication for this dissertation

This section has described the historical development of cereal and oilseed markets. Thereby, the development of increased population as well as increases in income levels are the main underlying drivers of increases in consumption. Especially the income growth and further shift towards a more meat-based diet in China contributed to corn and soybean expansions. Further, the emergence of the biofuel industry in several regions contributed to additional demand. The production side had no problems in keeping up with demand in the long-run as prices only slightly increased. Yields increased for all crops similar to their long-term trend and oilseed area expanded strongly, while area for cereals has only slightly increased.

The global aggregated figures for cereal and oilseed markets depict a smooth increasing development. However, regional changes dominate the market. While in some regions production declined, other regions have increased production strongly. This changed the structure of world markets. Often, a specific cereal and oilseed dominates production within a country. Still, the same countries often play major roles as producers, consumers, or traders in several markets.

The US and the EU are large crop producers with generally high yields and low area expansions. In some of their key export markets, they have lost shares to countries such as Brazil, Ukraine, and Russia which increased exports strongly over the observed period due to larger production growth. Argentina, another large exporter of several crops depends strongly on demand from the world market and has not extended exports to a large amount or even reduced them. Brazil strongly focuses on the production of corn and soybean and has become an important country on export markets besides the US. China is a large player in agricultural markets as well. While aiming for self-sufficiency in several cereal markets, it has become a main importer of barley and oilseeds to primarily satisfy its demand for feed.

Ukraine and Russia are two countries showing very strong production and export increases in nearly all markets over the observed period. It is worth to comprehensively investigate this development to understand why this development occurred and also how this development might continue or change in the future. Hence, Case Study 1 to 3 elaborate this in more detail and focus on possible future developments in those two countries.

2.3 Current and future challenges for cereal and oilseed markets

The Sections 2.1 and 2.2 have presented historical developments of cereal and oilseed markets as well as the various factors having affected them. This section evaluates current and future challenges for cereal and oilseed markets based on changes in the various factors. In the short-term, i.e., concerning the following marketing year, cereal and oilseed markets will be dominated a) by expected production levels which regularly change due to weather events and forecast, b) by likely changes in trade patterns due to changes in production, exchange rate, and policies, c) by short-term shifts in demand due to changing price relationships, and d) by the overall resulting stock levels. As a result of these short-term factors, prices vary more or less within a marketing year and from day to day. However, this dissertation – while aware of the short-term factors – focuses on long-term developments of cereal and oilseed markets. Here, long-term is defined as projections until

2030 as uncertainties increase with every timestep. For example, most policies end or are subject to change before 2030.

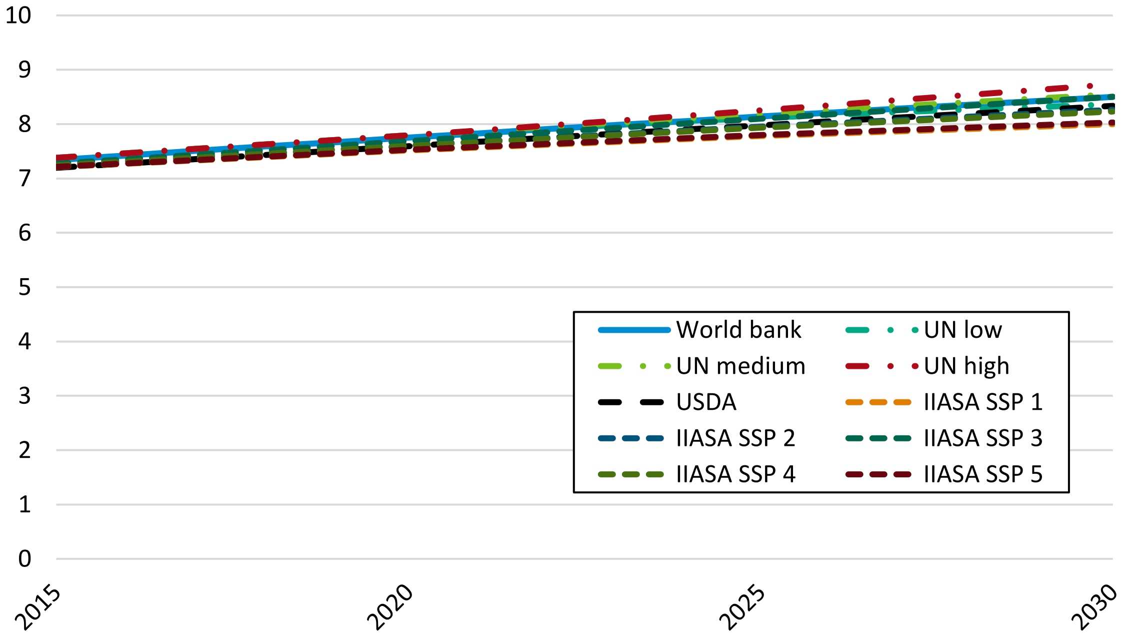
Cereal and oilseed markets have changed considerably in the time span from 2004 to 2018 with shifts between products and regions. However, the general development, i.e., growth, persisted. To analyze the future development of cereal and oilseed markets, the most important drivers, their development and the relationship to cereal and oilseed markets need to be considered. This chapter elaborates on possible future developments and uncertainties of factors and their influence on cereal and oilseed markets focusing on the 'important persistent long-term underlying factors' and the 'strong market-interfering factors' (compare Table 1, page 9).

2.3.1 Long-term drivers and future challenges

Population and income growth will remain dominant factors on the demand side and increase the demand for cereals and oilseeds. However, there is some evidence that this growth will slow down as population growth rates are further declining and income levels are so high that saturation levels of food or food subgroups are reached in several parts of the globe, while income in low-income countries is not catching up.

Estimates for population development are published on national and global levels. Several global institutions project population growth under a variety of assumptions, e.g., the International Institute for Applied Systems Analysis (IIASA), the United Nations (UN), the USDA, and the World Bank. These assumptions include, e.g., fertility rates and life expectancy. Figure 44 demonstrates the differences in projections between the institutions and their scenarios. It also shows how uncertainty increases with the number of projection years. Differences for population projections as shown in Figure 44 differ by as much as 9 % in 2030.

Figure 44 Global population projections from various institutes under different assumptions for 2015 to 2030, billion persons



Source: own representation based on data from UN (2019b), World Bank (2021b), IIASA (2018), USDA (2021c)

Currently, the projections for a middle of the road scenario assume a growing population but with slower growth rates than observed in the past and a decline in absolute growth per year. For example, the current medium variant of the UN, the longest existing projections, projects an average increase of annually 75 million persons from 2020 to 2030 corresponding to an average annual growth rate of 0.9 % (UN, 2019b). This is less than the 83 million additional persons per year from 2010 to 2020. Over time, these projections have been adjusted upwards and downwards, e.g., the medium variant of the UN projected a population for 2030 of 8.7 billion in 1994, 8.2 billion in 2004 and 8.5 billion in 2019 (UN, 2019a). Besides the total increase, regional differences in population growth are important too as the amount of cereals and oilseeds consumed varies strongly between the regions. For example, the medium variant of the UN projects the largest population growth in Africa and Asia and slight declines in Europe until 2030 (UN, 2019b).

Similar to population, projections for income, approximated by GDP, exist from several institutions, e.g., IMF (2020), USDA (2021c), and IIASA (2018). Global annual percentage growth rates of GDP declined in the past and are projected to decline in the future, i.e., incomes are growing but at slower rates. GDP projections cannot foresee economic crises such as the current Covid crisis and, hence, must be considered with more caution than population projections. In general, trends as observed in the past are projected for the future depending on different assumptions and varying between regions.

In several countries, per capita food consumption might not grow further as saturation levels of food or food subgroups are reached, e.g., cereals in many countries around the world, vegetable oil in several middle- and high-income countries and meat in several high-income countries (OECD and FAO, 2020b). Potential growth in food demand due to rising income levels are most likely in low-income countries, however, their income is projected to increase only slightly. Global meat demand will continue to increase but probably at a slower pace as historical trends show. The main reason is that growth of meat demand in China might slow down compared to the strong growth observed historically.

On the supply side, even more uncertainty exists. Growth of cereal and oilseed production is supported, if prices increase due to higher demand, and is realized by yield increases and expansion of area.

As yields depend on many factors, future developments of crop yields are highly uncertain. Due to new evolving technologies, e.g., precision farming, genome editing, and remote sensing, potential yields will increase in the future. However, recent research is not only targeted towards increasing yields but towards sustainable intensification, i.e., increase production with minimizing negative environmental impacts and even achieving positive environmental impacts (Pretty and Bharucha, 2014; Cassman and Grassini, 2020). Examples are sustainable resource management, e.g., reduced soil erosion, increased efficiency, e.g., reduced leakage of applied fertilizer, and stability, e.g., breeding more drought resistant varieties. Additionally, digitalization and big data increase transparency and effectiveness in markets. Yield growth as a measure of productivity gain omits these developments. This might slow yield growth down even though productivity continues to expand.

Furthermore, realized yields in many countries are not as high as economically feasible and even further away from bio-physically possible yields (van Ittersum *et al.*, 2013). Hence, the potential to increase realized yields through closing the yield gap are high especially in extensive production systems (Mueller and Binder, 2015). Depending on the region, an impact of increased yields due to intensification and technology adaptation, has effects on global cereal and oilseed markets.

Theoretically there is room for additional cropland expansion as potential useable area is ample (Prestele *et al.*, 2016). However, more cropland means less land for other land uses such as grassland, forests, and other natural vegetation. There are different reasons why this land is not used for agricultural production. First, it is not profitable to farm the land under the current economic situation. For example, large amounts of formerly farmed land lies idle in Russia (Schepaschenko *et al.*, 2015). Second, the land is already used for other purposes and involved costs prevent the conversion. Third, the land is conserved at its current state and, hence, conversion to agricultural land is restricted through policy intervention. For the use of land for cereal and oilseed production, two opposing developments are imaginable: expansion due to higher demand and restrictive expansion due to land conservation policies.

Policies will remain a key factor in shaping agricultural markets. While direct domestic support for agriculture is becoming less market distorting, trade, climate change, and environmental policies gain importance and directly affect agricultural markets. Trade policies go in two different directions. First, more bilateral trade agreements are negotiated and implemented around the world. Second, trade barriers are renewed between different regions not only because of protecting the specific market but also because of general disputes between countries.

In the case of biofuel policies, many countries have not achieved their originally set targets and revised their policies for the future, e.g., the EU and India, while other counties have introduced or increased their targets, e.g., Brazil and Indonesia. Because of the food vs. fuel as well as the indirect land use change debate, several countries limit or restrict the use of crop-based biofuels for the future including biofuels from cereals and oilseeds. However, these set limits or restrictions for the future are not below the current levels of use and even leave room for further expansion. Additionally, biofuel demand depends on overall transport fuel consumption as countries have often implemented blending targets in form of a biofuel share of transport fuel consumption. Globally, transport fuel consumption has been growing and is projected do so in the future (IEA, 2019). Consequently, biofuel demand from cereals and oilseeds will still be increasing in the future.

Other climate change policies, e.g., carbon taxes, are unlikely to be introduced for agriculture as a whole due to negative effects on food security. For example, Hasegawa *et al.* (2018) concluded from their modelling efforts that a global economic wide carbon tax would increase food prices more than climate change itself.

Environmental restrictions are more local and affect specific local production systems only. However, these environmental policies applied on a larger scale might also influence global cereal and oilseed markets. For example, the European Commission has set ambitious targets in the name of sustainability and environmental protection in their Farm to Fork Strategy, i.e., the reduction of crop protection and fertilizer use as well as the increase of organic farming, which requires strong changes in the European agricultural production systems should they be realized until 2030. A first modelling exercise points to reductions in production and price increases for agricultural products in the EU (Barreiro-Hurle *et al.*, 2021). Additionally, increased production in other parts of the world would partly offset the environmental achievements in the EU (Barreiro-Hurle *et al.*, 2021).

2.3.2 Other factors and relationship

The previous factors will certainly influence cereal and oilseed markets, while the factors presented here have the potential to change global agricultural markets if they will deviate from their long-term trend which is, however, less likely than for the factors above, given the time period until 2030. Additionally, changes in these factors are gradual, slow or very uncertain. Furthermore, their impact on cereal and oilseed markets is often partially included in other indicators, e.g., GDP or yield development, and often smaller than their impact on other agricultural markets. These factors are additional resource constraints such as water and nutrients, climate change, and reducing food losses on the supply side as well changes in food waste, diets, preferences, and upstream sectors on the demand side.

The availability of fertilizers and water restricts agricultural production. A physical shortage of nutrients to produce fertilizers will not occur for many more decades. Reserves of natural gas, phosphate, and potash are estimated to last for at least 55, 90, and 235 years, respectively (Fixen and Johnston, 2012). Consequently, fertilizer use in cereal and oilseed production will not be restricted by resource constraints but, as is currently the case, by economic and technical constraints, i.e., the ability to buy and apply fertilizers. Also, the impact of water shortages on cereal and oilseed markets will stay limited as most cereals and oilseeds are produced in rain-fed systems and are less water intensive than other agricultural products. A substantial expansion of irrigated cereal and oilseed production in the future seems unlikely given high installation costs, depleting water reserves, and associated environmental problems.

Climate change will only have a limited impact on cereal and oilseed markets for the coming years, as effects of climate change on yields will stay limited until 2030 (IPCC, 2014b). However, after 2030 negative impacts on yields will dominate and increase with rising temperatures (IPCC, 2014b).

The reduction of food loss and waste is a clear future goal. However, the potential of providing more food might be hugely overstated as there will always be non-avoidable losses and the reduction induces costs. Further, food loss and waste in the cereal and especially the oilseed sector are lower than in other agricultural sectors, e.g., fruits and vegetables (FAO, 2011).

New trends in diets are imaginable such as a reduction of meat products in developed countries where the meat intake lies far above recommended level for a healthy and sustainable diet (Willett *et al.*, 2019). Such a shift would result in less demand for cereals as the reduction in feed use is larger than the increase in food use as simulated by several studies (Geibel, Freund and Banse, 2021). However, these are very hypothetical scenarios which might not occur without active policy intervention or might happen slower than simulated. Changes in diets and preferences are typically slow and happen more in generations than in years. Hence, even though large impacts can be expected on cereal and oilseed markets, they might occur gradually and over a very long time.

For the coming years, livestock feed demand from cereals and oilseeds will grow further as livestock production grows. Several studies analyze and promote livestock feed from non-edible sources and by-products only (Röös *et al.*, 2016; J.M. Wilkinson, 2011; Schader *et al.*, 2015). This would restrict the direct use of cereals in feed rations. However, such a change, while possible on a small scale, is not envisaged to be realized on a larger scale until 2030 and has internal boundaries, e.g., the amount available from non-edible sources and by-products.

Demands from non-food, non-feed and non-energy industries might change in the future especially in countries promoting a bio-based economy, e.g., the EU (European Commission, 2018). Here, cereals and oilseeds might serve as feedstock to produce new sustainable, carbon-neutral products if food security is ensured, the environment protected, and climate change managed. Given these preconditions, an expansion of the use of cereals and oilseeds seems to have many obstacles and is not likely to be achieved in the near future.

2.4 Conclusion

Global agricultural production has been growing in the long-term driven mainly by population and income growth on the demand side and by productivity increases and intensification on the supply side. Thereby, productivity gains outpaced demand growth. Hence, agricultural real prices show a declining trend over time. Focusing on more recent developments, this general trend could be questioned, especially due to the price spike in 2007/08. Multiple factors have been identified and classified which influence agricultural markets and specifically cereal and oilseed markets.

While these factors are not always global, they can have impacts on global markets. In the case of cereal and oilseed markets, Westhoff and Thompson (2017) name four dominating drivers for recent developments: population growth, Chinese demand, biofuel demand and yield growth. These are confirmed in the dissertation. Additionally, several policies are identified as having a strong impact on cereal and oilseed markets. These are domestic agricultural, trade, and climate change mitigation policies. Their effect and impact on cereal and oilseed markets depend to a large extent on their specification and implementation, can be on local and global scale and of short- and long-term time frame.

In most cases, a specific market development is not the result of a single factor but an interaction of many factors. Further, annual fluctuations in the markets are predominately caused by short-term factors. An increase in food and feed demand due to population and income growth as well as productivity growth is quite certain for future long-term developments but the magnitude is surrounded by uncertainty. Population growth is slowing down, saturation levels for some food subgroups, especially cereals, are reached across the globe, yield growth is slowing down in some regions, land conversion to crop production is seen as critical, and tendencies for more extensification instead of intensification exist in some major intensively producing regions.

Contrary to this developments, new forms of demand such as biofuels have emerged in recent years, demand for meat is still growing, new technical developments contribute to increased agricultural productivity and crop area is expanding. Other developments and factors add to these developments but are even less certain and might themselves even go in different directions. If supply is not keeping up with demand, prices will increase and negatively affect consumers, especially the poor. However, increased prices support productivity gains as they are an incentive for producers to produce more. Hence, future demand will be met by future supply, it is just a question of price levels.

While the result of market developments is the interplay of all factors, it is important to quantify effects of single factors to analyze possible future changes in a specific factor. The aim of this dissertation is to show possible developments of cereal and oilseed markets given different assumptions on the development of important long-term factors. The analysis of all factors and their multiple imaginable developments would not lead to interpretable results nor informative conclusions. Hence, four factors are selected to be analyzed in more detail: yield growth due closing yield gaps to (1), trade policies (2), land use (3), and biofuel demand (4). They are likely to change in the future compared to their long-term trends and to be of high importance for future developments of cereal and oilseed markets.

First, yield gaps exist with an actual yield being lower than the 'maximal economic feasible yield'. Technology adaptation and intensification levels close this yield gap. Several regions have larger yield gaps than others. In many of these regions, a closing of the yield gap might not be achieved simply due to the unfavorable institutional environment. Other regions have shown their potential to reduce yield gaps and expand production such as Russia and Ukraine. As these two countries have become large producers and exporters of cereals and oilseeds, their development impacts global markets. The institutional environment in both countries allows to imagine closing in yield gaps further if it continues to improve with respect to the agricultural sector. Hence, yields might increase faster compared to their long-term trend.

Second, trade policies have been liberalized in recent years including the agricultural sector. However, tendencies towards protecting their own country's production sector or using trade policies in general conflicts have recently increased. Therefore, different likely developments from open markets to closed unions are imaginable. Again, an example where both developments are likely is Russia and Ukraine. As their increased production of cereals and oilseeds is mainly targeted towards exports, their attitude and relationship towards main trading partners is of high importance globally.

Third, land use is multifunctional and limited. On the global scale, agricultural area expansion is only possible by losing other valuable services provided by the land, e.g., saving GHG emissions and contributing to biodiversity. Nevertheless, there is still room for expansion on a global scale from a bio-physical perspective. For example, potential to expand agricultural area is imaginable as formerly farmed land currently lies idle in Russia and Ukraine. From an economic perspective, more land might be used for agricultural production if prices increase and land conversion is cheaper than yield growth through intensification. Further, crop land expansion, as observed in the past, comes at a higher price in the future as values of other land uses are increasing. Hence, area expansions due to economic pressure and actively restricting area expansion are two imaginable likely future developments.

Fourth, growth in biofuel production from cereals and oilseeds have changed the markets especially in main producing regions. Additional regions have implemented or pronounced ambitious biofuel aims and targets. Hence, demand will grow further. However, the proclaimed targets have often not been met and are subject to adjustments. Further, some regions limit the use of cereals and oilseeds as a feedstock in biofuel production. So, growth in biofuel production based on cereals and oilseeds might range from being moderate to high in the coming years.

These four factors are analyzed in detailed case studies in Chapter 4. The factors of closing yield gaps and changing trade policies are explored in detail with Russia and Ukraine as study region. The factors of restricting land use and expanding biofuel production are analyzed on a global scale. These case studies analyze possible options and quantify their impact on cereal and oilseed markets with a focus on the maximal expected impact. Hence, they also show the limited impact these factors have compared to other included factors.

To analyze possible future developments of cereal and oilseed markets given different developments of certain long-term factors requires specifying a clear relationship between the development of the different factors and their impact on cereal and oilseed markets. Further, the other underlying main long-term factors, even though they are not specifically subject of the analysis, need to be included. Therefore, dynamic scenarios need to be constructed which include important factors and vary in the factors to be analyzed. This allows isolating the effects of the analyzed factors on cereal and oilseed markets. Different large-scale economic equilibrium models have been developed for scenario analysis by approximating and quantifying some of the required relationships. Other models from various disciplines approximate and quantify specific aspects in greater detail such as yield developments and land use. In linking these models, the selected factors can be analyzed. The linkage of the models as developed in this dissertation and applied in the case studies is presented in the next chapter.

3 Methods to link large scale economic and other models

The previous chapter presented fundamental factors and the historical development of cereal and oilseed markets. This is the basis for analyzing the question on how cereal and oilseed markets can develop in the long-term. For an ex-ante policy analysis of cereal and oilseed markets, the most important long-term factors and their impact on cereal and oilseed markets need to be brought together. Furthermore, they need to be considered simultaneously with the factors to be analyzed.

Market stakeholders and experts analyzing the markets often incorporate these factors but focus on short-term factors as these influence the short-term developments of the market, i.e., the coming harvest, to a larger extent. They are often biased towards the most recent developments and towards the production side. Hence, they possibly overstate specific relationships such as environmental restrictions causing yield reductions or current infrastructure prohibiting future growth.

Dynamic economic multi-market multi-commodity equilibrium models based on economic theory have been developed for long-term analysis. They include the most important long-term underlying factors and have a specific focus, e.g., on trade policies, sector dependencies, or market specific domestic policies. Short-term factors are assumed to take average conditions over the projection period as their specific volatile development between the years cannot be projected. For example, the models assume average weather conditions and, hence, average production levels are an outcome, i.e., neither record harvests nor disastrous harvests are part of the projections. With these economic models, scenarios are constructed to project different possible pathways depending on assumed varying developments of factors to be analyzed.

Baselines or business-as-usual scenarios assume current trends to continue and incorporate implemented policies. The most prominent global baseline is the Agricultural Outlook published annually by the FAO and OECD (OECD and FAO, 2020b). Based on a baseline, various scenarios can be set up to single out the effect of changing the development of one or more factors on agricultural markets. The models are simplifications and abstractions of reality and, hence, include only selected factors and relationships of markets. A balance between data availability, accuracy, and handling need to be found. The four selected factors analyzed in the dissertation (Section 2.4) are often not all included or only slightly represented in existing models. To omit this shortcoming, three options exist to analyze the selected factors: a) built a new multi-market multi-commodity equilibrium model including all selected factors, b) include the missing factors more precisely in an existing model, or c) link different existing models with each other.

Each of the four selected factors have specific requirements for modeling. To analyze how increased productivity due to closing yield gaps (1) affects cereal and oilseed production, a model is required which partially endogenizes productivity depending on different management practices and production systems. To analyze how changes in bilateral trade policies (2) would affect markets, a model is required which represents bilateral trade and trade policies. To analyze how changes in land use and land use restricting policies (3) affect cereal and oilseed markets, a model on land use which includes local bio-physical properties and land type classification is required. To analyze how different developments in the biofuel markets (4) transfer to cereal and oilseed markets, a model including the biofuel sector and biofuel policies is required.

Additionally, a baseline is required as a reference scenario which assumes a continuation of current policies and trends as observed in the past until the end of the projection period for all analyses. Therefore, a model is required which includes the persistent underlying long-term factors and represents cereal and oilseed markets in detail. Furthermore, an up-to-date database as foreseen in outlook projections enriches the analysis further as it brings the model closer to reality by capturing the latest developments.

For each of the planned analyses, models exist which represent one aspect in great detail but neglect other aspects. These are economic equilibrium models, bio-physical models, and land use change models. Hence, the option c) of linking existing models for the analysis seems to be the most appropriate choice as neither of the questions can be answered with one model alone. Additional advantages of linking models compared to building a new model or extending an existing model are the reuse of models where considerable capital and time has already been invested for their development. Hence, linking models provides an option to save time and resources. Further, the projections are improved by including more relevant factors in greater detail and overcoming deficits of one model by using the strength of another model.

The system of linked models requires to cover the most important factors and the ones to be analyzed, while it can extract more from other factors. To use all advantages of model linkage, a model toolbox needs to be built which allows to choose the most appropriate combination of models for the research question, as different research questions require different models. This is developed in this dissertation and presented in this chapter.

The remainder of this chapter is structured as follows. Section 3.1 present the state of the art by reviewing existing models and model linkages. Section 3.2 describes the models applied in the case studies in Chapter 4. The developed model toolbox and model linkages are described in Section 3.3 and Section 3.4 concludes the chapter.

3.1 State of the art

Models and model links have been developed and are maintained for agricultural market analysis and related fields, e.g., land use. For each model type, various models exist, which even if originating from a similar basic idea, differ in methodology and data. This chapter gives an overview of the model types applied later in this dissertation, i.e., economic equilibrium, bio-physical and land use change models, as well as examples of model linkages with these models. Each model link is individually developed and depends on the models involved and foreseen applications. Therefore, the focus is laid on different degrees of implementations, applications and arising challenges when linking models.

3.1.1 **Models for agricultural market analysis**

Different model types are used in agricultural economics to project market developments, i.e., partial equilibrium (PE) and computable general equilibrium (CGE) models based on neo-classical microeconomic theory (Sadoulet and de Janvry, 1995). Bio-physical and land use change models are used to depict the supply side of agricultural production in greater detail with a focus on the properties and availability of the endowment land. Other model types exist which have been linked to economic agricultural market models such as farm type models, e.g., Deppermann, Grethe and Offermann (2014), integrated assessments models, e.g., Valdivia, Antle and Stoorvogel (2012) and life cycle assessment models, e.g., Dandres *et al.* (2012). However, they focus on different research questions than addressed in the current dissertation and are not further discussed.

Each model focuses on specific applications, differs in regional and sectoral coverage, represents specific factors more precisely than others, uses different data, and is based on different theories. The outcome of a model depends to a large extent on how the different relationships between factors and markets are represented. A model needs to find a balance between simplification and accuracy. Hence, each model has different boundaries and restrictions leading to differences in model specifications and results for similar applications. This stresses the fact that projections are very uncertain and a wide range of possible pathways exist for market developments under similar assumptions. Nevertheless, such models are useful tools to demonstrate the relationship between the different factors and markets.

PE models focus on a specific market. They include at least one sector and region for which at least demand, supply and price equations are set up and solved so that the market is in equilibrium, i.e., demand equals supply resulting in an equilibrium price. They can be extended to multiple sectors and regions. Additional details can be specified such as distinguishing between different production systems and management practices, different demands and various domestic policies influencing markets. Everything that is not included in a PE model is treated as exogenous, i.e., given to the model without the model being able to influence it. To analyze cereal and oilseed markets, PE models can be applied which cover both markets. Additionally, other land use sectors and feedstock demanding sectors should be incorporated in the chosen PE model because they are closely linked to cereal and oilseed markets. Hence, the assumption that they do not influence each other does not hold. Examples of such PE models covering the agricultural sector are AGMEMOD (Chantreuil, Hanrahan and van Leeuwen, 2012), CAPRI (Britz and Witzke, 2014), GLOBIOM (Havlik *et al.*, 2018), IMPACT (Robinson *et al.*, 2015), and AGLINK-COSIMO (OECD, 2015a). These models have been developed by different research teams and are still maintained, extended, refined and applied. They differ in their sectoral detail, regional coverage, projection horizon, applied theories, equation setup, data, and applications. The strengths of these models are their detailed sector representation as well as the ability to model specific sectoral policies. They are often applied for outlook projections, e.g., OECD and FAO (2020b) and European Commission (2020b), and to assess different domestic policies and their impact on the agricultural sector, e.g., Jansson *et al.* (2020) and Haß (2021). Typically, they express output in physical units and prices in currency.

CGE models connect the whole economy of a region or even several regions. The sectors of the economy compete for endowments, e.g., land, labor, and capital, and intermediate inputs provided by other sectors. Further, bilateral trade between regions connect the different regional economies and enables to model bilateral trade policies. Their broad coverage comes at the expense of detail. Examples of CGE models applied in the field of agricultural economic modeling are MAGNET (Woltjer *et al.*, 2014), GTAP (Hertel, 1997), DART (Calzadilla, Delzeit and Klepper, 2014), and MIRAGE (Bouët, Dimaranan and Valin, 2010). These models have been extended to represent the sector of biofuels and its interactions with the agricultural and energy market, e.g., Banse *et al.* (2008), Taheripour *et al.* (2010), and Laborde and Valin (2012). Nevertheless, their sectoral detail is limited.

Further, output is often expressed in percentage changes and based on values not on physical quantities.

Potential yields and area for agricultural production determines crop production and depends strongly on climatic and soil conditions at the small regional level. This aspect is often neglected in PE and CGE models because a small spatial resolution, i.e., beyond country level, is necessary. Bio-physical and land use change models explicitly focus on this aspect by including bio-physical components or bio-physical models with a detailed representation of climatic and soil properties at a small spatial resolution. Additionally, the supply side of agriculture can be modelled in greater detail through modelling different production systems such as some PE models have integrated in their supply side, e.g., GLOBIOM and CAPRI. However, economic markets are often modelled in a simple form. Models with small spatial resolutions are, e.g., LandSHIFT (Schaldach *et al.*, 2011), GLOBIOM, and IMAGE (Stehfest *et al.*, 2014). They include bio-physical crop models such as EPIC (Gerik *et al.*, 2015)or LPJmL (Bondeau *et al.*, 2007). Further, they allocate available area between different crops by including different restrictions with regard to potential use of land, e.g., restricting conversion of specific land types and expanding agricultural area only to land with specific thresholds in potential yields. Hence, these models can model changes in total agricultural area as well as changes in yields due to different production systems in more detail.

Each model type has its strength but also limitations and boundaries (Wicke *et al.*, 2015). For the analyzes in the current dissertation, PE models are seen to reflect market developments in cereal and oilseed markets most appropriately when the focus is laid on specific crops and regions due to their detailed product representation. CGE models are appropriate when global developments, sectoral interdependencies, and trade policies are in focus due to their coverage of the whole economy and representation of bilateral trade policies. However, land use changes and yield developments associated with closing yield gaps are only roughly represented in either of the models. Hence, a linkage to a bio-physical or land use change model seems appropriate to close this gap.

3.1.2 **Linkage of models for agricultural market analysis**

The idea of combining models in agricultural economics has emerged in recent years (Nowicki *et al.*, 2007; Banse and Grethe, 2008; van Ittersum *et al.*, 2008; Lampe *et al.*, 2014; Britz *et al.*, 2012) and is seen as a possible way forward in understanding and analyzing agricultural and related markets (Wicke *et al.*, 2015). The main advantages for this approach are summarized in Table 5 and can be categorized in three types, namely ‘improvement of representation’, ‘extension of coverage’ and ‘saving of resources’.

The ‘improvement of representations’ strengthens the projection power of the model system because it contains a higher coverage, more detail, and better data. Furthermore, the ‘extension of coverage’ is mostly realized by bringing different research disciplines together. The various enlargements and perspectives but also the differences in objectives and techniques in each model, are combined to produce consistent results. This strengthens the ability for projections and the transfer of results to the scientific communities, policy makers, and the wider public as they are supported by researchers from multiple research disciplines. Besides the improvement of projections and coverage, a model linkage saves resources by reusing previously developed models and generating a model system that can be reused for new research questions.

Table 5 Advantages in linking models and applying resulting model systems

Type	Advantages of model linkage
Improvement of representation	
	Consideration of a larger number of relevant aspects at once
	Use and exchange of best available data
	Exploitation of complementary strength of each model and research discipline
	Generation of consistent results from various perspectives
	Strengthened ability for projections
Extension of coverage	
	Joined analysis and results for different aggregation levels
	Implementation of aspects from various research disciplines
	Multiple research disciplines working together and supporting results
Save resources	
	Reuse of previously developed models
	Extrapolation from already existing knowledge
	Save time
	Joined effort from multiple research disciplines
	Facilitation of application to new research questions

Source: own collection based on Britz (2008), van Ittersum *et al.* (2008), Britz *et al.* (2012), Voinov and Shugart (2013), Wicke *et al.* (2015), Delzeit *et al.* (2020) and personal experience

The models which are chosen for a model linkage have complementing and overlapping features. The complementing features are the reason to link models, while overlapping features act as points of linkage. The strength of each model, i.e., what the model covers in most detail, contributes to the results in a linked model system, while weaknesses, i.e., what one model does not cover or only roughly covers, are overcome by contributions from another model. Hence, linking models has become a technique in agricultural economic analysis with different degrees of interaction between involved models (Britz *et al.*, 2012; Delzeit *et al.*, 2020). Entire modelling systems have been developed around a model, e.g., CAPRI (Britz and Witzke, 2014), IMPACT (Robinson *et al.*, 2015), and IMAGE (Stehfest *et al.*, 2014), or by combining several models, e.g., SEAMLESS-IF (van Ittersum *et al.*, 2008) and GLOBIOM (Havlik *et al.*, 2018). These modelling systems can include all degrees of interaction and have flexibility in applying the models, i.e., allow the included models to be run individually as well as in combination.

The lowest degree of interaction is the harmonization of common assumptions, running similar scenarios in each model, and comparing results between the models, e.g., Nowicki *et al.* (2007), Lampe *et al.* (2014), Nelson *et al.* (2014), Wicke *et al.* (2015), and Stehfest *et al.* (2019). This is not a true model link but helps to understand differences in model outcomes and is an important and necessary first step before starting to link models.

A higher degree of interaction is the transfer of data from one model to others to include the model specific aspects in the analysis. In this one-way linking approach, one model provides information to other models which treat this information exogenous in their scenario simulation. The focus lies on the results of the last model in the chain, i.e., the results of the first model are of interest only for variables which are not common in the other models. This approach has been applied by, e.g., Nowicki *et al.* (2007), Boulanger, Dudu, Ferrari, Himics and M'barek (2016), and Haß *et al.* (2020).

This one-way linking approach can be extended to become a two-way linking approach in which each model receives information from the others and the models are run in a successive iterative manner until the results converge, i.e., a defined threshold is achieved such that the common endogenous variables can be said to be consistent. This highest degree of interaction was applied in, e.g., Böhringer and Rutherford (2009), Pelikan, Britz and Hertel (2015), Hasegawa *et al.* (2016) and Delzeit *et al.* (2018).

In literature, model linkages are also distinguished between a soft and a hard link. This can have two meanings. First, it can refer to the technical implementation, e.g., data exchange between models by individual modeler or automated within a program (Delzeit *et al.*, 2020). Second, it can refer to the dependency between the models, e.g., pure data transfer vs achieving consistent results iteratively (Wicke *et al.*, 2015). The current dissertation uses the terminology of one-way and two-way approaches referring to soft and hard link according to Wicke *et al.* (2015), respectively.

Different economic models have been linked to bio-physical, land use and crop models to represent the interaction between the economy, land-use, and environment more precisely in their analysis, e.g., van Meijl *et al.* (2006), van Ittersum *et al.* (2008), Reilly *et al.* (2012), Mauser *et al.* (2015), Thrän *et al.* (2016), and Doelman *et al.* (2018). Typically, information about production is provided by the economic model, while yield, production intensities or land use changes are altered according to information from the other models.

CGE and PE models have been linked for various scenario analysis, e.g., trade scenarios (Grant, Hertel and Rutherford, 2007; Henseler *et al.*, 2013; Boulanger, Dudu, Ferrari, Himics and M'barek, 2016), agricultural policy scenarios (Pelikan, Britz and Hertel, 2015), and biofuel scenarios (Britz and Hertel, 2011). The linkages strongly vary between the applications ranging from pure one-way data exchange to model adjustments and iterative procedures until conversion.

Besides advantages which motivate a model link (Table 5), several challenges exist in the practical implementation and use of a model link. This is demonstrated by different attempts to link different models without having achieved the envisaged outcome in the first attempt, e.g., van Ittersum *et al.* (2008), Jansson, Kuiper and Adenauer (2009), Delzeit *et al.* (2010), and Wolf *et al.* (2016).

Further, modelers involved in linking large scale models are aware of these challenges and have presented and discussed them from various perspectives (van Ittersum *et al.*, 2008; Britz *et al.*, 2012; Voinov and Shugart, 2013; Wicke *et al.*, 2015; Delzeit *et al.*, 2020). Table 6 gives an overview of these challenges which are of general, methodological, practical, technical, and personal nature.

Table 6 Challenges in linking models and applying resulting model systems

Type	Description of challenge
General challenges	
	Lack of transparency of approach regarding implementation and validation
	Maintenance of model system often too time and resource consuming
	Deficits in collaboration with different research teams
	Restricted use because of data, software, and model property rights
	Difficulty in transfer of results to wider public and policy makers
Methodological challenges	
	Consistency in overlapping results often not ensured
	Deficiencies in validation and uncertainty analysis
	Inconsistencies stem from differences in, e.g., theoretical model background, variable definitions, policy representation, coverage, assumptions, structure, solution algorithms, parametrization
	Lack of appropriate methods for up- and downscaling
	Risk of meaningless results as method application lies outside originally developed purpose
	Risk of overruling feedback mechanisms and complex interactions in models by link
	Complexity increases in model system
Practical challenges	
	Implementation is time and resource consuming
	Overcoming differences in data, methodologies, definitions, classifications, and assumptions
	Constant modification and update of models requires adjustments in link
	Risk of specification errors and uncertainties around assumptions and methodology in one model to be transferred to whole system
Technical challenges	
	Achieving consistency probably results in additional assumptions, aggregations, loss of detail and flexibility, and overwriting of model internal feedbacks
	Increased complexity for calibration, harmonization and data initialization procedures
	Risk of viewing models purely as software, achieving consistent model link but resulting in meaningless results
	Involved modes use different software and code documentation is often poor
	Time consuming and error prone data exchange
Personal challenges	
	Different definitions and understandings for similar issues in different disciplines, between modelers, policy makers, and wider public
	Differences in aim of model linkage between involved teams
	Judgement of accuracy of projected developments differ between modelers from different disciplines

Source: own collection based on van Ittersum *et al.* (2008), Britz *et al.* (2012), Voinov and Shugart (2013), Wicke *et al.* (2015), Delzeit *et al.* (2020) and personal experience

In general, a system of models is even more complex than the individual models which in turn a) are complex in themselves, b) rely on different theories, methodological approaches and data, c) have different limitations and assumptions, and d) are only managed and understood by a few persons. This increased complexity requires additional effort to interpret and transport results to a wider public and make them useful for policy evaluation (Wicke *et al.*, 2015). Additionally, methodological, technical and practical obstacles need to be overcome before a successful model link can be achieved. These are overcome in the dissertation by following the five steps for a successful model linkage as developed below in Section 3.3. Personal obstacles can arise between the different modelers from different disciplines working together with probably different understandings, views and aims towards the model linkage. This can result in failing to implement a model link or implement only a reduced form of the model link.

Finally, the developed model links are often hard to judge from outside as it requires knowledge of the involved models, their detailed structure and the link itself. In scientific papers space often restricts a detailed presentation of the link. Further, the link itself is not a result but rather a tool to analyze the actual research question. Hence, the link is often not presented in large detail nor properly validated.

3.1.3 Conclusion

Economic equilibrium models are used for long-term market projections. They picture markets consistent with economic theory and abstract from reality through simplifications. Typically, models have been developed for a specific application or field of application. Model extensions but also the linkage of models enhance the possible applications. Both augment the representation of factors influencing markets. If changes in land use (2), yield developments (1), trade policies (3) and biofuel demand (4) and their influence on markets are the aim of the analysis, as in this dissertation, the analysis with an economic model can be enriched by linking economic models with each other and other model types, e.g., land use change and bio-physical models.

The linkage of existing models depends largely on the involved models and has to overcome several challenges. Several examples with different degrees of interaction between models demonstrated first attempts and successful implementation of model linkages and their usefulness. This was the motivation for applying the approach for projecting different possible developments in cereal and oilseed markets. Hence, after the selection of suitable models to analyze the four selected factors, the model links have been developed by the author. Thereby, the linkages in the resulting model systems are restricted as demonstrated in detail in Section 3.3.2 and 0 below.

3.2 The models applied

In the dissertation, four relevant factors are selected to analyze possible future impacts on cereal and oilseed markets in the long-run. These factors, i.e., closing yield gaps (1), trade policies (2), land use (3), and biofuel demand (4), can be analyzed with economic models linked to land use change models with a bio-physical component. Therefore, four different models, i.e., MAGNET, AGMEMOD, GLOBIOM, and LandSHIFT, are chosen and are linked together depending on the factors to be analyzed. For an overview, Table 7 presents the required properties of the models to be able to analyze cereal and oilseed markets and the selected factors.

Table 7 Inclusion of required properties for analysis in the chosen models

Relevancy	Property	MAGNET	AGMEMOD	GLOBIOM	LandSHIFT
prerequisite for any analysis on cereal and oilseed markets	Up-to-date data	+	**+++**	+	+
	Detail of cereal and oilseed markets	++	**+++**	++	-
	Population	+++	++	+++	+++
	GDP	+++	++	+++	-
	Productivity	+	+	**+++**	++
1	Different production systems	-	-	**+++**	+
2	Bilateral trade	**+++**	-	++	-
2	Trade policies	**+++**	+	+	-
3	Land use and land use policies	++	+	+++	**+++**
3 and 1	Small resolution on land use	-	-	**+++**	**+++**
3 and 1	Bio-physical properties	-	-	**+++**	**+++**
4	Biofuel sector and policies	**+++**	+	++	-
4	Energy sector	**+++**	-	-	-

Notes: Relevancy: 1 to 4 factors with 1 = closing yield gaps, 2 = trade policies, 3 = land use, 4 = biofuel demand; level of inclusion: - not included, + = roughly included, ++ = included, +++ = included completely or in detail; bold +++ = main reason for selection of model
Source: own representation

For the regional analyses with a focus on Russia and Ukraine, MAGNET, AGMEMOD, and GLOBIOM are selected to analyze market developments under different trade policies and yield developments. The strengths of MAGNET are the global representation of all sectors and the representation of bilateral trade and policies. This comes at the expense of detailed sector representation and up-to-date data. Hence, it is beneficial to link MAGNET with AGMEMOD when specific regional markets are a focus because the strengths of AGMEMOD is the detailed representation of cereal and oilseed markets for selected regions, i.e., including Russia and Ukraine. Both models lack a detailed representation of land use on a small resolution, differentiations between different production systems and inclusion of bio-physical properties. Hence, a linkage to models with these components benefit the analysis of closing yield gaps and land use changes. Therefore, GLOBIOM is chosen to analyze closing yield gaps as different production systems are represented in the model.

The global study is performed with MAGNET and LandSHIFT to assess impacts of changes in biofuel demand and land availability on global cereal and oilseed markets. The contribution of MAGNET to this analysis is the modeling of biofuel policies and the depiction of the relationships between energy, biofuel, and agricultural markets. The contribution of LandSHIFT is the detailed modeling of land use policies and land use change at a small spatial resolution.

3.2.1 The MAGNET model

The Modular Applied GeNeral Equilibrium Tool (MAGNET) is a global, recursive dynamic, CGE model used, e.g., for analyzing policies and projecting economic developments in the fields of agriculture, biofuels and bilateral trade relations (for applications see, e.g., Eickhout *et al.* (2009), Philippidis *et al.* (2018), Banse *et al.* (2008)). MAGNET is the successor of LEITAP developed, hosted and applied at Wageningen Economic Research (WEcR) and is used by the Joint Research Centre of the European Commission (JRC) in Seville and the Thünen Institute. The basis of MAGNET is the Global Trade Analysis Project (GTAP) model (Hertel, 1997) and the version for this analysis here uses the GTAP database version 8 (Narayanan, Aguiar and McDougall, 2012). In MAGNET, the GTAP model and database are extended by several modules which improve and detail the representation of certain parts of the model (Woltjer *et al.*, 2014).

3.2.1.1 **The conceptual framework**

The GTAP and MAGNET model, as other CGE models as well, are based on neo-classical microeconomic theory. Each represented economic region consists of a production and consumption side interacting with each other and all regions are connected to each other through bilateral trade relations. A CGE model is a system of equations which are solved simultaneously. The equations of a CGE model can be distinguished by behavioral and accounting equations. Behavioral equations are based on microeconomic theory, such as, the consumer to maximize utility given its budget constraint, the producers to operate under the zero profit condition, and products to be distinguishable by their origin of production (Hertel, 1997). Accounting equations balance the whole system and, hence, define the system as a general equilibrium model (Brockmeier, 2001).

On the production side, each sector per region produces output using intermediate inputs, i.e., products of other sectors, and endowments, i.e., labor, capital, land and natural resources. In GTAP, output of a sector is one product. In MAGNET, however, a sector can produce more than one product, e.g., the vegetable oil sector produces vegetable oil and the by-product oilseed cake. In MAGNET, the production side is set up by a fully flexible multilevel nested constant elasticity of substitution (CES) functional form (for details see Woltjer *et al.* (2014)). This production structure allows modelling detailed substitution possibilities of inputs for producing a specific product by attributing different elasticities of substitution to the various nests which are defined by the modeler. For example, the production of ethanol is defined in a four-level nest excluding substitutability between each other, but substitution within each nest, i.e., energy, feedstocks, other intermediate inputs and endowments, is possible with elasticities of substitution being above zero and taking different values in each nest.

On the demand side, a ‘household’ per region is set up and distributes income to private households, government and a savings account through a Cobb Douglas per capita utility function with constant shares (Brockmeier, 2001). Income for private households is generated through the provision of endowments to the producing sectors, while income for the government is generated through different taxes. Savings are computed not on a regional but on a global basis and equal global investments. While demand of the government, i.e., government spending, is represented by a Cobb Douglas sub-utility function with constant shares, demand of private households, i.e., consumption of various products, is represented by a constant difference of elasticities (CDE) implicit expenditure function (Brockmeier, 2001). This CDE function projects unrealistically high food demand, especially for fast growing economies, when applied for long-term projections (Yu *et al.*, 2003). Therefore, a consumption module which adjusts income elasticities over time based on changes in per capita income has been developed in MAGNET (Woltjer *et al.*, 2014).

All economic regions are connected to each other through trade relationships, i.e., a flow of products with accompanying trade policies in tariff equivalents. Trade is represented by the Armington assumption, i.e., products are differentiable by their regional origin (Armington, 1969). Consumers, i.e., households, the government and intermediate users, of a product decide first how much to purchase of the domestic product and imported product. Then they choose from where to import. In the model, this is implemented by a two-level nest with different substitution elasticities.

The main model parameters, such as substitution, transformation, price and income elasticities, are based on theory, econometric estimations, literature, and expert knowledge. Changes in these parameters influence the outcome of the model considerably as has been shown by, e.g., Kavallari, Smeets and Tabeau (2014). Over time, MAGNET is mainly driven by developments of population, GDP and technological change. GDP is only exogenous in the baseline and translated into technical progress which is an exogenous input to all scenarios and allows to capture changes in GDP due to changes in the scenarios. Additional exogenous drivers are changes in policies and constraints on land supply. The main outputs of MAGNET are welfare analysis, production, consumption, trade flows, the use of endowments and intermediate inputs, and price changes. Due to the underlying data, the output is mainly expressed in value terms and percentage changes. Further, the model distinguishes between percentage changes in volumes and in prices.

3.2.1.2 The MAGNET database

The main data source of MAGNET, as applied in the dissertation, is the GTAP database version 8 which is based on input-output tables by region for the year 2007 (Narayanan, Aguiar and McDougall, 2012). Further, it includes bilateral trade flows between all regions and border protection data. All data is expressed in value terms. On this basis, the model distinguishes between value terms at agent prices, market prices and world prices. Differences in the prices represent taxes or subsidies as well as transportation cost in the case of market and world prices (Hertel and Tsigas, 1997).

This main data source is extended by several sectors, products and satellite databases. The database of the MAGNET version applied in this dissertation distinguishes between 134 regions, 61 sectors, 64 products and 5 endowments. Regions, sectors and endowments can be flexibly aggregated to build a model focusing on the respective research question.

Additionally, several satellite databases are added which serve different purposes. One purpose is the provision of data for dynamic scenario analysis, e.g., population and GDP projections based on different international projections such as UN (2017b) and USDA (2017). Another purpose is the provision of data for the different modules in MAGNET. For example, the land use change model requires data about used and potential agricultural land in km². This data is sourced from, e.g., FAO (2012). A third purpose is the extension of output. For example, agricultural production data in tons published by FAO (2012) is mapped to the volume of production in MAGNET and updated with volume percentage changes as projected by MAGNET, similar to the approach in Junker, Wolf and Banse (2014). In these cases, the modeler can choose between different data sources or add additional data if required. The satellite databases are introduced at the most disaggregated level possible and mapped to the MAGNET database in order to ensure maximum flexibility in aggregating regions and sectors to set up a model.

3.2.1.3 **Modules in MAGNET**

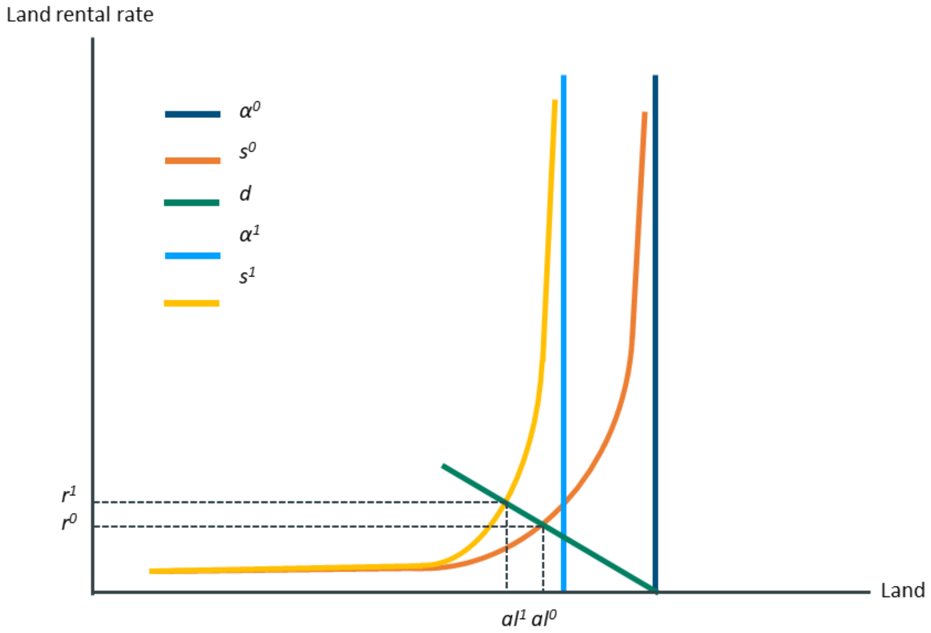
The main differences between GTAP and MAGNET are the additional modules in MAGNET. These improve and detail the representation of certain parts of the model, especially, to model agricultural and energy markets, their related policies, and interactions more accurately. These modules can be activated or deactivated depending on the research question. For a full list of modules and their documentation see Woltjer *et al.* (2014).

For this dissertation, two modules are of high importance because they are updated, modified and applied for the scenario analysis. These are the land use module which allows expansion of agricultural area and the reallocation of land between agricultural sectors (van Meijl *et al.*, 2006; Eickhout *et al.*, 2009; Woltjer *et al.*, 2014) and the biofuel module which enables a detailed modelling of biofuel blending targets, taxes and subsidies (Banse *et al.*, 2008; Woltjer *et al.*, 2014).

The land use module

The land use module developed by van Meijl *et al.* (2006) is a key component in MAGNET when answering research questions about agricultural production developments and the accompanying required land use changes. Land supply is modelled endogenously by setting up a land supply function, *s*, depending on land rental rates, *r*, and a maximum potentially available area for agricultural production, α, i.e., the asymptote of the land supply function, according to Figure 45.

Figure 45 Schematic representation of the land market in MAGNET



Source: own representation adapted from van Meijl *et al.* (2006) and Dixon *et al.* (2016)

All land left to the asymptote, α^0, is potentially usable for agricultural production and can include forest land and protected natural areas. Current aggregated agricultural land use, al^0, is the point where demand, *d*, and s^0 intersect. All area to the right of that point is an agricultural land buffer, i.e., area currently not used for agriculture but convertible to agricultural production. The closer the aggregated agricultural land demand is to the asymptote the higher the land rental rates and the more expensive the expansion of agricultural area. Reducing the land potentially available to agricultural production, e.g., by setting certain land under protection, shifts the asymptote from α^0 *to* α^1 and changes the supply curve from s^0 *to* s^1 as shown in Figure 45. Consequently, agricultural land is reduced to al^1 and the land rental rate increases to r^1. The magnitude of the shifts depends on the initial land demand.

The land supply function per region is implemented as a linearized version in MAGNET according to the following formula (Woltjer *et al.*, 2014):

$$\Delta\%s = \frac{\alpha}{s} \cdot \Delta\%\alpha + \varepsilon \cdot \Delta\%r \qquad \text{(Eq. 1)}$$

with s being the land supply for agricultural production, α being the maximum potentially available area for agricultural production, ε being the price elasticity of land supply and, r the real land rental rate. The prefix $\Delta\%$ means change in percentage from one period to the other. For the justification and derivation of the land supply function see Eickhout *et al.* (2009). MAGNET includes predefined asymptotes and allows the inclusion of own asymptotes. The price elasticity of land supply is defined as (Woltjer *et al.*, 2014):

$$\varepsilon = \left(\frac{\alpha}{s} - 1\right) \cdot \gamma \qquad \text{(Eq. 2)}$$

with γ being a positive parameter. In the standard MAGNET version, γ is set to one. Given the market equilibrium condition that land supply needs to equal land demand, the real land rental rate is implicitly determined and the market equilibrium conditions holds (Woltjer *et al.*, 2014). Land demand is defined as the sum of all land demand per sector in physical area and is calculated from FAO (2012). Physical area per crop is calculated by distributing the FAO land use categories 'Land under temporary and permanent crops' across all crops weighted by area harvested of the crop. Physical area for livestock production is determined by attributing livestock production to the FAO land use categories 'Land under temporary and permanent meadows and pastures'. Through this approach, the maximum potentially available agricultural area, land supply and land demand are connected and based on the same database which corrects possible inconsistencies between databases. In MAGNET, the allocation of land between different sectors is represented with a multi-level nested constant elasticity of transformation (CET) function and can be set up fully flexible by the modeler (Woltjer *et al.*, 2014).

The biofuel module

The biofuel module, first introduced by Banse *et al.* (2008) and further adjusted and applied by, e.g., Banse *et al.* (2014) and Thrän *et al.* (2016), links demand for biofuels specified as blending targets to feedstocks from agricultural production required to produce biofuels. The biofuel module includes a) the introduction of new sectors, e.g., ethanol, and products, e.g., oilcake as by-products from vegetable oil, b) the application and adjustments of the CES production function, e.g., biodiesel, ethanol and crude oil as substitutes for the production of fuel in the blending sector, c) initial biofuel shares in transport fuel based on data of International Energy Agency (IEA, 2017), and d) a budget-neutral implementation of achieving exogenously given blending targets through endogenizing the subsidy on biofuels used by the blending sector and the taxes paid by the consumers of the blended product (Woltjer *et al.*, 2014). For scenario analysis, the final absolute blending targets for each region and period are directly implementable in the model.

3.2.2 The AGMEMOD model

The Agricultural Member State Modelling (AGMEMOD) is a dynamic, multi-country, multi-market, partial equilibrium model (Chantreuil, Hanrahan and van Leeuwen, 2012) used for a) agricultural outlook projections, e.g., the latest publications in a series are Salamon *et al.* (2019) for an EU wide baseline, Haß *et al.* (2020) for a German baseline, and the contribution to European Commission (2020b)) as well as b) detailed domestic agricultural policy analysis, e.g., Erjavec *et al.* (2011), Salputra *et al.* (2011), and Haß (2021). Since 2001, AGMEMOD has been developed and is maintained by the AGMEMOD consortium. Currently the AGMEMOD consortium constitutes of a core group consisting of WEcR and the Thünen Institute as well as individual country modelers and experts contributing to the development and validation of the model. AGMEMOD is constantly enlarging in country and product coverage. Having started with a regional coverage of the EU member state countries to analyze the Common Agricultural Policy (CAP), AGMEMOD currently includes all EU member states and several EU neighbors. It covers the most important agricultural sectors within a country including the main cereals and oilseeds on individual product level.

3.2.2.1 The conceptual framework

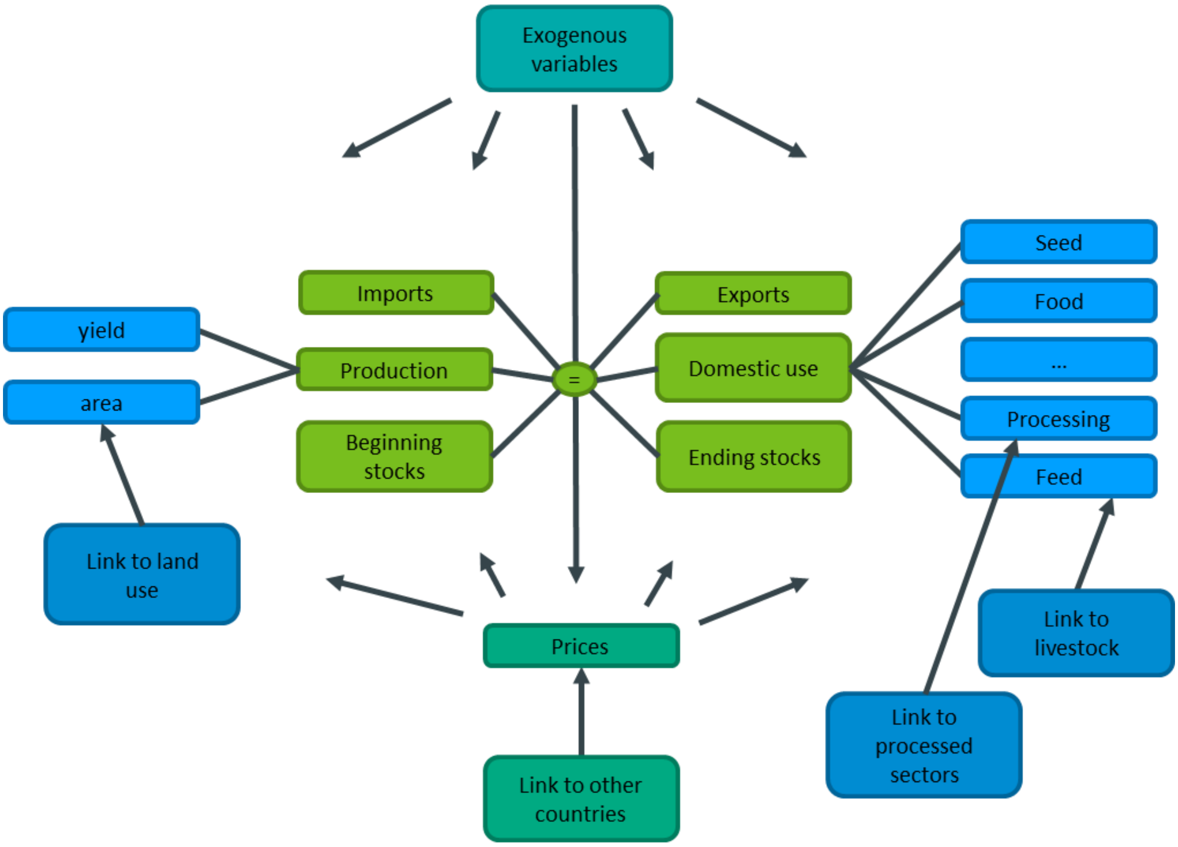
The AGMEMOD model, as other multi-country multi-product PE models, is based on neo-classical microeconomic theory. AGMEMOD connects individual county models covering the agricultural sector through price relationships to form a combined model (Salamon *et al.*, 2008). Each country has a similar set of estimated equations and identity equations per sector and a minimum requirement of dependent variables within an equation as described in Chantreuil, Hanrahan and van Leeuwen (2012). Ideally, the estimated equations are econometrically parametrized based on the time series the database provides. This approach distinguishes AGMEMOD from other PE models which are often calibrated and take elasticities from external sources. Only when estimations are not possible due to a lack of data, are the equations parametrized and calibrated based on external resources such as literature and expert knowledge. The identity equations act as residual and close the markets to ensure market clearing. The functional form of an equation as well as the inclusion of additional dependent variables is the responsibility of the individual product or country modeler and, hence, provide the freedom to estimate the individual equations according to product and country specific circumstances.

Figure 46 shows the interconnections within a (crop) sector in a country, to other sectors, and to other countries in AGMEMOD. The core of Figure 46 (in green) holds true for all sectors, while the outer parts (in blue) demonstrate the connections for any crop sector. The livestock sectors and processed sectors deviate from the latter.

In detail, the supply side of a product market consists of equations for at least production, beginning stocks and imports. In several product markets, the set of equations is extended. For example, production for crops is an identity depending on equations for area harvested and yield. Land demand per sector is modelled as a nested structure by using equations defined as shares within each subgroup.

The demand side of a product market consist of equations for at least domestic use, ending stocks and exports. Domestic use can be further distinguished by different use categories such as food, feed, seed, biofuel, processing, industrial and other uses and is product dependent.

Figure 46 Graphical representation of the connections of a crop sector in AGMEMOD



Source: own representation based on structure in AGMEMOD model

In each product market imports, exports or stocks are defined as identity equation to satisfy the market clearing condition that supply plus beginning stocks plus imports equal domestic use plus ending stocks plus exports. Prices in a sector depend on supply, demand, policies and a representative price. This representative price can be a price of another country, for the EU typically the price of the largest producer, or an exogenous world market price. Hence, the individual country models are linked to each other through the price relationship.

The individual product markets per country are modelled and interlinked with other product markets within the country through the use of joined resources, e.g., land, the demand of inputs from one product market to the other, e.g., feed demand in the livestock sectors originating from the crop sectors as well as through price dependencies between sectors which produce substitutes, e.g., cereals, or complements, e.g., oilseeds and their oils and meals. Several variables are given exogenously to AGMEMOD. These are product individual world market prices, population, GDP, exchange rates and detailed market policies. They influence the projected development over time together with the expectation of price and yield developments which are based on historical observations. These are included in the model equations in the form of lagged variables or trend variables. The main output of AGMEMOD are consistent market balances expressed in metric tons, prices expressed in national currency and euro per unit, and land use expressed in hectare on an annual basis until 2030.

3.2.2.2 The AGMEMOD database

The AGMEMOD database consists of 36 countries with similar predefined country model templates. More than 30 agricultural sectors and more than 20 processing sectors are modelled. However, the 36 countries only include the most important sectors within a country. Each sector includes several general activities, such as production and domestic use, but also specific activities, such as crushing for oilseeds. Further, general as well as country and product specific exogenous variables are included in the database. The compilation of the required data is a joined effort of the whole AGMEMOD consortium. Often various national statistics are the primary source for the data and are complemented by data from European or international databases. The data detail requires the use of different data sources and in turn requires adjustments to the data for consistency reasons.

As long time series are required for the econometrical estimation, the database tries to cover annual time series data dating back, if possible, until 1973. However, continuous time series data often do not exist, which requires further data harmonization. Also, AGMEMOD aspires to provide an up to date database which requires constant data updates and increases data work as preliminary data is included and later replaced by official data. Overall, data requirements for AGMEMOD are high in quantity and quality.

3.2.2.3 Updates and extensions for the current analysis

Given the research question and chosen application with a regional focus on Ukraine and Russia, these two country models were updated for the analysis. The first Ukrainian and Russian country models were developed by van Leeuwen *et al.* (2012) and Salputra *et al.* (2013), respectively. The update includes an extension of the database to available years and new estimation of the model equations for both countries (Wolf and Salputra, 2015). An additional revision has been undertaken in 2016 by the author of this dissertation.

3.2.3 The GLOBIOM model

The Global Biomass Optimization Model (GLOBIOM) is a bottom-up, global, recursive-dynamic, linear programming PE model focusing on land use sectors, i.e., forestry, bioenergy, and agriculture (Havlik *et al.*, 2014) used for climate change and climate change policy analysis, e.g., Havlik *et al.* (2011) and Mosnier *et al.* (2014). GLOBIOM has been developed and is maintained at IIASA. The model focuses on the supply side with a) a detailed representation of different land use on a resolution beyond country level and b) different production systems. It incorporates a) bio-physical properties and constraints, b) different technology options, and c) related GHG emissions. Documentation of the model is available in Havlik *et al.* (2011), Havlik *et al.* (2014), and Havlik *et al.* (2018) on which this section relies.

3.2.3.1 The conceptual framework

GLOBIOM is a linear programming model based on the spatial price equilibrium approach developed by Takayama and Judge (1971) with a detailed representation of land use and the supply-side for the forestry, the bioenergy and the agricultural sectors. It applies price endogenous mathematical programming and solves by maximizing the sum of consumer and producer surplus given multiple constraints based on the presentation by McCarl and

Spreen (1980). GLOBIOM includes different specific economic theories to represent demand, trade, and supply. The demand side is specified as demand for food depending on population, GDP and own price demand elasticities varying with GDP per capita, feed depending on livestock production and bioenergy use depending on exogenously given biofuel production. Products are assumed to be homogenous goods and net trade is modelled bilaterally depending on production costs, transport costs and tariffs according to Takayama and Judge (1971). The focus of GLOBIOM lies on the supply side which is modelled in rich detail by three sub-models for crops, livestock, and forest incorporating a) resources, i.e., water and land, b) bio-physical and technological constraints as well as c) profitability through market prices and costs. These three sub-models are linked to each other through the competition for land.

Land use and land use change is modelled based on different data on the basis of grid cells between five to 30 minutes of arc. A grid cell in GLOBIOM is a polygon and combines neighboring homogenous grid cells with respect to a) climate, b) topography, i.e., altitude and slope, c) soil, d) crop management, and e) country affiliation. Each grid cell includes one to nine different land cover types, i.e., 'unmanaged forest', 'managed forest', 'other natural vegetation', 'grassland', 'cropland', 'short rotation plantations', 'wetlands', 'other agricultural land', and 'not relevant', with specific conversion possibilities between the different land cover types. For example, 'unmanaged forest', 'grassland', and 'other natural vegetation' can be converted to 'cropland' and 'cropland' can be converted to 'other natural vegetation' and 'short rotation plantations' (Havlik *et al.*, 2018). Land conversion depends on conversion costs which increase with the amount of area converted.

The crop sector is modelled for 18 crops of which the main cereals, i.e., wheat, barley, and corn, and oilseed, i.e., soybeans, rapeseed, and sunflower seed, are modelled as individual sectors. Given the PE structure of the model, total production is determined per region. The model then optimizes land use required for the production of the different crops based on the chosen production system, potential yields, and conversion cost within a grid cell. Different production systems are modelled for each crop, i.e., 'subsistence farming', 'low input rainfed farming', 'high input rainfed farming' and 'high input irrigated farming'. Each production system consists of costs, yields, and specific fixed input levels such as fertilizer and water. The yields are determined per grid cell, per crop, and per production system based on the bio-physical crop model Environmental Policy Integrated Climate Model (EPIC) which is included in GLOBIOM. EPIC includes a detailed representation of bio-physical data, e.g., climate, soil properties, and water availability. Crop yields in GLOBIOM change through a) reallocation of land, b) switch of production system, and c) technical progress over time. The latter is exogenous to the model, while the others are endogenous driven by resource constraints and socio-economic drivers. The switch of production systems allows to simulate a closing of yield gaps.

The livestock sector is modelled for different animals, i.e., pigs, poultry, bovines, and small ruminants, and outputs, e.g., milk vs. meat, depending on eight different production systems (Havlik *et al.*, 2014). The livestock sector is linked with the crop sector through feed requirements and competes for land through land demand for pasture and forage production. The forestry sector competes with the agricultural sectors for land. It is modelled by incorporating information based on the Global Forestry Model (G4M) also developed at IIASA, see, e.g., Kindermann *et al.* (2006).

While the supply side is modelled based on grid cells with over 10,000 units, demand and trade is modelled for 34 regions. GLOBIOM projects supply, demand, net-trade, land use and GHG emissions for the represented sectors on a 10-year time step up to 2100. The main exogenous drivers over time are population, GDP, income and price elasticities, bioenergy demand, and productivity growth through crop yield and feed conversion efficiency changes. The main output of GLOBIOM are land use changes, GHG emissions in t CO_2 equivalent, market balances, and prices.

3.2.3.2 **The GLOBIOM database**

The GLOBIOM database combines and harmonizes data for its reference year 2000 from various sources and spatial scales. GLOBIOM uses the data 1998 to 2002 from FAO (2017a) for their representation of agricultural markets. Further, data is sourced, e.g., from Muhammad *et al.* (2013) for demand elasticities, from Gaulier and Zignago (2010) for bilateral trade, and from Bouët *et al.* (2008) for tariff equivalents.

Data for the crop sector is presented in Skalsky *et al.* (2008). Bio-physical and land use data consist of global data at spatial scales ranging from 30 seconds of arc, corresponding to about 1 km · 1 km at the equator and with reducing area towards the poles, to 50 minutes of arc, corresponding to about 50 km · 50 km at the equator, for elevation, land cover, land use, management system, weather, soil, crop calendars, and agricultural statistics (Skalsky *et al.*, 2008). These data were compiled and harmonized by Skalsky *et al.* (2008) to overcome inconsistencies within and between the different datasets. For example, cropland area results from a combination of land cover based on GVM and JRC (2004), land use based on You and Wood (2006), and area harvested based on FAO (2020a). Additional data for the livestock sector is presented in Herrero *et al.* (2013) and for the forest sector in Kindermann *et al.* (2006). GHG emissions accounting for all sectors is based on IPCC (2006).

The resulting database has a global coverage on different spatial scales for the year 2000. The amount, detail and coverage of the data restricts the extension of the complete database to more recent years.

3.2.3.3 **Updates and extensions for the dissertation**

GLOBIOM has been updated to represent Russia and Ukraine as single regions as well as extended to model abandoned land and yield gaps more precisely in these regions (Deppermann *et al.*, 2015). Therefore, data on land use (Schepaschenko *et al.*, 2015) and yield potential (Balkovic *et al.*, 2015) were updated. Additionally, the new land cover category ‘abandoned land’ was introduced and the two high input management systems adjusted to model the closing of yield gaps. This work was undertaken by colleagues at IIASA within the AGRICISTRADE project (compare Deppermann *et al.* (2015)).

3.2.4 **The LandSHIFT model**

Land Simulation to Harmonize and Integrate Freshwater Availability and the Terrestrial Environment (LandSHIFT) is a global, dynamic land use change model used, e.g., for analyzing human induced land use change and its impacts on the environment. For applications see for example Thrän *et al.* (2016), Hinz *et al.* (2020) and Göpel *et al.* (2020).

LandSHIFT is developed and applied at the Center for Environmental System Research (CESR) at the University of Kassel. It explicitly simulates the spatial-temporal dynamics of different anthropogenic land-use activities, i.e., settlements and agricultural production, by taking factors of demand, e.g., crop production, and supply, e.g., local biomass productivity, into account (Schaldach *et al.*, 2011). LandSHIFT includes spatially explicit socioeconomic and environmental landscape factors as well as constraints. A full model description is provided by Schaldach *et al.* (2011) on which this section relies.

3.2.4.1 The conceptual framework

LandSHIFT allocates the three main anthropogenic land use categories, namely 'settlements', 'crop cultivation', and 'livestock grazing', within a predefined region. The model operates on spatial grid cells with a cell size of 5 minutes of arc corresponding to around 9 km · 9 km at the equator. Therefore, a preference ranking approach is applied which calculates the preference value of each grid cell based on a Multi-Criteria Analysis and ranks them in a list. The preference value consists of weighted components representing factors of suitability for a particular land use category and constraints of converting the grid cell to a different land use category. In Table 8, these components are listed and attributed to the different land use activities.

Table 8 Factors and constraints to characterize a grid cell in LandSHIFT and their relevancy in the three anthropogenic land-use activities

	Settlements	Crop cultivation	Livestock grazing	Source
Factors				
Terrain slope	x	x	x	Fischer *et al.* (2012)
Road density	x			Meijer and Klein Goldewijk (2009)
Elevation	x	x	x	Danielson and Gesch (2011)
Soil properties		x	x	Fischer *et al.* (2001)
Crop and forage yields		x	x	Bondeau *et al.* (2007)
Population density		x	x	Klein Goldewijk *et al.* (2017)
Neighborhood to cropland cells		x	x	endogenous
River network density			x	Andreadis, Schumann and Pavelsky (2013)
Constraints				
Land-use transition	x	x	x	Internal assumption
Conservation area	x	x	x	IUCN and UNEP (2016)
Marginal yields		x	x	Bondeau *et al.* (2007)

Source: own compilation based on Schaldach *et al.* (2011) and Schüngel *et al.* (2022)

The three land use categories are attributable to the land cover categories 'urban areas', 'cropland' and 'grazing'. Besides these three land cover categories, nine other land cover categories are distinguished in LandSHIFT (compare Table B1 in Appendix B). Exactly one land use category is attributed to each grid cell. LandSHIFT only allows certain land cover categories to be converted, e.g., all land except 'urban areas' can be converted to 'cropland' but 'cropland' can only be converted to 'urban areas', 'grazing' and 'fallow land'.

The land use categories are represented in individual modules in LandSHIFT and are allocated to individual grid cells sequentially: first settlements via the METRO module, then crop cultivation via the AGRO module and finally livestock grazing via the GRAZE module (Schaldach *et al.*, 2011). In each module, the cell with the highest preference value for the respective land use category is used first and, hence, not useable for other land use categories anymore. This procedure continues until all exogenously given demand for land per country or region is satisfied.

In the METRO module, expansion of settlements is driven by changes in population over time which is an exogenous driver in LandSHIFT. Increased population increases the land cover category urban areas. Exogenously given production volumes for crop cultivation and livestock grazing are allocated to land in the AGRO and GRAZE module, respectively. Crop cultivation distinguishes between different crop types depending on the aggregate of external input data (for the dissertation see Table B1 in Appendix B and Table B4 in Appendix B).

LandSHIFT includes pattern stability, i.e., a cell with a specific crop type in one period will have the same crop type in the next period if the cell is not converted to urban land or less land is needed for the demanded production of the specific crop type. Only the additional land demand from increased production of a specific crop is then allocated to the most suitable grid cell, i.e., the grid cell on top of the ranking list of the respective crop type. If one grid cell is the top element on two or more lists, the crop type for which the grid cell has the highest preference value is allocated to this grid cell. The amount of production which is allocated to this grid cell depends on the yields for this grid cell. This procedure continues until all exogenously given crop production per country or region is allocated or all suitable area is used. In the case of livestock grazing, pasture is required to fulfill the required forage for the exogenously given, calculated livestock units. It is assumed that a specific fixed share of required feed comes from pasture and the rest from crop cultivation. If agricultural production cannot be allocated due to a lack of suitable land, the amount which is not allocated is an output of LandSHIFT and shows the bio-physical limits of a region to produce agricultural products.

LandSHIFT projects land use change up to 2050 and uses five-year time steps. Over time, preference values change due to changes in exogenous drivers, e.g., yield development, and endogenous drivers, e.g., land allocation in the previous period. Agricultural yield development over time is separately modelled by the dynamic global vegetation model Lund-Potsdam-Jena managed Land (LPJmL) (Bondeau *et al.*, 2007) which includes bio-physical constraints, such as precipitation, temperature, insolation, soil quality, and water availability, and gives potential yields per crop type for irrigated and non-irrigated production systems to LandSHIFT as well as forage productivity. Further, the use of the LPJmL model allows to define a climate change component affecting yields. These yields are further adjusted over time through an exogenously given technological change parameter representing improvements in management practices, e.g., fertilizer use, and plant breeding.

The main output of LandSHIFT are maps per simulation period at a grid level of five minutes of arc showing the different land use and cover categories. Further, results are aggregated to country or regional levels and serve as input to post-model analysis. For example, regional data of the amount of land use categories and the average yield per crop are used as input to MAGNET in the developed model system to recalculate the asymptote and yields (see Section 3.3.3.1 below).

3.2.4.2 The LandSHIFT database

LandSHIFT uses data on different spatial levels from the country or regional aggregate to grid cells with resolution of five minutes of arc. Compared to Schaldach *et al.* (2011) most data sources have been updated or changed for the dissertation as stated in Table 8 above. LandSHIFT requires data for the initialization of the base year (details see below) and data for projections over time.

For the initialization, the land cover map Climate Change Initiative (CCI) of the year 2010 (Defourny and ESA Land Cover CCI project team, 2017) and the three-year average of 2009 to 2011 for crop production (FAO, 2020a), ruminants (FAO, 2020f) and agricultural area (FAO, 2020e) are used. Ruminants, i.e., cattle, sheep, and goats, are converted to livestock units by applying an animal and country specific weighing factor based on Chilonda and Otte (2006). Each grid cell in a region is tagged with the criteria and constraints which are based on different sources as stated Table 8. Additionally, each grid cell is tagged by the Corruption Perception Index (CPI) of 2019 of the country or region (Transparancy International, 2020) which is a score indicating how corrupt a country is. The CPI lies on a scale between 0 (highly corrupt) and 100 (very clean) (Transparancy International, 2020). This information is required in Case Study 4 to decide on which grid cells protective measures are implemented (see Section 4.4.3.3).

The projections require data on population development (UN, 2017b), agricultural production, and yield changes induced by technical change. The latter two are taken from the output of MAGNET in this dissertation (compare Section 3.3.3.1 and 4.4.3.1 below).

3.2.4.3 Initialization

LandSHIFT needs to be initialized in its base year, i.e., 2010. Therefore, the CCI land cover map has been preprocessed as described in Schüngel *et al.* (2022). Then, observed agricultural area including the accompanying production and yields is allocated across the land cover map according to the model algorithm. In this dissertation, data based on FAO (2020c) as calculated by MAGNET is used for harmonization reasons (compare Section 3.3.3.1 below). Hence, this initialization takes place at the maximal disaggregated data level possible, i.e., 134 regions identical to the MAGNET database and the seven defined agricultural sectors (compare Section 3.3.3.1 below). The initialization in LandSHIFT determines the land use of each crop type and of livestock grazing as well as the land cover categories. This approach results in land use similar to the physical area as calculated by MAGNET using the FAO data. However, the physical area is not identical because a) LandSHIFT allocates the agricultural areas as calculated by MAGNET over the land cover map CCI with their model algorithm and b) LandSHIFT is working with full grid cells and, therefore, overestimates allocated area on the last used cell.

In some cases, grazing area in a region is larger according to FAO data than the total available grassland area according to CCI. This happens especially if the potential grassland yields are low and the FAO data seems to over-report the amount of available grassland. Hence, the LandSHIFT outcome corrects the FAO data on grassland. The largest adjustment reduces grassland area by 400,000 km^2 or -24 % in Saudi Arabia compared to the reported area by FAO. In the case of cropland, differences between the LandSHIFT outcome compared to the FAO data are below 200 km^2 or 4 % for all crops in each region. This deviation is attributed to the fact that LandSHIFT works with full grid cells and is seen as small enough to judge the LandSHIFT outcome as plausible and accurate. Working with full grid cells implies that, if only a small amount of production needs to be allocated, still the whole grid cell is reserved for this production, even though only a fraction of the cell is required for the production. Hence, each last cell attributed to a crop type or livestock grazing overestimates the need for land and as a consequence results in reduced calculated yields. However, this technical inaccuracy is negligible as it is always smaller than one grid cell.

3.2.5 Comparison of the models and conclusion

The four presented models have properties required to analyze cereals and oilseed markets and the chosen factors of closing yield gaps (1), trade policies (2), land use changes (3), and biofuel demand (4). MAGNET, AGMEMOD, and GLOBIOM are able to model cereal and oilseed markets but from different perspectives, while LandSHIFT allocates given production to land. The models differ in data, theory, coverage, and application (Table 9).

Each model combines data from different sources to produce the model specific databases. These databases as well as the models differ in regional, product, thematic, time and unit coverage. The economic models all rely on neo-classical microeconomic theory where supply equals demand resulting in an equilibrium price. However, specific relationships and theories vary, e.g., for trade representation. Further, each model is applied to answer different research questions and in different contexts which justifies the differences in coverage, data and theory.

GLOBIOM is the model best suited to simulate closing of yield gaps (1) as well as land use changes (3) in Russia and Ukraine as it models different production systems on a small spatial resolution for cereals and oilseeds. MAGNET considers sectoral interactions and models bilateral trade (2) in detail. Further, AGMEMOD is based on the most up-to-date database of the three models for Russia and Ukraine. This is seen to be of high importance to reflect the current market situation as the growth of cereal and oilseed markets was strong in both regions in the recent past. For example, Russia turned from a wheat net importer in 2000/01 to the largest net exporter in 2017/18 (USDA, 2020a). Hence, a model link between AGMEMOD and GLOBIOM is beneficial to take latest market developments into account and analyze closing yield gaps (1) and land use changes (3). Further, an extension of this link to MAGNET is beneficial to analyze trade polices (2). The three models have multiple overlapping features as they all represent cereal and oilseed markets but with different foci. This fact complicates a close model link and a loose one-way model link is realized (compare Section 3.3.2 below).

MAGNET is further able to simulate changes in biofuel demand (4) on a global scale which increases demand for cereals and oilseeds. Hence, demand driven land use expansion (3) for these crops is imaginable. The link of MAGNET with LandSHIFT depicts land use changes more accurately than stand-alone MAGNET. Additionally, protection of specific land covers which restrict agricultural area expansion (3), can be modelled with LandSHIFT on a global scale. MAGNET and LandSHIFT complement each other as they have limited overlapping features. Hence, a two-way model link is realized consisting of iterative model runs and data exchange until conversion (compare Section 3.3.3 below).

Table 9 Model comparison

Properties	AGMEMOD	MAGNET	GLOBIOM	LandSHIFT
Conceptional framework				
model type	PE for agricultural and some processing sectors	CGE with a focus on agriculture and biofuel sectors	PE for land use sectors with detailed spatial resolution of supply side	land use change
model solving	systems of equations to achieve market clearing	Walras's law: excess supply equals excess demand	linear programming with a strong integration of bio-physical parameters	preference ranking with suitability factors and conversion constraints
parameterization	econometrical estimation, calibration	calibration, elasticities	calibration, elasticities, constraint equations, process-based models	calibration (initialization)
trade representation	whole exports and imports of a country	bilateral trade (Armington assumption)	bilateral net-trade	-
Data				
database	own based on various sources	GTAP with satellite data from other sources	own based on various global sources	own based on various sources
primary data sources	national statistics	GTAP	FAO, GLC2000	CCI, FAO
data years/ base year	historical time series1)	2007	2000	2010
main units	tons, Euro, hectare, head of livestock	percentage changes, values in USD, hectare	tons, USD, hectare, head of livestock, CO_2 equivalents	km^2, tons
Coverage				
regional coverage	Ukraine and Russia, EU28 (25 regions), other single countries	global (flexible aggregation of 134 regions)	global (maximal 34 regions)	global (flexible aggregation of 190 regions)
sectoral coverage	agriculture and processing sectors	whole economy (flexible aggregation out of 52 sectors)	crop, livestock, forestry and bioenergy sector	-
parameter coverage	economic	economic	economic, bio-physical	bio-physical

Properties	AGMEMOD	MAGNET	GLOBIOM	LandSHIFT
Application				
main exogenous drivers	GDP, population, exchange rates, world market prices	GDP, population, technological change, taste changes	population, GDP, bioenergy demand, crop yield and feed conversion efficiencies, soil properties, water availability	population, agricultural production, technological change
main scenario analysis	agricultural market policies	trade, agricultural and biofuel policies	bioenergy, climate and environmental policies, yield potential	land use policies
main output focus	outlook projections, commodity balances and prices, area harvested and yield	bilateral trade, input use, demand, production, consumption, prices, land use	commodity balances and prices, land use change, yields, GHG emission savings	land use change, yields
projection periods	yearly up to 2030	flexible time steps up to 2050	10-year time steps up to 2100	5-year time steps up to 2050
Additional properties				
applying institutes	Thünen Institute, WEcR	WEcR, Thünen Institute	IIASA	CESR
programming language	GAMS	GEMPACK	GAMS	C++

Note: [1)]historical time series from 1973 to 2015 depending on data availability, varies between countries and products

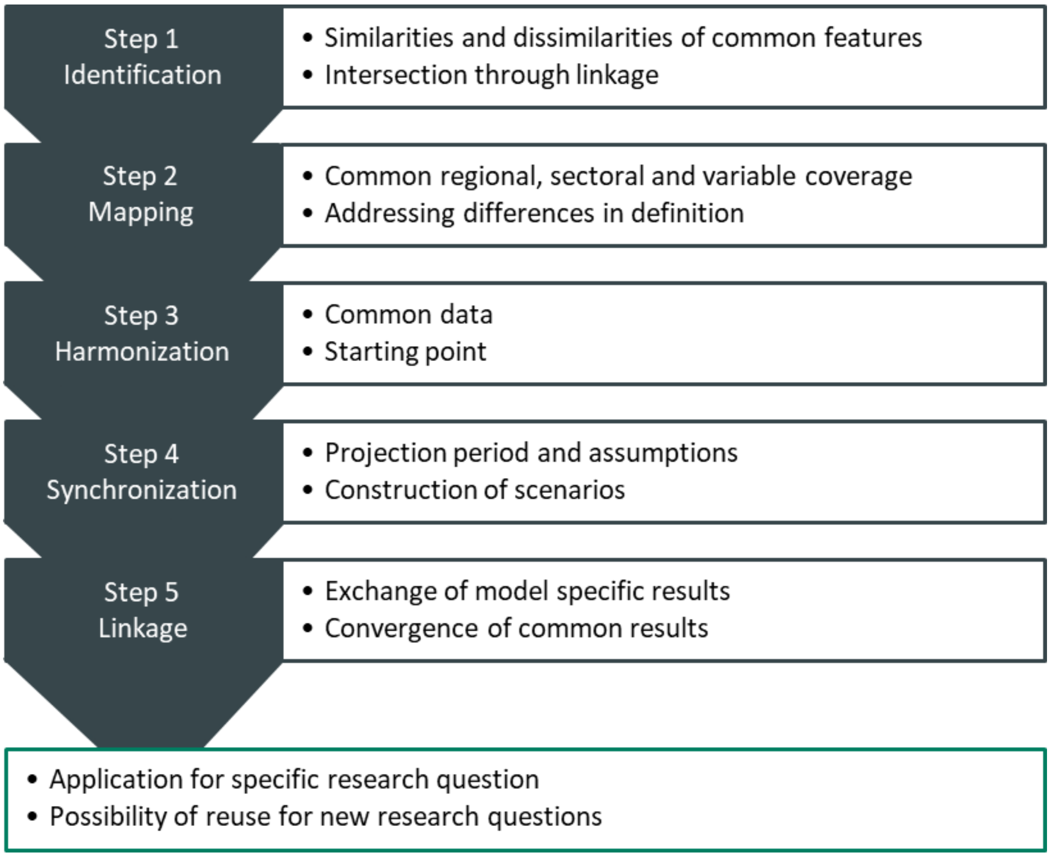
Source: own representation based on model documentations and personal communication with active model users

3.3 The model linkages developed

The variety of model linkages as presented in Section 3.1 demonstrate the necessity but also the different approaches of applying models jointly. Each model link depends on the models to be included, the research question to be answered and the ambitions of the persons applying the models. The challenges of model linkage presented in Section 3.1.2 need to be addressed in each model link. Therefore, five general steps are identified to implement a model link as pictured in Figure 47.

Step 1 diagnoses all overlaps and intersections of the individual models, i.e., common features are identified. This includes depicting similarities and dissimilarities of these common features in the models with respect to applied theory, databases, model properties as well as, regional, sectoral, time, and variable coverage. Further, the intersection needs to be clearly defined, i.e., what output of a model should be input to another model. Especially, the dissimilarities of the variables in the intersection need to be carved out exactly, such as differences in definitions, units, data sources, and drivers of projection. This first step is important to decide what kind of linkage can be implemented and which dissimilarities related to the common features need to be overcome before. Steps 2 to 4 overcome the dissimilarities, and Step 5 implements the actual link.

Figure 47 Steps for a model link



Source: own representation

In Step 2, the common coverage is mapped between all models. Differences in definitions need to be addressed accurately. All variables which are included in more than one model require a one-to-one mapping. Region and sectors should be mapped at the most disaggregated level possible before a higher common aggregation can be chosen for the simulation or result presentation.

Models rely on historically observed data. The data of the models are often not compatible as they come from different sources, have different units, are for different years or even have different definitions. For example, area can either refer to area harvested or physical area and production can be expressed in quantity as in PE models or value as in CGE models. Step 3 aims at harmonizing all common data and define a common starting point for the model link. In linking models this is not always possible nor necessary and depends on the used databases, the involved models, the degree of the model linkage and the value added in harmonizing the data given time and resource constraints. However, the model link is facilitated if the data is harmonized and can be hampered if the data differs.

Step 4 includes the identical setting of the projection period, the assumptions and the construction of scenarios. The projection period including starting and ending point should be the same over all models. Time steps in the projection need to be mapped to common time steps. All common exogenous assumptions need to be synchronized in the projection in all models. Ideally, the same data is used for these assumptions across all models. Further, assumptions need to influence common output similarly. The scenarios need to be constructed identical in each model as far as the individual model covers the specificity of the scenario. If these points are not ensured, outputs of the linked model system cannot converge. It is often the case that one model covers the specificity of a scenario or parts of it, while the other models do not fully cover it or only in less detail. Through the joined use this information can and needs to be transferred to the other models in an appropriate form, e.g., using results of one model as inputs to the others or translating detailed assumptions to an assumption the other model includes.

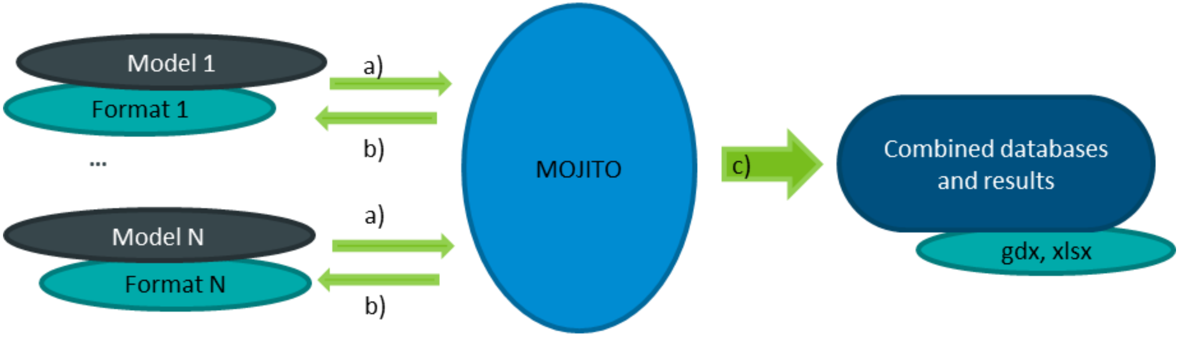
Finally, the actual model link is implemented in Step 5. This model link depends largely on the individual models to be linked as well as the successful realization of Steps 1 to 4. The model link can range from a loose one-way link where some output of a model is input to another model to a close two-way link where outputs are exchanged sequentially and iteratively between the models until joined results converge. The one-way link can be established even if Steps 1 to 4 are not perfectly undertaken, while the two-way link requires the complete realization of Steps 1 to 4. The respective model link is then applied in the baseline and the scenarios to answer the specific research question but could also be applied for later use and different research questions.

The five steps have to be performed in each model link individually depending on the applied models and their linkage. The technical implementation of a model link can be facilitated by tools which automates necessary steps in a model linkage such as data transfer between the models.

3.3.1 The MOJITO tool

The Model Junction Linkage Tool (MOJITO) has been developed to facilitate the technical realization of model linkages. In short, MOJITO facilitates all elements required for a successful model link, namely the mapping, harmonization, data exchange, scenario runs and result comparisons. The models involved in the linkages are applied at different institutes, use different software and report results in different data formats. Therefore, the exchange of data between the models requires a coordinated approach. Additionally, data exchange between the models is a repetitive step for each scenario run and each iterative model run. Hence, automated data exchange between the models saves time and reduces copy and paste errors. Figure 48 depicts the general concept of MOJITO.

Figure 48 Schematic drawing of the interaction between MOJITO and individual models



Notes: Interaction between MOJTO and models: a) output of model to MOJITO, b) selected input to model based on information from other models translated into receiving model mnemonics, c) storing results in one file for comparison and presentation
Source: own representation

MOJITO acts as a translation tool between the different models. The result files of each model are input to MOJITO which transforms them to a common data format, i.e., a gdx file. The data is mapped to common mnemonics between the models and stored in one central data file. This central data file is used to compare results between the models and scenarios as well as extract results of the individual models which act as input to other models. MOJITO calculates this input based on other model results as required by the new model, e.g., absolute values, differences, percentage changes, or indexes. This input is then translated into the mnemonics of the receiving model and transferred to the model. With the new input data, the model runs and produces new results which are transferred back to MOJITO. This process is repeated for the iterative scenario runs (compare the link between LandSHIFT and MAGNET in Section 3.3.3) and between scenarios (compare the case studies in Chapter 4). Optionally, the results between iterative runs are compared in MOJITO to decide if the convergence criterion is met and the modelling task is finalized (compare Section 3.3.3).

Theoretically, an iterative run until convergence with several models can be started with one click after having set up the link between MOJITO and the different models as well as defining the convergence criterion. Practically, this setup requires that all models and MOJITO are stored on one computer or server. As the models are applied by different model teams at different institutes, this full link has not been achieved. Instead the data between MOJITO and the models were sent by e-mail or transferred by cloud. The technical set up of MOJITO is based on the software GsePro (Dol and Bouma, 2006) and was set up by Foppe Bouma. Required changes in the models are minimal for the link to MOJITO and concentrate on the exchange of information and data coming from the other models through MOJITO. For each specific model linkage, MOJITO has been adjusted. The mapping, data transfers, and post-run calculations have been coded by the author of this dissertation. A more technical description of MOJITO is available upon request based on the example of the link between AGMEMOD, GLOBIOM, and MAGNET (Wolf and Bouma, 2016).

3.3.2 The link between AGMEMOD, GLOBIOM, and MAGNET

Section 3.2 concluded that a model linkage between AGMEMOD, GLOBIOM, and MAGNET is theoretically beneficial for market projections of cereal and oilseed markets in Russia and Ukraine and the analysis of closing yield gaps (1), different trade policies (2), and land use change (3). For market projections, AGMEMOD has the strong advantage of a) an updated database including a long historical time series, i.e., dating back to 1992 for Ukraine and 1990 for Russia, b) a detailed representation of the markets of agricultural and processed products as well as c) annual projections based on an updated set of equations (compare Wolf and Salputra (2015)). The drawbacks of AGMEMOD are that a) the availability of agricultural area is fixed, b) yields depend on an econometrically estimated trend over time without including bio-physical properties, and c) trade is only depicted as total exports and imports. In GLOBIOM, land use and resulting yields are based on bio-physical properties and different management types per grid cell. MAGNET represents trade bilaterally and is able to explicitly show the effects of bilateral trade agreements between two countries or country groups. Hence, information from GLOBIOM on land use and yield changes as well as information from MAGNET on trade changes is used to improve AGMEMOD projections.

This results in a one-way link which is described in detail following the five steps of a successful model linkage (compare Figure 47, page 89).

3.3.2.1 Implementation of the model link

Step 1: Identifying overlaps and intersections

Overlaps of the three models are numerous. They project results for identical or similar variables such as land use, area harvested, yields, production, demand, trade, and prices. These results vary considerably between the models as they are the projected outcome based on different data and theories. The models were developed for different purposes and by different teams of researchers applying different behavioral assumptions, parameters, and starting values (compare Table 9, page 87). Additionally, definitions and coverage of variables, products, and regions vary. These circumstances pose a challenge to use models consistently as they are not directly compatible to each other.

The main exogenous drivers over time are population growth, GDP development and technical progress. While population growth and GDP development are based on external sources such as discussed in Section 2.3, technical progress is defined heterogeneously in the three models. This is one intersection which requires special attention.

Harmonizing the exogenous drivers and running the three models separately results in differences in all market variables. Therefore, a two-way model link with consistent results across all models is not likely to be achieved nor would it be meaningful. Hence, the model link concentrates on specific parts of the models and transfers the value added of these parts to the other models. As a result, the use of one model, i.e., AGMEMOD, enriched with information from the other models for specific parts of the market seems to be the most appropriate way forward to link the models and improve projection outcomes. This approach is elaborated in Step 4 and the technical implementation is presented in Step 5.

Step 2: Mapping the coverage of the models

Before the actual linkage, the overlapping coverage in the models need to be mapped. Regions, sectors, variables and periods of the models are mapped to each other in order to be able to compare results and exchange data. Therefore, MOJITO is applied.

A mapping for all regions is required even though the focus of the case studies is Russia and Ukraine. AGMEMOD covers individual countries which can be aggregated to regions after the model run. In the standard GLOBIOM, countries are aggregated to 34 regions covering the whole world. MAGNET can aggregate the 134 regions in the GTAP database flexibly. For this analysis, 27 GTAP regions are aggregated such that they are compatible with the GLOBIOM regions after some further aggregation in both models. This leads to a comparable set of regions across all models. Russia and Ukraine are represented as single countries in each model. The whole mapping and post model aggregations in each model is presented in Table A1 in Appendix A.

Similar to the regional mapping, a sectoral mapping is required for all overlapping sectors even though the focus lies on cereal and oilseed markets. While MAGNET covers all sectors of the economy, GLOBIOM and AGMEMOD focus on specific sectors in more detail. Hence, an aggregation of sectors is necessary to be compatible with MAGNET sectors and one-to-one mappings are seldom. GLOBIOM and AGMEMOD sectors are mainly one-to-one mappings; however, each model covers sectors the other does not. The set of comparable sectors across all models is small while it is larger between GLOBIOM and AGMEMOD. The mapping including post model aggregations is presented in Table A2 in Appendix A. The main cereals, i.e., wheat, barley, and corn, as well as the main oilseeds, i.e., soybeans, rapeseed, and sunflower seed, are represented in AGMEMOD and GLOBIOM as individual sectors, while MAGNET distinguishes only between wheat, other cereals, and oilseeds.

Each model includes numerous variables and parameters. Variables and parameters which are comparable between the models are presented in Table A3 in Appendix A. Special attention has to be paid to the units of these variables, which differ between the models. While MAGNET reports percentage changes of volumes and prices per period, GLOBIOM and AGMEMOD report physical quantities and prices in different currencies in real and nominal terms, respectively.

Step 3: Harmonization of data

The different units for the same variables in the different models complicate the model linkage. Further, each database and, hence, starting year for the model projections depicts a different year. GLOBIOM and MAGNET are based on data for 2000 and 2007, respectively. AGMEMOD includes data up to 2015. As the overlapping variables are numerous, a harmonization of the databases even in only specific parts would require considerable resources, time and even new data which might not be available or would be based on outdated data, e.g., if 2000 is selected as starting year. Further the issue with different units persists if the models are not extended or adjusted to include the specifications of the other models. Hence, the harmonization of the databases is judged as infeasible and omitted.

The non-harmonization of the databases is bypassed by a) transferring data based on percentage changes from one model to the other, b) setting 2015 as a common start year even though it already includes projections, and c) realizing a one-way model link without requiring consistency in results. The latter translates into a model system where the last model in the chain, i.e., AGMEMOD, is enriched by information from the previous model runs, i.e., GLOBIOM and MAGNET.

Step 4: Synchronization of scenario construction and assumptions

The projection period is set up from 2015 to 2030 with 2020 as an intermediate time step for all three models. AGMEMOD projects on an annual basis, while GLOBIOM only uses 10-year steps from 2000 to 2030 and MAGNET, starting in 2007, projects to 2015, 2020, and 2030. To start from a common year, i.e., 2015, GLOBIOM results are linearly interpolated between 2010 and 2020 to get 2015 figures.

Identical or similar scenario construction over the three models pose yet another challenge because a) the exogenous drivers impact the same variables differently and b) assumptions based on the scenario narratives are implementable in each model differently. Hence, the linkage focuses on improving projections in the baseline and the scenarios for AGMEMOD given results from the other models.

Productivity changes influence the supply of cereals and oilseeds in all models. Thereby, endogenous and exogenous components define final productivity in each model. Endogenous components of productivity change are prices in all models. In GLOBIOM changes in the land allocation and management system further affect productivity endogenously, while in MAGNET changes in the composition of inputs, including endowments and intermediate inputs, to produce a specific output impact productivity.

Hence, exogenous components of productivity change, i.e., technical progress, are defined differently in each model. Additionally, technical progress in GLOBIOM and AGMEMOD is based on a time trend, while it depends on a combination of GDP development and an exogenously assumed change over time in MAGNET. As a result, exogenous technical progress cannot be harmonized across models. However, total productivity gains in cereals and oilseeds result in increased yields and, therefore, changes in yields are harmonized to overcome this discrepancy. GLOBIOM endogenizes yield developments the most of the three models and has further been updated to model closing of yield gaps (Balkovic *et al.*, 2015). Therefore, GLOBIOM yields are transferred to MAGNET and AGMEMOD (compare Step 5).

Land use and especially agricultural area expansion is also modelled differently in each model. In AGMEMOD, total agricultural area is mostly set fix over the projection period and area reallocation occurs only within the agricultural sector. This approach is justifiable as AGMEMOD has been developed primarily for European countries where agricultural area expansion is limited. However, Russia and Ukraine show potential to expand agricultural area as currently 31.6 million hectares and 2.7 million hectares of arable land are not utilized, respectively (Schepaschenko *et al.*, 2015). GLOBIOM and MAGNET explicitly include an option for agricultural area expansion. The option of area expansion in GLOBIOM is modelled on a detailed small spatial resolution and has been updated to model abandoned land and its potential for reuse for Russia and Ukraine explicitly (Deppermann *et al.*, 2015). Therefore, changes in total agricultural area are transferred from GLOBIOM to AGMEMOD (compare Step 5).

Trade policies in the form of bilateral trade agreements are another focus of the current analysis for cereal and oilseed markets in Ukraine and Russia. As AGMEMOD aggregates imports and exports of one country independent of the trading partner, bilateral trade policy changes cannot be modelled. Hence, trade developments from MAGNET are included in AGMEMOD because MAGNET is able to explicitly show effects of bilateral trade agreements between two countries or country groups.

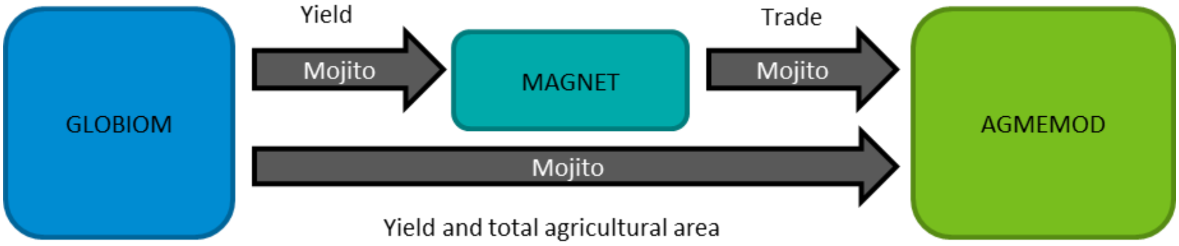
Population and GDP development are important drivers of demand for cereals and oilseeds in all models depending on the underlying equations. Hence, while the influence is according to economic theory, the magnitude depends on the specific theory implemented and so varies between the models. For example, different demand elasticities are implemented in the models which change with GDP and over time. Further, demand depends on additional parameters, e.g., livestock production, biofuel production, and prices. An attempt to harmonize the respective effects seems not to be constructive given that each applied theory is justifiable and that the database is not harmonized which would be a prerequisite for a successful model link. Nevertheless, synchronization of assumptions, i.e., population and GDP development, are required. Therefore, percentage changes of population and GDP changes are harmonized in all models. The data source is the AGMEMOD database for all countries in AGMEMOD and the SSP2 path of the SSP database (IIASA, 2015) for all other regions.

The three models are used for the construction of an outlook and two different scenario analyses of closing yield gaps (1) and changes in trade policies (2). Thereby, the effect on cereal and oilseed markets including land use change in the respective countries is the focus of the analysis. AGMEMOD is selected as the model which projects general market developments best as it relies on econometrical estimations based on the latest available data. However, AGMEMOD is not able to simulate the envisioned scenarios alone. Hence, GLOBIOM and MAGNET contribute to the realization of these scenarios by varying assumptions on yield gaps and trade policies, respectively. This contribution is realized by explicitly modelling the specific scenario changes in GLOBIOM and MAGNET, respectively, and transferring results to AGMEMOD which uses them as input through the established model link (compare Step 5).

Step 5: The model link

Steps 1 to 4 show that a model link between the three chosen models is only realizable as a loose one-way approach. Compared to the GLOBIOM and MAGNENT, AGMEMOD includes the latest available data and projections for cereals and oilseeds are most detailed. Therefore, AGMEMOD is used as the model to be modified by selected input from the other models as depicted in Figure 49. AGMEMOD receives data on yield changes and land conversion from GLOBIOM as well as export and import changes from MAGNET for Russia and Ukraine. Additionally, yield changes from GLOBIOM replace the yield developments of all crops in MAGNET. This further contributes to a better harmonization of model assumptions. The data exchange between the models is realized through MOJITO. Thereby, AGMEMOD and MOJITO are closely linked so that AGMEMOD is able to be run from MOJITO, while GLOBIOM and MAGNET are run by the respective model teams at IIASA and WEcR.

Figure 49 Schematic drawing of the model linkage between GLOBIOM, MAGNET and AGMEMOD



Source: own representation

In detail, MOJITO calculates new yield developments for the projection periods in AGMEMOD based on historical observed yields from AGMEMOD and calculated annual percentage changes from the 10-year projections of GLOBIOM. Annual percentage changes, rather than the absolute projected yield from GLOBIOM, are used because AGMEMOD's database is more up to date and the actual historical data should always be preferred over projections from the past. Therefore, the yields of the first projection year represent a three-year average of historically observed yields and are then updated annually by the calculated annual percentage changes from GLOBIOM until 2030. This allows to include yield changes based on bio-physical properties of the cultivated land, changes in land allocation and switches between management systems. This information is necessary for the yield gap closing scenario. These yield changes are implemented for the main important crops which are identical in AGMEMOD and GLOBIOM, i.e., corn, wheat, barley, rice, rapeseed, soybeans, sunflower seed, and potatoes (compare Table A2 in Appendix A). Implicitly, the endogenous price effects on yields as modelled in AGMEMOD are replaced by the information from GLOBIOM. However, as GLOBIOM also includes a price effect on yields, this replacement is feasible.

Total cropland area per country is exogenously given in AGMEMOD based on endogenous GLOBIOM projections to convert other areas into cropland. This captures land conversion given bio-physical and economic restrictions and allows to model the reuse of abandoned land in Russia and Ukraine. Technically, absolute annual changes in 'forest', 'grassland' and 'other land' (compare Table A2 in Appendix A) from GLOBIOM is used to update the respective categories in AGMEMOD. In the stand-alone version of AGMEMOD these categories are set constant. The update of these land use categories automatically translates in changes of cropland in AGMEMOD. The allocation of cropland among the different crops is determined endogenously within the AGMEMOD model. Hence, area harvested and production per crop is not harmonized between GLOBIOM and AGMEMOD. The aim of this part of the link is to solely allow land use changes in AGMEMOD. The allocation between different crops is judged to be accurately modeled in AGMEMOD and preferred to the allocation in GLOBIOM, primarily because GLOBIOM relies on older data.

MAGNET in contrast to AGMEMOD is able to model bilateral trade and, hence, the effects of different trade agreements between countries. In order to take these effects in AGMEMOD into account, MAGNET scenario data on the changes of export and import volumes are transferred as annual percentage changes to AGMEMOD. In the AGMEMOD database, historical imports and exports are available until 2015. Afterwards, an econometrically estimated equation or an identity which ensures the closing of the market balance, determines the projected trade figures. These are replaced by the aggregated annual percentage changes from MAGNET based on the latest historical value. In order to ensure market balance, domestic use and within domestic feed use is now defined as an identity in AGMEMOD. In MAGNET trade data is reported in USD at constant 2007 prices, while in AGMEMOD data is reported in tons. Also, trade in MAGNET only covers the actual raw product while trade in AGMEMOD includes also trade of processed products of the raw product. These two facts are the reasons to use annual percentage changes from MAGNET as a proxy for trade changes in AGMEMOD. This approach is implemented for selected cereals and oilseeds (compare Case Study 1 to 3) and for Russia and Ukraine only. It strongly interferes in the model solution of AGMEMOD and can only be justified for these two regions. Both regions aim to increase self-sufficiency levels in livestock farming. However, in the past exports of cereals where more competitive than using them as feed domestically (compare Section 4.1.2 below). Hence, changes in trade policies are assumed to affect feed use in Russia and Ukraine by either encouraging it, if trade becomes less competitive on international markets, or further discouraging it, if trade becomes more competitive on international markets. Additionally, both countries apply ad hoc trade policies, e.g., exports bans, quotas or taxes, under the pretext to ensure domestic demand at reduced domestic consumer prices (compare Section 4.3.1 below).

MAGNET's strength is the inclusion of the whole economy. In contrast, AGMEMOD takes the economy which is not explicitly represented as exogenous. Hence, AGMEMOD considers exogenous GDP and world market prices to impact projections. In MAGNET, these two variables are endogenous in scenarios. Hence, percentage changes in GDP and world market prices per scenario compared to the baseline are transferred from MAGNET to AGMEMOD for all mapped sectors and regions. This approximates the cross-sectoral economic effects caused by the different scenario assumptions.

The original idea of linking the models has been to transfer production responses from AGMEMOD back to the other models (Wolf *et al.*, 2016) with the aim to align results between the different models more closely. However, the tested approach in Wolf *et al.* (2016) did not produce expected results. The largest obstacles were the limited harmonization of data. To remedy this, Steps 2 and 3 would have to be perfectly aligned first and possibly additional changes within the models are required. However, this would have increased time and resources beyond a manageable level. A similar approach to implement CAPRI production projections into MAGNET also question their outcome and suggest a closer alignment of internal model relationships instead (Philippidis, Helming and Tabeau, 2017). Further, the chosen scenario analyses justify the one-way approach (compare the case studies in Section 4.1 to 4.3 below).

3.3.2.2 **Discussion of the implemented model link**

The current model link is a one-way link from GLOBIOM and MAGNET to AGMEMOD. The main aim of the link is to answer questions about cereal and oilseed market developments in Ukraine and Russia, if yield gaps are closed and trade policies change (compare Case Study 1 to 3). Given this condition, convergence of model results is not an aim nor a prerequisite. Nevertheless, some comparisons between AGMEMOD results for the baseline without a link 'not linked' and with the link 'linked' demonstrate the wide range of results and highlights the caution necessary when interpreting results.

As yields in AGMEMOD rely on historically observed developments in combination with expected prices, projected yield growth mimic these to some extent, e.g., barley yields are expected to grow the least (Table 10). Using information from GLOBIOM for yield developments instead results in more homogenous yield growth between the different crops and regions in the projection period (Table 10). Both approaches are based on transparent assumptions and underlying theories. Hence, they are justifiable but result in different projections. The replacement of yield developments in AGMEMOD by GLOBIOM projections weights the influence of bio-physical properties and technology application on yields higher than past historical developments and expected prices.

Table 10 Comparison of yield developments between the not linked and linked baseline in AGMEMOD, annual average growth rates in %

	Russia			Ukraine		
	1992-94 to 2013-16	2017 to 2030		1992-94 to 2013-15	2016 to 2030	
	historical	not linked	linked	historical	not linked	linked
Wheat	1.54	0.87	1.54	1.27	0.95	1.59
Corn	2.83	1.66	1.40	4.00	2.41	1.69
Barley	0.80	0.65	1.32	-0.47	0.67	1.49
Sunflower seed	1.40	1.03	1.59	2.69	3.36	1.63
Soybeans	2.29	1.39	1.92	3.56	2.50	1.58
Rapeseed	0.44	0.96	1.82	2.91	2.95	1.88

Note: Historical data are available for Russia until 2016, for Ukraine until 2015. Not linked = AGMEMOD projections without input of other models, linked = AGMEMOD projections based on input from GLOBIOM

Source: AGMEMOD database and own projections based on AGMEMOD and the combination of AGMEMOD and GLOBIOM

Assuming different yield growth in AGMEMOD results primarily in different production. This is triggered by changes in land use and product prices. The different yield developments change the competitiveness between the crops for land. Hence, land is allocated differently between the crops. Further, prices decrease (increase) given higher (lower) productivity growth. Exports or imports in AGMEMOD are modelled as a residual to balance markets, e.g., in the case of Russia and Ukraine, cereals which are not consumed domestically are exported. In the linked AGMEMOD version exports and imports change according to MAGNET which also incorporated the yield changes based on GLOBIOM. Together, this results in different domestic use.

Hence, the market developments for cereals and oilseeds are quite different in AGMEMOD with and without the link (Table 11). In general, cereal and oilseed production in Russia is higher in the linked version than in the unlinked version, while corn and oilseed production in Ukraine is less. This is primarily due to the different yield assumptions. The changes between the two model runs are large but explainable. For example, Russia exports nearly twice as much wheat in the linked AGMEMOD version than in the unlinked AGMEMOD version in 2030. As wheat yields increase in the linked version more strongly than in the unlinked version, wheat becomes more competitive compared to the other products. Hence, production increases by nearly 40 % compared to the 'not linked' projections resulting in increased exports and domestic use. A judgement on the most likely developments is out of the scope of projections, nevertheless both are in the range of possible pathways.

Table 11 Differences in net exports, consumption, and production between the 'not linked' and 'linked' AGMEMOD baseline, 2030

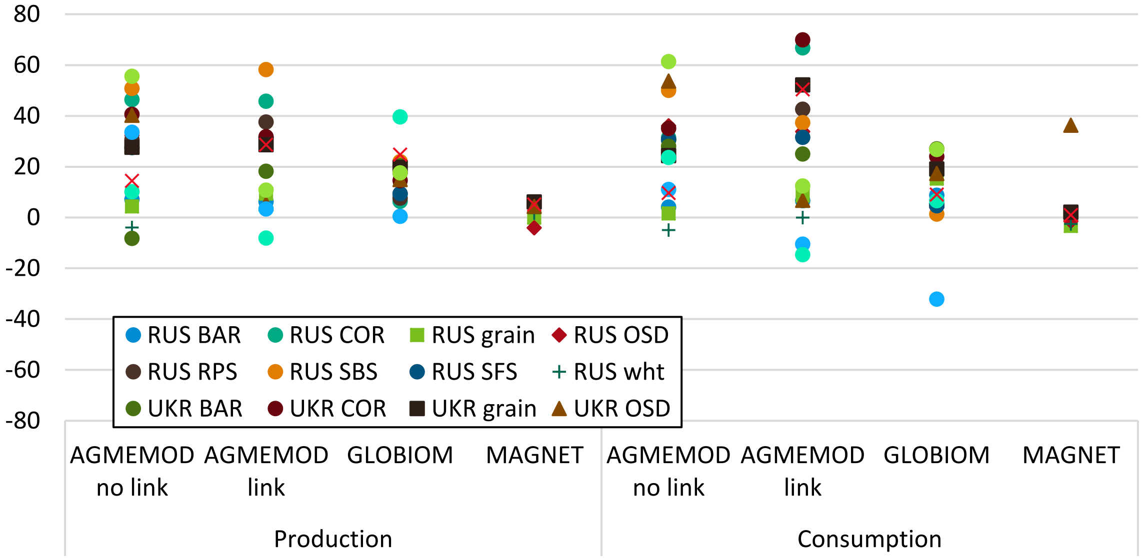
	Net exports		Domestic use		Production	
	∆ million tons	∆%	∆ million tons	∆%	∆ million tons	∆%
Russia						
Wheat	14.6	93	4.0	11	18.8	37
Corn	0.3	6	3.0	30	3.4	23
Barley	1.9	62	-0.6	-5	1.3	8
Sunflower seed	0.3	-85	1.2	9	1.5	12
Soybeans	0.6	-25	0.1	2	0.7	18
Rapeseed	-0.1	-56	0.1	12	0.1	5
Ukraine						
Wheat	4.5	57	1.3	10	5.7	28
Corn	-16.7	-41	2.7	12	-14.0	-22
Barley	2.1	83	2.1	33	4.1	48
Sunflower seed	-0.6	-93	-10.2	-41	-10.9	-42
Soybeans	-2.6	-55	-1.4	-34	-4.0	-45
Rapeseed	-0.8	-36	-0.1	-23	-0.9	-34

Note: not linked = AGMEMOD projections without input of other models, linked = AGMEMOD projections based on input from GLOBIOM and MAGNET

Source: own AGMEMOD projections based on AGMEMOD and the combination of AGMEMOD, MAGNET, and GLOBIOM

This link does not have the aim to fully align results in the three models. Nevertheless, the behavior and results of the models are relevant for information transfer between the models and result interpretation. The model results are difficult to compare as base years, data sources, units, and coverage vary between the models. The period of 2020 to 2030 exists in all models and consists only of projected data which allows to compare the development over time in percentage changes between the models. Figure 50 shows the projected percentage changes between 2020 to 2030 for production and consumption in all models for cereals and oilseeds in Russia and Ukraine. These percentage changes are highest and vary the strongest in AGMEMOD with and without information from the other models, while lowest and vary the least in MAGNET. In most cases, the models project positive growth but differ strongly in the magnitude. In other cases, clear deviations are detectable, e.g., soybean production in Ukraine decreases in AGMEMOD and increases in GLOBIOM (Figure 50). Trying to judge which of these percentage changes are most likely is not appropriate given the different model frameworks, i.e., differences in data and methodologies, even if common key drivers are harmonized.

Figure 50 Variety of model results for production and consumption growth, percentage changes between 2020 to 2030

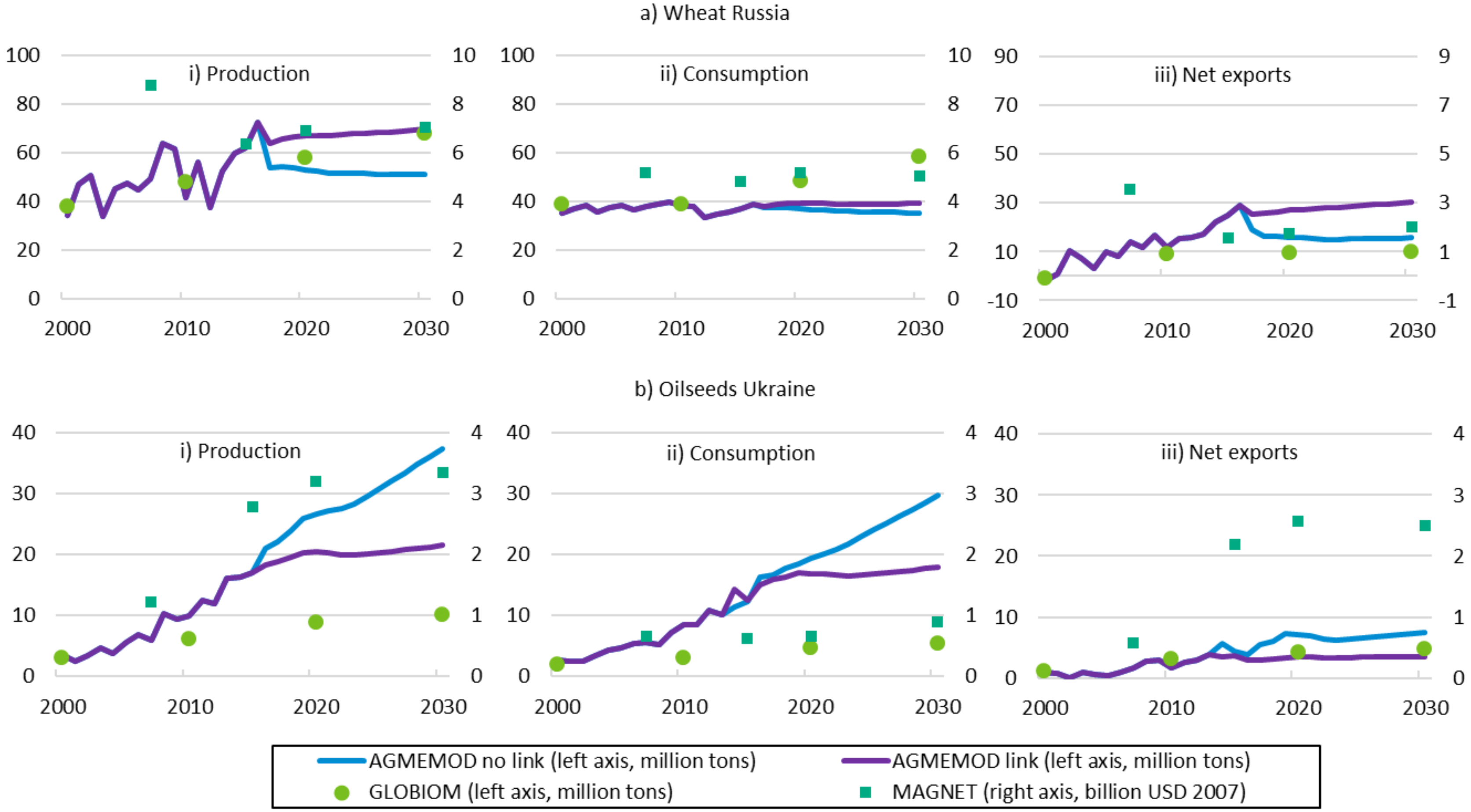


Note: no link = AGMEMOD projections without input of other models, link = AGMEMOD projections based on input from GLOBIOM and MAGNET, RUS=Russia, UKR=Ukraine, BAR = barley, COR = corn, grain = sum of all cereals, OSD = sum of all oilseeds, RPS = rapeseed, SBS = soybeans, SFS = sunflower seed

Source: own representation based on results from MAGNET and GLOBIOM, own AGMEMOD projections based on AGMEMOD, and the combination of AGMEMOD, MAGNET, and GLOBIOM.

The different results are consistent within their framework as shown in Figure 51 on the example of the wheat market in Russia and the oilseed market in Ukraine. From a market perspective the results can be judged as wrong, unlikely, or possible. In the case of wheat production in Russia, the model-individual developments seem to be in a possible range, even though production might be understated in ‘AGMEMOD no link’ and consumption overstated in GLOBIOM.

Figure 51 Results based on the individual models and linked model system for the Russian wheat market and the Ukrainian oilseed market, 2000 to 2030



Note: AGMEMOD no link = AGMEMOD projections without input of other models, AGMEMOD link = AGMEMOD projections based on input from GLOBIOM and MAGNET, Results for AGMEMOD and GLOBIOM are presented in million tons, for MAGNET in billion constant 2007 USD

Source: own representation based on results from MAGNET and GLOBIOM, own AGMEMOD projections based on AGMEMOD, and the combination of AGMEMOD, MAGNET, and GLOBIOM.

In the case of oilseed production in Ukraine, the picture is more heterogenous. Thereby, it becomes clear that up to date data and detailed sector representations are important to project possible results from a market perspective. For example, oilseed production in GLOBIOM is understated as the recent strong growth between 2000 to 2015 is not incorporated in GLOBIOM projections. The production levels in 2030 are far below already observed levels even though GLOBIOM projects an increase over time. 'AGMEMOD no link' might overstate its production growth in oilseeds in Ukraine as large yield growth levels are projected for oilseeds. By the adjustments based on GLOBIOM, this is corrected and a possible development presented. The additional projected production of Ukrainian oilseeds is exported in MAGNET which seems unlikely from a market perspective. The main oilseeds are sunflower seed and are traditionally crushed in Ukraine, i.e., export levels are low. Hence, in a baseline this development might most likely continue. For the rapeseed market, these reactions might be accurate but the share of rapeseed on total oilseed production is low (compare Section 4.1.4.1 below). Hence, the projected growth from MAGNET for trade but used in AGMEMOD which has lower export levels might be more realistic than the MAGNET stand-alone developments. In the case of the oilseed sector in Ukraine, the linked model system seems to project the best outcome from a market perspective

Concluding, a judgement of the accurateness of results between the models with respect to market developments is not straightforward. In other words, the question which model or model system tends more to be right cannot be answered as all models are correct given their framework and incorrect when trying to project reality. However, introducing yield changes based on GLOBIOM into AGMEMOD and trade changes from MAGNET into AGMEMOD seems to produce possible results, while individual model runs might be judged to be out of the scope of likely developments. This judgement is based on an individual market perspective but might be judged totally differently by other individuals, e.g., different modelers or market experts not using modelling.

The developed model link is a first approach to apply different models in the same context. Clearly, improvements are required to generate a credible model system and produce consistent results between the models. Due to the difference in data, theory, methodological specifications, and structural set up, attempting to create a two-way iterative model system bears the danger to produce a technically valid system which is meaningless as model (Voinov and Shugart, 2013). Therefore, this approach restricts itself to a one-way link where results of AGMEMOD are generated by including information from the other models. This changes the internal AGMEMOD structure and can only be justified for the current applications, i.e., Case Study 1 to 3 in Sections 4.1 to 4.3, and not transferred to other scenarios, products, and countries. Specifically, internal model feedbacks in AGMEMOD are omitted in the linked approach. These are yield changes depending on prices and consumption changes depending on changes in the livestock sector.

3.3.3 The link between MAGNET and LandSHIFT

One identified challenge for crop production is the availability of land for agricultural production (3). This is especially important when analyzing crop production growth. Is there enough land to produce food for a growing population, to satisfy a growing demand of animal products, and to additionally grow feedstocks for biofuel production (4)? Section 3.2.5 concluded that a model linkage between MAGNET and LandSHIFT is theoretically beneficial for global projections of cereal and oilseed markets and the analysis of changes in land use (3) and biofuel policies (4).

MAGNET gives projections about agricultural production depending on varying demand for agricultural goods. Further, MAGNET projects the accompanying land used for agricultural production considering a possible maximum available area for agricultural production as a given restriction. Land, as modelled in MAGNET, is defined as a heterogenous input between agricultural sectors through a nested CET structure but homogenous in a sector, i.e., omitting different potential yields per crop. This assumption might affect results, especially if land used for agriculture is expanding or declining. For example, the expansion of land for agricultural production can be accompanied with lower potential crop yields compared to land already used for agricultural production. Therefore, a linkage to a land use change model, like LandSHIFT, improves results with respect to land use by explicitly including socioeconomic and environmental landscape criteria, e.g., dominant land type, infrastructures, terrain slope and potential yields, as well as constrain criteria like protected areas as determinants for agricultural areas. This information is crucial especially for land which has not yet been used for agricultural production.

While MAGNET projects agricultural production from an economic perspective driven by demand as well as input and output prices, LandSHIFT distributes an exogenously given amount of production and determines land used on a five minutes of arc grid cell basis driven by socioeconomic and bio-physical properties as well as land cover and uses. The combined use of MAGNET and LandSHIFT brings these complementing features together and, hence, give a more precise projection about land use and production distribution between regions and crops. Through iterative data exchange and model runs, MAGNET learns from the distribution of production in LandSHIFT whether initial production of a product in a region is in line with bio-physically conditions.

3.3.3.1 Implementation of the model link

As defined at the beginning of Section 3.3, the linkage of models consists of five steps (see Figure 47, page 89) and its implementation is dependent on the research question, the model, and the linkage. The following paragraphs describe these steps for the newly developed two-way, sequential, iterative linkage between MAGNET and LandSHIFT which is applied in Case Study 4 (Section 4.4). This linkage is set up under the assumptions that a) MAGNET projections for supply and demand of agricultural products are accurate and b) LandSHIFT projections about land allocation are accurate. As stated in Chapter 3.2, both models – as all other applied models as well – are abstractions from reality and limited by their underlying theory, used data, applied coverage, and implemented relationships between variables. Hence, an improvement of the models other than their linkage is beyond the work of this dissertation.

Step 1: Identifying overlaps and intersections

For a successful model link, overlaps and common features of the involved model need to be identified. Further, the envisaged intersection of the models needs to be specified.

As described in Chapter 3.2, MAGNET and LandSHIFT are both dynamic, global models. Overlapping variables or parameters of the two models are population development, agricultural production, yields and area. Population development is an exogenous input to both models, while agricultural production is an endogenous outcome of MAGNET and an exogenous input to LandSHIFT. Agricultural yields and area are endogenous outcomes of both models. This is the intersection of the two models used for the model linkage. Hence, special attention must be given to the exact definition and modelling of yields and area.

Step 2: Mapping the coverage of the models

Before the actual linkage, the existing coverage in both models need to be mapped. In the case of MAGNET and LandSHIFT, these are the regional aggregation, agricultural products, and the variables for agricultural production, yield and area.

In MAGNET 134 countries or regions are distinguishable and in LandSHIFT regions are clustered according to 190 regions but any spatial formation on the grid level with cell size of five minutes of arc is possible. Both models are flexible in aggregating their regions for scenario analysis. Hence, the regional aggregation in MAGNET and LandSHIFT is harmonized by aggregating both models to 35 identical regions (see Table B2 in Appendix B). MAGNET distinguishes between eleven agricultural sectors, while LandSHIFT distinguishes between seven agricultural land use categories. Hence, agricultural sectors in MAGNET and agricultural land use categories in LandSHIFT are mapped resulting in seven overlapping agricultural sectors and land use categories for MAGNET and LandSHIFT, respectively (see Table B3 in Appendix B). The common variables and parameters, i.e., agricultural production, yield, area, and population, are mapped one-to-one. However, they differ in data and units. Hence, these are harmonized in the next step.

Step 3: Harmonization of data

The data harmonization ensures that the models start from a common database and facilitates the linkage, especially if a two-way sequential, iterative model link is implemented as in the current application. The common variables and parameters between MAGNET and LandSHIFT are few and manageable because data from only two databases need to be harmonized. Hence, a complete harmonization of the common starting values is implemented in contrast to the approach in Section 3.3.2.

Data on agricultural production, area and yields is harmonized by updating the currently implemented data published by the FAO in both models to the latest available data, i.e., data up to 2016 is included (FAO, 2020c). This update is implemented at the maximal disaggregated data level, e.g., for MAGNET this means 134 regions and 11 sectors, to fit the MAGNET philosophy of maximizing aggregation flexibility and to ensure the most exact initial distribution in LandSHIFT.

In detail, LandSHIFT requires agricultural production expressed in tons for crops and in livestock units for animals and uses data based on FAO (2020c) in its database when applied. In MAGNET, data on agricultural production is expressed in million US dollar based on Narayanan, Aguiar and McDougall (2012). Through the inclusion of satellite databases in MAGNET, the option of including physical volumes exists. Therefore, the infrastructure of the existing FAO satellite database in MAGNET is used and adjusted. Crop production data is updated by data published in FAO (2020a). Livestock production data is replaced by data published in FAO (2020f) and converted to livestock units by weighing the different animals with livestock unit factors according to the approach used in LandSHIFT (compare Section 3.2.4). The production data is expressed in three-year averages to level out fluctuations due to specific occurrences, e.g., weather impacts. In MAGNET, this data is mapped to the original production data and updated with the same volume percentage changes in projections. This approach includes some inaccuracy as physical data and value data match only if prices within an aggregate are identical (Delzeit *et al.*, 2020).

Both models express agricultural land use in physical area. In MAGNET, the FAO data on land use (FAO, 2020e) combined with FAO data on area harvested FAO (2020a) is updated similarly to the production data update. On this basis physical area is calculated as required for the land use module (compare Section 3.2.1). LandSHIFT uses the identical data as calculated by MAGNET for its initialization. The initialization in LandSHIFT results in slightly different areas per crop and regions and corrects the area for grassland (compare Section 3.2.4). Hence, in MAGNET, the land use data based on FAO is replaced with the land use data from the initialization of LandSHIFT. The combination of the updated production and land use data allows to calculate yields defined as production per physical area. Additionally, a new default asymptote in MAGNET representing maximal potentially available area for agricultural production (Section 3.2.1) is implemented based on the information from LandSHIFT. The asymptote is the sum of agricultural land and potential agricultural area including the land use categories of LandSHIFT as presented in Table B1 in Appendix B (for further details see also Section 3.2.4). The asymptote amounts to 10,763 million hectares in 2015 with 42 % used for agricultural production globally. As a consequence, the parametrization of the land supply function in MAGNET is based on this data update.

Both models need population figures over time from external data sources and are flexible in choosing a data source. Hence the populations figures as reported and projected in the 'World Population Prospects Medium Variant' by the United Nations (UN, 2017b) are used in both models. So, all common data between LandSHIFT and MAGNET is harmonized.

Step 4: Synchronization of scenario construction and assumptions

The identical construction of scenarios in each model and the synchronization of accompanying assumptions including their effects on common output variables are a prerequisite for a successful model linkage. As MAGNET and LandSHIFT are models designed for different purposes, no conflicts arise in the construction of the scenarios. The construction of scenarios is limited to deciding the general setting of the scenarios and the transfer of model specific assumptions, i.e., assumptions the other model does not include, to the other model.

The time scope for the scenarios is set from 2015 to 2030. Each model solves in five-year steps, i.e., three periods per scenario are run. As the model linkage is implemented per period this is important for Step 5. The starting point for the scenarios is set to 2015 even though the databases of LandSHIFT and MAGNET are 2010 and 2007, respectively. However, this is possible because of the update of the common data presented in Step 3 which includes historically observed data for 2015.

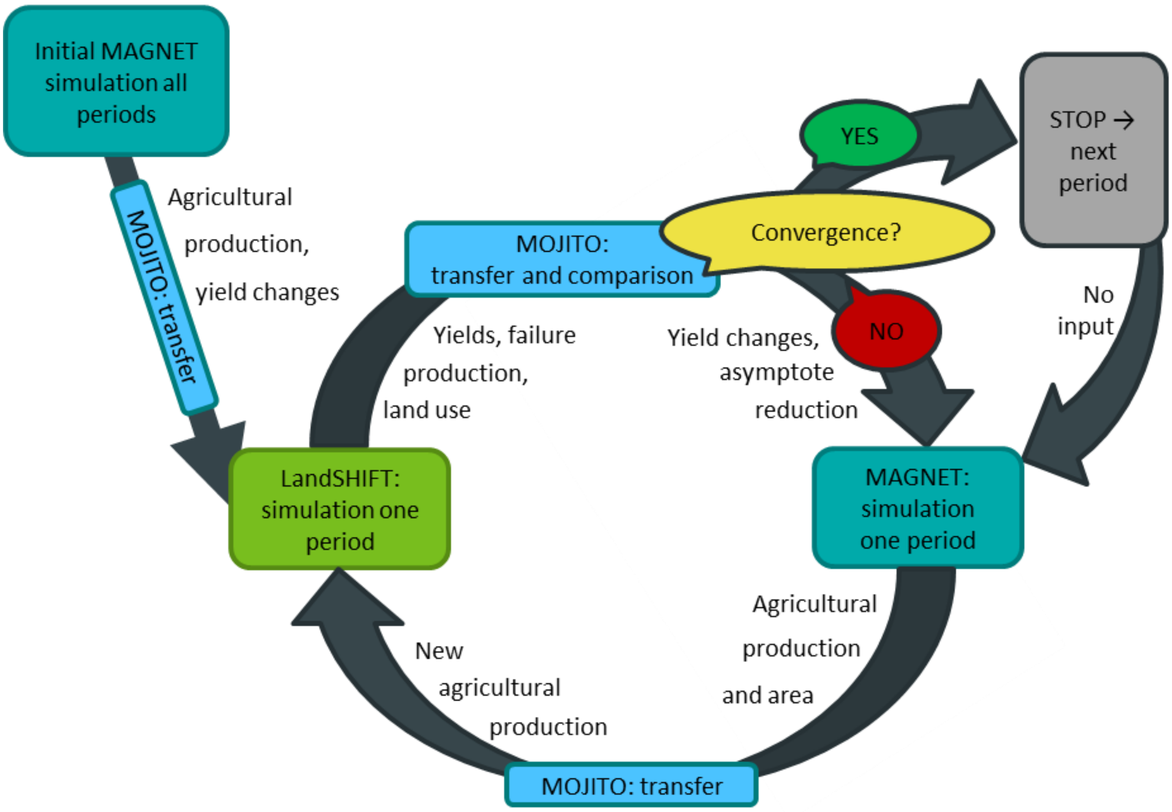
Population development is the only common assumption and it does not influence any common output of MAGNET and LandSHIFT directly. In MAGNET population development influences the provision of labor and the demand for products, while in LandSHIFT population development influences the area necessary for urban settlements and infrastructure. Hence, the harmonization of population development in the scenarios based on the same source is sufficient for the scenario construction.

Varying assumptions between scenarios which are included only in one model explicitly are transferred to the other model by giving the model a different level of input. To make this more explicit, the scenarios as later applied in Section 4.4 simulate different levels of area convertible to agricultural production and policies influencing the demand of crop-based biofuels. Therefore, protecting specific land use categories is simulated by LandSHIFT and transferred to MAGNET through the implementation of a new asymptote. MAGNET simulates different biofuel policies and gives new agricultural production levels to LandSHIFT. Hence, varying assumptions in the scenarios are included in the output of both models without the necessity to model them explicitly in both models.

Step 5: The model link

In Step 3, data between the models have already been exchanged and it could be argued that this is already a form of model linkage. However, this was necessary to bring the models to a common starting point. In Step 5, the actual model linkage is set up as pictured in Figure 52. In contrast to the model linkage as described in Section 3.3.2, a two-way approach is implemented with sequential, iterative model runs until joined results converge.

Figure 52 Schematic drawing of the model linkage between MAGNET and LandSHIFT



Source: own representation

As Figure 52 shows, the starting point of the iteration is an initial unlinked MAGNET simulation that includes the land use data based on the initialization for 2010 and the land use data based on the FAO update for 2015 (compare Section 3.2.1). The resulting agricultural production and average yield changes per sector and region are given to LandSHIFT via an Excel file generated by MOJITO. In this model linkage MAGNET and MOJITO are closely linked, while LandSHIFT only sends and receives standardized data files.

LandSHIFT uses the percentage changes of the average yields per sector and region as an exogenous shifter to potential yields per grid cell, i.e., yield changes from MAGNET represent overall technological progress over time in LandSHIFT. It is important to note that the same exogenous shifters are used in the iterative runs as well. Then LandSHIFT allocates the given production per sector and region from MAGNET according to their model algorithm (compare Section 3.2.4, Schaldach *et al.* (2011) and Schüngel (forthcoming)). This leads to different land demand and average yields than projected by MAGNET because LandSHIFT explicitly considers the yield per grid cell while MAGNET assumes that all land within a country has the same yield. Over time, maximal potentially available area for agricultural production changes in LandSHIFT with changes in urbanization due to population changes (compare Section 3.2.4 and Schüngel (forthcoming)). Furthermore, the case exists that LandSHIFT is not able to allocate all agricultural production projected by MAGNET in a region when the available area is not suited for agricultural production (for specific definition see Section 3.2.4 and Schüngel (forthcoming)). This outcome of the LandSHIFT model is given in form of an Excel file to MOJITO which reads in all data for further comparison, processing, and transfer to MAGNET.

The LandSHIFT outputs about average yields per crop and region, changes in the maximal potentially available area for agricultural production per region, and the inability to allocate all agricultural production per crop and region are important inputs for the next run with MAGNET. The information about yields is used to calculate a shock in yields between periods according to the following equation:

$$\Delta\%y = \frac{\frac{y_{LS_t} + y_{M_t}}{2} - y_{M_{t-1}}}{y_{M_{t-1}}} \qquad \text{(Eq. 3)}$$

with $\Delta\%y$ being the implemented shock in the next iteration run of MAGNET in the form of percentage change $\Delta\%$ in yields y from period $t-1$ to t, y_{LS} being the yield from the current LandSHIFT model outcome and y_M being the yield from the last MAGNET model outcome.

In MAGNET, changes in yields are determined by an exogenous part $\Delta\%\beta$ representing technical change, such as improved crop varieties through breeding, and an endogenous part reacting to price changes and representing input substitution, such as between land and fertilizer. Hence, in order to shock total yields per sector and region from one period to the other, MAGNET is extended by the following equations:

$$\Delta\%y = \Delta\%p - \Delta\%l \qquad \text{(Eq. 4)}$$

with p being production and l being land use per sector and per region. The yield shock is then implemented by swapping $\Delta\%\beta$ with $\Delta\%y$, i.e., total yields become exogenous and technical change endogenous. This implies implicitly that changes in yield have a larger influence on land use than on production which is logical in the current application as LandSHIFT does not give us information about how much is produced but only about how much land is needed for given production levels.

Changes in the maximal potentially available area for agricultural production due to urbanization are implemented as shocks to the asymptote in MAGNET according to the following equation:

$$\Delta\%\alpha = \frac{\alpha_{LS_t}}{\alpha_{M_{t-1}}} - 1 \qquad \text{(Eq. 5)}$$

with $\Delta\%\alpha$ being the implemented shock in the next iteration run of MAGNET in form of percentage change of the asymptote from period $t-1$ to t, α_{LS_t} the calculated maximal available area for agricultural production based on the current LandSHIFT run for the current period and $\alpha_{M_{t-1}}$ the asymptote from the last MAGNET model outcome from the previous period. The asymptote is further shocked, if LandSHIFT is not able to allocate all agricultural production in a region by recalculating the α_{LS_t} as follows:

$$\alpha_{LSadj_t} = \alpha_{LS_t} - \max(0.5 \cdot b_t, f) \qquad \text{(Eq. 6)}$$

with α_{LSadj_t} being the recalculated asymptote based on the LandSHIFT output, b_t the sum of all land in the asymptote that is currently not used for agricultural production and f being the area that would be required to produce the not allocated agricultural production assuming average regional yields based on the LandSHIFT output. Hence, the equation for the implemented shock to the asymptote changes to:

$$\Delta\%\alpha = \begin{cases} \frac{\alpha_{LSadj_t}}{\alpha_{M_{t-1}}} - 1, \text{if } f > 0 \\ \frac{\alpha_{LS_t}}{\alpha_{M_{t-1}}} - 1, \text{if } f = 0 \end{cases} \qquad \text{(Eq. 7)}$$

These shocks are automatically calculated by MOJITO and transferred to the MAGNET data shock files. In MAGNET, the linked scenario is set up by including these data shock files and the required command shock files for the current period. MAGNET is then run for this period and resulting data in form of new production volume is given back to LandSHIFT. LandSHIFT is run for the same period and allocates this new production volume to area endogenously. The same output as in the previous LandSHIFT run is given back to MAGNET and MAGNET is run again for the same period with different shocks in yield and asymptote. While changes in yield occur in all sectors and regions, a change of the asymptote only occurs if production could again not be allocated in a region. Hence, the shock of the asymptote changes in the iterative process until all production from MAGNET can be allocated to area by LandSHIFT and stays constant in successive iterative runs. This iterative process is continued until the converging variable, i.e., in this case land demand for each sector and region, meets the defined convergence criterion.

This convergence criterion is: the differences between land demand per sector and region in both model outcomes need to be less than 2 % or less than 100 km². The percentage change was set to 2 % because in test runs it was observed that in several cases changes in land use jumped around 1.5 % between the successive runs of the models and, hence, convergence did not improve. Additionally, iterations with little changes in the outcome seem to be not worth the effort of an additional iterative run as the model linkage is not fully automated. The criterion must hold true for all sectors except one and all regions except one and 98 % of the possible cases must converge. For example, one sector in several countries and several sectors in one country can be above the criterion and convergence is still achieved. Further, in the current application with 35 regions and seven sectors, five cases need not converge. These exceptions are necessary because not all cases converge due to small scale production or underlying data issues.

If the convergence criterion is meet after a LandSHIFT run, the next period is run iteratively in the same fashion. First, MAGNET is run without shocks from LandSHIFT but based on the iterative result of the previous period. Then LandSHIFT allocates the new production for this period again. Afterwards, the linked scenario in MAGNET is set up and iteration starts until the convergence criterion is met for the period.

The implemented model link is neither changing the structure of the models nor replacing parts of a model as compared to other linking approaches, e.g., van Meijl *et al.* (2006), Böhringer and Rutherford (2009), or Pelikan, Britz and Hertel (2015). Already existing parameters, shocks and equations are used. In the case of MAGNET, only one new equation is introduced. Hence, the link can be said to be minimally invasive. This approach has the advantages of a) being easily transferable to newer model versions, b) allowing the models to be run as stand-alone if appropriate, c) building upon the validated theories of the models without changing them and, d) achieving consistency through an automated iteration process between the models. However, model linkages are always model dependent and the developed approach could only be implemented because of the minimal overlapping of common variables, parameters and assumptions between the two models.

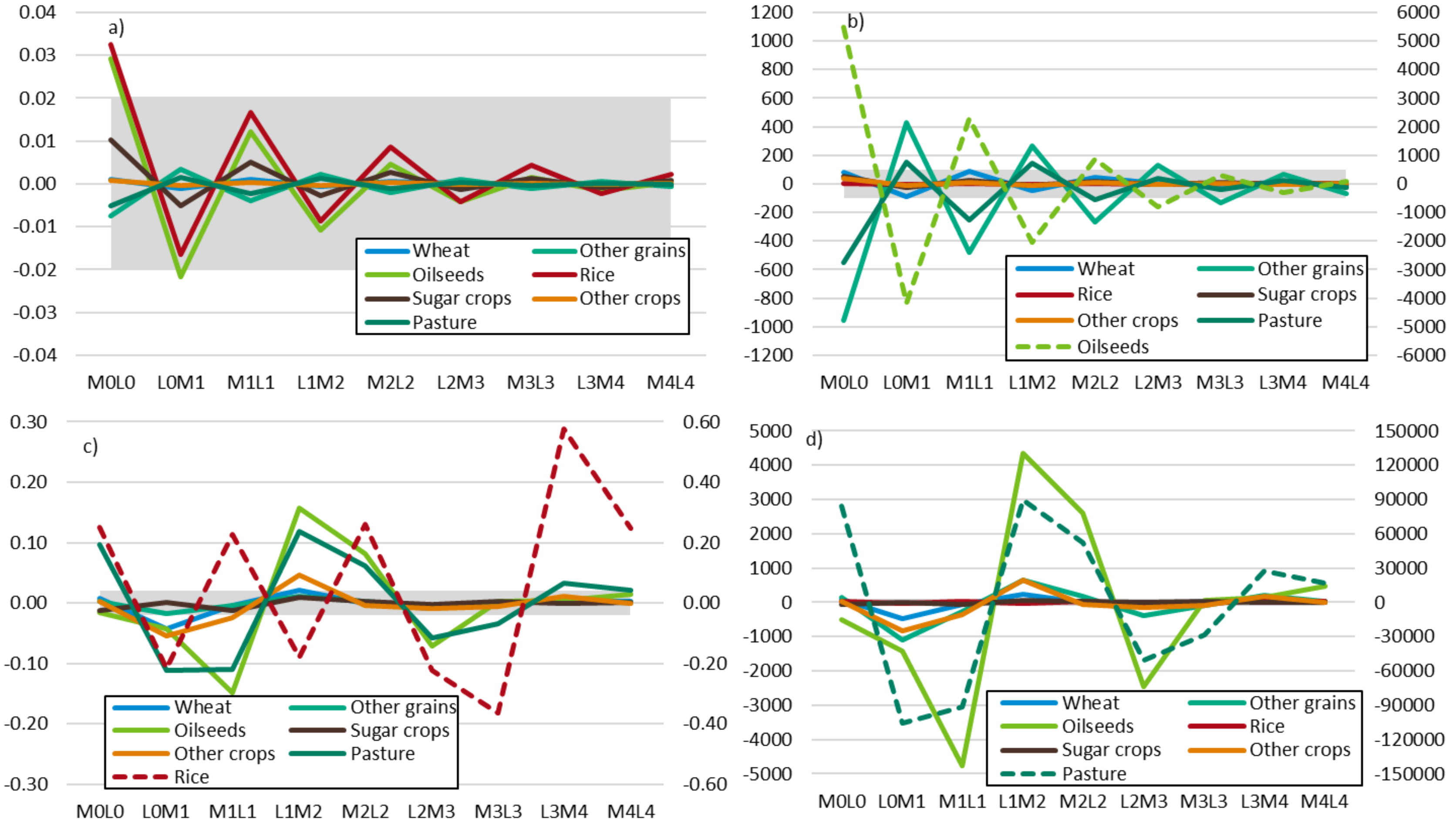
3.3.3.2 Discussion of the implemented model link

This model link is successfully applied in all scenarios of Case Study 4 (compare Chapter 4.4). In Chapter 4.4, the content-relevant results of these scenarios are presented and discussed, while here very specific and selected results including temporary results of the iterative steps are presented to demonstrate and justify the approach of the model link.

The largest differences between the models occur in the first linked period, i.e., 2015 to 2020. Comparing the first LandSHIFT run of a period with the first MAGNET run, 143 to 214 out of 245 cases are already below the convergence criterion. In the scenarios of Case Study 4, three to seven iterations per period are required to complete the model link according to the convergence criterion.

In most cases, area per sector and region converges at a fast pace. As an example, one period of a scenario, i.e., 2025 to 2030 for the scenario ProBio (described in Case Study for in Section 4.4.3.3 below), is selected to demonstrate the iterative process. The period started with 50 cases above the convergence criterion and ended after four iterations with three cases above the criterion. As an example, Figure 53 shows these changes between the iterative model runs for two selected regions, i.e., 'Ukraine Belarus Moldova' and South Africa, representing typically observed developments.

Figure 53 Changes in area between iterative model runs for the period 2025-30 in the scenario ProBio on selected examples



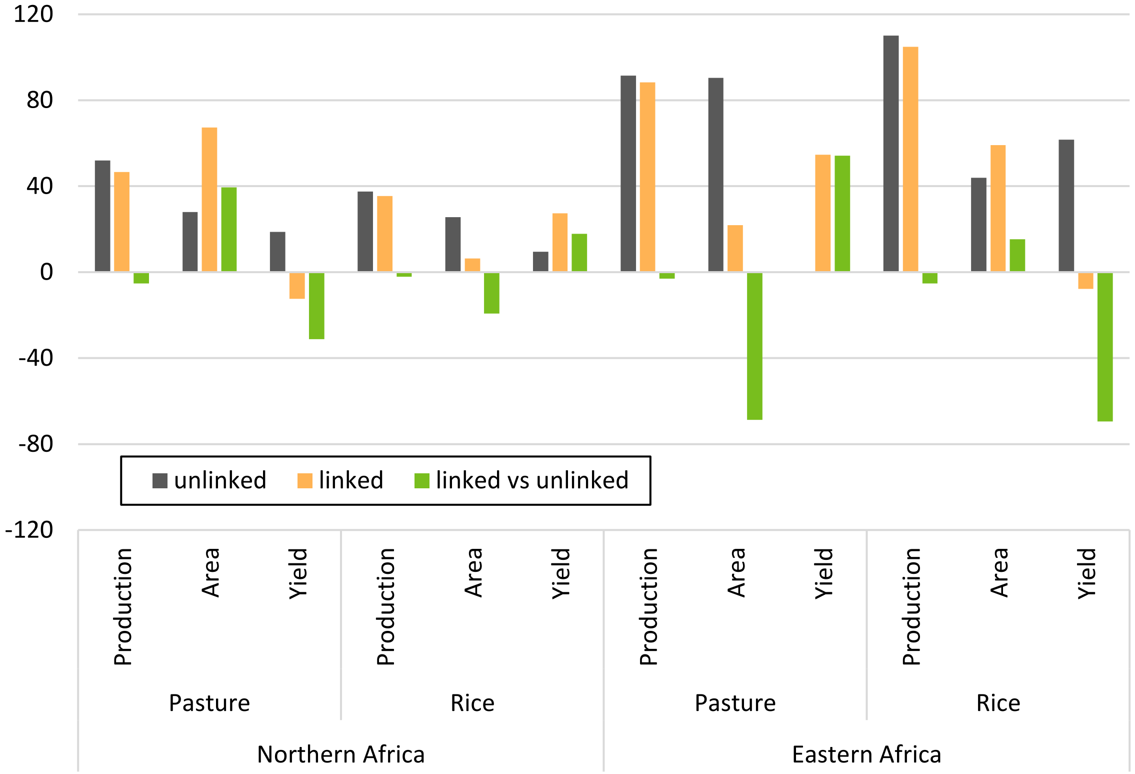
Note: 1. a) represents percentage changes between iterations in the region 'Ukraine Belarus Moldova', b) represents absolute changes between iterations in the region 'Ukraine Belarus Moldova', c) represents percentage changes between iterations in South Africa, d) represents absolute changes between iterations in South Africa, 2. M= MAGNET, L=LandSHIFT, 0-4 corresponds to the model runs ,e.g., M1L1 equals the change from the first MAGNET iteration to the first LandSHIFT iteration. 3. Dotted lines correspond to the left axis. 4. The grey field indicates the results which are within the convergence criterion for the left axis only

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

The region 'Ukraine Belarus Moldova' represents an example of perfect convergence. While at the beginning two sectors are above the convergence criterion, after the 2nd MAGNET run, convergence is already complete with all sectors below the criterion of 2 % differences between the model runs (Figure 53a). Additionally, all sectors converged further in the successive runs, so that after four iterations also the absolute difference between the 4th MAGNET run and the 4th LandSHIFT run is below the criterion of 100 km² (Figure 53b). In South Africa, convergence looks less smooth (Figure 53c and d). At the beginning, only pasture is above the convergence criterion but LandSHIFT was not able to allocate all production of pasture. Hence, in the first iterative MAGNET run the asymptote is additionally shocked according to (Eq. 7). This results in new production levels for all sectors and three sectors are above the convergence criterion after the 2nd LandSHIFT run. After four iterations, two of these sectors, i.e., oilseeds and other crops, are below the convergence criterion, while pasture is very close to it. Rice in South Africa is a good example to demonstrate why the convergence criterion must be 2 % or 100 km². In percentage terms, rice does not converge but in absolute values rice is so small that LandSHIFT only allocates one to two grid cells to the production of rice. As one grid cell is the minimal resolution in LandSHIFT the model cannot be more detailed and, hence, a small technical inaccuracy occurs in specific cases (compare Section 3.2.4).

From a MAGNET perspective, the linkage with LandSHIFT improves the projections on land demand for different agricultural products in the different regions. Comparing the initial MAGNET runs with the final linked runs, several observations can be made. First, the influence of LandSHIFT on global agricultural production levels is low, i.e., varying in the four scenarios between 0.07 % and -1.18 %. This is in line with expectations. Second, global land demand expands less in the linked model runs than in the initial model run in all four scenarios. This result is contrary to initial expectations. Hence, MAGNET as stand-alone model overstates the need to convert land into agricultural production given the current model settings and assumptions. In the linked scenarios, land that is additionally used for agricultural production from 2015 to 2030 is between 22.6 % and 39.1 % lower than in the unlinked scenarios corresponding to a maximum of 2.4 million km², i.e., nearly 5 % of global agricultural area or the territory of Algeria. The global level gives first insights and a brief overview of the linked approach, while it omits several aspects further justifying the linked approach, especially developments at the regional and sectoral level. Showing all variations in all sectors, regions and scenarios would be excessive and is neither necessary nor constructive. Hence, two sectors in two regions from the baseline (described in Section 4.4.3.3 below) are selected and presented here to underline the justification of the linked approach. The regions Northern Africa and Eastern Africa are strongly expanding agricultural area, i.e., between a minimum of 28 % and a maximum of 68 % from 2015 to 2030, and are corrected through the linked approach differently. In Northern Africa, area expansion is higher in the linked outcome than in the unlinked MAGNET outcome, while in Eastern Africa it is lower. Even between the sectors the behavior varies. Figure 54 shows the percentage change for production, area and yield between 2015 to 2030 for the linked and unlinked scenarios for the sectors pasture and rice in Northern Africa and Eastern Africa and the percentage point difference between them.

Figure 54 Comparison of unlinked and linked simulation from 2015 to 2030 in the baseline for production, area and yield for selected products and regions, %

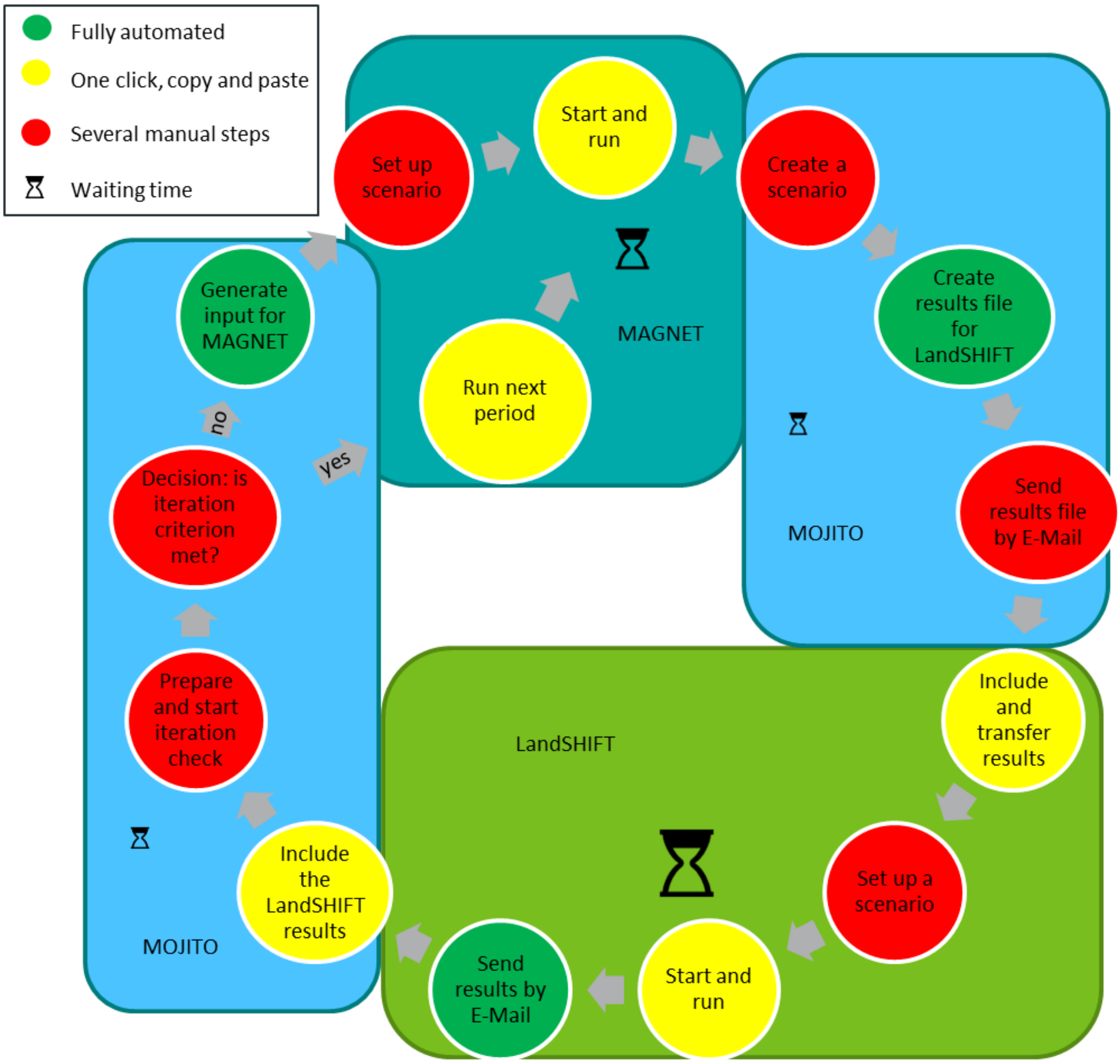


Note: Grey and orange = percentage changes, green = percentage point differences between unlinked and linked simulation
Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

It can be observed that a) production changes only slightly between the runs, b) yield reductions from the unlinked to the linked outcome results in area increases and the other way around, c) in Northern Africa the area for pasture and in Eastern Africa the area for rice is less productive in the linked scenario than in the unlinked scenario resulting in area expansion to satisfy production levels and d) for pasture in Eastern Africa and rice in Northern Africa the areas used for production are more productive in the linked scenario compared to the unlinked scenario. Further, the sector pasture is the predominant factor why overall land use in a country is corrected up or downward. These two cases demonstrate the variety of adjustments using the linked approach and the resulting corrections with respect to realizable yields and required area. MAGNET – without the link to LandSHIFT – would have overstated the additionally required area in Eastern Africa by 37 percentage points and understated it in Northern Africa by 30 percentage points.

In order to validate the linked approach, additional scenarios with varying assumptions and model settings, i.e., sensitivity analysis, could be conducted. Therefore, it is necessary to automate the linked approach further as it requires at the current state several manual steps by the modelers to run the next iteration and, hence, is very time consuming. Figure 55 shows the technical steps during the iterative model run. While some steps are already fully automated, others are partially automated and need manual interference by the modelers.

Figure 55 Technical steps during the iterative model runs between MAGNET and LandSHIFT



Source: own representation

The manual steps could be automated by completely integrating both models in MOJITO and running the whole system on one server. However, this further automatization of the linkage is beyond the scope of this dissertation.

3.3.4 Discussion of developed links

Theoretical considerations led to the conclusion that a model linkage between the different models is beneficial to answer the envisioned scenario analyses. From a methodological point of view, a two-way linkage is preferable to a one-way linkage. However, this is not the case from a theoretical nor practical point of view. Models rely on a consistent theory and, hence, interfering too much into the model itself might result in meaningless results (Voinov and Shugart, 2013). Further, the practical linkage of models needs to overcome multiple challenges (compare Step 1 to 4) before the actual link can be constructed (Step 5). The degree of overcoming these challenges, restricts the implementable link. Achieving a two-way model link requires that overlapping features are little and the databases are aligned in these overlapping features. While this is also desirable for a one-way model link, it is not a strict prerequisite.

One aim of linking existing models is to avoid constructing a model from scratch to answer a specific research question and, hence, save time and resources. Therefore, the model link itself should include these aspects, i.e., implementing the link and applying the resulting model system should save time and resources. This has been realized by developing and applying the MOJITO tool which automatizes repetitive steps. Hence, MOJITO is a useful tool to save time and avoid errors.

The developed link between AGMEMOD, GLOBIOM, and MAGNET is only a first approach to combine the advantages of the different models. From a methodological point of view, additional research is required to align the models further as overlapping results are currently inconsistent between the models. At the moment, obstacles for a successful model link outweigh possible envisioned benefits given the various overlaps of projected results and the differences in the individual models with respect to data, theory, coverage, units, base years, and structure. Hence, the application of the model link is limited.

The developed link between MAGNET and LandSHIFT is a successful two-way iterative link between the two models. This model link could be applied in other research with a focus on global land use changes. Further research to refine the model link is possible. For example, the information that not enough suitable land for production is available in a region is translated in an ad hoc manner from LandSHIFT to MAGNET. This translation could be adjusted.

3.4 Discussion and conclusion

Applied economic models are used for ex-ante analysis of cereal and oilseed markets. They are built on neo-classical microeconomic theory and incorporate different factors directly impacting these markets, e.g., population change, income development, and policies. Economic models can be distinguished between PE and CGE models. PE models represent specific sectors in detail, while CGE models cover the economy as a whole. Bio-physical and land use change models can contribute to a specific analysis through representing bio-physical properties and land use changes in detail which the stand-alone economic model only includes by rough approximations or not at all. Therefore, model linkages between existing large-scale models across research disciplines are developed.

In this dissertation, two different links are developed to analyze the consequences of closing of yield gaps (1), changing trade policies (2), land use change (3), and enhanced biofuel policies (4). First, AGMEMOD, GLOBIOM, and MAGNET are combined in a one-way approach where AGMEMOD receives information from the other two models to analyze (1), (2), and (3). Second, MAGNET and LandSHIFT are linked in a two-way approach to analyze (3) and (4). The stand-alone models are consistent within their framework as has been demonstrated in various publications. A linkage of models is not as straight forward as suggested by some applications presented in the literature and need to overcome several challenges.

First, a basic understanding of the models is required to identify similarities and dissimilarities between the models. This identifies common features of the models which can act as intersection for the model link. Additionally, it is especially relevant to be aware of the model boundaries, i.e., the existing underlying relationships in a model but also the simplified or omitted relationships. For example, the representation of trade can vary from depicting only total net trade of a region to bilateral trade flows between different regions. Further, the awareness of detailed definitions and specification of common features is necessary. An example, relevant for both linkages, is the definition of exogenous technological progress for yields in each model. In the chosen models, yield productivity includes an exogenous part but also a model-specific endogenous part. To identify the differences, it requires a close cooperation between the different modeling teams and any attempt to link these models has to consider these differences to achieve a meaningful and successful model link.

Second, the application of any model is limited by their respective specification with regard to sectoral, regional and variable coverage. For a successful model link, a mapping between the common coverage is necessary. Regions and sectors need to be aggregated to a common level. Additionally, differences in definitions need to be considered, e.g., are prices expressed in real or nominal terms and in what currency or is land use specified as physical area or harvested area?

Third, harmonizing common data, i.e., using the same source and year, facilitates a model linkage and is a prerequisite for an iterative two-way approach where results converge. This can also be assured by using satellite databases such as in the case of MAGNET where physical units are not present in the model but can be mapped to volume changes. This has been implemented for crop production to have a common ground with LandSHIFT. Often a complete harmonization of all common data is not feasible if large-scale models are linked and have many common features such as PE and CGE models. The differences in data sources but also units are large and harmonization would require time and resources which were intended to be saved by applying a model link and building on existing work.

Fourth, the models need to be synchronized. This means the projection period, common exogenous assumptions, and scenario constructions need to be similar and comparable. This is an absolute prerequisite for a model link but is also important if model results are compared across models. While the alignment of the projection period and common exogenous assumptions is straight forward, scenario construction needs careful consideration and might be least synchronized. For example, if a scenario restricts land available for agricultural production, each model including agricultural land need to simulate this restriction. Parts of the scenario construction which are not included in each model, require transfer via information from one model to the other and are realized through the implemented link. For example, changes in yield due to closing of yield gaps are only modelled in GLOBIOM. This is transferred to AGMEMOD by exogenously changing AGMEMOD yields based on the information from GLOBIOM.

Fifth, the technically correct implementation of a model link is another obstacle and implementing a useable and meaningful link even more challenging. For the technical part, additional software such as the developed MOJITO, facilitates the model linkage. Implementing a meaningful link also requires the models themselves to behave similarly given the same assumptions. This might require changes in the models' parametrization or even methodology. For example, higher technical process in the production of wheat in Russia should *ceteris paribus* lead to increased yields. Resulting market adjustments, e.g., in prices, production, demand, trade, and land use, depend on the defined relationships in the models. These adjustments should be similar for all common variables, i.e., at least going in the same direction and preferable also have a similar range. This includes not only reactions on the wheat market in Russia but also reactions in other crop or even livestock markets and in other countries. This is clearly not achieved in the one-way link between AGMEMOD, GLOBIOM, and MAGNET as the model's internal relationships stay heterogenous for common variables. Hence, the link between AGMEMOD, GLOBIOM, and MAGNET can only be judged to be meaningful in the chosen applications and is not transferable to other applications. In contrast, the two-way link between MAGNET and LandSHIFT is generally meaningful and, hence, might be used for different applications if desired. The few overlaps between MAGNET and LandSHIFT as well as the data harmonization are seen to have contributed the most to this achievement.

Some challenges have not been overcome yet and are beyond the scope of this dissertation. First, resources might not have been saved as the development of the model link is time-consuming. Each individual model is an abstraction from reality and needs to be understood first. Additionally, having a closer look at the models reveals imperfectness. Therefore, the models have been adjusted and updated for the current application and the model linkage implemented afterwards. Nevertheless, imperfectness will most likely persist in large-scale models as there are many possibilities where errors can be made starting from data use over coding to result interpretation. This is similar for the model link. Hence, given the rough approximations a model system is able to simulate it is questionable whether or not it is worth the effort.

Second, the validation of the developed links is limited to the technical implementation and applications in the case studies. There is no standard method on how to validate the individual large-scale models or even a system of models. In fact, Britz *et al.* (2012) point out that user feedback, applications and peer reviewed publications might be the only possible validation. Uncertainty or sensitivity analysis are possible but incomplete approaches. They are partly executed in the case studies (compare Section 4.1).

Third, the maintenance and reuse of the developed link, is possible for the link between MAGNET and LandSHIFT but incurs high costs. The models are hosted at different institutions and various property rights need to be considered which hinder the possibility of cooperation. The reuse of this link depends on a new research question which would probably require adjustments in the involved models as well as in the model linkage. Additionally, the models themselves are constantly updated which would require an update of the link. Resources are limited as new analysis with the link would require additional funding.

The development of software facilitating a link, such as MOJITO, saves time and reduces copy and paste errors. Such a tool, if implemented fully, would facilitates running the whole model system repetitively, e.g., for new applications and sensitivity analysis. Additional effort is required to fully automatize the model link through MOJITO, i.e., running the whole model system without manual steps in between. However, this is only practical if a long-standing relationship and joined applications are a common future aim of the involved institutes as additional efforts are necessary to get the system working. These efforts include building up a common infrastructure and adjusting MOJITO further.

Concluding, some envisioned advantages of model linkages can be questioned. Are time and resources saved by combining large-scale models for specific research questions or should the research question be analyzed by other means? Can projections be improved just by using more data, more detail, and more models? How can consistency across models be ensured? Nevertheless, both developed model links are justifiable which is underlined by their application in the case studies (Chapter 4).

4 *Ex-ante* analysis of cereal and oilseed markets

The development of cereal and oilseed markets is uncertain and depends on the uncertain developments of numerous factors which impact them as shown in Chapter 2. Focusing on long-term drivers, four factors and their influence on cereal and oilseed markets have been identified to be important (Section 2.4) and are analyzed in this chapter. Again, these four factors are closing of yield gaps (1), trade policies (2), land use change (3), and biofuel demand (4). They are a) highly uncertain, b) directly impact cereal and oilseed markets, c) influenced by the behavior of actors in the markets, d) changeable through policy intervention, and e) most probably not following observed historical trends in the future. Therefore, four case studies are undertaken to address these factors. Table 12 gives an overview of the case studies.

Table 12 Overview of the case studies

	Factors addressed	Model system applied	Regional coverage	Scenarios
Case Study 1	(3)	GLOBIOM, MAGNET, and AGMEMOD	Ukraine and Russia	baseline for Case Study 2 and 3
Case Study 2	(1) and (3)			increased intensification and productivity in production
Case Study 3	(2)			liberalization vs. increased protection
Case Study 4	(3) and (4)	LandSHIFT and MAGNET	global	baseline, biofuel scenario, land protection scenario, combination of biofuel and land protection

Notes: factors:(1) = closing of yield gaps, (2) = trade policies, (3) = land use change, (4) = biofuel demand
Source: own representation

A range of possible pathways is presented by setting up scenarios within the developed model systems (compare Chapter 3), and the impact of variations in the chosen factors on cereal and oilseed markets is quantified. Additionally, other factors which impact cereal and oilseed markets are explicitly considered in the analysis but not varied. These are represented by exogenous drivers, e.g., population and GDP development, or modelled sectors, e.g., the livestock sector.

Case Studies 1 to 3 address the factors (1) to (3) and are presented in Sections 4.1 to 4.3, respectively. Therefore, Ukraine and Russia are selected as study regions because they could increase a) their yields through intensification, b) change their trade policies, and c) recultivate land that is currently idle but had been used for agricultural production in the past. First a baseline is developed which is presented in detail in Case Study 1. Case Studies 2 and 3 built upon this baseline and present scenarios of closing yield gaps and trade policy changes, respectively. For the analysis, the developed model system of GLOBIOM, MAGNET, and AGMEMOD is used (compare Section 3.3.2).

These three case studies expand on the work done in the scope of the AGRICISTRADE project, funded by the EU Commission (for more details visit https://cordis.europa.eu/

project/id/612755). This dissertation would not have been possible without the project and the different research teams involved. Special thanks go to our Ukrainian partners at the Institute for Economic Research and Policy Consulting (IER) and our Russian partners at the Institute for Agricultural Market Studies (IKAR), who provided the data used in AGMEMOD, the GLOBIOM team at the IIASA who updated and generated results from GLOBIOM, and the MAGNET team at WEcR who updated and generated results from MAGNET. Contributions of the author are a) the database and model updates of Russia and Ukraine in AGMEMOD based on the provided data, b) the developed model link between AGMEMOD, GLOBIOM, and MAGNET (compare Section 3.3.2), c) the coordination of the baseline and scenario runs, d) the results generated by AGMEMOD, and e) the analysis and presentation of the results generated by the model system.

Case Study 4 addresses the factors (3) and (4) and is presented in Section 4.4. Therefore, a global perspective is selected to quantify the effects and interlinkages of land preservation on the one hand and biofuel expansion on the other hand. The two options are possible pathways to tackle climate change but might contradict each other as the increased use of biofuels requires more land for agricultural production. The developed model system between MAGNET and LandSHIFT is applied (compare Section 3.3.3).

The work builds on the work done in the Meilensteine2030 project (Thrän *et al.*, 2015). This dissertation would not have been possible without the close collaboration between the Thünen Institute and CESR. Enormus thanks go to Jan Schüngel who is responsible for the input from LandSHIFT and the setup of the assumptions on land use in the scenarios. Additionally, the setup of the model link between LandSHIFT and MAGNET is an outcome of joint work. Contributions of the author are a) the setup and application of the MAGNET model, b) the setup of the assumptions on biofuel use in the scenarios, c) the setup of the data exchange between the models via MOJITO, and d) the analysis and presentation of the results generated by the model system.

The chapter closes with a discussion of the results from all case studies and their implications for the future of cereal and oilseed markets. One highlight is that the subsectors of cereals and oilseeds might develop quite differently depending on the scenario and region.

4.1 Projections for Ukrainian and Russian cereal and oilseed Markets[6]

Cereal and oilseed production in Ukraine and Russia have expanded strongly in the last few years. Hence, Ukraine and Russia became important exporters of cereals and oilseeds and their processed products (compare Section 2.2). The dominant aim of this case study is to project the development of cereal and oilseed markets in Ukraine and Russia until 2030 and, hence, lay the foundation to analyze closing of yield gaps (1), trade policies (2) and land use changes (3) which are explored in depth in Case Study 2 and 3 (Section 4.2 and 4.3). Thereby, the focus lies on the assessment of whether the analyzed markets can grow as dynamically as observed in the recent past or whether constraints are reached hindering this development. These baseline projections are generated by applying the developed model link between AGMEMOD, GLOBIOM and MAGNET (compare Section 3.3).

This case study, i.e., Case Study 1, is structured as follows. Section 4.1.1 motivates the necessity of applying a system of models to analyze cereal and oilseed markets in Russia and Ukraine, followed by brief descriptions of the economic environment of Russia and Ukraine with a focus on the agricultural sector in Section 4.1.2. The applied method, data and underlying assumptions for the projections are presented in Section 4.1.3. In Section 4.1.4, historical and projected developments of cereal and oilseed markets for Russia and Ukraine are presented. Based on these projections, sensitivity analyses are conducted (Section 4.1.5), results are compared to other projections (Section 4.1.6) and actual historical developments (Section 4.1.7), before Section 4.1.8 concludes.

4.1.1 Motivation

Ukraine and Russia have become important global players in agricultural markets, especially for cereals and oilseeds. Their cereal and oilseed production increased over the last years due to increases in area harvested and yield and have the potential for further increase. This increased production was mainly exported. Hence, Russia and Ukraine became important players on international markets, especially for wheat, corn and processed sunflower products. However, the future development of Ukrainian and Russian cereal and oilseed sectors are uncertain and depend on international developments, e.g., global supply and demand and trade relations, as well as on national developments, e.g., income development, exchange rates, land expansion and management practices to realize potential yields.

In general, these uncertainties exist for the future development of most markets at national and global level (compare Section 2.3). Therefore, there is a long tradition of projecting agricultural market developments with PE models. The most prominent examples are the OECD/FAO outlook (OECD and FAO, 2016) based on the AGLINK-COSIMO model (OECD, 2015a) and the USDA outlook (USDA, 2016a) based on model results and judgment-based analysis (USDA, 2016b). They provide 10-year projections for the largest producing countries as well as for regional and global levels annually. Other projections focus on

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[6] This chapter is based on own work by the author within the AGRICISTRADE project and presented at the IAMO Forum 2017 as Wolf and Banse (2017). It represents an extension in content and towards Russia. Consequently, the most recent data refers to 2015 and an analysis of the implications of the Russian invasion of Ukraine in 2022 is not included.

regions or single countries. A modified version of the PE model AGLINK (iMap modelling team, compiled by Nii-Naate, Z., 2011) has been applied for the EU outlook (European Commission, 2016), and AGMEMOD has been applied for country specific projections, e.g., for Ukraine (van Leeuwen et al. 2012) and Russia (Salputra *et al.*, 2013).

These projections, however, only poorly represent two aspects which are relevant for the projection of cereal and oilseed markets in Ukraine and Russia. First, trade relations are not presented bilaterally. Ukraine and Russia are major exporters of cereals and oilseeds, and their production depend on demands from other countries. Hence, changes in bilateral trade relationships impact cereal and oilseed markets. Second, different bio-physical properties of the agricultural area which affect yield levels and area allocation are not considered. Ukraine and Russia have the potential to further increase its yields (Balkovic *et al.*, 2015) and put more land into agricultural production (Schepaschenko *et al.*, 2015). Therefore, an approach is necessary which explicitly includes these two aspects in the general PE approach. As a solution, the PE model AGMEMOD is applied in combination with GLOBIOM and MAGNET as described in Section 3.3.2. As stated in this Section 3.3.2, each model contributes its own strengths to the model system. AGMEMOD contributes an updated database, detailed sectoral representation, and annual projections based on historical time series estimations. GLOBIOM contributes information on land use changes and yield developments based on bio-physical properties, while MAGNET contributes bilateral trade and economic wide impacts.

4.1.2 Economic and political environment for agriculture in Ukraine and Russia

Ukraine and Russia have transformed from centrally planned economies during Soviet times to market economies (Schmitz and Meyers, 2015). During the transition in the 1990s, the two economies faced weak commercial, institutional, and physical infrastructure (Anderson and Swinnen, 2008). Anderson and Swinnen (2008) highlight especially poor business regulations and commercial law as well as weak or lack of functioning market information systems as examples of weak commercial infrastructure. Problems in the institutional infrastructure were manifold and included unstable political systems, poor educational systems, limited functioning of land markets, and weak financial systems (Anderson and Swinnen, 2008). Further the physical infrastructure was characterized by deficits and poor conditions of existing road and rail transportation, storage, as well as port capacities (Anderson and Swinnen, 2008). And then, corruption was widely spread and policy interventions were often ad hoc and unreliable (Anderson and Swinnen, 2008). Since the early 2000s, these structural problems have improved partly but are still main obstacles for economic development (Schmitz and Meyers, 2015). The financial crisis in 2009, had disrupted the positive economic development in Russia and Ukraine with Ukraine struggling to recover (compare Figure 57 below).

In 2013, political unrest in Ukraine and the following conflict between Russia and Ukraine have impacted the economic development further and resulted in especially high devaluations of the national currencies in Russia and Ukraine (compare Figure 58 below). The mentioned disruptions resulted in negative economic growth in specific years and an overall slowdown of economic growth. Neglecting the disruptions, Table 13 presents main economic indicators as well as selected indices for Russia and Ukraine to describe the economic environment in 2000 and 2015. The economy grew in Russia and Ukraine from 2000 to 2015 with increasing GDP per capita but also high inflation and exchange rate devaluation. The institutional environment improved slightly over time but still ranks low compared to other countries, especially in Ukraine which faces high corruption and problems in providing a stable environment to do business.

Table 13 Economic environment in Ukraine and Russia

		Ukraine			Russia		
Indicators	Unit	2000	2015	Δ% 2000-2015	2000	2015	Δ% 2000-2015
Population	Million persons	49	45	-8	147	144	-2
GDP per capita	Constant 2010 USD	1818	3154	73	6491	11355	75
Exchange rate	LUC per USD	5	22	302	28	61	117
Consumer price index	2010=100	35	180	418	31	152	393
		Ukraine			Russia		
Indices	Range	Score	Rank	Total countries	Score	Rank	Total countries
Corruption perception index 2000	0 (high) to 10 (low)	1.5	87	of 90	2.1	82	of 90
Corruption perception index 2015	0 (high) to 100 (low)	27	130	of 167	29	119	of 167
Ease of doing business index 2006	-	-	124	of 155	-	79	of 155
Ease of doing business index 2015	0 (hard) to 100 (easy)	62	96	of 189	67	62	of 189
Logistic performance index 2007	1 (low) to 5 (high)	2.55	73	of 150	2.37	99	of 150
Logistic performance index 2016	1 (low) to 5 (high)	2.74	80	of 160	2.57	99	of 160

Note: Indicators are based on World Bank (2021b); the scores of the indices are not directly comparable between the years due to changes in data and methodology; data on indices is shown for 2015 or closest year and 2000 or first year of publication; the Corruption perception index is based on Transparency International (2000) and Transparency International (2015), the Ease of doing business index is based on World Bank (2006) and World Bank (2016); the Logistic performance index is based on World Bank (2018).
Source: own representation based on sources indicated in notes

The agricultural sector plays an important role in the economy, especially in Ukraine (Table 14). Ukraine has favorable natural conditions for agricultural production with large amounts of arable land consisting of fertile black soil and favorable but very volatile weather. Russia is the largest country on Earth in terms of area but most crop production is located in the western and south western parts of the country where natural conditions are more favorable than in other parts of the country.

After the collapse of the Soviet Union, agricultural output dropped in Russia and Ukraine mainly due to reductions in subsidies especially in the livestock sector and reduced use of input (Liefert, Serova and Liefert, 2010). This led to land abandonment, declining yields and the reduction of livestock numbers. Since the early 2000s, agriculture output is increasing again (Table 14) which is attributed to structural changes, i.e., large farms and agroholdings with improved productivity (Schmitz and Meyers, 2015). These coexist besides private smallholder farms and household production (Schmitz and Meyers, 2015). Agricultural output growth is predominantly observed in the crop sector, especially cereals and oilseeds of which large shares are destined for exports. However, production levels are below levels observed during Soviet times as large amounts of land are abandoned and intensification levels are still lower compared to observed levels in Soviet times (for a further discussion see Section 4.2).

Table 14 Agriculture in the economy and agricultural characteristics in Ukraine and Russia

		Ukraine		Russia	
	Unit	2000	2015	2000	2015
Agricultural share of GDP	%	14	12	6	4
Agricultural share of employment	%	27	15	14	7
Agricultural share of land	%	71	72	13	13
Agricultural land	Million hectares	41.4	41.5	217.2	215.5
Arable land	Million hectares	32.6	32.8	124.4	121.6
Fertilizer consumption	Kg per hectare	13.5	43.2	11.4	16.7
Value of Agricultural production	Billion constant 2014-16 I$	27.9	43.6	61.6	89.2
of this: livestock	%	41	26	48	44
crops	%	59	74	52	56
of this: cereals	%	32	40	46	46
oilseeds[a)]	%	4	9	3	5

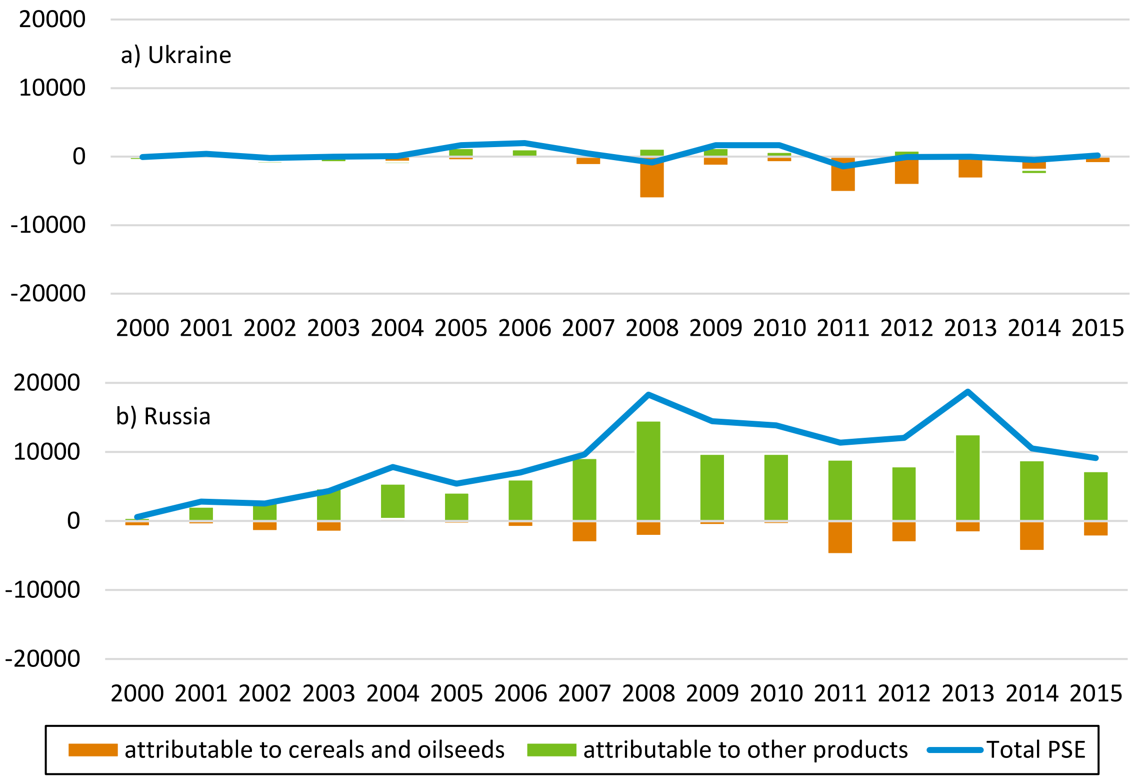
Note: [a)]here oilseeds corresponds to the aggregate 'oilcrops' of FAO (2021c). Agricultural share of GDP and employment includes agriculture, forestry, and fishing; value of agricultural production and derived shares from FAO (2021c), rest from World Bank (2021b)

Source: own representation based on World Bank (2021b) and FAO (2021c)

The agricultural sector in Ukraine and Russia is influenced by agricultural policies which have changed dramatically from large support during Soviet times, especially for the livestock sector, to limited support due to financial restrictions during the transition phase, to increased but fluctuating support since 2000 (Schmitz and Meyers, 2015). In general, the two countries subsidize sectors with a net-import position, i.e., the livestock sector, and tax sectors with a net-export position, i.e., the crop sector, (OECD, 2015b). Due to food security reasons, they aim at increasing production in sectors where self-sufficiency rates are low. Figure 56 shows the support to agriculture measured as PSE and demonstrates the taxation of cereals and oilseeds in both countries.

In Ukraine, support to agriculture has been reduced in recent years due to budget constraints, while Russia further focused on policies aiming at increasing self-sufficiency in livestock products (OECD, 2015b). Most applied agricultural policies are still market distorting in both countries and comprise domestic price regulation, input subsidies, output payments, tax preferences and border protection (OECD, 2015b, 2021). In the cereal markets for example, prices can be regulated in both countries by market intervention, i.e., the government buys or sells cereals if the price is below or above a certain price corridor, respectively (OECD, 2015b). Border protection in the form of import tariffs and export tax, quotas and other non-tariff measures are the main applied market measures (for details see Case Study 3 below in Section 4.3).

Figure 56 Policy support to agriculture in Ukraine and Russia, 2000 to 2015, PSE in million USD



Note: Total PSE = producer support estimates; attributable = part of PSE (sum of 'market price support', 'payments based on output', and 'transfers to producers from taxpayers'); cereals and oilseeds = sum of 'barley', 'maize', 'oats', 'rye', 'sunflower', and 'wheat'; other products = 'beef and veal', 'eggs', 'milk', 'other commodities', 'pig meat', 'potatoes', 'poultry meat', and 'sugar'
Source: own representation based on OECD (2020)

Both countries are WTO members, i.e., Ukraine since 2008 and Russia since 2012, which lead to reduced tariffs and further integration into world markets. Additionally, both countries are negotiating and concluding bi- and multilateral trade agreements (for details see Case Study 3 below in Section 4.3). Trade policies are applied in both countries as sanctions in political conflicts. For example, Russia imposed an import ban on meat, dairy products, fruits and vegetables, prepared foods and fish coming from the EU, the US, Canada, Australia, and Norway in 2014 (OECD, 2015b). The ban was introduced as a counter measure to sanctions imposed by the mentioned countries in responds to the annexation of Crimea by Russia.

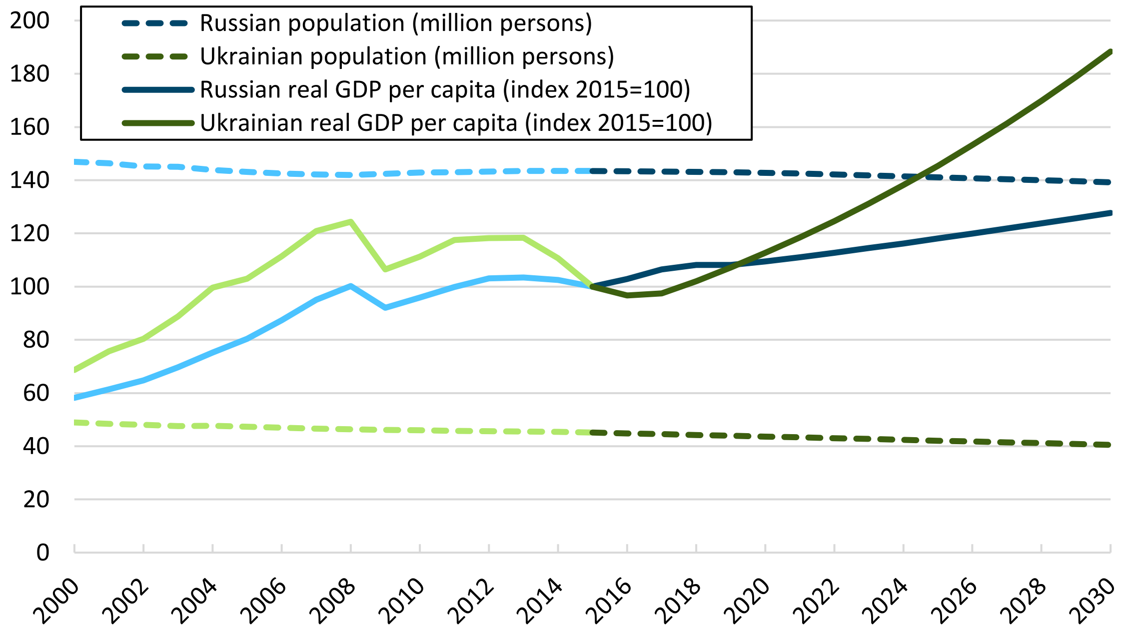
Further, the cereal markets in Ukraine and Russia are often influenced by ad hoc policies such as temporary export bans, increased export taxes, or export quotas (for details see Case Study 3 below in Section 4.3). These have been introduced on short notice to decrease or stabilize domestic consumer prices and ensure food security in times of high world market prices or domestic production shortfalls. However, these measures increased market uncertainty and world market prices, and only partially decreased consumer prices (Götz, Djuric and Glauben, 2015).

4.1.3 Method, data and assumptions

The model linkage between AGMEMOD, MAGNET, and GLOBIOM is applied as described in Section 3.3.2. The updated version of AGMEMOD (compare Section 3.2.2.3) is used with historical data for Ukraine and Russia until 2013 or 2016, depending on their availability in 2016. A baseline is set up which is based on exogenous assumptions and represents a certain economic development based on historically observed trends. This baseline can also be referred to as a business-as-usual scenario and projections start with the first year for which historical data is not available.

Exogenous assumptions in the model system are the harmonized population and GDP developments as well as exogenously assumed exchange rates and world market prices in AGMEMOD. These assumptions are also based on data available in 2016 and therefore deviate from actual observed values between 2015 to 2020. Therefore, an additional section, i.e., Section 4.1.7, is devoted to the comparison of the assumptions and results with historically observed data. Figure 57 shows the historical and assumed developments for population and GDP per capita for Ukraine and Russia in AGMEMOD. Population has declined in the past in both countries and is assumed to decline further between 2015 to 2030 with average annual decreases of 28,000 and 31,000 people in Russia and Ukraine, respectively. GPD per capita is higher in Russia than in Ukraine. In 2015, GDP per capita was 11,355 constant 2010 USD in Russia and 2,829 constant 2010 USD in Ukraine (World Bank, 2021b). Historically, GDP dropped in both countries in 2009 due to the global financial crisis. While Russia’s economy started recovering, the Ukrainian economy stayed in a recession (Figure 57). For the projection period, this is assumed to change. Real GDP per capita is projected to increase more in Ukraine than in Russia with an annual average growth rate of 4.3 % and 1.6 % from 2015 to 2030, respectively.

Figure 57 Historical and assumed developments of population (in million persons) and GDP per capita (as Index 2015=100) for Ukraine and Russia in AGMEMOD, 2000-2030

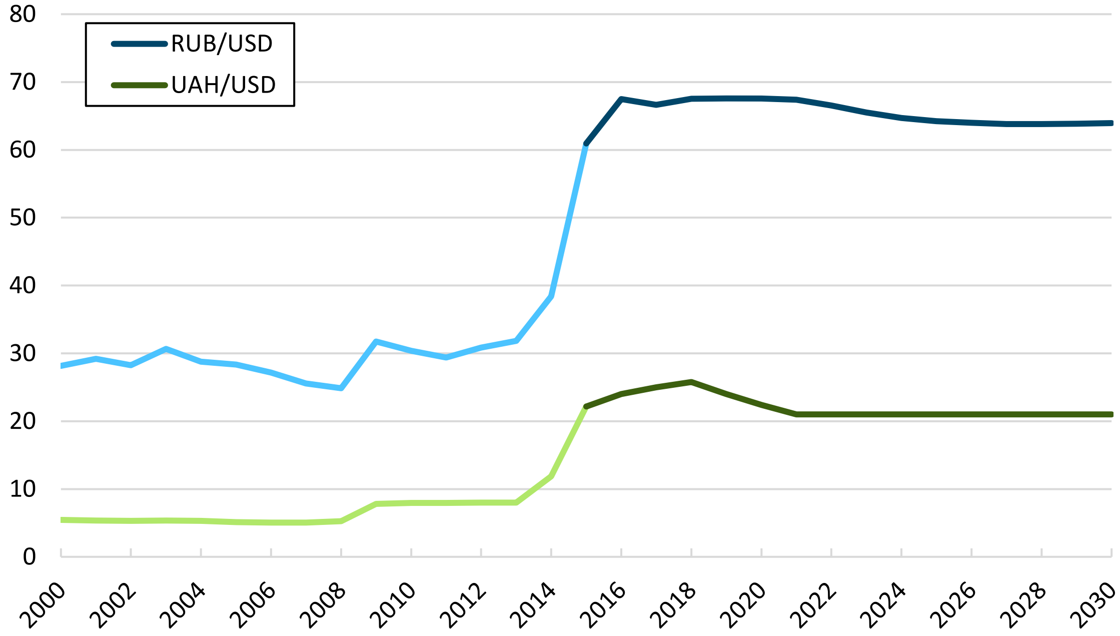


Note: Real GDP per capita index based on constant 2000 RUB for Russia and constant 2000 UAH for Ukraine; historical data from 2000-2015 (light colors) and projections 2016-2030 (vibrant colors)

Source: own representation from AGMEMOD database based on State Statistic Service of Ukraine (2015), Rosstat (2016), World Bank (2021b), and USDA (2014).

Of the three models, AGMEMOD is the only model specifically including currency exchange rates as an exogenous assumption. The historical and assumed nominal exchange rates for the Ukrainian hryvnia (UAH) and the Russian ruble (RUB) to the USD are depicted in Figure 58. After the devaluation of both currencies following the crisis starting in 2014, the exchange rates are assumed to decrease slightly in the long-term but stay above observed levels post-crisis.

Figure 58 Historical and assumed nominal exchange rates for Ukraine and Russia, 2000 to 2030, RUB and UAH to USD

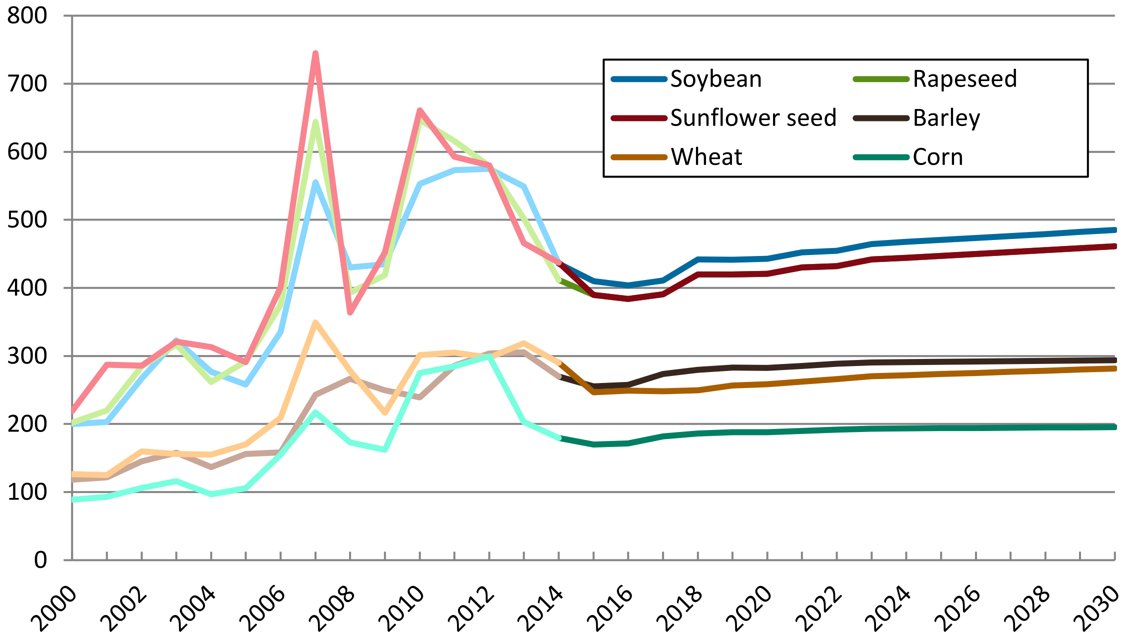


Note: historical data from 2000-2015 (light colors) and projections 2016-2030 (vibrant colors)
Source: own representation from AGMEMOD database based on World Bank (2021b) until 2016 for historical data and own assumptions based on USDA (2014) from 2017 onwards

Additionally, AGMEMOD uses exogenous world market prices for each product in its projections, which are shown for the main cereals and oilseeds in Figure 59. Price development of the OECD/FAO outlook 2015 (OECD and FAO, 2015) are used and further extended to 2030 by assuming the same annual percentage changes as in the last time step covered by the OECD/FAO outlook 2015, i.e., 2024 to 2025.

The assumed price projections seem smooth in comparison to actually observed historical data with a slight upward trend in nominal terms which correspond to a slight downward trend in real terms. This is mainly due to a) the underlying assumption showing less volatility in the projection than in the past as well as b) the omission of representing short term influencing factors, e.g., weather variability. This smoothness will not be observed in reality and developments between the years will stay volatile. Hence, these prices can only be interpreted as trends under the defined assumptions and do not represent a prediction or forecast.

Figure 59 World market prices for main cereals and oilseeds as implemented in AGMEMOD, 2000 to 2030, nominal USD/ton



Note: historical data from 2000-2014 (light colors) and projections 2015-2030 (vibrant colors)
Source: own representation from AGMEMOD database based on OECD and FAO (2015) and own assumptions

Furthermore, agricultural policies continue as in the past. Only changes due to negotiated trade agreements are additionally included. These trade agreements are implemented in the integrated modelling approach through MAGNET because MAGNET depicts bilateral trade. The implementation in MAGNET includes changes in bilateral tariffs and bilateral trade cost reductions, i.e., reduction of NTMs, and is described in detail in Philippidis *et al.* (2016).

Two trade agreements are of high importance to the Ukrainian and Russian cereal and oilseed sectors. First the DCFTA of the EU with Ukraine and second the formation of the EAEU between Russia, Armenia, Belarus, Kazakhstan and Kyrgyzstan. The DCFTA is implemented with the agreed tariff reductions and further a reduction in NTMs of 25 % until 2030 compared to 2015, i.e., the implemented *ad valorem* tax equivalent of the NTM in MAGNET is reduced by 25 percentage points. The EAEU is implemented by aligning the tariffs of Armenia, Belarus, and Kazakhstan with the tariffs of Russia. Within the EAEU, the tariffs are set to zero and NTMs are reduced by 10 % until 2030 compared to 2015.

Neither export quotas, nor export bans, nor export taxes beyond the generally agreed levels under WTO commitments are included in the projections, as these measures are implemented in an ad hoc and unpredictable way. Further, the Russian import ban (details see Section 4.1.2) is lifted in the period of 2015 to 2020 as it was set to be applied for one year only (European Commission, 2021). As described in Philippidis *et al.* (2016), the inclusion of the import ban and lifting follows the novel approach developed by Boulanger, Dudu, Ferrari and Philippidis (2016). This import ban has been renewed annually and, currently, is still in force (USDA, 2020b). However, as neither cereals nor oilseeds are directly affected by the ban, this slight inaccuracy is tolerable for this dissertation.

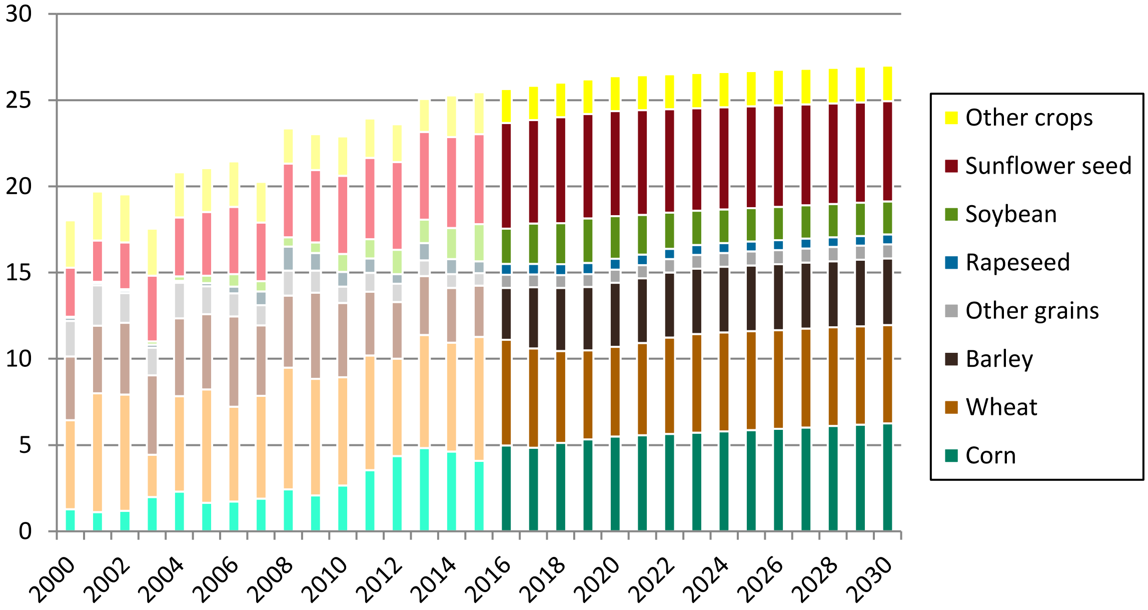
4.1.4 Historical development and projections

This section provides a detailed description of the cereal and oilseed markets for Ukraine and Russia complementing the information in Section 2.2 and 4.1.2. Further, the projections until 2030, which are generated by the model system of AGMEMOD, GLOBIOM, and MAGNET, are presented and interpreted.

4.1.4.1 Ukrainian cereal and oilseed markets

Historically, the crop area in Ukraine expanded strongly, while projections show a slowdown in expansion (Figure 60). The area under cultivation expanded from 19.1 million hectares (average 2000-2002) to 25.3 million hectares (average 2013-2015), i.e., by more than 30 %. Additionally, the oilseed and corn areas increased in shares and absolute terms, whereas all other crops except wheat decreased.

Figure 60 Crop area distribution in Ukraine, 2000 - 2030, million hectares



Notes: Other grains include oat, rice, rye, buckwheat, and millet; Other crops include potatoes, sugar beets, protein crops and tobacco; historical data from 2000-2015 (light colors) and projections 2016-2030 (vibrant colors)

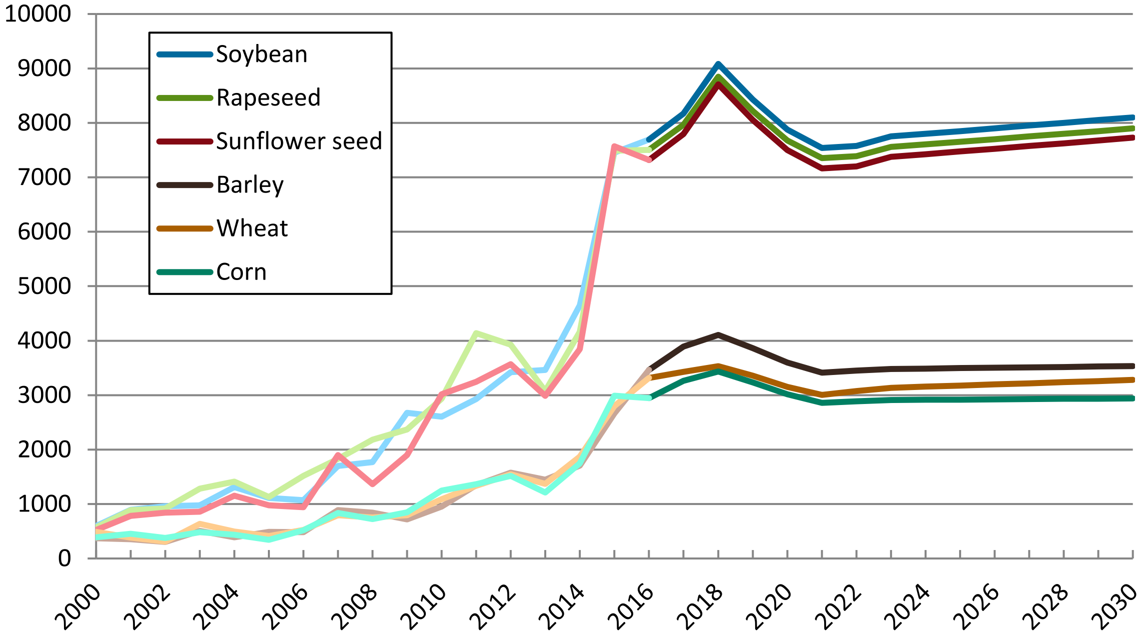
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

From average 2013-15 to 2030, crop area is projected to increase further by 1.6 million hectares to 27 million hectares. This increase in area is partly due to taking abandoned land into production again, i.e., 0.4 million hectares of the assumed 2.6 million hectares in GLOBIOM, but the majority comes from turning grassland into cropland (for a further discussion on abandoned land in Ukraine see Section 4.2 below). The shift in area towards corn cultivation continues, whereas the share of oilseed area in the crop area stays relatively stable.

Ukrainian crop prices depend on the development of world market prices, the national currency exchange rates, supply and demand, as well as domestic and trade policies. Historically, an increase in national cereal and oilseed prices can be observed over the years

(Figure 61). Prices jumped upwards from 2014 to 2015, mainly because of the UAH devaluation. For the projected period, prices will not continue to increase at the pace observed historically. The price dynamics in the first several years of the projection are dominated by the assumed changes in the exchange rate, whereas the subsequent slight increase is driven by world market price developments.

Figure 61 Nominal producer prices of cereals and oilseeds in Ukraine, 2000 -2030, UAH/ton



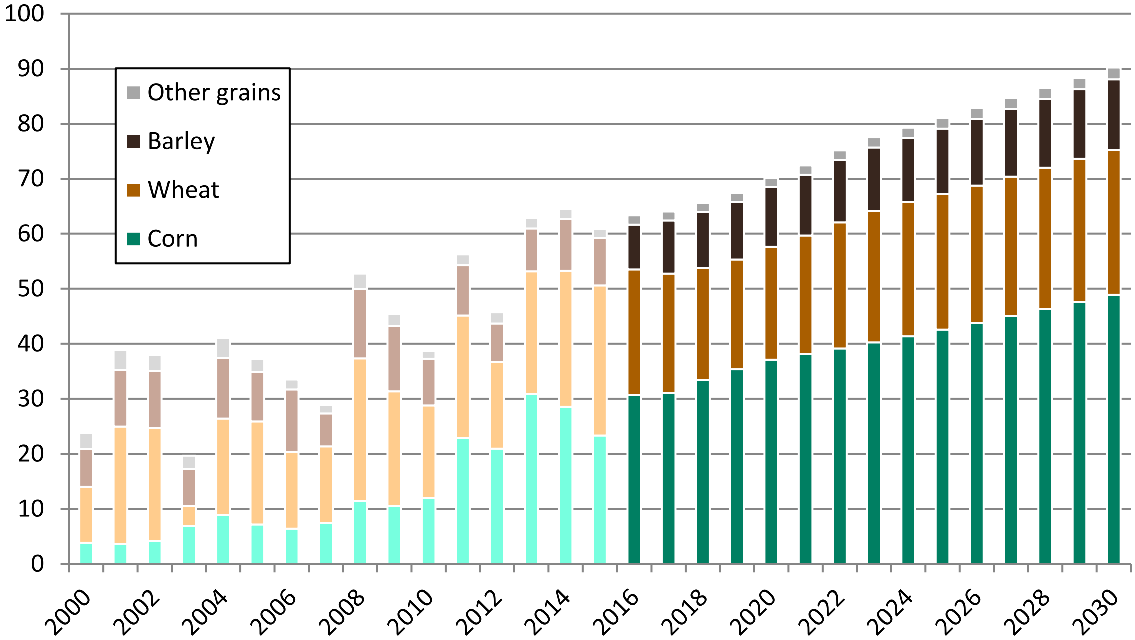
Notes: historical data from 2000-2016 (light colors) and projections 2017-2030 (vibrant colors)
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Cereal sector

The cereal production increased by 29 million tons or 87 % (average 2000-2002 to 2013-2015) with the majority of 23.7 million tons resulting from increases in corn production. This corresponds to an annual growth rate of 4.9 % and 16.3 % for all cereals and corn, respectively (Figure 62). In the projection period (refers to average 2013-15 to 2030 for Ukraine), the expansion of corn production will continue with an increase of 21.3 million tons or 3.6 % annually. Wheat production increased between 2000 and 2015, but with a high annual variability compared to barley and corn. Wheat production is projected to increase only slightly by 1.6 million tons or 0.4 % annually (average 2013-15 to 2030). Historically, barley production was relatively constant. Due to the higher price of barley, Ukraine will expand its production in the projection period by 4.2 million tons or 2.5 % annually.

Yield increases are the main reason for the observed growth. Although corn yields have experienced a stronger growth than the other cereal yields in the past, its growth will slow down to an annual increase of 1.6 % over the projection period. In the same period, wheat and barley yields will increase annually by 1.4 % and 1.3 %, respectively.

Figure 62 Cereal production in Ukraine, 2000 - 2030, million tons



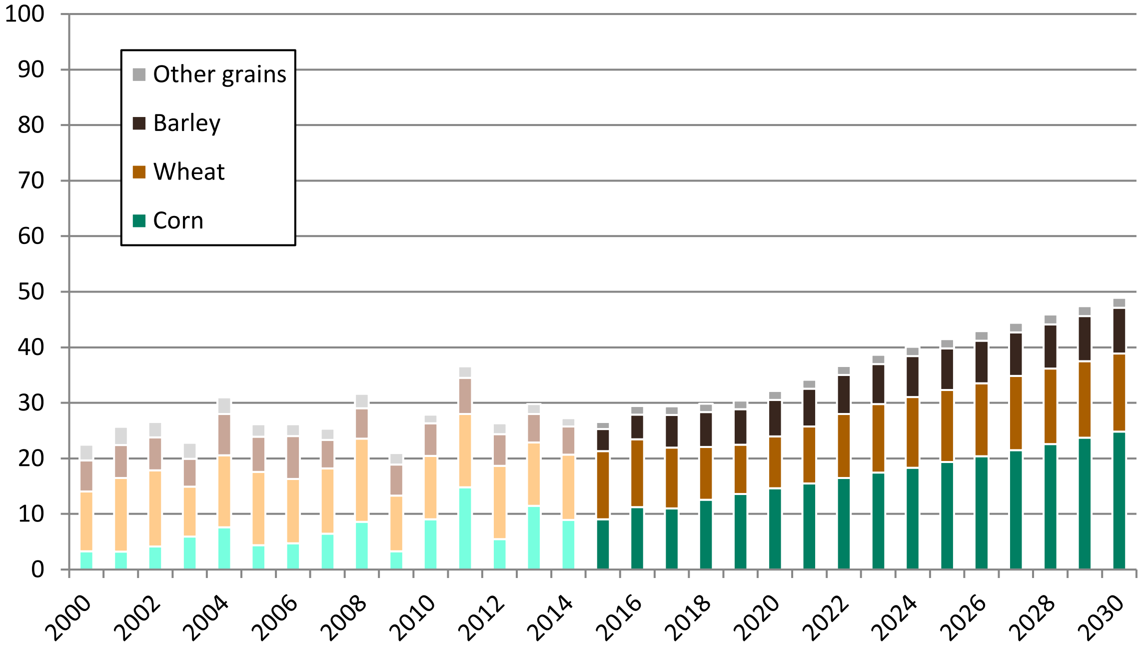
Notes: Other grains include oat, rice, rye, buckwheat, and millet; historical data from 2000-2015 (light colors) and projections 2016-2030 (vibrant colors)
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

The area cultivated was expanded strongly only for corn, i.e., by 3.3 million hectares or nearly four times (average 2000-2002 to 2013-2015). Over the whole projection period, the total cereal area will increase by 1.4 million hectares or 10 %. Although the wheat area will decline by 1 million hectares, the corn and barley areas will expand by 1.7 million hectares and 0.7 million hectares, respectively.

Historically, most of the increased production of cereals is exported, whereas domestic consumption even decreased for wheat and barley (Figure 63 and Figure 64). An increase in domestic use is observed only for corn, i.e., 6.3 million tons (average 2000-2002 to 2013-2015). Domestic use will increase in the projection period (Figure 63) mainly because of the continued increase in the demand for corn as feedstuff. The projected additional demand results from the continued increase in pork and especially poultry production. This development is mainly driven by the domestic per capita consumption affected by income growth and export opportunities affected by the exchange rate of UAH to the USD. In this context, the underlying assumptions in the model play a crucial role and strongly influence the outcome.

In 2000, cereal exports were minor but increased until 2015 (Figure 64) with increases in production. Decreases in exports between the years are mainly due to weather related production shortfalls. In 2015, record export levels were reached with exports amounting to 37.4 million tons or 62 % of production. Main export destinations were China, Egypt, and Spain (UN, 2017a). Due to the increase in meat production, cereal exports will not increase as fast as observed in the past (Figure 64). Imports of cereals were and stay negligible.

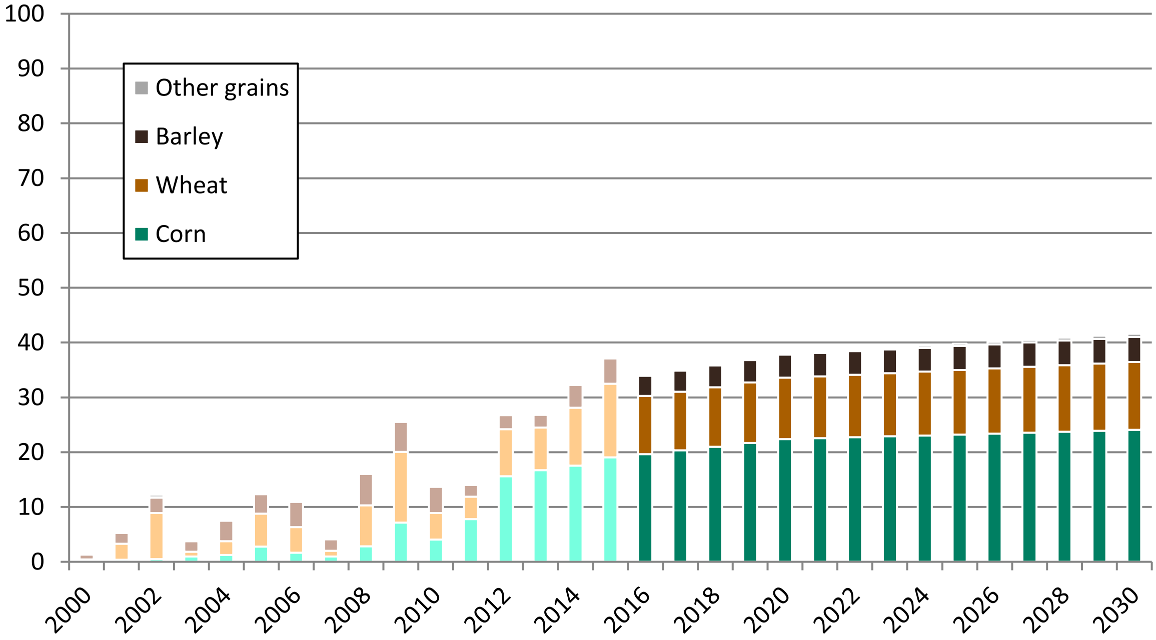
Figure 63 Domestic use of cereals in Ukraine, 2000-2030, million tons



Notes: Other grains include oat, rice, rye, buckwheat, and millet; historical data from 2000-2014 (light colors) and projections 2015-2030 (vibrant colors)

Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Figure 64 Ukrainian cereal exports, 2000 - 2030, million tons



Notes: Other grains include oat, rice, rye, buckwheat, and millet; historical data from 2000-2014 (light colors) and projections 2015-2030 (vibrant colors)

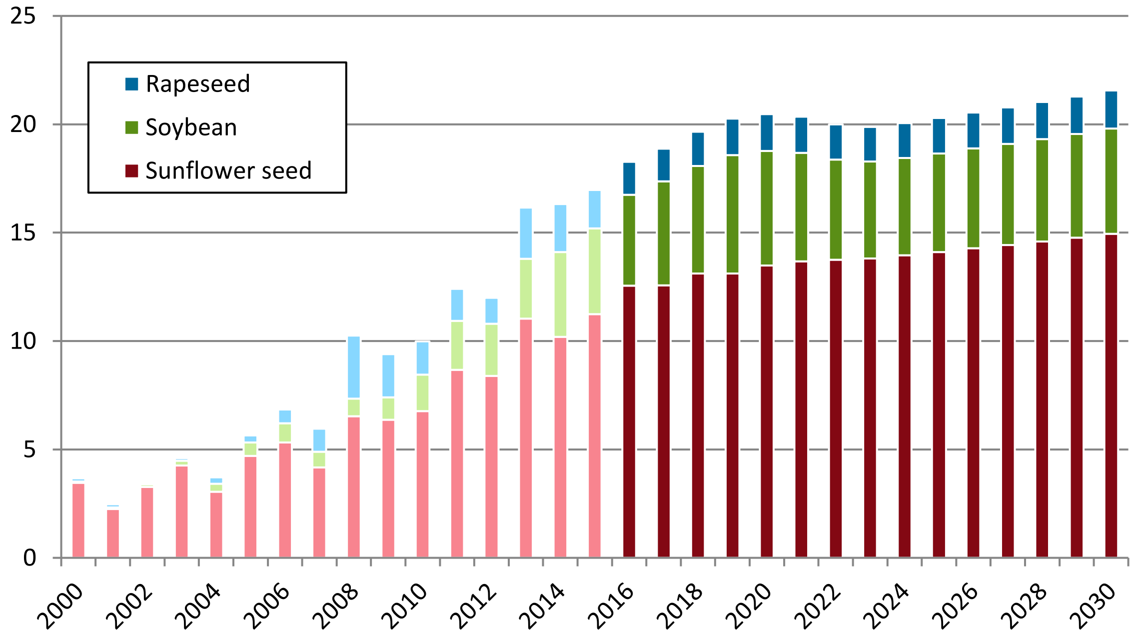
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

The oilseed, meal and vegetable oil sectors

In Ukraine, oilseed production has increased rapidly over the last 15 years (Figure 65). It increased from 3.2 million tons to 16.5 million tons (average 2000-2002 to 2013-2015) with the largest absolute growth in sunflower seed by 7.8 million tons, followed by soybeans (3.5 million tons) and rapeseed (2 million tons). This growth was due to both yield and area increases. In the projection period, oilseed production loses competitiveness to cereals and, hence, does not continue the strong growth that was observed historically.

The oilseed market in Ukraine is dominated by sunflower seed. Although sunflower seed production is projected to increase steadily at an average annual rate of 2 % (average 2013-15 to 2030), the production of soybean and rapeseed increase until 2020, slightly decrease afterwards and recover again in the long term, amounting on average to an annual growth of 2 % and -1.2 %, respectively (Figure 65). This production increase is mainly due to increased yield by an annual average growth between 2016 and 2030 for sunflower, soybean and rapeseed of 1.6 %, 1.6 % and 1.9 %, respectively. In the first projected years, oilseed area is projected to increase slightly and decrease afterwards to 8.3 million hectares in 2030. The relatively large share of sunflower seed on cropland area in Ukraine, i.e., 20 % (average 2013-15), restricts further sunflower seed area expansion due to crop rotation restrictions.

Figure 65 Sunflower seed, soybean and rapeseed production in Ukraine, 2000 - 2030, million tons



Notes: Historical data from 2000-2015 (light colors) and projections 2016-2030 (vibrant colors)
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Sunflower seed is processed domestically to sunflower oil and sunflower meal. The produced sunflower oil is mainly exported. Although domestic sunflower oil consumption increased only slightly, i.e., by an annual average rate of 1 % (average 2000-02 to 2013-15) to 0.5 million tons (average 2013-15), exports grew from 0.5 million tons (average 2000-02) to 3.9 million tons (average 2013-15). The major importing countries of Ukrainian sunflower oil were India, China, and Spain in 2015 (ISTA Mielke GmbH, 2016). For sunflower meal, the same development is observed resulting in 0.5 million tons of domestic consumption and 3.7 million tons of exports (average 2013-15).

In contrast to sunflower seed and similar to cereals, rapeseed and soybeans are exported as unprocessed products. Exports amounted to 51 % and 84 % of the produced soybeans and rapeseed (average 2013-15), respectively. These shares are projected to decrease to 43 % for soybeans and to 80 % for rapeseed by 2030.

As observed historically, a large share of the produced vegetable oil and meal, mostly from sunflower seed, is exported, i.e., 88 % and 81 % in 2013, respectively. These export levels continue to grow in the projection period with export shares of produced vegetable oil and meal of 89 % and 91 % in 2030, respectively. Although oil and meal production have increased strongly in the past, their growth slows down in the projections (Table 15). Consumption of vegetable oil is projected to grow slightly faster than observed historically. This is mainly due to the assumed increases in income. However, this consumption growth has only minor influences on the market because it is dominated by exports. The meal market exhibits a slightly different picture as overall meal consumption increases more slowly in the projection period than observed historically (Table 15). However, the composition of meals used as feed changes. Ukraine has started to substitute sunflower meal with soybean meal in feed use which continues over the projected period. Hence, domestic use of soybean meal increases while sunflower meal declines.

Table 15 Vegetable oil and meal markets in Ukraine

	Absolute volumes in million tons			Average annual change in %	
	2000-02	2013-15	2030	2000-02 to 2013-15	2013-15 to 2030
			Vegetable oil		
Production	1.00	4.56	6.50	12.4	2.2
Net Exports	0.51	4.01	5.66	17.2	2.2
Consumption	0.50	0.57	0.83	1.0	2.4
			Meal		
Production	1.01	4.84	6.49	12.8	1.9
Net Exports	0.44	3.90	5.39	18.3	2.0
Consumption	0.58	0.98	1.10	4.2	0.7

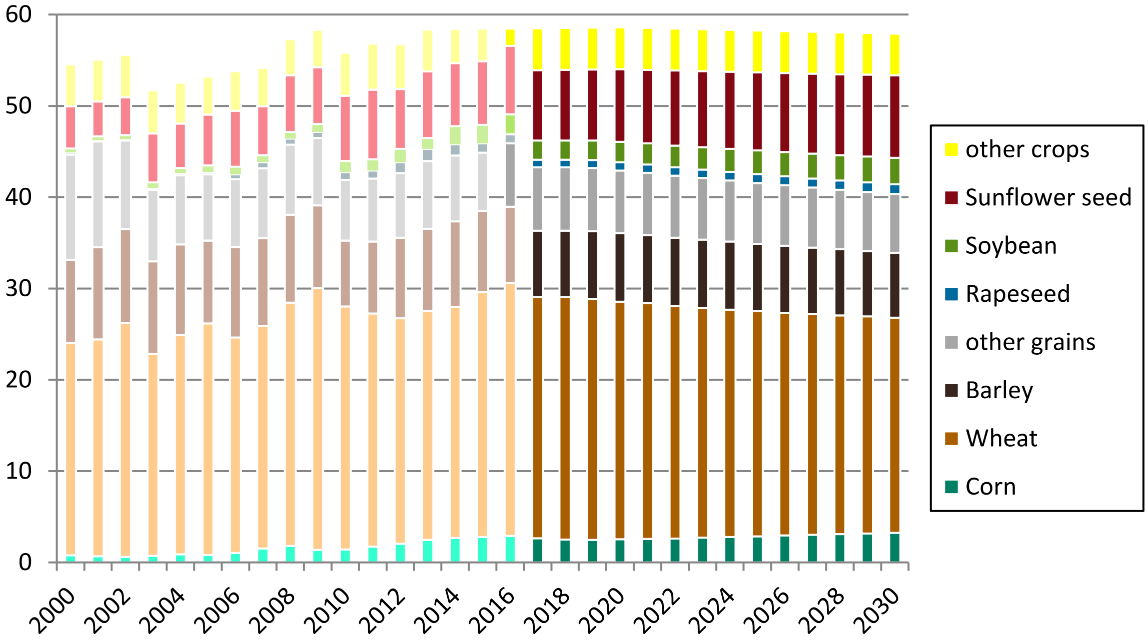
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

4.1.4.2 Russian cereal and oilseed markets

The Russian cereal and oilseed markets show parallels to the Ukrainian markets. This is not surprising as the two countries are neighbors and former countries of the Soviet Union. However, distinctive differences are also found. Therefore, this section includes a comparison of the Russian markets to the Ukrainian markets where notable parallels as well as differences are observed.

Historically, the crop area in Russia expanded only slightly in contrast to Ukraine. The area under cultivation expanded from 55.1 million hectares (average 2000-02) to 58.4 million hectares (average 2013-15), i.e., by just 6 % (Figure 66). The largest absolute growth is observed for sunflower area which increased by 2.9 million hectares (average 2000-02 to 2013-15) followed by corn area with an additional 1.9 million hectares. Soybean, rapeseed, and corn area increased the most in relative terms but from small starting values. In contrast, area for barley, other grains, and other crops declined. These developments are similar to the developments in Ukraine, except that wheat dominates the cereal market in Russia.

Figure 66 Crop area distribution in Russia, 2000 - 2030, million hectares



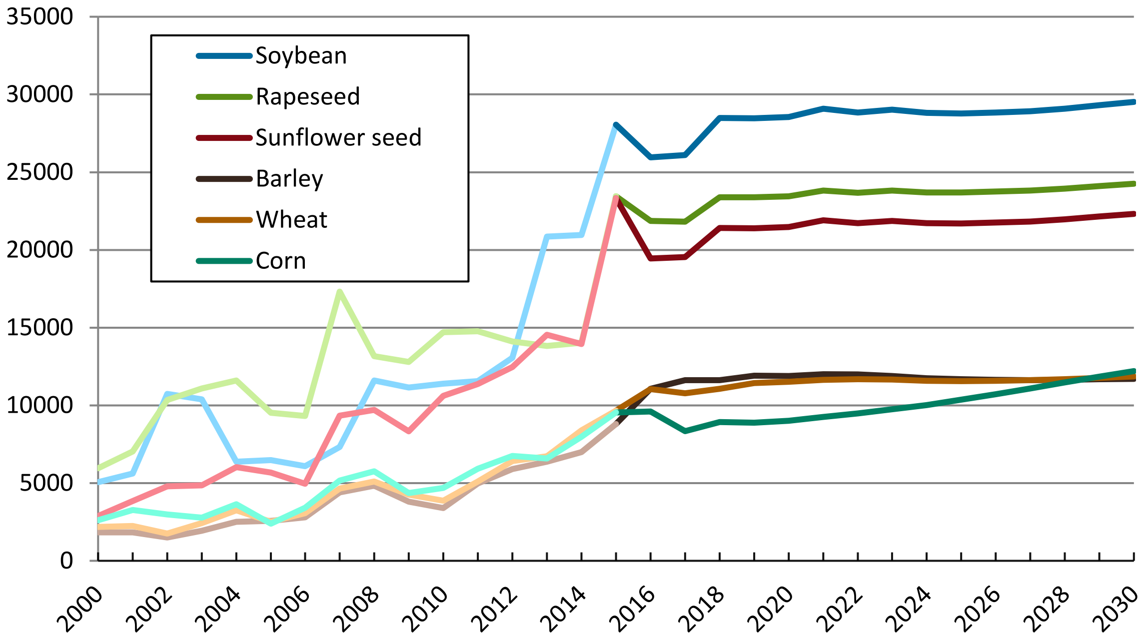
Notes: Other grains = rye, oats, rice, triticale, and mixed grains; Other crops = potatoes, sugar beets, and protein crops; historical data from 2000 to 2015 or 2016 (light colors) and projections 2015 or 2016 to 2030 (vibrant colors)

Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

In the projection period (for comparability reasons to Ukraine, here also average 2013-15 to 2030 even though some historical data for 2016 are included in the analysis for Russia), crop area is projected to slightly decrease. This is mainly due to a reduction in wheat and barley area and a slowdown in corn and oilseed area expansion compared to historically observed developments. In fact, despite 31 million hectares of abandoned agricultural land in Russia, as assumed in GLOBIOM, even more land is projected to be abandoned until 2030, i.e., 3.6 million hectares, as its use is not economically profitable. The main reasons for this development are that the abandoned land is less fertile due to lower soil qualities and weather-related constraints, located in areas with declining demographics and an unsuitable labor force, as well as being further away from potential consumers such as big cities and exporting ports compared to already cultivated land (Meyfroidt *et al.*, 2016). In Ukraine, these constraints are not as prominent as in Russia so that further land expansion is projected (for a further discussion on abandoned land see Section 4.2 below). Hence, the opposite responses of the two countries to the same world market conditions are explainable.

Similar to Ukraine, Russian cereal and oilseed prices depend on the development of world market prices, the national currency exchange rates, supply, demand, and policies. The large devaluation of the exchange rate in 2014 and 2015 brought prices to a new level (Figure 67). For the projected period a stabilization of the national exchange rate to the USD is assumed. Hence, the developments of the projected prices are dominated by the world market price developments with the exception of corn. The corn price shows an increase surpassing wheat and barley prices at the end of the projection period because domestic demand is projected to increase faster than supply.

Figure 67 Nominal producer prices of cereals and oilseeds in Russia, 2000 -2030, RUB/ton



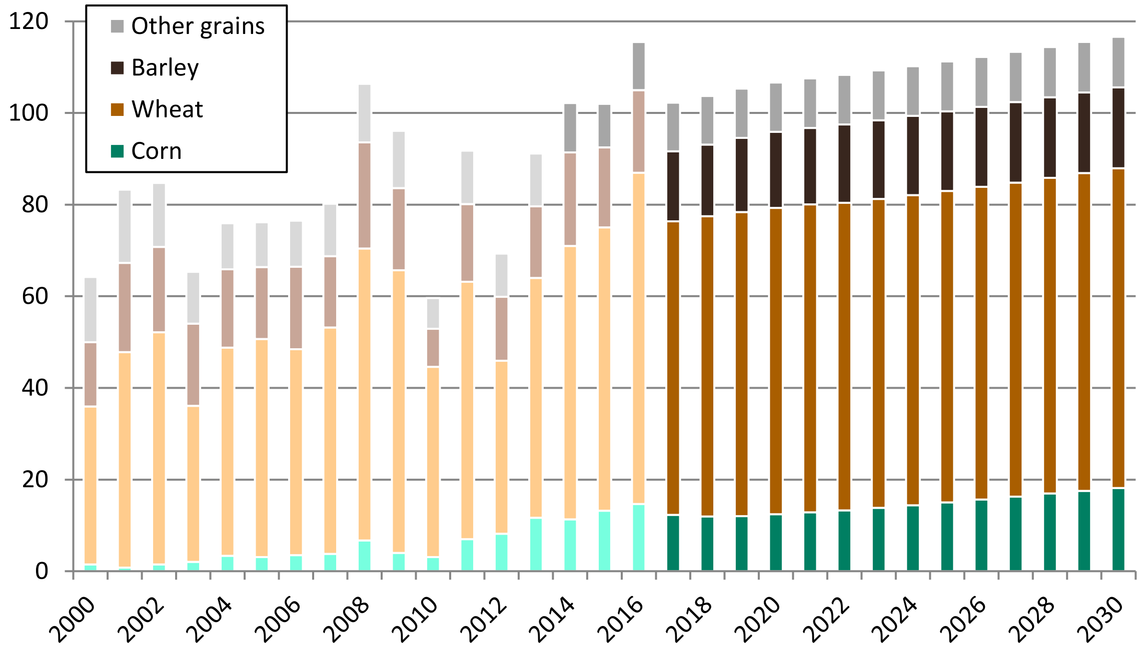
Notes: historical data from 2000-2015 (light colors) and projections 2016-2030 (vibrant colors)
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Cereal sector

In Russia, wheat dominates cereal production. Cereal production increased by 21 million tons (average 2000-2002 to 2013-2015) with wheat and corn production contributing an additional 14 and 11 million tons, respectively (Figure 68). 2016 was an exceptional year with record production levels due to favorable weather conditions resulting in very high yields. Wheat and corn yields were on record levels with 2.6 and 5.1 tons per hectare, respectively. Weather impacts cereal yields to a large extent in Russia. For example, yields for wheat and corn only reached 1.6 and 2.2 tons per hectare in the exceptionally dry year of 2010, respectively. The projections assume normal weather conditions and, hence, exclude the influence of weather on production variability. Consequently, projections show a development based on average yield trends, while actual yields will fluctuate around this average. As a result, cereal production is projected to grow by an additional 18 million tons in the projection period (average 2013-15 to 2030) but does not reach the record levels observed in 2016. Corn production grows strongest with an annual average rate of 2.6 % (average 2013-15 to 2030), while wheat only grows by 1.1 % and barley even slightly declines.

Historically, corn yields have increased exceptionally by 7.2 % annually (average 2000-02 to average 2013-15) but are projected to slow down to an average annual growth rate of 1.3 % in the projection period. This annual yield growth is lower compared to wheat (1.7 %) and barley (1.5 %). Nevertheless, corn is very competitive as demand increases resulting in increased prices. Hence corn area expands, while total cereal area declines by 4.1 million hectares (average 2013-15 to 2030).

Figure 68 Cereal production in Russia, 2000 - 2030, million tons

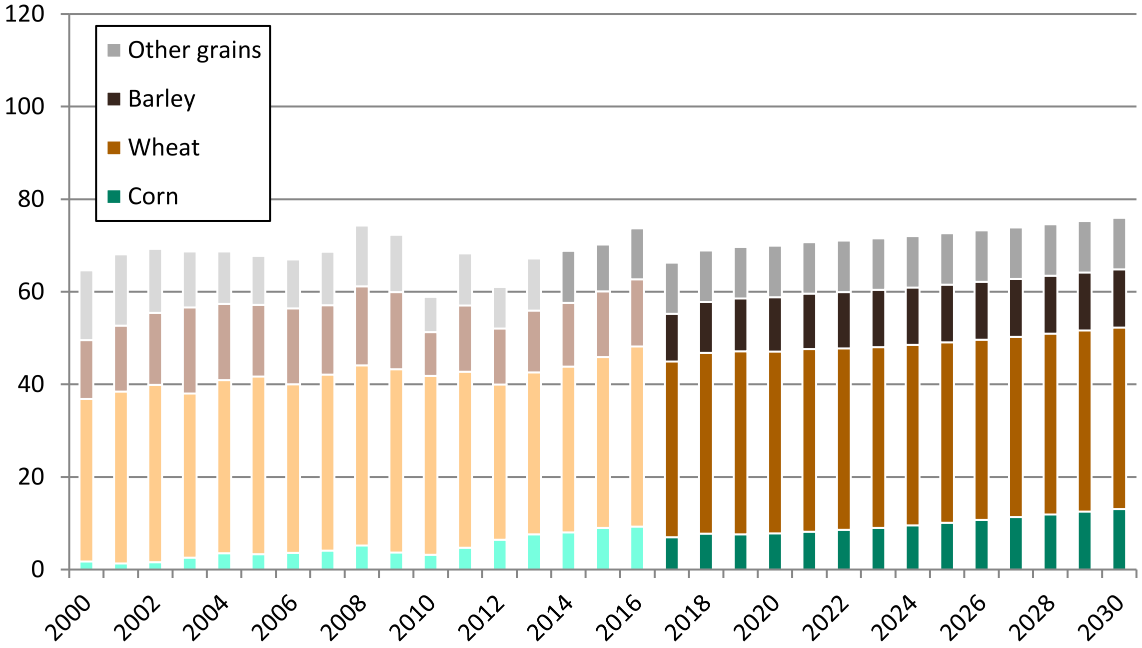


Notes: Other grains include rye, oats, rice, triticale, and mixed grains; historical data from 2000 to 2013 or 2016 (light colors) and projections 2013 or 2016 to 2030 (vibrant colors)
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Similar to Ukraine, most of the additionally produced production of cereals was exported with the exception of corn where exports as well as domestic use increased (Figure 69 and Figure 70). Domestic use of wheat and barley slightly declined by 1 million tons and 0.4 million tons (average 2000-02 to average 2013-15), respectively. In the projection period, this trend continues for barley but wheat shows an increase by 3.3 million tons (average 2013-15 to 2030). Domestic use of corn continues to grow and reaches 13.1 million tons in 2030 compared to 8.2 million tons (average 2013-15). However, the growth slows down compared to historical observations mainly because of a relative higher increase in corn prices than other cereal prices. Barley use in feed rations continues to decline as more energy-rich cereals, mainly corn, but also partly wheat, are preferred in feed rations. This substitution is especially visible for corn in feeding rations for pig and poultry. Additionally, pork and poultry production in Russia is projected to increase. From 2006, pork and poultry production increased steadily at a rate of 4.6 % and 12.6 % per year, respectively, but this increase slows down in the projection period to an annual growth rate of 1 % for pork and 2.4 % for poultry.

In 2000, Russia was a net importer of all cereals which changed from 2001 onwards for wheat and barley and from 2009 onwards for corn. Currently, imports are negligible compared to exports and are projected to stay negligible, i.e., below 1.5 million tons over the whole projection period. Cereal exports are dominated by wheat but only a small growth in exports is projected until 2030 (Figure 70) as production growth slows down. However, Russia continues to produce cereals for the world market with an export share on cereal production of 36 % in 2030. In Ukraine, this export share is 46 % in 2030, which makes Ukraine more dependent on world markets than Russia.

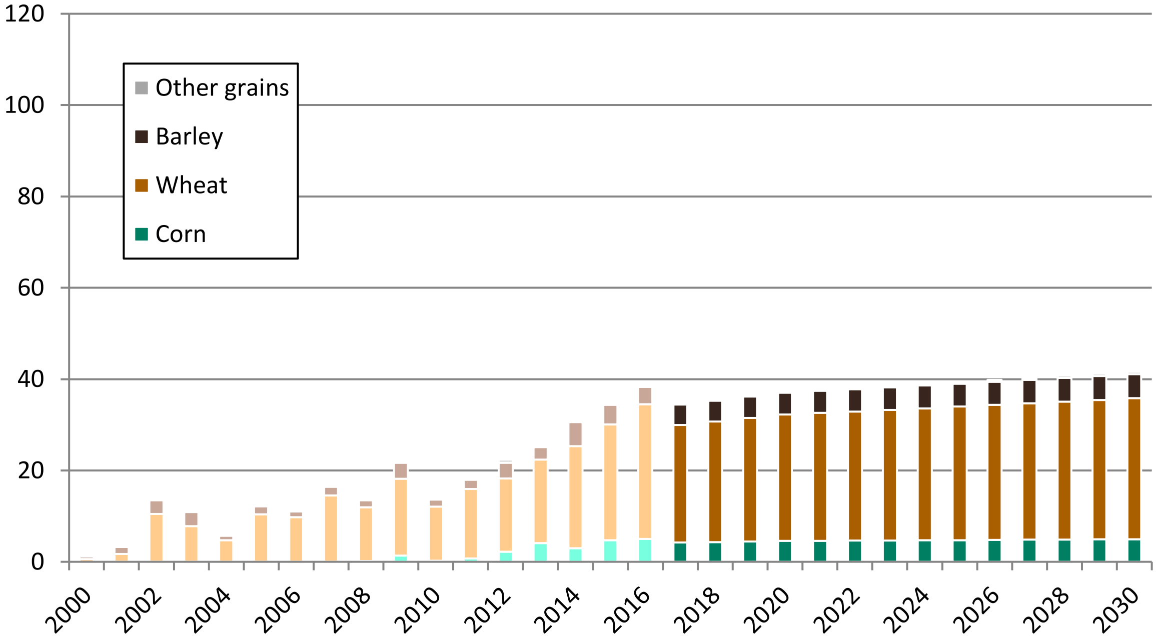
Figure 69 Domestic use of cereals in Russia, 2000-2030, million tons



Notes: Other grains include rye, oats, rice, triticale, and mixed grains; historical data from 2000 to 2013 or 2016 (light colors) and projections 2013 or 2016 to 2030 (vibrant colors)

Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Figure 70 Russian cereal exports, 2000 - 2030, million tons



Notes: Other grains include rye, oats, rice, triticale, and mixed grains; historical data from 2000 to 2013 or 2016 (light colors) and projections 2013 or 2016 to 2030 (vibrant colors)

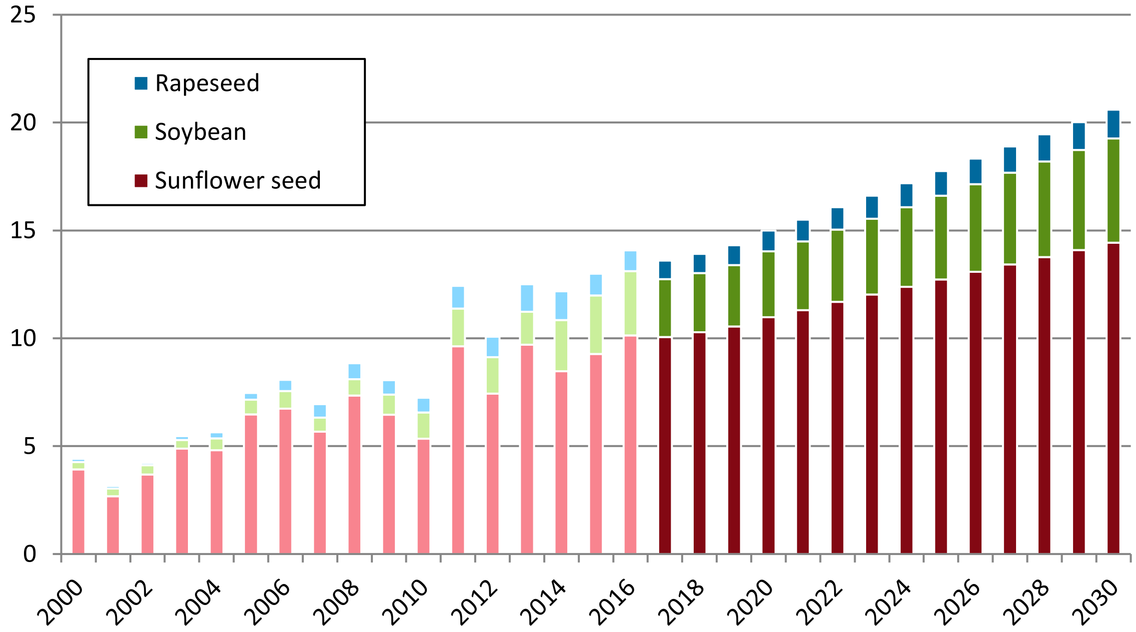
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

The oilseed, meal and vegetable oil sectors

Oilseed production grew even faster than cereal production in Russia. Compared to Ukraine, the oilseed sector has shown similar structures and developments historically. Sunflower seed is dominating the market but its share in total production declined from 87 % (average 2000-02) to 73 % (average 2013-15) because soybean and rapeseed production grew relatively faster during this time (Figure 71). In contrast to the projections for Ukraine, oilseed production continues to grow rapidly in Russia during the projection period mainly because of further increase in sunflower seed and soybean production. The strong production growth is realized by increases in area and yield historically and in the projection period.

In the projection period, an additional 2 million hectares are cultivated with sunflower seed and 1.2 million hectares with soybean (average 2013-15 to 2030), while rapeseed area slightly declines. The share of sunflower seed in total area is not as large as in Ukraine and, hence, further sunflower seed area expansion is not hindered by crop rotation restrictions in Russia. Historically, high average annual yield growth is observed for oilseeds. The yield growth declines in the projection period but is still approximately 1.5 % per year with soybean having a slightly higher average growth rate than rapeseed and sunflower seed (for details compare Figure 75 below in Section 4.2.1). Consequently, soybean becomes the most competitive oilseed due to highest price and highest yield growth in the projection period.

Figure 71 Sunflower seed, soybean and rapeseed production in Russia, 2000 - 2030, million tons



Notes: historical data from 2000 to 2016 (light colors) and projections 2016 to 2030 (vibrant colors)
Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Nevertheless, demand of soybeans increases faster than production resulting in continued net imports of soybeans also in the projection period of nearly 2 million tons annually. Imports and exports of sunflower and rapeseed are negligible and stay below 0.2 million tons. Consequently, most oilseeds are crushed into vegetable oil and meal. Hence, crushing capacities in Russia do not focus solely on sunflower seed as in Ukraine.

In Russia, production of vegetable oil and meal has increased stronger than consumption historically and this is projected to continue but at reduced levels (Table 16). In the projections, vegetable oil exports outpace vegetable oil consumption. Most rapeseed and soybean oil are exported, i.e., more than 60 % of production (average 2013-15) and more than 80 % in 2030, while sunflower oil is predominantly consumed domestically. However, export shares of production increase for sunflower oil as well from 41 % (average 2013-15) to 46 % in 2030. Increased production in the livestock sector, especially pork and poultry production, results in increased demand for meal. In the feed rations a shift away from sunflower meal towards soybean meal is observed historically and continues in the projection period. While in 2000-02 sunflower meal had a share of 77 % on total meals and 43 % in 2013-15, this is projected to decline to 38 % until 2030. In contrast soybean meal shares increased from 21 % (average 2000-02) to 50 % (average 2013-15) and are projected to increase further to 55 % in 2030. Exports are dominated by sunflower meal with a share of 64 % of total exports and are projected to stay dominant with a share of 79 % in 2030.

Table 16 Vegetable oil and meal markets in Russia

	Absolute volumes in million tons			Average annual change in %	
	2000-02	2013-15	2030	2000-02 to 2013-15	2013-15 to 2030
Vegetable oil					
Production	1.30	4.91	7.79	10.8	2.9
Net Exports	-0.55	2.22	4.21	1)	4.1
Consumption	1.85	2.69	3.58	2.9	1.8
Meal					
Production	1.85	7.35	11.91	11.2	3.1
Net Exports	-0.09	1.80	3.65	1)	4.5
Consumption	1.94	5.55	8.26	8.4	2.5

Notes: 1)calculation not possible because Russia turned from a net importer to a net exporter

Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

4.1.5 Sensitivity analyses

In order to validate the presented results, sensitivity analyses have been performed on two assumptions with AGMEMOD: exchange rates and yields. In the model system, AGMEMOD is the only model explicitly considering effects of a change in the exchange rates on agricultural markets. For Ukraine and Russia, a depreciation of the exchange rate results in increased export competitiveness for cereals and oilseeds (compare Section 2.1.1). As the exchange rate of the national currency to the USD rose sharply in 2014 and 2015, further fluctuations might occur. To visualize this consequence of fluctuating exchange rates, the exchange rate of the UAH and the RUB against the USD is exogenously shifted up and down by 15 % from 2017 onwards resulting in four different scenarios. These changes approximately reflect the highest difference between projected and observed historical values between 2016 and 2020 (compare Figure 72 c) below in Section 4.1.7). For example, the exchange rate of Russia was 13 % lower in 2017 than projected and the exchange rate of Ukraine was 20 % higher in 2020 than projected.

In the model system, yields are projected by GLOBIOM which uses the crop model EPIC to determine yields at the grid cell level. As has been shown by Balkovič *et al.* (2013), EPIC might underestimate yields in low-input production systems and overestimates yields in high-input production systems. In their study focusing on the EU, projected yields for a given year with the observed weather conditions mostly differed from observed yields by less than 30 %, while the long-term average projections performed better (Balkovič *et al.*, 2013). In the projections, average weather conditions depending on historical observations are assumed. Given the uncertainty in crop model projections as well as in future weather conditions partially also due to climate change, yields are exogenously shifted up and down by 15 % from 2016 for all crops and countries in AGMEMOD. These simultaneous shifts result in two scenarios, i.e., 'increased yields' and 'decreased yields'. These rather large changes in average yield can be interpreted as reflecting extreme improved and worsened weather conditions in the projection period. In fact, between 2015 and 2020, cereal and oilseed yields in Ukraine and Russia surpassed their average yield in that period by more than 15 % only in five cases out of 72 and fell short of their average yield by more than 15 % in three cases (own calculations based on USDA (2021d)).

In all scenarios for the sensitivity analysis, trade is determined endogenously by AGMEMOD because changes in the exchange rate are expected to impact trade in a manner which MAGNET is not able to simulate. Further fluctuations in yields, often result in adjusted trade. Table 17 shows the percentage changes of the different scenarios compared to a baseline with endogenous trade in AGMEMOD for selected products and variables in 2030.

Table 17 Impact of sensitivity scenarios for cereals and oilseeds (Domestic use, Export and Production) in Ukraine and Russia, 2030 compared with the baseline, %

		Domestic use		Export		Production	
Scenarios	Country	Cereals	Oilseeds	Cereals	Oilseeds	Cereals	Oilseeds
Increased UAH/USD	Ukraine	-0.7	2.6	-4.3	18.8	-2.6	5.7
Increased RUB/USD	Russia	0.8	0.0	-0.6	0.5	0.2	0.2
Decreased UAH/USD	Ukraine	0.7	-3.0	4.2	-17.9	2.5	-5.9
Decreased RUB/USD	Russia	-0.7	-0.1	0.8	-0.6	-0.1	-0.3
Increased yields	Ukraine	0.4	16.7	22.6	40.5	12.1	21.2
Increased yields	Russia	5.0	14.4	31.7	3.7	14.7	13.9
Decreased yields	Ukraine	-0.4	-16.4	-23.8	-33.9	-12.8	-19.7
Decreased yields	Russia	-5.0	-14.8	-30.9	-3.7	-14.4	-14.3

Source: Own projections based on the model system of AGMEMOD and GLOBIOM

An increase in the exchange rate of the national currency against the USD, i.e., a depreciation of the national currency, makes a country more competitive on global export markets, hence increased exports are expected. This is true for oilseed exports and further triggers production growth in Ukraine. The production growth of oilseeds in Ukraine comes at the expense of cereal production, which then results in the counterintuitive effect of less cereal exports even though the exchange rate made Ukraine more competitive. In Russia, the effect of the exchange rate is less than for Ukraine, probably because they depend less on the world market. However, while slight production increases are projected, domestic consumption of cereals increases. This can only be explained by consumers shifting food consumption to more stable foods as their income declines with an increase in the exchange rate. The decrease in the exchange rates has opposite effects within a similar range.

Increased (decreased) yields increase (decrease) exports and production as expected. In this case as well, oilseeds are affected more than cereals in Ukraine, while both crops are similarly affected in Russia. In all sensitivity scenarios changes in consumption patterns are expected to be less than changes in production. As changes in oilseed consumption can be attributed to increased (decreased) exports of vegetable oil and meal, this holds true except for cereal consumption in Russia if the exchange rate changes. However, these changes are minor, i.e., below one percent.

4.1.6 **Comparison to other projections**

The projections for the Ukrainian and Russian cereal and oilseed markets show a dynamic development with potentials for increases especially in cereal markets in Ukraine and oilseeds in Russia. Other projections show different developments. Table 18 compares the projections generated by the applied model system of AGMEMOD, GLOBIOM, and MAGNET with the results from the OECD/FAO and USDA outlook for corn and wheat. These two cereals are selected because they are directly comparable between the different projections and make up a large fraction of the Ukrainian and Russian crop production.

Table 18 Projections of different studies for corn and wheat in Ukraine and Russia

	Ukraine						Russia					
	Corn			Wheat			Corn			Wheat		
	Million tons		Δ% 2015-2025	Million tons		Δ% 2015-2025	Million tons		Δ% 2015-2025	Million tons		Δ% 2015-2025
Projections	2015	2025		2015	2025		2015	2025		2015	2025	
Production												
OECD	22.0	28.7	31	26.4	29.3	11	13.0	15.3	17	59.8	60.3	1
USDA	23.0	33.2	44	27.0	26.1	-3	13.5	15.1	12	60.5	60.8	1
AGMEMOD	23.4	42.6	82	27.3	24.7	-9	13.2	15.0	14	61.8	67.9	10
Net Exports												
OECD	15.9	19.1	20	14.5	15.6	8	3.7	4.3	18	21.7	23.0	6
USDA	15.0	18.7	25	15.0	12.8	-14	4.0	4.1	3	23.2	27.9	20
AGMEMOD	19.0	23.2	22	13.5	11.8	-13	4.6	4.7	1	24.7	28.6	16
Consumption												
OECD	8.5	9.6	13	12.4	13.6	10	9.0	10.9	21	37.0	37.4	1
USDA	8.4	14.4	72	12.5	13.2	6	9.3	11.0	18	36.5	32.9	-10
AGMEMOD	9.1	19.4	114	12.3	12.9	6	9.0	10.1	12	36.9	39	6

Notes: OECD = OECD FAO Agricultural Outlook 2016-2025 (OECD and FAO, 2016), USDA = International Long-Term Projections to 2025 (USDA, 2016a), AGMEMOD = AMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Source: own representation based on sources indicated in notes

It can be observed that the figures for 2015 are mostly similar, but sometimes show some deviations which are highest for net exports. The reasons for deviations in historical data are manifold, i.e., a) different data source, b) different time of data collection, c) different time span, e.g., calendar year vs. market year, and d) different definitions of items, e.g., variables or products. The latter two arguments apply for the projection period as well. When considering outlook projections, one should focus more on the observed development over time than the absolute figures because they often depend on the last observed values, which can bias the results. In order to understand why markets are projected to develop in a certain manner, one must know the exogenous assumptions and the properties, methodology and dependencies of and in the applied models, which are beyond the scope of this dissertation. Nevertheless, some comparisons and conclusions can be drawn.

For corn, all projections show an increase in production combined with increasing net exports as well as consumption. AGMEMOD projects the largest increase in Ukraine. Production increases are due to yield increases, which are similar in the AGMEMOD and USDA projections but lower in the OECD/FAO projections, and area expansion in AGMEMOD to 5.9 million hectares in 2025, whereas USDA and OECD/FAO project corn area to be 4.5 million hectares and 4.4 million hectares, respectively. For Russia, the OECD/FAO outlook projects the largest increases, while the USDA and AGMEMOD projects lower growth especially in exports. All three models project an increase in corn yields and area for Russia with AGMEMOD projecting largest increases in yields and lowest in area. The expansion of corn cultivation is not a phenomenon unique to Ukraine and Russia. Farmers have increased corn production at the expense of less productive feed and food crops in other countries, and this trend is likely to continue as corn is a monoculture and, hence, no crop rotation problems occur.

For wheat, the picture is more diverse than in the corn market. Although AGMEMOD and USDA project that the levels of production in 2015 will not be reached on average again until 2025 in Ukraine, the OECD/FAO projection sees more potential for wheat production. For Russia, AGMEMOD is the most optimistic in increasing wheat production. Yield developments are projected to increase with the exception of USDA which projects a decline in wheat yield in Ukraine. Yields increased historically because of the growing of new varieties, improved management practices and optimized input use of fertilizer and plant protection. This trend is still continuing in Ukraine and Russia, and there is potential for further yield increases (Balkovic *et al.*, 2015). Hence, yield declines can only occur if wheat is grown on less fertile soil, as probably expected by the USDA projection, where the wheat area expands in Ukraine and Russia. For both countries, AGMEMOD projects a decline in wheat area, while the OECD/FAO projects only a slight increase.

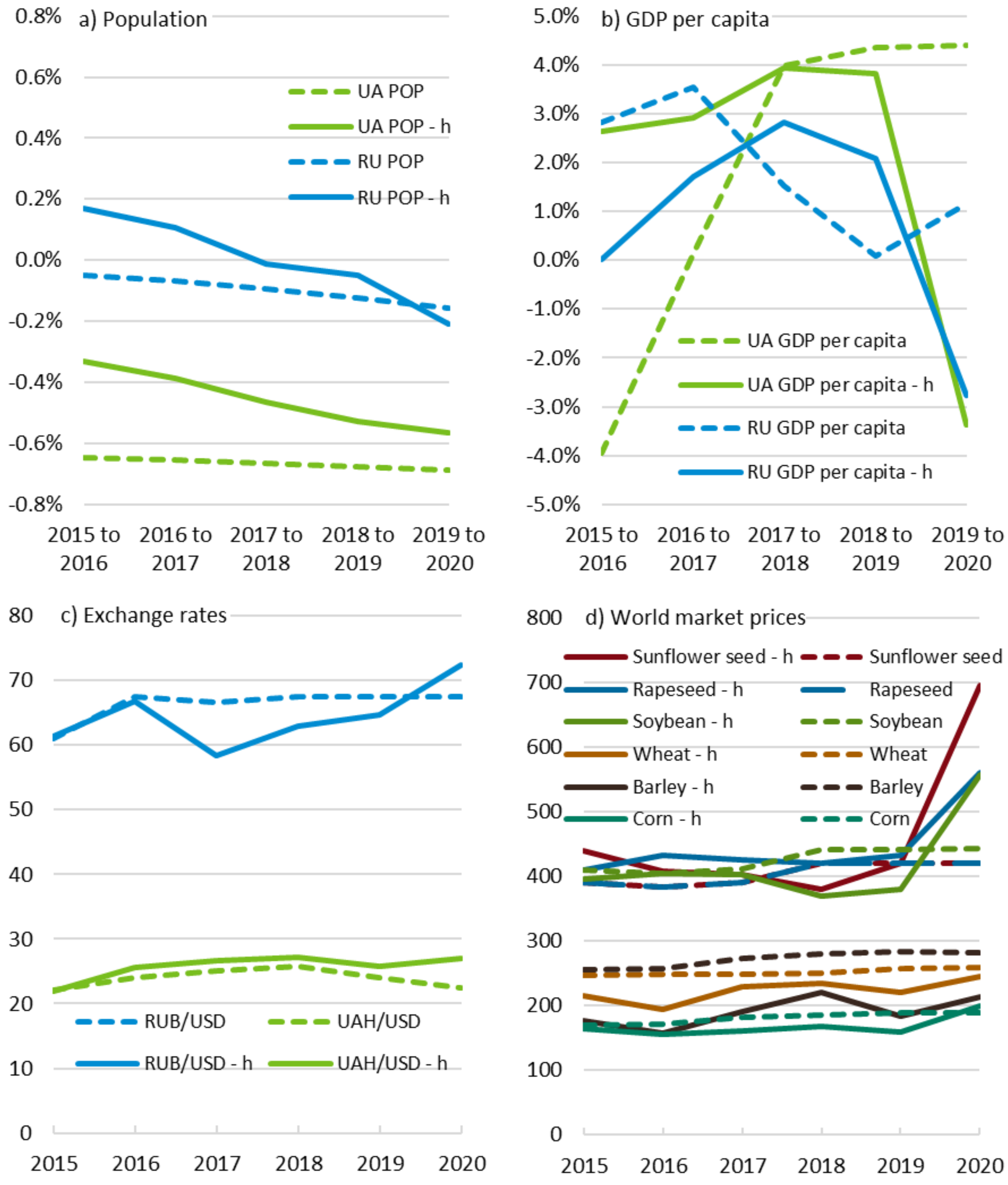
The different results of the projections emphasize the uncertainty in market projections and the necessity to interpret the results carefully. Additionally, the results can be complemented by the judgement of market experts and active market participants. It is further important to mention, that the models and their projections depend on long term trends and include main market drivers, e.g., population growth, GDP development, and technological progress, but are not able to consider short term events, such as wars, economic crises, volatility in prices and fluctuations in yield due to weather that disrupt a market.

4.1.7 Comparison to historical data

The presented analysis is based on data up to 2016. This gives the opportunity to compare projections to actual developments and underline that projections are neither forecasts nor prediction even though they try to replicate reality but in a simplified form.

Various factors impact cereal and oilseed markets (Chapter 2) and the most relevant have been included in the models as exogenous assumptions or are endogenously modelled (Chapter 3). Figure 72 shows the assumed and historical development of some of the most important exogenous assumptions for Ukraine and Russia in the model system between 2015 and 2020, i.e., national development of population, GDP, and exchange rates, as well as world market prices for cereals and oilseeds.

Figure 72 Development of underlying assumptions in projections compared to actual historical development, 2015-2020



Notes: a) Annual changes of population in percentage, b) annual changes of real GDP per capita based on local currency at constant prices in percentage, c) exchange rates in national currency to USD, d) World market prices in USD/t; h = historical data; dotted lines underlying assumptions in projection based on AGMEMOD database, continues line historical data as available in July 2021 for GDP per capita and Population from World Bank (2021b), for exchange rates from Bank of Russia (2021) for RUB to USD and National Bank of Ukraine (2021) for UAH to USD, for world market prices based on OECD and FAO (2021a) for cereals (note: 2020 does already include some projected data and, hence, does not include the latest increases in prices) and ISTA Mielke GmbH (2021) for oilseeds

Source: own representation based on AGMEMOD database and different data sources as indicated in notes

Population has decreased less than assumed in Ukraine and even increased in Russia compared to the assumed decrease until 2017 (Figure 72a). Therefore, expectations are that food consumption including cereal and vegetable oil consumption might be projected to be slightly lower than historically observed. However, the differences are very minor so that this effect might be easily overlapped by the differences in other underlying assumptions.

Assumptions on the development of GDP per capita deviate strongly for 2015 to 2016 where the projected negative impact of the Ukrainian crisis on GDP in Ukraine was not observed as assumed and the negative impact on the Russia economy was underestimated (Figure 72b). Additionally, the projections could not foresee the sharp drop in GDP per capita in 2020 due to the COVID crisis. Higher projected than observed GDP growth might result in higher projected than observed demand of cereals and oilseeds mostly due to increased feed demand. Lower projected than observed GDP growth might result in the opposite but cloud also lead to a higher projected than observed demand of cereals for food consumption if more staple foods are consumed.

The projected exchange rates of the UAH to the USD are very similar to the observed exchange rates with only a slightly higher devaluation as assumed (Figure 72c). Consequently, the conditions for projected Ukrainian exports might have been less favorable than observed and projected exports should be less than observed for cereals and oilseeds. The projected exchange rate of the RUB to the USD was higher for 2017 to 2019 than the historical, which might result in higher projected exports than observed. The impact of the exchange rate on markets is of a short-term nature (Chapter 2). Hence, long-term projections do not consider their variability but assume an average development which seems to fit the observed data quite well.

Projected world market prices for cereals were higher than observed except for corn in 2020, while oilseed prices fluctuated around the projected levels until 2019 (Figure 72d). Consequently, the production of cereals might be relatively more profitable in the projections as historically observed resulting in higher projected cereal production than observed. Additionally, the largest difference lies in the assumption of the barley price compared to its historical development. In the projections the barley price is assumed to be above the wheat price while actually it stayed below the wheat price. Hence, the competitiveness of barley production might be overestimated in the projections. So projected barley production might be higher than actually observed.

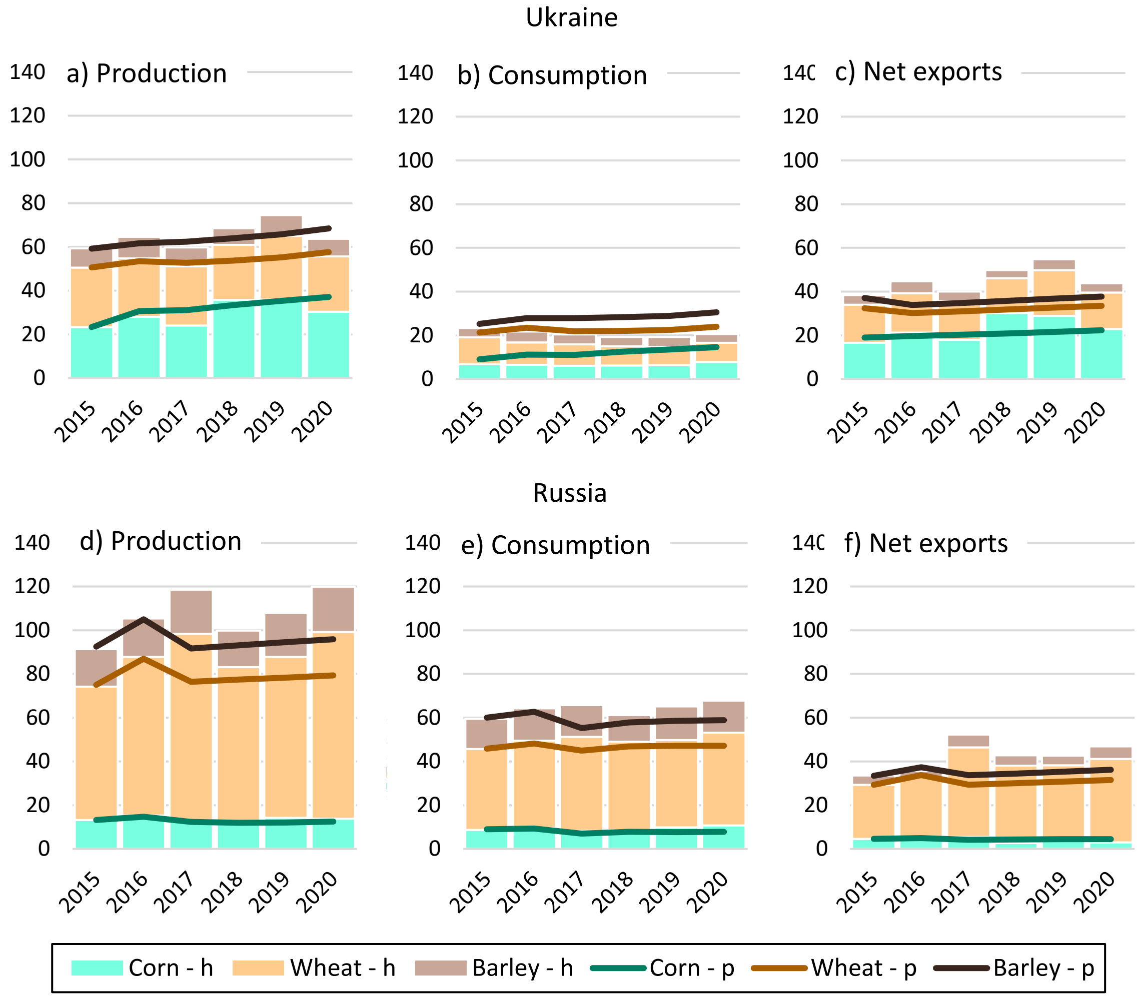
Also, the sharp increase in prices in 2020, especially for oilseeds, could not be foreseen in projections. This increase is due to a tightening of the market with reduced production due to mainly unfavorable weather but continuous strong demand for oilseeds. In the projections, weather is assumed to reflect average conditions, i.e., variability in weather is not considered. Consequently, projected production for oilseeds might be higher in 2020 than observed. A price increase results in reduced demand and higher production in the long-term. Consequently, demand for oilseeds might be projected higher in 2020 than observed. On the production side, an increase in production might only occur in the next year if prices are expected to stay on the higher level and production is not negatively impacted by weather again.

Besides these included assumptions, other changes are not considered in the projections. The most significant would be the annexation of the Crimea peninsula by Russia and the ongoing tensions in eastern regions of Ukraine. This adds to market uncertainty and might result in higher domestic prices. Related to this, the Russian import ban on certain agricultural products, e.g., animal products, from western countries has been renewed on an annual basis since 2014 with slight modifications and is still in force. This ban might have increased the domestic livestock production in Russia and, consequently, the projections might have underestimated the production of the livestock sector resulting in lower projected feed demand than observed.

Having theoretically derived possible market impacts due to differences in assumptions and observed data, the actual market developments are expected to have been developed differently than the projected developments. These different developments might be explainable by the differences in the included assumptions but probably also by factors and developments which are not included in the model system. An attempt to disentangle and identify these factors is done for the cereal and oilseed markets in Ukraine and Russia. Therefore, Figure 73 and Figure 74 display the projected and historical market developments for the cereal and oilseed markets, respectively.

For the cereal market of Ukraine, differences between projections and actual developments can be explained by the difference in the underlying assumptions: barley production did not increase as much as projected as prices were lower, while wheat production increased more than projected. The total projected development of cereals production fit observed levels well, as differences can be mostly explained by weather variability (Figure 73a). Further, domestic consumption did not increase as projected (Figure 73b) probably due to the lower GDP per capita growth but also the uncertain economic and political environment as well as the tensions between Ukraine and Russia. The main difference appears in the consumption of corn as projections assumed much higher domestic consumption in the form of feed use as actually observed. Exports surpassed projections (Figure 73c) due to the slightly higher exchange rate which favors exports and the reduced domestic demand. The variability in exports is a direct consequence of the varying production levels.

Figure 73 Projected (lines) and actual (bars) cereal market developments in Russia and Ukraine, 2015-2020, million tons



Notes: h = historical data (as stapled bars) based on USDA (2021d), p = projections (as stapled lines) based on presented projections
Source: own representation based on data sources as indicated in notes

In Russia, cereal production grew faster than projected (Figure 73d). This increase is due to a high expansion of wheat area by 12 % between 2015 and 2020 and stronger yield growth than projected for all three cereals. The projections underestimated both developments for area expansion and yield increase in Russia. This deviation is not explainable through the differences in the exogenous assumptions presented above but probably by assumptions regarding the recultivation of abandoned land. It might be that it is more profitable and easier to achieve than assumed in the model system due to a factor which is not included in the model system. Further, intensification levels in Russia have significantly increased in recent years compared to historical developments which are the basis of the model projections. This can be seen by the increased use of nitrogen fertilizer in Russian agriculture which increased from 2000 to 2014 by an annual average rate of 1.6 % but by an annual average rate of 8.1 % between 2015 to 2019 (FAO, 2021a). The earlier statement that 2016 was an exceptional record year in cereal production need to be revised as further record years followed. Consequently, the model system would need revisions in assumption about intensification levels due to the newly available data.

Further, consumption increased faster than projected (Figure 73e) due to the ongoing expansion of the own livestock sector which also increased faster than projected. One explanation for this is the imposed import ban on meat and dairy products. However, Liefert *et al.* (2019) argue that this continued increase in the expansion of the livestock sectors is slightly below observed levels than before the import ban and, hence, the import ban has not triggered an additional increase in the livestock sector. While this statement is correct, it also supports the projections because they projected an even stronger decline in the growth rate of the livestock sector for Russia in the absence of an import ban. Despite the consumption increase, the large increases in wheat production compared to the projections resulted mainly in higher exports (Figure 73f). Hence, Russia became the largest exporter of wheat in 2017 (USDA, 2021d).

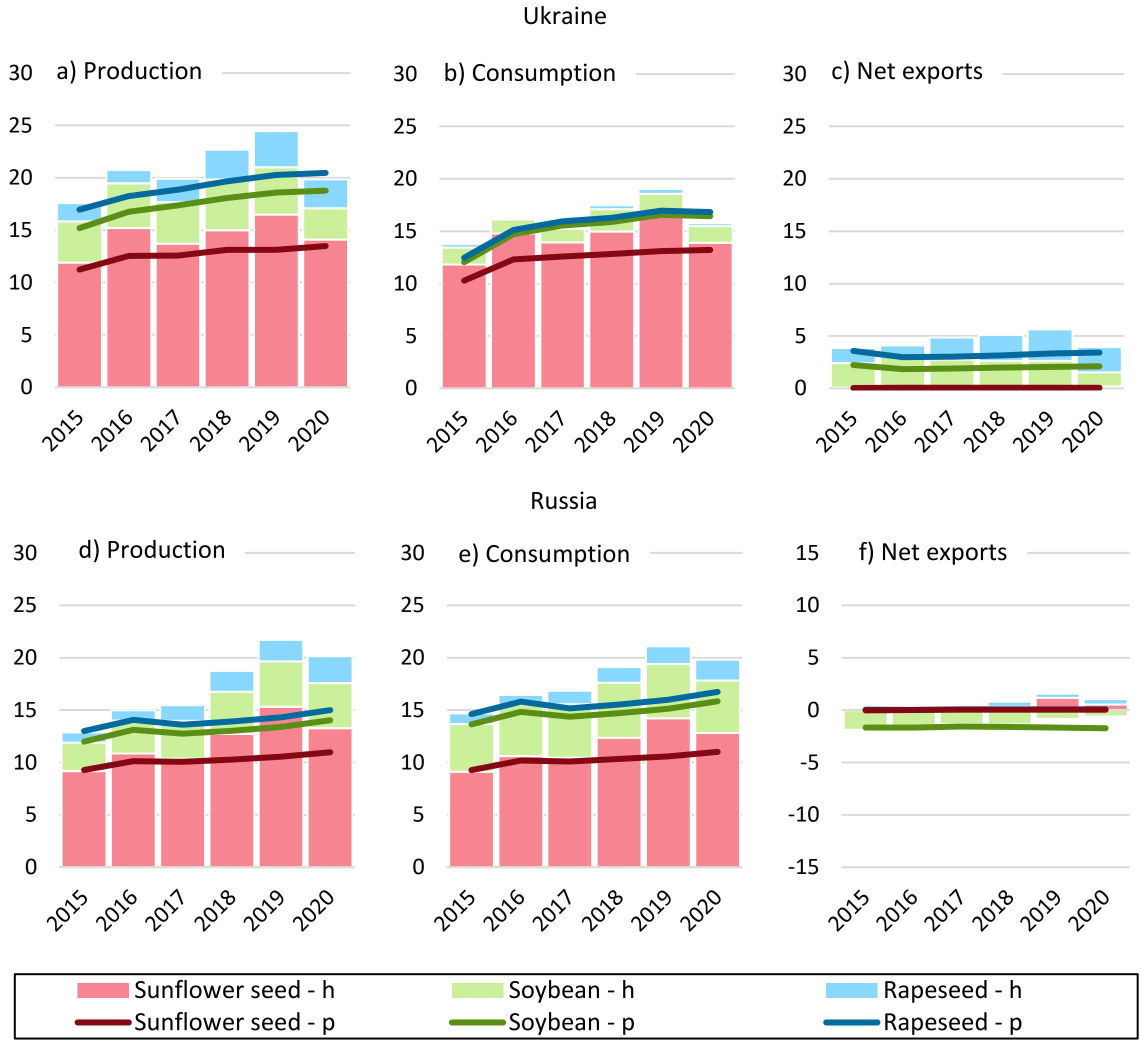
In the case of oilseeds, the dynamic development as observed in the past with strong growth rates continued in Ukraine and Russia. In both countries, the projections fall behind observed developments (Figure 74). This might have been caused by differences in the projected and actual relative prices of oilseeds and cereals. The projected relative price was more favorable for cereal production than oilseed production compared to observed developments.

Ukraine expanded especially rapeseed production which was mainly exported to the EU (UN, 2021a). This development might have been supported by the reduction in rapeseed production in the EU which was not projected and the closer relationships between the two regions. This closer relationship in the form of the DCFTA between Ukraine and the EU might have a stronger impact than modelled which would require a model revision.

In Russia, oilseeds expanded much more strongly than projected. Besides the price advantage, higher observed than projected area expansion and increased yields due to intensification for Russia can explain the differences similar as in the case of cereals. Record sunflower seed harvests, especially in 2019 due to favorable weather conditions, led to direct sunflower seed exports, while before nearly all produced sunflower seed was processed within the country. Hence, crushing capacities in 2019 reached their limits. Further soybean production expanded quicker than projected which lead to reduced imports compared to approximately constant projected imports.

As shown, the deviations of the projections compared to actual developments are partly explainable through a systematic variation in the developments of the factors considered in the model system which supports the strong projection capacity of the applied model system. However, some factors which are not considered in the model system probably impacted the markets significantly such as the Russian import ban. Additionally, new data revealed changes in historical trends in recent years such as higher intensification and area expansion in Russia. As the projections strongly rely on historical trends a changing trend is not anticipated, again confirming the projection capability of the model system within given limitations.

Figure 74 Projected (lines) and actual (bars) oilseed market developments in Russia and Ukraine, 2015-2020, million tons



Notes: h = historical data (as stapled bars) based on USDA (2021d), p = projections (as stapled lines) based on presented projections

Source: own representation based on data sources as indicated in notes

4.1.8 **Conclusion**

The presented analysis provides a better understanding of the drivers of Ukrainian and Russian cereal and oilseed markets. The projections suggest that growth in cereal and oilseed markets in both countries might continue differently than observed in the most recent past. While cereal production is projected to be more competitive than oilseed production in Ukraine, it is the opposite in Russia. Hence, in the projections, Ukraine focuses on increasing cereal production, while Russia further expands oilseed production.

In detail, the projections for Ukraine show that the historical increase in cereal production, especially corn, might continue to increase. In the oilseed sector, the observed historical expansion does not continue after 2020, but slows down. A substantial fraction of the production is exported and, hence, Ukrainian cereal and oilseed markets are strongly linked to world market developments. Furthermore, it can be shown that an increase in the exchange rate favors the production of oilseeds at the expense of cereals. Comparison to real world developments, show that projections of production are similar to observed levels until 2020. However, Ukraine has increased exports more and consumption less than projected probably due to lower GDP growth and the unstable economic and political environment which hinders investments in, e.g., the processing industries.

For Russia, projections point to a further increase in oilseed production, while cereal growth is slowing down. The oilseeds are crushed domestically and large shares of the resulting oil and meal are exported. Changes in the exchange rate are projected to change cereal consumption patterns the most as the consumer income changes. In reality, Russia has surpassed projected cereal and oilseed production growth until 2020 to a large extent. The main reasons seem to be cereal and oilseed area expansion and a strong increase in intensification levels which both surpass observed historical trends.

The analysis demonstrates that Ukrainian and Russian cereal and oilseed markets can be successfully modelled and projected with the developed model system. AGMEMOD was modified by introducing yield developments based on a detailed spatial resolution including bio-physical aspects, overall agricultural area developments and bilateral trade effects through the link to GLOBIOM and MAGNET. This extension enables AGMEMOD to capture more realistic assumptions on yield, area, and trade developments than in previous projections. The robustness of the results is tested by conducting sensitivity analyses, which show that by varying exchange rates or yields, production and exports of cereals and oilseeds vary within an expected range.

The uncertainty of projections is further underlined by comparing the results with two other projections. The comparison shows variations among all three projections presented. However, none of the projections can be interpreted to be better than the others. Hence, the projections can be seen as three different possible paths. Where the projections coincide, the results can be interpreted as more robust than the projections which show different trends. Additionally, it is stressed that projections are always based on specific assumptions and do not reflect actual real-world developments. This is underlined by comparing the projections which are based on data available in 2016 with actual developments until 2020. The model system projected reasonable results for most developments given the coverage of the factors impacting the markets and their specific assumptions and factors. However, projections for cereal and oilseed production in Russia have been lower than observed mainly due to changes in historical trends which were not foreseen in 2016.

In conclusion, projections based on different approaches are important to give various pictures of possible development paths. Furthermore, a comparison of different projections gives insights in the robustness of the results for specific variables. However, it always has to be kept in mind that projections rely on the applied models with their specific underlying database, economic theory, assumptions, dependencies and influencing factors when comparing and interpreting the results. Despite these limitations, the developed baseline is a good starting point for scenario analyses which are conducted in Sections 4.2 and 4.3.

4.2 Potential increase of Ukrainian and Russian cereal and oilseed production

The economic and political environment in Ukraine and Russia are obstacles for long-term investments in agriculture and contribute to low productivity. Improving the institutional environment is assumed to increase productivity. Transferred to cereal and oilseed markets, this would result in a reduction of yield gaps, i.e., one of the four factors identified to be an important long-term driver impacting cereal and oilseed markets (compare Chapter 2). Despite recent growth in production (compare Section 4.1.4 and 4.1.7), Ukraine and Russia have the potential to further increase production by increasing yields and area (Swinnen *et al.*, 2017). Hence assuming improvements in the institutional environment[7], this case study explores the impact of increasing yields by intensification and technology adaptation, i.e., closing the yield gap (compare Section 2.1.1), for cereals and oilseeds until 2030 on domestic land use and agricultural markets. Therefore, a scenario is constructed and the developed model link between AGMEMOD, GLOBIOM and MAGNET (compare Section 3.3) is applied.

Section 4.2.1 motivates the analysis and puts it into the context of existing literature. Afterwards, Section 4.2.2 describes the scenario construction and methodical adjustments compared to Section 3.3.2. The results are presented in Section 4.2.1 and compared to Deppermann *et al.* (2018) in Section 4.2.2. Section 4.2.3 discusses the methodological approach as well as the results before Section 4.2.4 concludes.

4.2.1 Motivation and literature review

The institutional and commercial environment in Russia and Ukraine has improved in recent years but is still characterized by several issues which hinder the development of businesses (compare Section 4.1.2). This transfers to low productivity because of low input use, obsolete machinery and low quality of education in the agricultural sector (Liefert and Liefert, 2012; Schmitz and Meyers, 2015). Improving the institutional and commercial environment and increasing public and private investments can contribute to remedy this and leads to increased productivity, i.e., higher yields (compare Section 2.1.1 for a general discussion on causes of yield developments). For cereal and oilseed production, this means that yields might increase and come closer to its potential yields and, hence, its potential production. In countries with better institutional and commercial environment and intensive production systems, yields are as close as 80 % to their bio-physical potential yields (Lobell, Cassman and Field, 2009) and can be interpreted as ‘maximal economic feasible yield’.

The potential production of cereals and oilseeds in Russia and Ukraine is of global interest from a food security point of view (Gomez y Paloma *et al.*, 2016). Therefore, several studies (see below and in Table 19) estimate production potentials for cereals or oilseeds by focusing on yield increases and expanding land use in the region. Both aspects seem to have the potential to increase production.

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[7] In the current situation with the ongoing war of Russia against Ukraine, this assumption is unrealistic. However, during the start of this research in 2014, improvements in the institutional environment seemed a reasonable assumption.

Productivity increase, in the form of increases in cereal and oilseed yields, have been observed in recent years (compare Section 4.1.4). However, the potential to increase yields further is large as considerable yield gaps for cereals and oilseeds exists (Swinnen *et al.*, 2017). Yield gap is the difference between observed and potential yields. Potential yields in turn have various definitions and their magnitude depends on them (for a discussion see Lobell, Cassman and Field (2009)). In this case study, potential yields are defined as maximal bio-physically achievable yields under rainfed conditions. The total closing of yield gaps is achieved if 80 % of this potential yield is reached, i.e., the 'maximal economic feasible yield'.

Several studies have quantified existing potential yields and yield gaps for cereals and in some cases also oilseeds on a global scale, e.g., Licker *et al.* (2010), Neumann *et al.* (2010), and Mueller *et al.* (2012) or in the regions, e.g., Neumann *et al.* (2010), Mueller *et al.* (2012), Schierhorn, Faramarzi *et al.* (2014), Deppermann *et al.* (2018), Schils *et al.* (2018), and Ryabchenko and Nonhebel (2016). The spatial resolution in the studies is as detailed as 5 minutes of arc depending on the data availability. They apply different definitions, methods, and data to quantify potential yields. For example, Schierhorn, Faramarzi *et al.* (2014) and Schils *et al.* (2018) use crop models to determine maximal bio-physically achievable yields distinguishing between rainfed and irrigated conditions, while Neumann *et al.* (2010) develop a stochastic frontier production function including besides bio-physical parameters also economic parameters such as labor availability, market access, and purchasing power parity to determine 'frontier yields', i.e., the highest observed yields for each combination of included parameters. Licker *et al.* (2010) and Mueller *et al.* (2012) define 100 different climate zones and 'climatic potential yields' or 'attainable yields' as the 90th or 95th percentile of observed yields in each climate zone, respectively. Yield gaps are the difference between the potential yield as defined in each study and observed yields. Consequently, the results of the studies differ but all studies conclude that large yield gaps exist in Russia and Ukraine. For example, all studies include wheat and estimate yield gaps between 1 t/ha (Swinnen *et al.*, 2017) to 2.9 t/ha (Schierhorn, Faramarzi *et al.*, 2014) in Russia and 1.2 t/ha (Deppermann *et al.*, 2018) to 5.1 t/ha (Schils *et al.*, 2018) in Ukraine.

Besides an increase in yields, production can also increase due to increased land use. In Russia and Ukraine, large amounts of land are abandoned which had been used for agricultural production during Soviet times due to state regulations and considerable subsidies (Swinnen *et al.*, 2017). Several studies have estimated this amount of abandoned land or analyzed how much of it could be cultivated again given bio-physical, economic, social, and environmental constraints (Alcantara *et al.*, 2013; Meyfroidt *et al.*, 2016; Schierhorn *et al.*, 2013; Deppermann *et al.*, 2018; Smaliychuk *et al.*, 2016; Lambin *et al.*, 2013). While actual estimates differ, all studies conclude that only a part of the abandoned land could be recultivated. Smaliychuk *et al.* (2016) found that the bio-physical suitability of land for agricultural production is the main reason to recultivate abandoned land followed by the distance to major cities in Ukraine. Additionally, the recultivation of abandoned land is costly and results in biodiversity loss and greenhouse gas (GHG) emissions in Ukraine and Russia (Schierhorn *et al.*, 2013). Further constraints are market accessibility and demographics which hinder the recultivation of abandoned land in the region (Meyfroidt *et al.*, 2016). In Russia, for example, abandoned land is estimated to be more than 30 million hectares but the potential for recultivation is estimated to be less than 10 million hectares according to the studies.

Based on these two aspects, several studies estimated large production potentials in Russia and Ukraine for cereals and oilseeds or only wheat. The range of their results are presented in Table 19 together with the results from Case Study 1 (Section 4.1). While the production potentials cannot be compared directly, several conclusions can be drawn. First, the only study including an economic and a time component and with it technical change due to research and development is Deppermann *et al.* (2018). The other studies estimate increased potential if yield gaps and land recultivation would happen in the reference year. Second, the reference years of Mueller *et al.* (2012) and Ryabchenko and Nonhebel (2016) lie so far in the past that actual production in 2015 (see left value of results baseline in Table 19) has reached or even surpassed their estimated production potential. Third, the production potentials for wheat in Swinnen *et al.* (2017) and Schierhorn, Müller *et al.* (2014) are based on the assumption that wheat is grown on all grain area. This assumption omits the fact that other grains and crops compete with wheat for area.

Table 19 Estimates for actual and potential production for cereals and oilseeds in Russia and Ukraine, million tons

Paper	Corn	Wheat	Barley	Oilseeds	Corn	Wheat	Barley	Oilseeds
	Russia				Ukraine			
Deppermann *et al.* (2018)a)	10 - 22	68 - 133	22 - 31	13 - 19	28 - 48	23-26	11 - 14	14 - 31
Swinnen *et al.* (2017)b)		95 - 160				49 - 80		
Mueller *et al.* (2012)c)	1 - 6	36 - 74	15 - 35	4 - 9	4 - 12	14 - 35	8 - 16	3 - 5
Schierhorn, Müller *et al.* (2014)d)		59 - 91						
Ryabchenko and Nonhebel (2016)e)						18 - 27		
Results baseline (Case Study 1)f)	13 - 18	62 - 70	18 - 18	13 - 21	23 - 49	27 -26	9 - 13	17 - 22

Notes: a)projections for 2030, variations in intensification and land recultivation; b)reference 2008-2013 with assumption of average yields and wheat grown on all land used for grains, based on data from Mueller *et al.* (2012) for intensification and Meyfroidt *et al.* (2016) for land expansion; c)reference 2000 and yield gaps closed to 100 % potential yields, no recultivation; d)only European Russia, base years 1995-2006 for yield potential and wheat grown on all land used for grains, recultivation of land abandoned after 2000; e)reference 1995-13, short-term if fertilization is optimized; f)historical data 2015 and baseline projections for 2030
Source: own compilation based on data presented in the papers

Following these arguments, there is only one study which assesses production potentials of cereals and oilseeds as a whole and within an economic context, i.e., Deppermann *et al.* (2018). However, Deppermann *et al.* (2018) relies on data covering the year of 2000 with partial data updates to 2013 which might be one reason why their production potentials for oilseeds are as low as already observed values in 2015. To overcome this, the developed model system is applied which uses data up to 2016. The aim is to estimate production potentials for cereals and oilseeds considering besides bio-physical components, i.e., yield increase and land use change, also the interdependencies between the national and global cereal and oilseed markets. Thereby the focus is laid on a simulation to close yield gaps and let the model system endogenously decide if additional land is used for production. The resulting changes in production impact cereal and oilseed markets which are analyzed as well.

4.2.2 Scenario design and methodological adjustments

To analyze potentials of cereal and oilseed production increases in Ukraine and Russia, a scenario, namely the 'Technology scenario', is constructed which simulates a switch from extensive to intensive crop production until 2030. A similar scenario with the same reasoning has been applied in Wolf *et al.* (2016) and Deppermann *et al.* (2018), both works originated from the AGRICISTRADE project as well.

In narrative terms, the 'Technology scenario' represents an improved institutional and commercial environment with increased public and private investments in the agricultural sector in Russia and Ukraine. This includes developments such as reduction of corruption, establishment of proper land rights, improved financial system and commercial infrastructure as well as investments in transport and storage infrastructure. For the agricultural sector, this translates to improved access to fertilizers and crop protection products, reduced credit constraints and increased quality of agricultural education. These developments lead to intensified production systems, i.e., increased use of fertilizer, crop protection products, and modern machinery, and better management practices, i.e., higher efficiency levels.

In the model system, the improved institutional and commercial environment is simulated by the elimination of yield gaps between current and 'maximal economic feasible yields'. This rather extreme assumption was chosen to show maximal possible production increases in Russia and Ukraine and their impact on domestic markets. In GLOBIOM a high input production system is constructed which simulates a closing of yield gaps under rainfed conditions based on yield projections from the crop model EPIC (for a more detailed description see Deppermann *et al.* (2018)). As EPIC tends to underestimate yields (Balkovič *et al.*, 2013) this closing of yield gaps can be interpreted as achieving 80 % of potential yields which van Ittersum *et al.* (2013) refers to as exploitable yield gap and is the maximum possibly obtainable level as historically observed (Lobell, Cassman and Field, 2009), i.e., what is termed 'maximal economic feasible yields' in this dissertation. The closing of yield gaps is simulated by switching from the low input production systems, which dominates in the baseline, to the high input production system in GLOBIOM which uses more inputs but is also more efficient. Potential yields increase over time due to technical progress (compare Section 2.1.1) which are also considered in the analysis besides the closing of the yield gap.

Additionally, the option to take abandoned land into production is endogenously modelled in GLOBIOM and as stated before another source of increased production potential. However, this land is only taken into production if its use is economically feasible, e.g., due to higher achievable yields, and land can also be taken out of production if it is not economically feasible to cultivate, e.g., because of too low yield potentials. In fact, our baseline projections show only little land in Ukraine is taken into cultivation, while agricultural land use in Russia declines. Hence, no additional assumptions or variations about the reuse of abandoned land are considered here as its potential seems to be low.

In general, information from GLOBIOM is then transferred to MAGNET and AGMEMOD as in the baseline (compare Case Study 1) and described in Section 3.3.2. One exception here is the transfer of yields from GLOBIOM to AGMEMOD. As the ‘Technology scenario’ simulates maximal attainable yields, the absolute number instead of percentage changes are transferred so that yields in 2030 are identical in the projections of GLOBIOM and AGMEMOD (compare Figure 75 below). These yields in AGMEMOD are obtained in 2030 by assuming constant percentage yield growth during the projection period with the first year of projection equaling – as in the baseline – the average yield of the last three historically observed years.

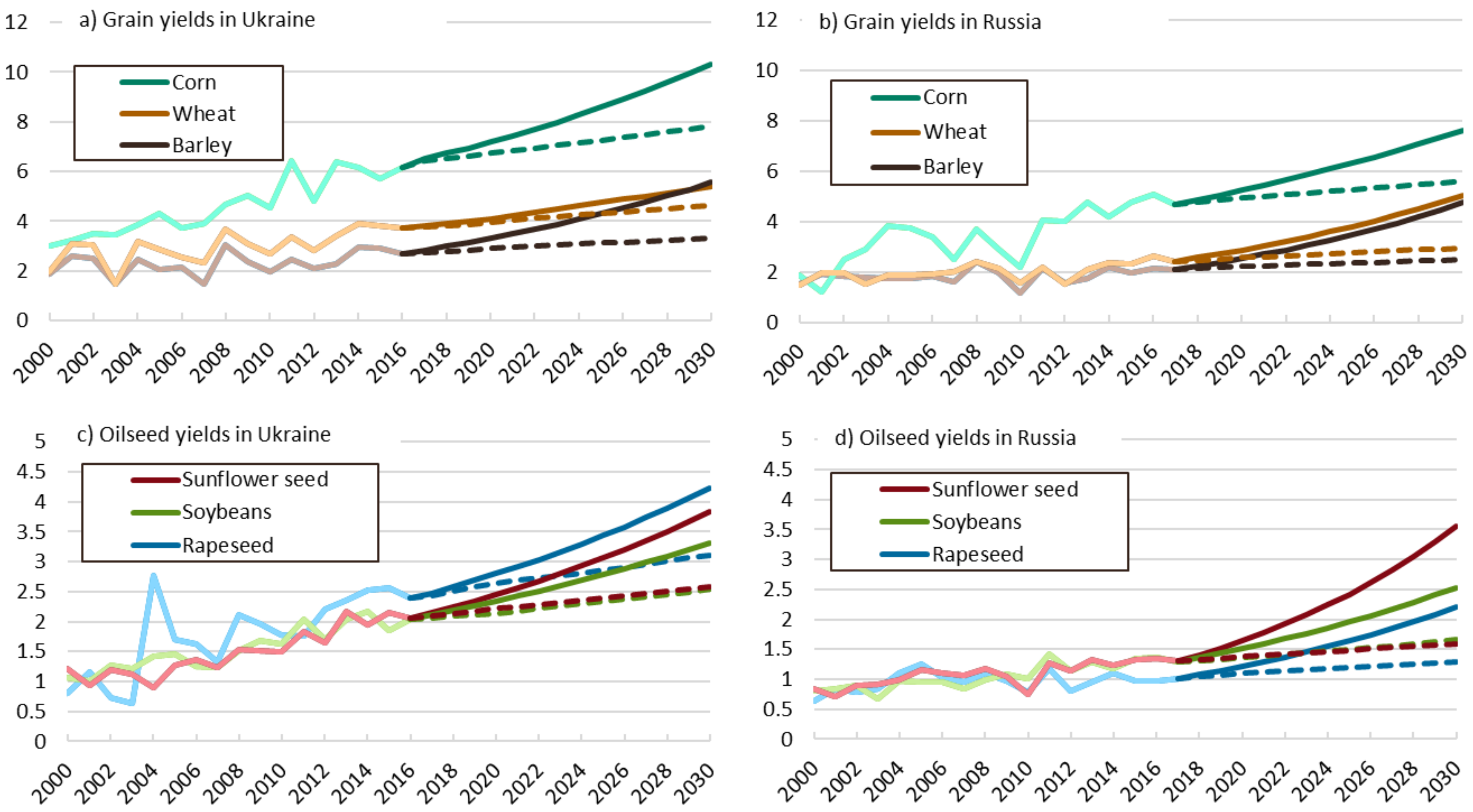
AGMEMOD, as a partial general equilibrium model focuses on the agricultural sector in certain countries and, hence, does not include feedbacks to GDP or world market prices caused by changes in agricultural markets. Hence, changes in GDP and world market prices between the baseline and the ‘Technology scenario’ as simulated by MAGNET were transferred to AGMEMOD as described in Section 3.3.2. This transfer can be seen as improving the AGMEMOD results because the alternative would have been to keep GDP and world market prices constant in AGMEMOD, i.e., assume the two countries are small producers for cereals and oilseeds without having an influence on world markets.

4.2.1 **Results**

The ‘Technology scenario’ differs from the baseline mainly in the assumption of yield developments as described in the previous section and displayed in Figure 75. The yield increases have two reason, i.e., increased input use such as fertilizer and crop protection products as well as improved efficiency due to better management and equipment. Comparing the ‘Technology scenario’ with the baseline, yield growth is not uniform across the crops as yield increases between 17 % for wheat in Ukraine and 123 % for sunflower seed in Russia in 2030.

In Ukraine, especially barley yields increase strongly and even surpass wheat yields at the end of the projection period, while soybean yields grow less than sunflower seed and rapeseed yields. In Russia, the strong increase of sunflower seed yields is most remarkable. The yields in Russia increase more strongly in percentage terms but are below yields in Ukraine as the weather condition in Ukraine are more favorable for cereal and oilseed production than in some parts of Russia. This can be observed especially in the case of corn and rapeseed (Figure 75).

Figure 75 Cereal and oilseed yields in Russia and Ukraine for the baseline and 'Technology scenario', 2000 - 2030, tons per hectare



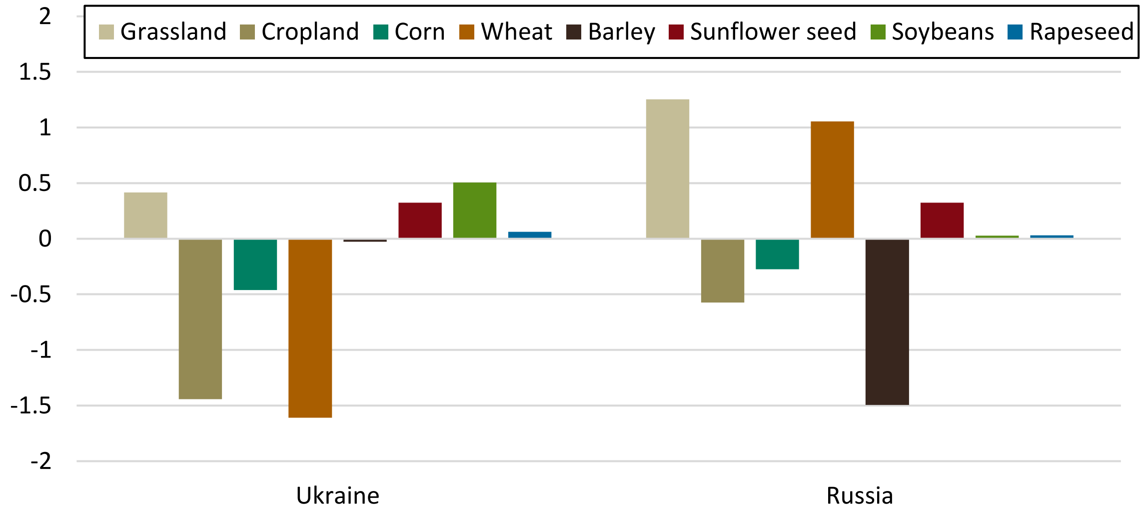
Notes: historical data in light colors, projections in vibrant colors with baseline as dotted lines and 'Technology scenario' as solid line, changes in yields are a result of the simulated closing of yield gaps in GLOBIOM

Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

As a result of the simulated yield growths, total agricultural area increases in Russia by 0.7 million hectares, i.e., 0.5 %, and decreases in Ukraine by 1 million hectares, i.e., 3 %. This counterintuitive effect in Ukraine can be explained by the fact that less productive area is not used for agricultural production anymore. To clarify, the increased input use seems to be unprofitable on land with low yields and some land might not be suitable for larger machinery. Hence, the decline in area used is observed as projected by GLOBIOM which considers these effects on a small spatial resolution. Cropland declines and grassland expands in both countries (Figure 76). This shift is attributed to the fact that more feed is available at lower costs which makes livestock production more profitable. Hence, more grassland is required for the ruminant sector. As a result, Russia is expanding its ruminant sectors further given more available feed, while Ukraine focuses on exporting its raw products and only slightly increases its ruminant sectors.

Further, both countries expand oilseed area with Russia increasing sunflower seed area the most and Ukraine rapeseed area followed by sunflower seed area (Figure 76). Cereal area decreases in both countries with only Russia increasing wheat area. This can only be explained by the fact that low productive area is taken out of cereal production due to no or low efficiency gains. The area changes correlate with the changes in yield. For cereals, for example, lowest yield growth for wheat in Ukraine is accompanied with highest area reduction and highest yield growth for wheat in Russia is accompanied by highest area expansion. An exception is the case of sunflower seeds in Ukraine. While highest yield growth is observed for sunflower seed, rapeseed area is growing more than sunflower seed area. One explanation for this is that crop rotation is a limiting factor for further expansion of sunflower seed area.

Figure 76 Changes in land use, 'Technology scenario' vs. baseline in 2030, million hectares



Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Cereal production increases in the 'Technology scenario' compared to the baseline as a result of yield and area changes with the exception of wheat in Ukraine (Table 20). The assumption of increased technical progress leads *ceteris paribus* to a decrease in prices. This is observed on the world market by slightly reduced world market prices, i.e., the decline as projected by MAGNET is less than 0.3 % for any cereal in the 'Technology scenario' compared to the baseline in 2030. However, higher yields based on closing of yield gaps are also attributed with higher costs due to increased use of fertilizers and crop protection products which increases prices. Given further that Ukraine and Russia are integrated in the world market, the small changes in prices of less than 4 % seem plausible. One exception is the barley price in Ukraine which declines by 10 % in the 'Technology Scenario' compared with the baseline. This is due to the exceptionally strong yield growth. So, barley becomes very competitive on the world market and the additional production is exported.

Table 20 Cereal market developments, differences 'Technology scenario' to baseline in 2030

	Production	Domestic use	Net exports	Production	Domestic use	Net exports
		Ukraine			Russia	
			Δ million tons			
Corn	10.9	9.5	1.4	4.4	0.0	4.2
Wheat	-4.3	-4.5	0.2	54.4	8.6	43.7
Barley	8.5	-0.8	9.3	8.9	8.4	0.2
			Δ%			
Corn	22.2	38.2	5.7	24.2	0.3	86.2
Wheat	-16.3	-32.1	1.7	78.0	21.9	144.4
Barley	66.4	-9.2	204.0	50.4	67.4	4.2

Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

In Ukraine, wheat loses competitiveness to other cereals due to the low yield increases. Hence, less wheat is planted in Ukraine in the projection. Additional production of corn in Ukraine is predominantly used to satisfy domestic demand substituting wheat in feed rations further and satisfying increased feed demand. The competitiveness of barley over wheat is mainly due to the high technical progress projected which is attributed with lower production costs and results in decreased prices making barley export highly competitive on world markets.

In Russia, wheat production is expanding strongest and the focus on wheat production is further enhanced compared to the already strong focus in the baseline. Additional corn and wheat production are projected to be exported. In contrast, barley, and partially wheat, satisfies increased feed demand due to an expansion in the livestock sectors. These circumstances are explainable because a) corn is projected to become relatively more expensive then barley and wheat (compare also baseline developments in Figure 67, page 133) and b) corn and wheat production are more closely located to export ports than barley, especially to the Black Sea region (USDA, 2021b), and, hence, their export potential is higher due to reduced transportations costs within Russia. The distance to ports and attributed transportation costs are important factors explaining the existence of market segmentation within Russia between exporting regions and regions supplying the domestic market as has been shown for wheat in Svanidze and Götz (2019). Supposing the projected additional expansion of the livestock sector is taking part in the areas far from ports or moving towards them, the different market developments between the cereals are further underpinned. These possible structural changes might also explain the increase in barley prices contrary to expectations.

Oilseed production increases strongly in the 'Technology scenario' compared to the baseline until 2030 (Table 21), thereby sunflower seed increases the most, followed by soybeans and rapeseed in both countries. Global demand of oilseeds stays strong and world market prices decrease only by 0.3 % as projected by MAGNET. The oilseed prices strongly depend on world market prices and because both countries are small producers of oilseeds, their prices only slightly change. The fact that Russia and Ukraine are large producers of sunflower seed counts little because the share of sunflower seed in total oilseed production is relatively small on global scales.

The additional production in Ukraine is nearly completely exported, either as seed in the case of rapeseed or as meal and oil in the case of soybeans and sunflower seed. In contrast, Russia increases its domestic consumption of seeds, oils and meals. Imports of soybeans even increase despite the own production increase. The increased domestic demand comes from the increase in the livestock sector which also enhances the shift towards more soybean meal and less sunflower meal.

Table 21 Market developments for the oilseed complex, differences 'Technology scenario' to baseline in 2030

	Production	Domestic use	Net exports	Production	Domestic use	Net exports
		Ukraine			Russia	
			Δ million tons			
Rapeseed	0.9	0.0	0.9	1.0	1.0	0.0
Soybeans	3.2	3.1	0.1	2.6	5.4	-2.8
Sunflower seed	8.5	8.2	0.0	18.8	18.8	0.0
Vegetable oil	4.1	0.0	4.1	9.6	3.4	6.2
Meals	5.7	0.0	5.7	12.9	7.7	5.2
			Δ%			
Rapeseed	51.1	-0.3	63.8	76.8	79.3	14.4
Soybeans	65.2	111.3	4.8	54.2	81.2	153.7
Sunflower seed	56.8	55.3	9.9	130.5	130.0	-22.6
Vegetable oil	63.1	0.1	72.3	122.7	94.2	146.9
Meals	87.7	0.1	105.6	108.3	93.6	141.5

Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

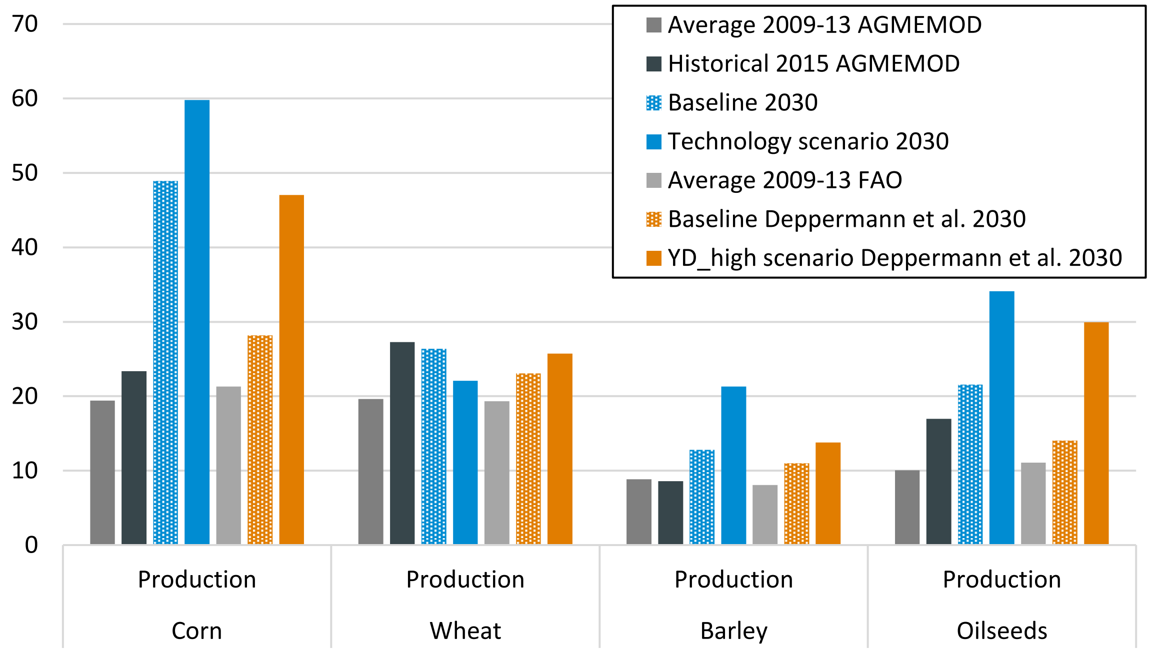
4.2.2 Comparison to Deppermann *et al.* (2018)

The single scenario performed here with the model system can be compared to the work presented in Deppermann *et al.* (2018). They used GLOBIOM alone to analyze different possible levels of intensification and recultivation. One of their eight scenarios, i.e., 'YD_high', is based on similar assumptions as the 'Technology scenario' presented here. In fact, yield projections for wheat, barley, corn, and oilseeds are identical except for corn and barley in Russia where Deppermann *et al.* (2018) projects even higher possible yields with an additional 1.0 ton per hectare for corn and 0.3 tons per hectare for barley. Hence, own results are compared to the baseline and 'YD_high' scenario in Deppermann *et al.* (2018).

It is necessary to note that their historical data and baseline results differ substantially from the baseline used here. One reason is that historical data in GLOBIOM covers the year 2000 with partial data updates until 2013 from FAO (2016). The used historical data differ from the AGMEMOD database due to different sources and time coverages. Hence, the advantage in using the model system over GLOBIOM alone can be seen in the incorporation of most recent data for the analysis through AGMEMOD (Figure 77, Figure 78, and Table 22).

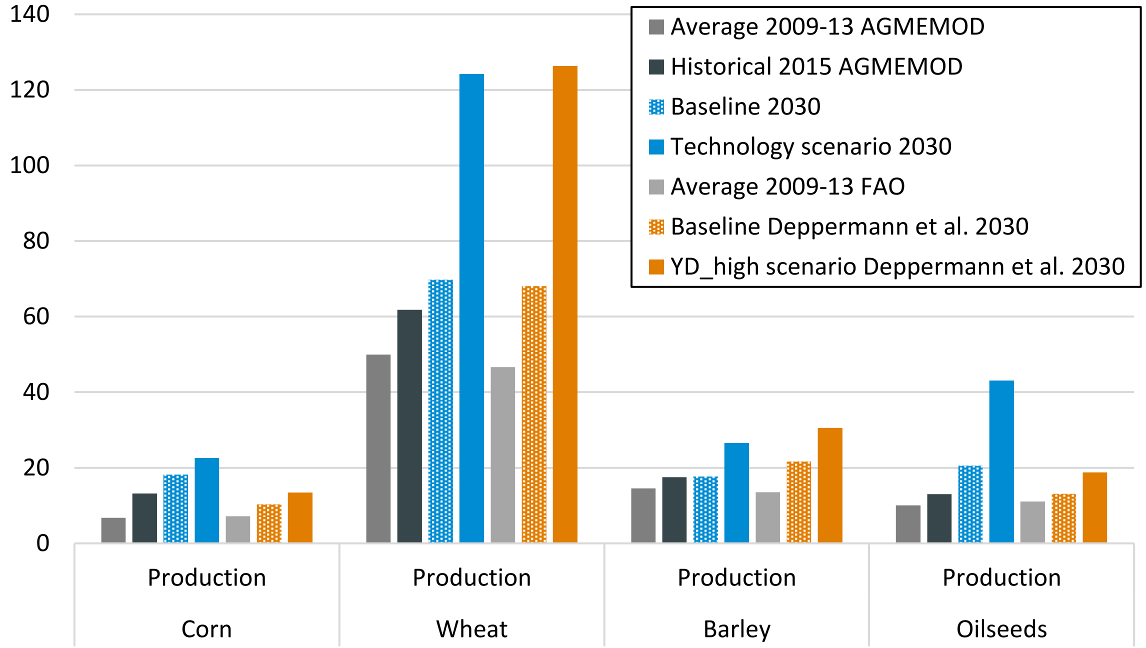
This is most pronounced for corn and oilseeds which have shown a strong production increase historically which is not considered by GLOBIOM. In fact, GLOBIOM projects production levels in the baseline for 2030 for oilseeds in Ukraine (Figure 77) and corn in Russia (Figure 78) well below historically observed levels in 2015, i.e., 17 % and 22 % lower, respectively. Consequently, the applied model system for the presented case study projects higher production for corn and oilseeds in both countries in the baseline and 'Technology scenario' compared to Deppermann *et al.* (2018). This can be explained by a) the difference in area (compare Table 22), which starts historically at higher levels than in Deppermann *et al.* (2018) and b) the projections relying on latest observed trends.

Figure 77 Comparison of cereal and oilseed production in Ukraine between historical data, own projections and projections of Deppermann et al. (2018), million tons



Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET and Deppermann *et al.* (2018)

Figure 78 Comparison of cereal and oilseed production in Russia between historical data, own projections and projections of Deppermann et al. (2018), million tons



Source: AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET and Deppermann *et al.* (2018)

The increase in yields results in decreased cropland use in both studies. Deppermann *et al.* (2018) also simulate a facilitation in taking abandoned land into production in combination with increased yields but all scenarios result in lower land use than in their baseline. Differences are observed in the amount of area cultivated with cereals and oilseeds. In the model system more area is cultivated than in Deppermann *et al.* (2018) because of differences in data sources and historical time coverage (Table 22). For example, cropland expansions have already been historically observed until 2015. Especially the wheat area in Russia is 4 million hectares or 18 % higher in 2015 according to the AGMEMOD baseline than reported in FAO (2016) for the average of 2009-13.

Relying on observed trends for projections bears several caveats and might be questioned especially if a strong historical growth is observed. This growth might slow down due to reaching different constraints so that production might be overestimated by the model system. Nevertheless, the model system already projects higher production levels in the baseline than Deppermann *et al.* (2018) except for barley production in Russia (Figure 78). This is also due to the assumption in Deppermann *et al.* (2018) that no reductions of yield gaps occur in their baseline, while the baseline of the model system implicitly includes them if the reduction of yield gaps has been observed historically.

In the 'Technology' and the 'YD_high' scenario total production levels are more similar. But, it can be noted that the model system is more responsive in production changes between different crops than GLOBIOM. For example, wheat yields increase much less in percentage terms in the 'Technology Scenario' than any other crop in Ukraine. Hence, wheat production in Ukraine loses competitiveness especially relative to barley production which experiences large yield growth in the 'Technology scenario' and, hence, production even declines in the model system, while GLOBIOM projects production increases for all cereals and oilseeds. Both developments seem plausible depending on the willingness and speed of farmer to change cultivations between crops.

On the demand side, the model system also reacts more differentiated than GLOBIOM (Table 22). In GLOBIOM additional production is mostly exported, while in AGMEMOD it is partially also used domestically to satisfy an increased demand from the growing livestock sector, especially in Russia. Deppermann *et al.* (2018) state that they have not considered a change in the livestock sector but acknowledge that it is a possibility. The projected net trade positions in the baseline of Deppermann *et al.* (2018) seem low compared to recently observed developments. For example, Russia is projected to be a net importer of corn and barley in 2030 in the baseline, while historically it has been a net exporter since 2009 for corn and 2001 for barley. This could also be caused by the data used, i.e., due to the lack of incorporating more recent developments.

As summarized in Table 22, additional production of cereals and oilseeds in Ukraine and Russia in 2030 due to increased yields, i.e., a complete closing of existing yield gaps, is similar between both studies but the model system projects even higher absolute production levels due to larger area. The additional export potentials vary substantially with 97 million tons projected by Deppermann *et al.* (2018) and only 57 million tons projected by the model system. However, total levels differ only by 6 million tons. This shows that it might be misleading to look only at potentials, changes or differences as important information to interpret the results, i.e., the reference value and absolute numbers, are omitted.

Table 22 Sum of area, production, net exports and consumption for cereals and oilseeds in Russia and Ukraine

	Area	Production	Net exports	Consumption
	Million hectares	Million tons		
Average 2009-13 FAO	60.8	139.7	38.2	101.5
Average 2009-13 AGMEMOD	65.9	141.2	42.6	101.6
Historical 2015 AGMEMOD	70.8	181.7	72.4	112.4
2030 baseline AGMEMOD	71.0	235.8	83.0	152.3
2030 Technology scenario AGMEMOD	69.4	353.6	140.2	210.1
Change Technology scenario to baseline AGMEMOD	-1.5	117.8	57.3	57.8
2030 baseline Deppermann et al.	59.4	189.5	49.0	140.4
2030 YD_high scenario Deppermann et al.	57.2	305.6	145.8	159.8
Change YD_high scenario to baseline Deppermann et al.	-2.2	116.2	96.8	19.4

Source: own aggregations based on AGMEMOD database and own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET and Deppermann *et al.* (2018)

4.2.3 **Discussion**

The results seem reasonable under the assumptions and within the modelling framework. Nevertheless, some aspects which are worth mentioning have not be considered. Further, the methodological limitations are especially pronounced in performing this scenario compared to the baseline (Case Study 1) or the trade scenarios (Case Study 3). Hence, they are discussed here in detail as well.

Increasing production intensities due to higher input use and improved management in Ukraine and Russia can contribute to increased global food security as major parts of their additional production is exported and, hence, global consumption increases. However, the analysis omits that large areas of Ukraine and Russia face high variability in yields due to variations in weather conditions between the years as shown by, e.g., Pradhan *et al.* (2015). Therefore, economic optimal input use might be lower than in regions with lower variability in weather conditions and, hence, extensive production systems might be economically optimal instead of the simulated intensive production systems.

Further, extreme weather events have substantially reduced cereal and oilseed production in these regions, e.g., the drought in 2010 (Fellmann, Hélaine and Nekhay, 2014). Hence, a harvest failure in Russia and Ukraine can decrease global food security as has been analyzed by Fellmann, Hélaine and Nekhay (2014). This conclusion is not only due to the harvest failure itself but also due to the fact that Ukraine and Russia frequently apply trade distorting policies, e.g., export taxes, quotas, and bans, accompanying a small harvest (Fellmann, Hélaine and Nekhay, 2014). Hence, besides closing of yield gaps efforts should be made to achieve more stable yields.

The chosen ‘Technology scenario’ assumes a complete closing of the yield gap as modelled by the crop model EPIC within GLOBIOM. To achieve this, optimal conditions in Russia and Ukraine are assumed. These optimal conditions include increased investments in the agricultural sector, a favorable institutional and commercial environment, optimal farm management, and intensive production systems. Even if the outbreak of the war of Russia against Ukraine in 2022 had not occurred, not all of these conditions would have been satisfied until 2030 which would have resulted in a smaller yield gap as observed today but not a closing of the yield gap. For Ukraine, Pradhan *et al.* (2015) identify adequate fertilizer application in the north and west, soil quality management in the parts close to the Polish and Belarussian border, and weather induced yield variability management in the south and east as main strategies to close yield gaps (Pradhan *et al.*, 2015). For European Russia main strategies to close yield gaps are soil quality management in the north, weather induced yield variability management in the south, and adequate fertilizer application in-between, while for the Russian regions in Asia improving accessibility to markets is added to these strategies (Pradhan *et al.*, 2015). Hence, simulating different levels of yield gap closure depending on specific improved conditions and applied strategies would give a more detailed picture of possible yield levels.

The analysis projects small changes in total agricultural area use. Given that prices will mostly drop instead of increase, there is no incentive to expand agricultural production to less suitable land, i.e., the existing abandoned land, that is attributed with higher production costs. This is in line with analysis of Liefert and Liefert (2015) who argue that taking more land into cereal production in Russia would require a substantial increase in output prices as production cost rise steeply if the abandoned land would be recultivated. From this perspective, an increase in cereal and oilseed prices beyond the projections for the baseline or the ‘Technology scenario’ could lead to increased use of abandoned land for cereal and oilseed cultivation in Russia and Ukraine. Hence, theoretical production potentials are even higher.

The variability of yields, different levels of yield gap closure, and increased output prices have not been analyzed in this case study but would enrich the analysis further to evaluate the robustness of the model results, e.g., through additional scenarios and sensitivity analysis. Performing additional scenarios and sensitivity analysis is hindered by several factors, e.g., time and resource constraints, ending of cooperation with the other research teams, and missing automatization to run the model system. Most importantly, the developed model system between GLOBIOM, MAGNET, and AGMEMOD shows several limitations (besides the once already discussed in Section 3.3.2.2) which are specific for the conduction of the analysis of closing yield gaps.

First, the information of yield changes given from GLOBIOM to MAGNET and AGMEMOD differs and is introduced in the models differently. While MAGNET uses increased percentage changes in technological change to mimic closing of yield gaps, AGMEMOD incorporates the absolute yields received from GLOBIOM. Within this dissertation, it was not possible to adapt the scenario in MAGNET. Hence, the construction of scenarios (Step 4 of linking models) is not perfectly aligned and leads to inaccuracies within the model system and the produced results.

As a consequence, the scenario in MAGNET simulates lower yield increases and consequently lower production increases. This translates in overall smaller economic effects with respect to a) trade quantities, b) world market price changes, and c) GDP development which are an input from MAGNET to AGMEMOD. Hence, the AGMEMOD internal projections for trade developments where used as an ad hoc solution if trade projections from MAGNET seem unlikely. These concerned corn, wheat and soybean in Russia and barley in Ukraine. Here the AGMEMOD internal specifications for trade and consumption adjustments are used. Despite the non-perfect alignment of the scenario construction, the changes in world market prices and GDP from MAGNET – even though they are probably too small - were used in AGMEMOD. This is judged as an improvement because both parameters are constant in the AGMEMOD stand-alone version, i.e., assume that Russia and Ukraine are small market participants without an influence on world markets and the agricultural sector is small within the overall economy of the country. However, both assumptions do not apply for Russia and Ukraine.

Second, the area for cereals and oilseeds in AGMEMOD is larger than in GLOBIOM. Therefore, maximal potential yields on the country level from GLOBIOM to AGMEMOD might be overestimated. This can be because if the area is larger, more land with lower yields might be cultivated and, hence, aggregated yields would be lower. To quantify the level of inaccuracy, a simplified calculation can be made by assuming that the additional 17 million hectares or 25 % of cereals and oilseeds area in AGMEMOD in the 'Technology scenario' in 2030 compared to the cereal and oilseed area as projected by GLOBIOM in the model system for the 'Technology scenario' in 2030 achieve only yields as in the baseline in 2030. Then total aggregated yields would be 9 % lower in the 'Technology scenario' in 2030.

This inaccuracy of yield transfer could be improved by aligning the projected area between the models more closely, e.g., through transferring information of land use from AGMEMOD back to GLOBIOM. However, this would require to extend the model link towards a two-way link which is out of the scope of this dissertation. The two-way link would require specifying not only an exchange of land use but also other data where the internal model feedbacks in AGMEMOD are of importance, e.g., production and consumption data, (compare Section 3.3.3.2). Further, an iterative model system would require additional data transfers between all models including MAGNET, which in turn can only be realized if the data harmonization is improved (Step 3 of linking models). However, the definitions and model specifications are too different to realize Step 3.

The methodological limitations are relevant especially for this scenario but to a lesser extent also for the baseline and the trade scenarios in Case Study 3. Hence, the analysis with the model system can be seen as an improvement of AGMEMOD to model closing of yield gaps which requires external information on potential yields as well as its effects on world market prices and GDP. This information could have come from the literature or as in this case from other models, i.e., GLOBIOM and MAGNET. The application of the model system ensures the taking of more relevant factors for the analysis into account. However, inaccuracies are newly introduced due to the chosen approach of how the data is transferred between the models.

4.2.4 **Conclusion**

The improvement of the institutional environment in Ukraine and Russia can lead to substantial public and private investment in the agricultural and related sectors. This assumed more business-friendly environment is assumed to lead to a (partly) closing of yield gaps in cereal and oilseed yields. This closing of yield gaps consists of increased intensity levels by using more inputs and efficiency gains in the form of technology adoption and better management. This has been simulated with the developed model system of GLOBIOM, MAGNET, and AGMEMOD.

The simulation shows that Ukraine and Russia are able to significantly increase their production of cereals and oilseeds and that global, and in the case of Russia domestic, demand is willing to absorb the additional production. Hence, only slight price decreases are observed. Further, shifts between production patterns are mostly absorbed in the cereal markets where Russia focuses on expanding wheat production, while Ukraine decreases it. Oilseed production increase more than cereal production in both countries of which most additional production is exported as meal and oil except in the case of rapeseed and soybean of Ukraine which exports seeds directly.

Rada, Liefert and Liefert (2020) investigated the causes of total factor productivity growth between 1994 to 2013 in Russia and found that most efficiency gains cannot be attributed to government intervention but to a time trend which they term ‘informal technical change’. This informal technical change includes innovation which is difficult to measure such as improved management practices, private technology adoption, vertical integration, and private research (Rada, Liefert and Liefert, 2020). It requires a stable institutional environment and confirms the assumption in the case study of private investments contributing to the closing of yield gaps. Rada, Liefert and Liefert (2020) observe the highest productivity growth in the southern parts of Russia. Hence, the other parts of Russia might accelerate in the future.

In most recent years, i.e., 2015 to 2019, Russia has strongly increased its use of fertilizers and achieved higher yields compared to its long-term trend (compare Section 4.1.7). Hence, an additional part of the yield gap has already been closed. Nevertheless, yields are still below the simulated ‘maximal economic feasible yields’. In contrast, Ukraine has also increased yield but not significantly more than its long-term trend. Given the current situation, this might be delayed even longer.

The advantage of the analysis compared to other studies, especially Deppermann *et al.* (2018), is the use of more recent data. While the results are judged to be consistent and within expectable ranges, the methodological approach will need further refinement which is out of the scope of this dissertation. The stand-alone application of GLOBIOM in Deppermann *et al.* (2018) clearly outperforms the model system in methodological consistency and model validation. This underlines the fact that further research is needed to link models and make use of their envisaged and proclaimed advantages.

4.3 Cereal and oilseed markets in Ukraine and Russia under different trade policies

The strong growth of cereal and oilseed production in Ukraine and Russia has led to a significant increase of exports. Hence, the access to global markets is an important factor for the cereal and oilseed sectors in Ukraine and Russia. Trade policies, including tariffs and non-tariff measures, can restrict trade. Therefore, efforts have been undertaken to reduce the impact of trade policies through trade liberalization globally. In recent years, however, the increase in trade measures have been observed worldwide. Therefore, this case study explores the impact of different trade policy strategies until 2030 on domestic markets. Three scenarios are constructed based on the already presented model link between AGMEMOD, GLOBIOM and MAGNET (compare Section 3.3).

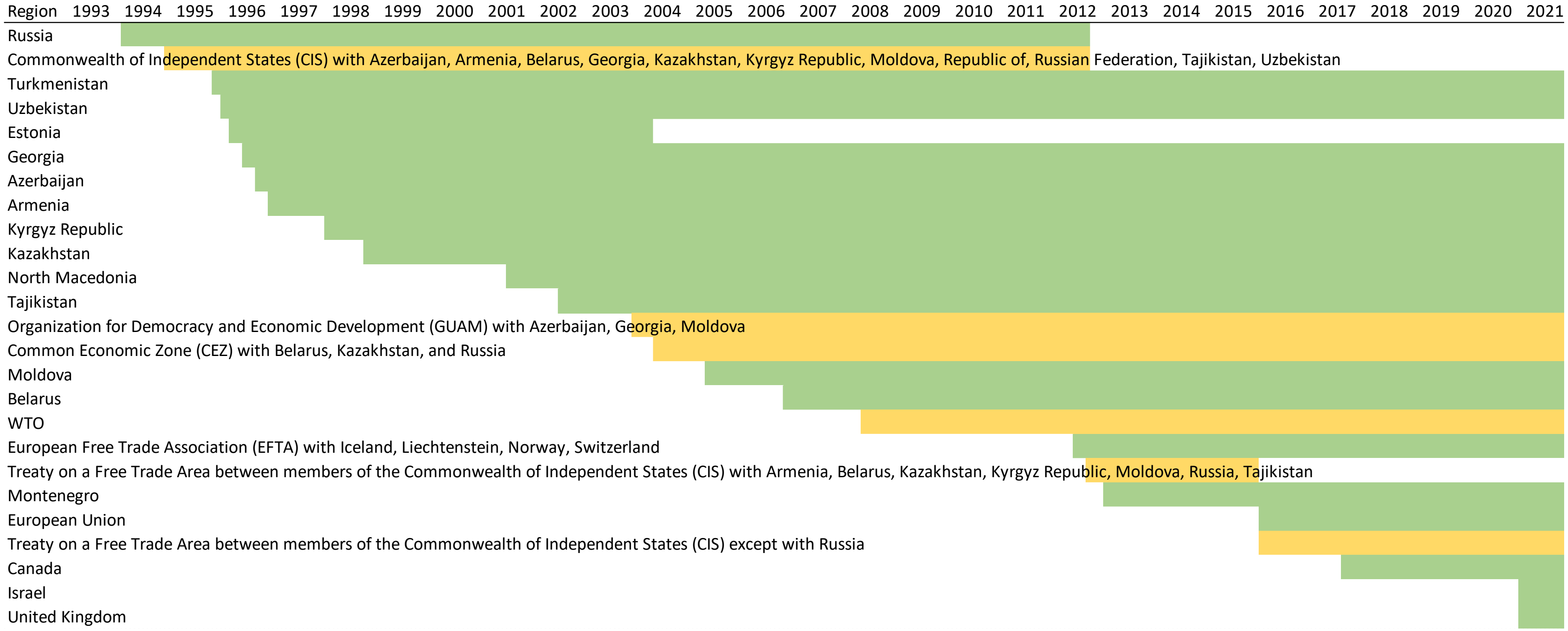
The case study is structured as follows. An overview of trade policies is given in the introduction (Section 4.3.1), followed by a literature review on trade policy analysis for Ukraine and Russia (Section 4.3.2). Section 4.3.3 describes the scenarios analyzed in the case study. Afterwards the results are presented (Section 4.3.4). Finally, the discussion (Section 4.3.5) sets the results into real world context and elaborates on limitations of the case study before Section 4.3.6 concludes.

4.3.1 Introduction and trade policies

The liberalization of trade contributes to an increased competitiveness of the export-oriented sectors of cereals and oilseeds in Ukraine and Russia. A reduction of export taxes, quotas and other trade barriers is desirable from an exporter’s point of view. Ukraine and Russia are, however, protective of their domestic industry and aim to secure the availability of agricultural raw materials at affordable prices as well as aiming for high self-sufficiency ratios in several agricultural products. On the importing side, tariffs, quotas, and sanitary and phytosanitary measures are the most common trade barriers applied, e.g., for the livestock sector and the sugar sector in Russia and Ukraine. Hence, the agricultural sectors face traditionally higher protection levels than non-agricultural sectors often justified by food security reasons. Additionally, trade measures are often used as sanctions in political conflicts.

One option to reduce trade barriers is the conclusion of bilateral and multilateral free trade agreements (FTAs). These FTAs can vary in their amount of integration from solely tariff reducing to complete market integration. Thereby, the elimination of NTMs such as administrative and technical barriers as well as different certifications, standards, and requirements, can significantly reduce trade cost (Ederington and Ruta, 2016). Figure 79 and Figure 80 give an overview of concluded bilateral and multilateral FTAs by Ukraine and Russia, respectively. Both countries focused on trade agreements with countries of the former Soviet Union in the 1990s and early 2000s. The countries opened themselves more widely to the world market by reducing tariffs and export taxes in the process of joining the WTO, i.e. Ukraine in 2008 and Russia in 2012.

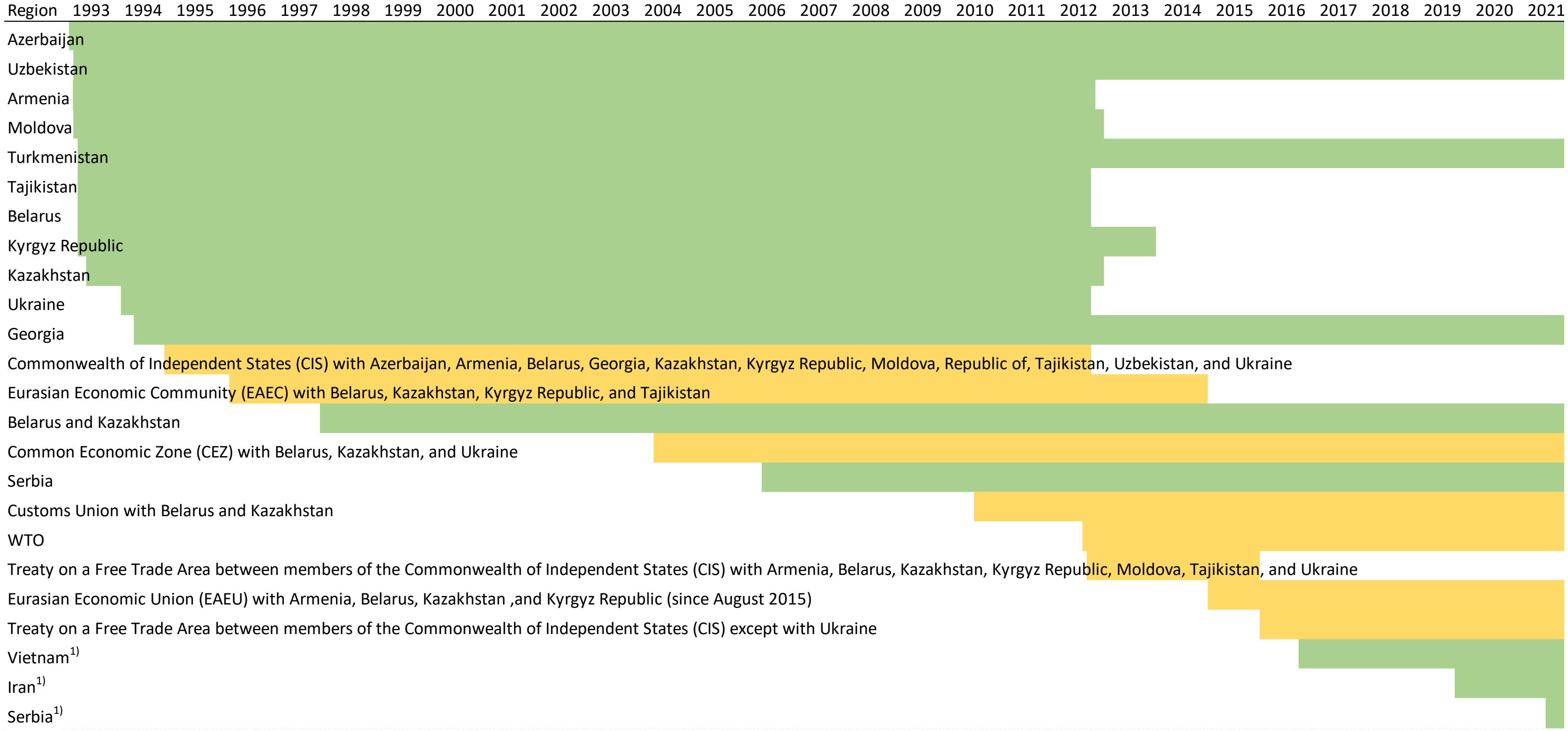
Figure 79 Conclusion and duration of bilateral trade agreements of Ukraine (green) and membership in multilateral agreements (yellow), from 1993 onwards



Notes: all trade agreements in 2021 are ongoing as of February 22, 2022

Source: own compilation based on WTO (2022a)

Figure 80 Conclusion and duration of bilateral trade agreements of Russia (green) and membership in multilateral agreements (yellow), from 1993 onwards



Notes:[1)]trade agreement with EAEU; all trade agreements in 2021 are ongoing as of February 22, 2022

Source: own compilation based on WTO (2022a)

After joining the WTO, Ukraine enhanced trade negotiations with countries outside of the former Soviet Union region, especially with western countries, e.g., the European Free Trade Association (EFTA), the EU, and Canada. The DCFA between Ukraine and the EU facilitates trade through the reduction of export taxes, tariffs, and NTMs. Russia strengthened its ties within the region of the former Soviet Union by the formation of the EAEU after previously unsuccessful attempts (Tarr, 2016). The EAEU is a free trade area with Belarus, Kazakhstan, Armenia and the Kyrgyz Republic applying zero tariffs between the members and common tariffs to third countries. However, NTMs are still high between the countries and efforts to reduce them are slow (Tarr, 2016). After its formation, the EAEU, as one entity, has concluded bilateral trade agreements with Vietnam, Iran, and Serbia.

Besides these trade liberalizations, bilateral trade restrictions have increased due to political tensions for Ukraine and Russia. As a consequence of the dispute between Ukraine and Russia the two countries have suspended their free trade agreement under the Treaty on a Free Trade Area between members of the Commonwealth of Independent States (CIS) and implemented new restrictions by increasing tariffs and banning imports of some products.

Additionally, Russia has implemented an import ban on several agricultural products including meat, dairy products, fruits and vegetables, prepared foods and fish coming from the EU, the US, Canada, Australia, and Norway as of August 2014 (OECD, 2015b), i.e., the countries opposing the annexation of Crimea. This ban was originally announced for one year but it has been renewed ever since and is still in place. Interestingly, the other members of the EAEU have not banned these products, leading to, e.g., EU imports via Belarus (Tarr, 2016). This increases NTMs within the EAEU as border inspections and requirements for country of origin labeling increased (Vinokurov, 2017).

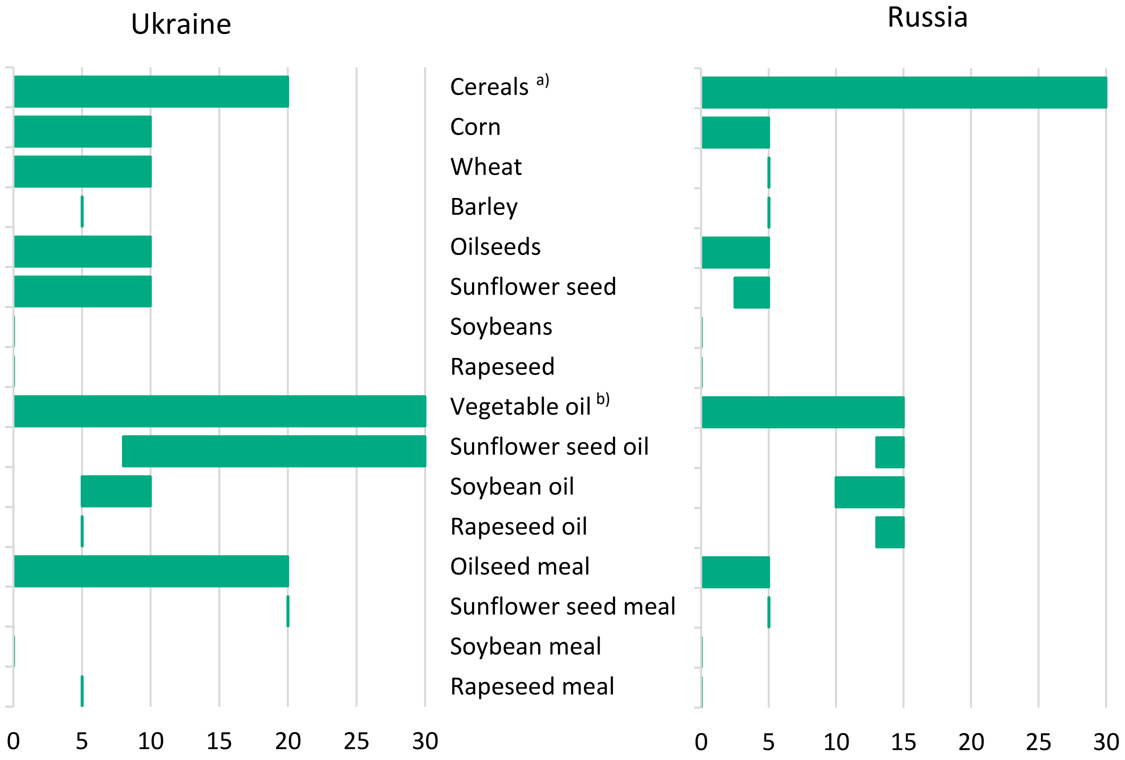
To avoid increasing consumer prices, export quotas, bans, and export taxes have been implemented by Ukraine and Russia in years with high prices or low domestic production (Götz, Djuric and Glauben, 2015). These measures, often targeted towards cereals and oilseeds, are implemented in an ad hoc manner, on short notice, and are subject to frequent adjustments. Further, Russia frequently applies non-tariff measures to control trade by claiming that sanitary and phytosanitary regularities are not met, e.g., banning dairy products from Germany and the Netherlands in January 2014 (Banse *et al.*, 2019).

Taking a closer look at the cereal and oilseed markets, it can be observed that these markets face several trade restrictions. These range from import tariffs and export taxes conform with WTO rules to ad hoc trade restrictions in the form of temporary export quotas, bans, and additional tariffs and taxes.

Under WTO rules, Ukraine and Russia apply most favored nation (MFN) tariffs for cereal and oilseed which are different from zero. Figure 81 shows the minimum and maximum MFN tariffs for 2020. Thereby, Ukraine has implemented higher import tariffs than Russia, i.e., the Ukrainian domestic cereal and oilseed markets have higher protection levels. Further, the highest protection is observed for the sunflower market including import tariffs for oilseed, oil and meal imports in both countries. In the case of sunflower seed, the import tariff might prevent the crushing industry to compensate for a domestic production shortfall by imports. Hence, crushing capacities would be underutilized and less oil and meal produced as observed, e.g., in Russia in the years 2010 and 2012. As shown in Case

Study 1 (Section 4.1.4), Ukraine and Russia import negligible amounts of cereals and oilseeds. Highest import levels are observed for soybean meal to Russia, which face zero tariffs. Hence, import tariffs play currently a very minor role in cereal and oilseed markets.

Figure 81 Minimum and maximum MFN import tariffs for cereals and oilseeds in Ukraine and Russia, 2020, percentage *ad valorem* rate



Notes: [a]maximum MFN in Ukraine for rye, in Russia for rice, [b]minimum MFN in Ukraine for palm, coconut (copra), palm kernel, babassu and other vegetable (HS code 1516) oil, in Russia for palm, coconut (copra), palm kernel and babassu oil

Source: own compilation based on WTO (2022b)

In contrast, trade policies on the export side strongly interfere in cereals and oilseed markets. Both countries have used and use export taxes, quotas, and bans to restrict exports. Under WTO commitments, Ukraine and Russia reduced their export tariffs of sunflower seed to 10 % as of 2012 (OECD, 2015b) and to 6.5 % as of September 2016 (USDA FAS, 2017), respectively. This ensures that domestic prices are below world market prices for sunflower seed and domestic sunflower seed is processed mainly within the countries. However, competitiveness on global markets is reduced. The trade restrictions on the import and on the export side for the sunflower seed market reduces the capability of trade to act as a buffer in case of production shortfall or production surplus.

In Ukraine, export quotas had been implemented for cereals in 2006/07, 2007/08, and 2010/2011 and for sunflower seed and oil in 2008. In 2011, export tariffs for cereals were applied. Since the marketing year 2011/12, the Ukrainian government and the main cereal exporters agreed annually and in advance on a maximum volume of cereals to be exported in the coming marketing year by signing a memorandum of understanding (OECD, 2015b). If the maximum volume is reached, the government has the option to implement trade restrictions. However, the agreed trade volumes are subject to revision within the marketing year and have even been exceeded without any consequences (OECD, 2021).

Hence, Ukraine successfully reduced but did not eliminate the use of market distorting instruments to intervene into the market.

In contrast, Russia sticks to its policies to interfere in cereal and oilseed markets by applying ad hoc and frequently changing trade policies until today. For example, export taxes applied for some cereals, mostly wheat, in several month of 2004, 2007, 2008, 2015, 2016 and an export ban on cereals was introduced in August 2010 lasting until June 2011. In 2020, a cereal export quota was introduced in April lasting till June but being filled already at the end of April (OECD, 2021). For the same period, export bans of several food products including soybeans and sunflower seed were introduced (USDA FAS, 2020c). In 2021, tariff quotas for cereals with in quota and out of quota export tariffs as well as export tariffs for oilseeds and sunflower oil have been increased or were newly introduced (OECD, 2021).

4.3.2 **Literature review**

Several studies have analyzed *ex ante* changes in trade policies for Ukraine or Russia in general and with a focus on the agricultural sector. Thereby, the focus is mostly laid on current and anticipated trade changes such as the implementation of an FTA or trade restrictions. Only a few studies focus on more visionary scenarios such as general tariff reductions or an FTA between Russia, i.e., the EAEU, and the EU. Further, the majority of studies apply CGE models, while the use of gravity models and partial equilibrium models is rare.

For Ukraine, a considerable number of ex-ante studies exists which analyze the DCFTA with the EU (for a literature review see Nekhay, Delgado and Cardenete (2021)). Most of these studies apply static CGE models, focus on tariff reductions, and assess welfare and GDP changes, while some consider the role of NTMs. The majority of the studies point towards a gain for Ukraine in terms of GDP growth and welfare increase (Nekhay, Delgado and Cardenete, 2021).

A few studies explicitly focus in more detail on the agricultural sector (Chauffour *et al.*, 2010; von Cramon-Taubadel, Hess and Brümmer, 2010; Nekhay, Fellmann and Gay, 2012). Their analysis differ in the actual implementation of the DCFTA and with respect to methodology, assumptions, reference period, and data, including initial tariffs. While all studies project overall welfare gains for Ukraine through tariff reductions or eliminations, the results per sector differ. In the cereals sector, Chauffour *et al.* (2010) and von Cramon-Taubadel, Hess and Brümmer (2010) project welfare gains, while Nekhay, Fellmann and Gay (2012) projects gain in producer revenue for coarse grains, i.e., corn and barley, but not for wheat. For oilseeds and vegetable oils, slightly positive gains in export quantity and producer revenue are projected by Nekhay, Fellmann and Gay (2012) but slightly negative welfare gains by Chauffour *et al.* (2010) and von Cramon-Taubadel, Hess and Brümmer (2010).

There is one study which evaluates the impact of the DCFTA between Ukraine and the EU on the sunflower seed sector including oils and meals in detail (Baryshpolets and Devadoss, 2021). Baryshpolets and Devadoss (2021) built a spatial equilibrium model for the sunflower seed, meal and oil market distinguishing between eight regions. They find that the welfare of Ukraine increases most from the DCFTA, namely for sunflower seed producers, while the global welfare and the welfare of the EU, namely for sunflower seed producers and tariff revenues, declines (Baryshpolets and Devadoss, 2021).

For Russia, most studies focus on the impacts of the import ban of certain agricultural products, the formation of the EAEU, and further trade liberalizations, e.g., with the EU. Several studies have analyzed the effects of the Russian import ban with economic models (Banse *et al.*, 2019; Boulanger, Dudu, Ferrari and Philippidis, 2016; Kutlina-Dimitrova, 2017; Dillen, 2015). Three papers simulate the short-term effects of the ban by applying CGE models (Boulanger, Dudu, Ferrari and Philippidis, 2016; Kutlina-Dimitrova, 2017) and PE model (Dillen, 2015). Banse *et al.* (2019) focus on the long-term effects by simulating a baseline with the ban in place until 2030 and a scenario where the ban is lifted in the period 2020-2023 with MAGNET. Their overall findings are similar in that the projected losses are mainly occurring for Russia and only slightly impact the exporting countries. The results for the affected sectors vary to a higher degree but as neither the cereals nor the oilseed sectors fall under the ban further discussion is out of the scope of this dissertation.

For Russia, the EU is a main trading partner. Therefore, it is not surprising that several research teams have envisioned a reduction in tariffs (Philippidis *et al.*, 2018) or even an FTA between the two regions (Banse *et al.*, 2019; Felbermayr, Aichele and Gröschl, 2016; Knobel' and Chokaev, 2014; Tochitskaya and Vinhas de Souza, 2009). Tochitskaya and Vinhas de Souza (2009) and Knobel' and Chokaev (2014) apply a CGE model without considering NTMs and find that an elimination of tariffs between Russia and the EU is beneficial for both sides. However, Russia gains more in terms of welfare increase with estimated increases of GDP by 0.6 % (Tochitskaya and Vinhas de Souza, 2009) and 2 % (Knobel' and Chokaev, 2014). This is also confirmed by Felbermayr, Aichele and Gröschl (2016) which apply a gravity model. Felbermayr, Aichele and Gröschl (2016) project an increase in GDP by 0.4 % if tariffs are eliminated and 3.1 % if NTM are reduced additionally. These three studies treat the agricultural sector as one entity and, hence, a sectoral analysis for cereals and oilseeds is not presented. In contrast, Banse *et al.* (2019) focus on the agricultural sector and distinguishes between livestock, fruit and vegetable products, and crops including cereals and oilseeds, i.e., banned and non-banned agricultural and food products under the imposed import ban of Russia since 2014. They find that for Russia only production of non-banned agricultural products would increase (Banse *et al.*, 2019). The optimism of these studies that an FTA is likely between Russia and the EU is far from achievable given current political tensions. Philippidis *et al.* (2018) simulate reductions in tariffs and NTMs between the EAEU and the EU. They find GDP increases for the EAEU countries of 6 % but reductions in cereals and oilseed production as well as oilseed trade (Philippidis *et al.*, 2018). While the different studies are not directly comparable, they all confirm an overall benefit for Russia if trade is liberalized but report positive and negative effects on sectoral level.

As highlighted by Tarr (2016), the EAEU faces high internal NTMs. Knobel *et al.* (2019) simulate a reduction of NTMs within the EAEU as well as towards non-EAEU countries and find that Russia would increase overall consumption between 0.8 % to 3.6 %. This underlines the findings of, e.g., Kee, Nicita and Olarreaga (2009), that NTMs can be more trade restrictive than tariffs.

Given the rich body of existing literature, this case study contributes twofold to the research field. First, it presents different trade policy strategies and their impacts on cereal and oilseed markets based on trade policy developments up to 2015. These trade policy strategies incorporate trade liberalization for the EAEU and Ukraine as well as increased protection level by increasing tariffs for the EAEU, i.e., a counter scenario to liberalization.

Second, the applied model system incorporates CGE and PE models which allow modelling of trade measures at the bilateral level and focus explicitly and in more detail on the cereals and oilseed markets. It explicitly incorporates NTMs and their reductions, which have been found to be trade barriers for Russia (Tarr, 2016) and Ukraine (Movchan, Shepotylo and Vakhitov, 2019). Additionally, the model system is recursive dynamic in contrast to most static applications in the literature.

4.3.3 Method and trade scenarios

To analyze three different trade policy strategies, the developed model system combining GLOBIOM, MAGNET and AGMEMOD (Section 3.3.2) is applied. Thus, two different trade scenarios have been developed to analyze a further trade liberalization of Ukraine and Russia and one scenario of an increased protectionism of the EAEU. The narratives of the scenarios and their implementation into the models have been developed within the AGRICISTRADE project (Philippidis *et al.*, 2016; van Berkum, 2016). As MAGNET is the model which covers bilateral trade flows and trade policies, the trade policy changes are implemented in MAGNET. A paper has been published which employs the same scenarios by using MAGNET as a stand-alone model (Philippidis *et al.*, 2018). In AGMEMOD, the trade scenarios differ from the baseline in changes in GDP, world market prices and trade flows which are endogenous outputs of MAGNET as described in Section 3.3.2. Changes of trade flows based on MAGNET are implemented in AGMEMOD as annual average percentage changes in the focus countries, i.e., Russia and Ukraine, and for selected products as in the baseline (compare Case Study 1 in Section 4.1).

Using the model system, the relevant factors influencing cereal and oilseed markets (compare Section 2.1) and the necessary relationships with the markets (compare Section 3.3.2) are incorporated to analyze trade policy. The factors to be analyzed are trade policy and trade cost changes. Their variation impacts a market directly but also results in indirect effects as changes in world market prices, economic development, and in related sectors affect a specific sector. Here, the specific sectors are cereals and oilseeds in Ukraine and Russia and the most closely related sector are cereal and oilseed markets in other countries as well as the domestic livestock sectors. The mentioned factors affect cereal and oilseed markets differently in terms of direction but also in terms of magnitude. The latter is aimed to be quantified by the model system in this case study to show the individual sectoral changes incorporating the many interdependencies considered in the model system.

The baseline as a reference for all trade scenarios is already presented in Case Study 1 (Section 4.1). As stated, this baseline incorporates all trade developments up to 2015 including the formation of the EAEU with Russia at the heart of it. Additionally, the DCFTA of Ukraine and the EU is included and the import ban of Russia is lifted in the period of 2015 to 2020. Against this baseline, three scenarios which represent different policy strategies in trade relationships up to 2030 are developed:

- Scenario ‘Towards EU integration’: Ukraine further adapts its law and standards to comply with EU regulations and the EAEU, including Russia, reduces their tariffs towards third countries
- Scenario ‘Global liberalization’: as ‘Towards EU integration’ with additional trade liberalization of Ukraine towards third countries and between all other countries

- Scenario 'Increased protection': as baseline but with increased tariffs of the EAEU towards all third countries

The first and second scenario focus on liberalization strategies of Ukraine and Russia towards the EU as well as non-EU countries. The third scenario represents a strategy where trade is used to increase protection of domestic markets in Russia within the EAEU. The focus is laid on general tariff and trade cost changes for all products as it seems unlikely that trade changes might only occur in the cereal and oilseed markets. Table 23 summarizes the changes as implemented in MAGNET. Their technical implementation is explained in detail in Philippidis *et al.* (2016) and Philippidis *et al.* (2018). Ad hoc trade restrictions cannot be anticipated and are hence not considered in the ex-ante application but included in the discussion below.

Table 23 Changes in trade policies from 2015-2030 for the different scenarios

	Baseline	Towards EU integration	Global liberalization	Increased protection
changes in tariffs between				
Ukraine and EU	according to DCFTA			
EAEU countries	set to 0 within EEU, Russian tariffs to all other countries			
all other countries	as in ratified trade agreements between other countries (e.g., South Korea and EU)			
tariff shocks (as percentage change) between				
EAEU and EU	0	-60	-60	50
EAEU and third countries	0	-50	-50	50
Ukraine and third countries	0	0	-50	0
all other countries	0	0	-50	0
NTM changes (as percentage point changes of *ad valorem* tax equivalent) between				
Ukraine and EU	-25	-35	-35	-25
EAEU countries	-10	-15	-15	-10
EAEU and EU	0	-10	-10	0

Source: own adaptation after Philippidis *et al.* (2016) and Philippidis *et al.* (2018)

In the scenario 'Towards EU integration', Ukraine and Russia improve bilateral trade relationships with the EU. Also, the EAEU opens its economy for the global market. Certifications, standards, and regulations are aligned so that trade, investments and knowledge transfer increases in Russia and Ukraine. It simulates rapprochements between Ukraine and the EU, within the EAEU, between the EAEU and the EU as well as between the EAEU and other countries. Trade costs are reduced in the first two cases through a further reduction in NTMs, while in the latter two cases import tariffs and export taxes are reduced.

Liberalizing trade further, i.e., not only between the EAEU and the rest of the world but between all countries as envisioned and by the WTO, is simulated in the 'Global liberalization' scenario. This scenario builds upon the 'Towards EU integration' scenario and represents a worldwide rapprochement between all countries which is simulated as an additional cut in all other bilateral tariffs by 50 % from 2015 to 2030. In this scenario, the export taxes and import tariffs of Ukraine towards all third countries are lowered, i.e., not only towards the EU.

Contrary to these two optimistic scenarios, the scenario 'Increased Protection' simulates an increased protectionism of the EAEU towards all third countries. Tensions between

Russia and especially western countries increase and the protection of the domestic market to achieve high levels of self-sufficiency in key products dominates Russia's trade strategy. This is implemented by raising import tariffs and export taxes of the EAEU towards all third countries by 50 %.

Given the current political environment, the two liberalization scenarios seem to be far away from possible developments as tensions between Russia and western countries increases in the light of the still ongoing Ukrainian war and the sanctions and counter sanctions implemented on both sides. The 'Increased Protection' scenario seems too mild compared to current sanctions. However, the current sanctions might only be short-term, while the 'Increased Protection' scenario takes a long-term perspective.

4.3.4 Results for cereal and oilseed markets

Before the results for the cereal and oilseed markets in Ukraine and Russia are analyzed, the general economic development as an outcome of MAGNET is presented. These developments are important to interpret the results of the model system because AGMEMOD uses this information as exogenous input.

MAGNET, as a global general equilibrium model, covers the whole economy. In general, the results show that the cereal and oilseed sectors in Ukraine and Russia are less directly influenced than other sectors, e.g., livestock and non-agricultural sectors, by the simulated trade policy changes in the scenarios. This does not come as a surprise as, e.g., import tariffs are negligible (compare Section 4.3.1). However, indirect effects due to changes in income, prices, and the demand from the livestock sector, result in changes in the cereals and oilseed sectors in Ukraine and Russia as well. These indirect effects are considered in the analysis and Table 24 shows the changes relevant to this case study for GDP and world market prices.

Table 24 Selected exogenous assumptions from MAGNET to AGMEMOD, percentage change of trade scenarios compared to baseline in 2030

	Towards EU integration	Global liberalization	Increased protection
	GDP		
Russia	5.48	5.47	-0.26
Ukraine	1.18	1.66	0.58
	World market price		
Cereals	-0.92	-1.03	0.04
Wheat	-0.43	-0.45	-0.01
Oilseeds	-1.08	-1.25	0.06
Vegetable oil	-0.48	-0.58	0.00
Meals	0.81	0.52	0.19

Source: MAGNET projections

In the two scenarios with reduced trade barriers, i.e., 'Towards EU integration' and 'Global liberalization', GDP increases compared to the baseline for Russia and Ukraine which is mainly due to efficiency increases as a result of reduced tariffs and NTMS. In the 'Global liberalization' scenario, tariffs and export taxes do not change for Russia compared to the 'Towards EU integration' scenario which results in approximately identical GDP increases for Russia. In contrast, Ukrainian tariffs and export taxes are reduced which leads to further increases in GDP in the 'Global liberalization' scenario compared to the 'Towards EU integration' scenario.

In the 'Increased protection' scenario, GDP declines slightly for Russia. This decline in GDP for Russia stems from higher cost for imports and exports, leading to overall higher but less efficient domestic production and lower domestic consumption. Ukraine profits from the higher protectionism of Russia as their products become relatively more competitive than Russian products on the world market. This outweighs the losses occurring due to less trade with Russia and, hence, Ukrainian GDP increases.

Overall changes in the world market prices for cereals and oilseeds are only moderate. Generally, with a reduction in trade barriers, trade costs decline and trade becomes more efficient. Consequently, world market prices in the long-term equilibrium are expected to decrease which can be observed for all products except meals in the scenarios 'Towards EU integration' and 'Global liberalization'. Similarly, the increase in trade barriers might lead to increasing world market prices which can be observed for all products except for wheat. These exceptions can be explained by two facts. First, some trade policies decrease the world market prices in the long-term equilibrium, i.e., export subsidies and import tariffs of large countries, and their removal has the opposite effect. Second, production and consumption patterns in all sectors shift as a result of changing trade policies in both importing and exporting countries.

Focusing on a more disaggregated level, the reactions on the sectoral level are more divers and less straight forward. In the cereal and oilseed markets for Ukraine and Russia, the reduction in NTMs leads directly to efficiency gains in trade but export tax and import tariff changes are very small compared to other sectors, i.e., the livestock sector. Hence, indirect effects from changes in global cereal and oilseed sectors and the domestic livestock sector as well as in the general economic development dominate the market reactions in the cereal and oilseed markets in Ukraine and Russia.

The results for the cereal and oilseed markets in the different scenarios, give insights into the markets, their internal relationships, and sensibility to external changes. The changes within the cereal markets are larger and more divers than in the oilseed markets for all scenarios. Consequently, the analysis here focuses on the cereal markets, while results for all markets are presented in Table A4 as absolute differences between the different scenarios and the baseline and Table A5 as percentage differences in Appendix A.

In all scenarios, domestic price changes for cereals and oilseeds (Table 25) are mostly similar to the changes in world market prices (Table 24). This shows that cereal and oilseed markets of Ukraine and Russia are closely integrated in the world markets. The only exceptions are the price changes in the 'Increased Protection' scenario for corn and barley in Russia where higher domestic price increases than on the global market are observed. These price increases are caused from stronger domestic demand due to an expansion of the livestock sector as tariff increases do not play a role in the Russian cereal markets given their negligible import volumes.

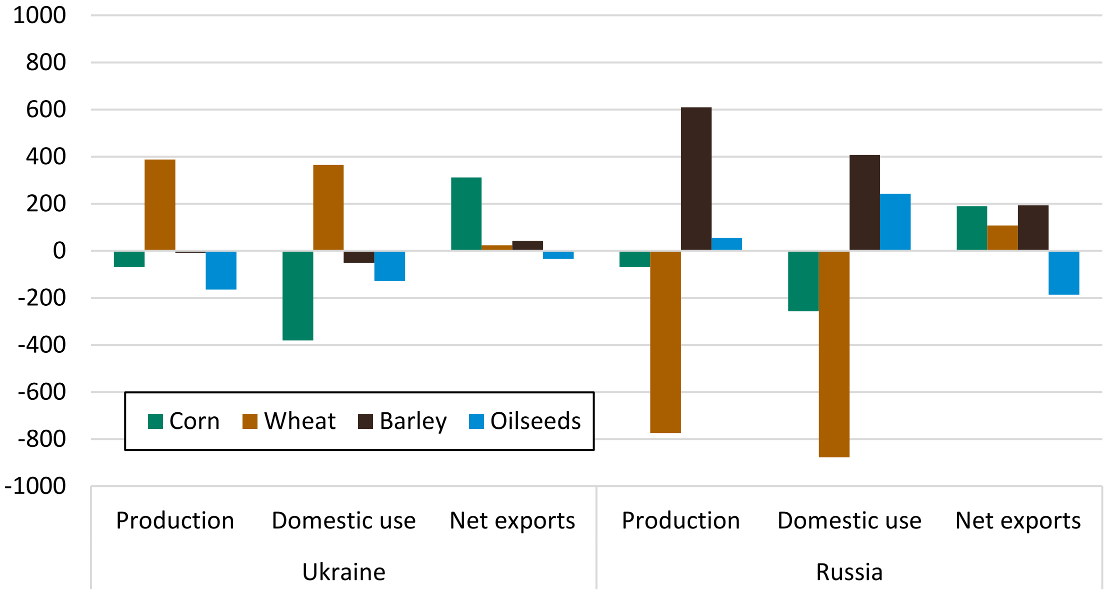
Table 25 Cereal and oilseed price changes in Ukraine and Russia, percentage change of trade scenarios compared to baseline in 2030

	Towards EU integration		Global liberalization		Increased protection	
	Ukraine	Russia	Ukraine	Russia	Ukraine	Russia
Corn	-0.92	-1.57	-1.03	-1.57	0.04	1.33
Wheat	-0.34	-0.55	-0.84	-0.44	0.13	0.04
Barley	-0.99	-1.05	-1.09	-1.17	0.06	0.31
Oilseeds	-1.17	-1.10	-1.35	-1.28	0.05	0.04

Source: Own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

As shown in Figure 82, Ukraine expands wheat production the most in the 'Towards EU integration' scenario as it becomes more competitive to other cereals and oilseed, i.e., the price reduction is the least. Consequently, the production of the other cereals and oilseeds decline slightly as the crops compete for land. The increased wheat production is mainly consumed domestically as income of people increase and they can afford more food. The decrease in the consumption of feed cereals is explainable as Ukraine increases its imports of animal products instead of expanding its own livestock production. Consequently, domestic use of corn declines and exports increase.

Figure 82 Changes of production, consumption, and net exports of cereals and oilseeds for Ukraine and Russia in the 'Towards EU integration' scenario compared to the baseline in 2030, thousand tons



Source: Own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

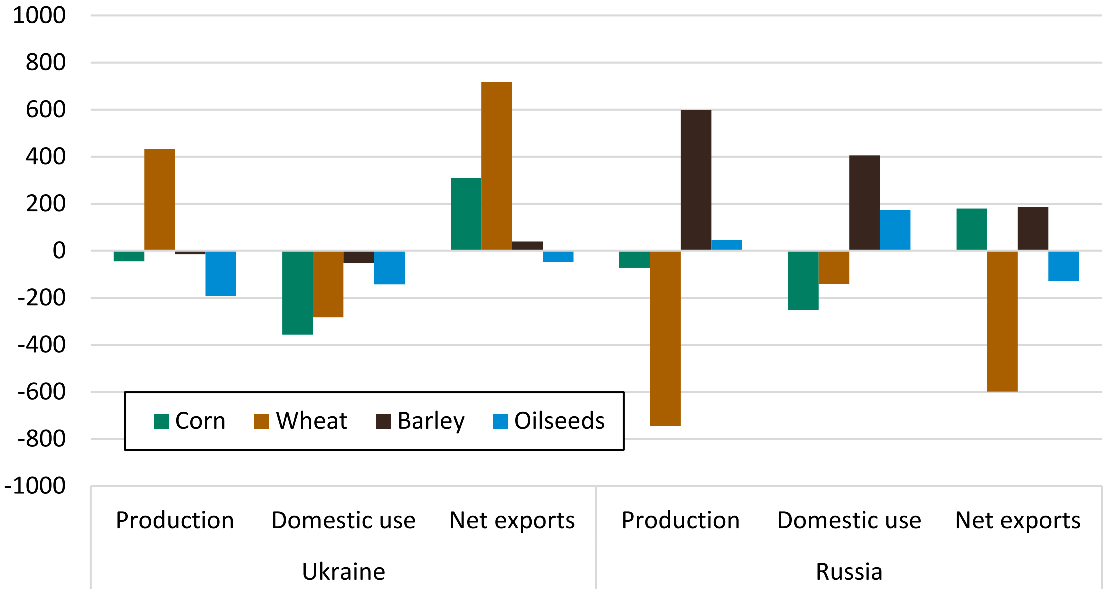
Contrary, Russian production of wheat declines while barley and oilseed production are expanded (Figure 82). Also, the livestock sector expands and more feed use, i.e., barley and oilseed meals, is demanded. These changes are explainable by demand shifts as diets of the people shift towards more vegetable oil, meat and dairy product consumption and away from staple crops, i.e., wheat, as a consequence of increased incomes.

In the scenario 'Towards EU integration', Russia benefits from reduced trade barriers more than Ukraine and especially increases cereal exports and soybean imports. This underlines Russia's competitive advantage in producing cereals. Also, Ukraine is less developed than

Russia and the people are poorer, hence, the general increase in food consumption in Ukraine and the dietary shift in Russia given the new market situation seem to be plausible.

In the 'Global liberalization' scenario (Figure 83), Ukraine also slightly shifts its diets away from staple crops and towards more vegetable oil and animal product consumption as incomes increase further. Production changes for cereals and oilseeds are similar as in the 'Towards EU integration' scenario, however, Ukraine becomes more competitive in wheat and exports more as tariffs of all countries towards Ukraine are reduced.

Figure 83 Changes of production, consumption, and net exports of cereals and oilseeds for Ukraine and Russia in the 'Global liberalization' scenario compared to the baseline in 2030, thousand tons

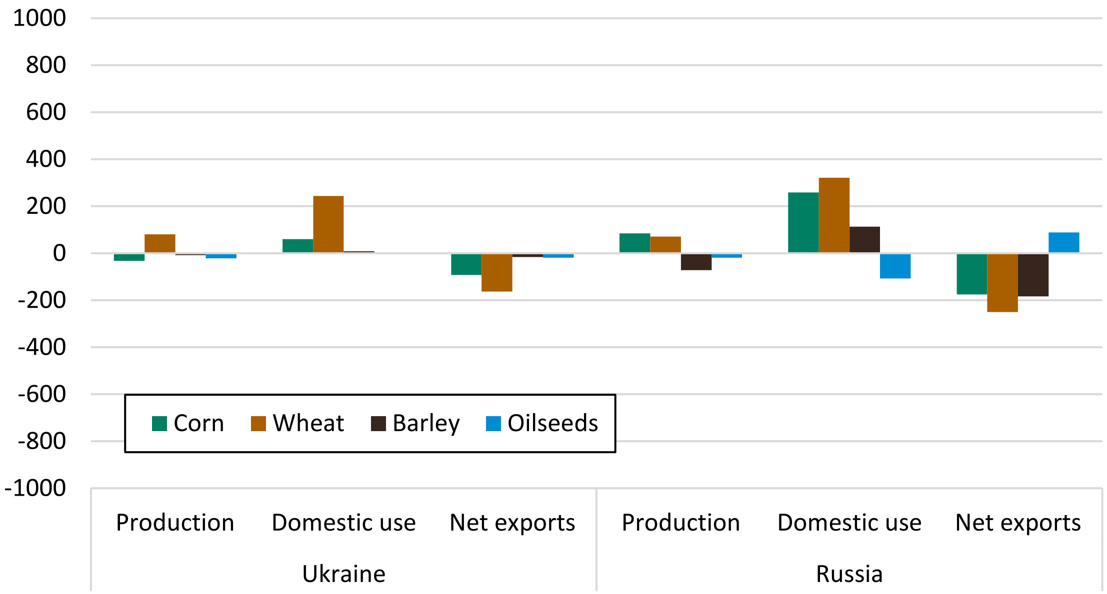


Source: Own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

The Russian tariffs do not change between the 'Towards EU integration' and 'Global liberalization' scenario. Hence, changes are expected to be small. However, the Russian cereal and oilseed markets are slightly worse of in the 'Global liberalization' scenario than in the 'Towards EU integration' scenario as production, consumption, and trade are slightly reduced (Figure 83). This is especially pronounced for wheat exports which become less competitive compared to other origins. Consequently, Russia will not have an interest in further trade liberalizations among other countries, especially Ukraine, as it diminishes its competitiveness.

The increase in Russian tariffs and export taxes in the 'Increase Protection' scenario lead to increased domestic prices in Russia and Russia focuses on consuming more of its own production, i.e., cereals, and imports less, i.e., soybeans (Figure 84). Hence, the production of cereals increases, while the production of oilseeds decreases as their products, especially sunflower meal and oil, are mostly produced for exports. Overall, income in Russia declines compared to the baseline.

Figure 84 Changes of production, consumption, and net exports of cereals and oilseeds for Ukraine and Russia in the 'Increase Protection' scenario compared to the baseline in 2030, thousand tons



Source: Own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Ukraine benefits from the increased tariffs of Russia, i.e., people's income increases compared to the baseline. Hence, consumption of cereals and oilseeds increase despite a slight increase in prices (Figure 84). Production slightly shifts in favor of wheat and sunflower seed and its processed products, i.e., the two products where Russia is a main exporter but less competitive now. However, trade in cereals and oilseeds is also reduced for Ukraine, i.e., Ukraine does not compensate the reduced exports of Russia in the cereals and oilseeds sector.

Overall, the impact of the simulated trade policy changes on cereal and oilseed markets in Ukraine and Russia are not large. Trade changes for cereals and oilseeds in Ukraine and Russia are moderate with the largest percentage change being below 12 %. These changes in trade are accompanied with changes in the domestic markets of less than 5 % (compare Table A5 in Appendix A).

The changes in the vegetable oil and meal market are even smaller than the changes in the cereal and oilseed markets with the exception of the soybean meal market (results are shown in Table A4 and Table A5 in Appendix A). In the soybean meal market, Russia increases net exports in the 'Towards EU integration' scenario as well as in the 'Global liberalization' scenario, i.e., by 21 % and 15 %, respectively. This underlines again the observation that Russia increases trade given own trade liberalization but is slightly negatively affected if other countries also liberalize trade. Simultaneously, Ukraine increases net imports of soybean meal, i.e., by 15 % and 18 % in the 'Towards EU integration' scenario and in the 'Global liberalization' scenario, respectively.

4.3.5 Discussion

Overall, the changes in import tariffs, export taxes, and NTMs only slightly affect cereal and oilseed markets in Ukraine and Russia despite their export orientation. One explanation is, that trade barriers are generally lower for cereals and oilseeds than meat, dairy and other processed products. Hence, other sectors will benefit or lose more if trade regulations change. These observations can be concluded from Philippidis *et al.* (2018) who analyzed the same scenarios for the whole economy and Banse *et al.* (2019) who analyzed different trade policies of Russia for the whole agricultural sector. Both find that the impact on the livestock sectors is higher than for the cereal and oilseed sectors.

While Russian and Ukrainian cereals are competitive on the world market, the sectors are often influenced by short-term, ad hoc policies which restrict trade as discussed in Section 4.3.1. The ex-ante analysis of these ad hoc measures is often not possible because the measures are announced on short notice, are in place only for a short-term, e.g., less than a marketing year, and are frequently adjusted. Therefore, these short-term measures have not been incorporated in the current analysis. However, it is necessary to have these in mind and consider them in the discussion.

Several studies analyze the effects of trade restrictions in Ukraine and Russia ex-post, e.g., Götz, Glauben and Brümmer (2013) and Götz, Djuric and Glauben (2015). Fellmann, Hélaine and Nekhay (2014) simulate the low production levels of 2010 to occur in 2015 and analyze the short-term effects of export restrictions ex-ante. The studies find that export restrictions increase global prices and food insecurity in importing countries as well as reduce producers' revenue due to lower domestic producer prices in the short run (Götz, Glauben and Brümmer, 2013; Fellmann, Hélaine and Nekhay, 2014; Götz, Djuric and Glauben, 2015). In the long run, export restrictions or the threat to introduce these measures if prices are high, increase market uncertainty and discourage investments in the affected market (Götz, Glauben and Brümmer, 2013; Götz, Djuric and Glauben, 2015). As a consequence, production is more volatile, less competitive, and more extensive than under favorable investment conditions (Fellmann, Hélaine and Nekhay, 2014). Both countries justify these measures by aiming to reduce or stabilize domestic consumer prices to ensure domestic food security. However, Götz, Djuric and Glauben (2015) found that the domestic price reductions in wheat due to imposed export bans, quotas, and taxes were not transmitted to consumer prices but have favored the milling industry in Ukraine and Russia. Hence, these ad hoc trade restrictions disrupt markets considerably without yielding the proclaimed effects.

As Ukraine and Russia are now both members of the WTO, one would expect that these trade restrictions are used less frequently. However, Russia has already implemented various measures in the cereals and oilseed markets during the Covid-19 crisis (Section 4.3.1). In Ukraine, the government negotiated for the first time a memorandum of understanding with representatives of the sunflower oil industry in the marketing year 2020/21 to set sunflower oil exports to maximum of 5.4 million tons (USDA FAS, 2021). Hence, both countries still see a need to interfere in cereal and oilseed markets, reducing their reliability as exporters. Consequently, high prices (as observed in the marketing year 2020/21) might trigger trade restrictions for cereals and oilseeds in Ukraine and Russia in the future and affect global markets negatively.

This case study shows that, the analyzed trade policy changes have small direct effects on cereals and oilseed markets mainly caused by NTM reductions. However, the indirect effects cause several shifts within the market. In Ukraine, wheat becomes more competitive than other cereals and oilseeds leading to a production increase which is highest in the ‘Global liberalization’ scenario. In contrast, Russian wheat production declines in both liberalization scenarios. In the ‘Global liberalization’ scenario, wheat exports decline as other origins are more competitive on the world market. In the ‘Increased Protection’ scenario, Russian demand shifts slightly towards domestically produced products, i.e., cereals, however, the effects of this scenario on cereal and oilseed markets are very low.

Several limitations of this case study should be mentioned here. First, the analysis is based on data and information available until 2016. Hence, it does not incorporate specific events that happened after 2016, i.e., the still existing import ban of Russia, the newly concluded FTAs, the ad hoc trade restrictions in the cereal and oilseed markets of Russia during the Covid crisis, and the Russian invasion of Ukraine. It is worth stressing again, that the application of the model system is a projection and neither a forecast nor a prediction of future developments. The main aim in the scenario analysis is to quantify the impact of specific changes, i.e., here changes in tariffs and NTMs. Hence, slight inaccuracies to real world observations do not render the results invalid.

Second, trade cost in the form of NTMs are reduced uniformly over all sectors in the analysis, i.e., representing general trade costs. However, the steps which are necessary to achieve general trade cost reductions are neglected here. For Ukraine, considerable investments, e.g., in new technologies, equipment, and knowledge transfer, as well as changes in national law to adapt to EU requirements and support to producers to adjust to EU standards are required to reduce trade cost between Ukraine and the EU (Yatsenko *et al.*, 2017). For the EAEU, the lack of harmonized standards including sanitary, phytosanitary, quality, and production requirements, is the main reason for high internal trade costs (Tarr, 2016). The analysis assumes that these obstacles are partially overcome but does not consider the costs or steps needed to achieve it. Additionally, NTMs are often targeted to a specific sector, e.g., to ensure food safety, which is neglected in the current analysis.

Third, even though showing plausible results for cereals and oilseeds in Russia and Ukraine, the presented analysis has several methodological caveats. Some of these caveats have been discussed in Section 3.3 and are not repeated here. However, one is stressed here as it relates to how trade is handled in the model system. Trade changes are only transferred for selected products of Ukraine and Russia from MAGNET to AGMEMOD and not for other countries in AGMEMOD, i.e., the member states of the EU. These trade changes had to be disaggregated to be used in AGMEMOD as MAGNET only produces changes in wheat, other cereals, and total oilseeds. Hence, the rapeseed, soybean, and sunflower sectors face the same trade changes and price reductions. Historically, however, these sectors have different structures and developments in both countries and, consequently, their future development might be different too. Consequently, the transfer of trade changes from MAGNET to AGMEMOD for the rapeseed sector in Ukraine was skipped upon the first evaluation of the results and is justified by market expert judgment.

Fourth, the methodological approach does not ensure consistent projections between the different models as only a one-way linkage is implemented, i.e., no feedback loops exist.

Consequently, MAGNET and AGMEMOD can project different production and consumption effects for the different sectors, not only in magnitude but also in direction. The analyzed scenarios show several of these effects. However, their differences are generally small, e.g., in the 'Global liberalization' scenario, MAGNET projects a decline in oilseed production of 6 % in Russia compared to the baseline in 2030, while the model system projects and increase of 1 %. Both developments can be justified given different assumptions about the competitiveness in production of sunflower seed compared to alternative crops. This underlines the general insecurity of market projections and the dependence of the results on assumptions and their modelled relationships in the system. Hence, even though the model system incorporates more relevant factors for the analysis than stand-alone models, their interaction is still in the infant state (compare Section 3.3).

4.3.6 Conclusion

This case study analyses the impact of different long-term trade policy strategies on the cereal and oilseed markets in Ukraine and Russia with the developed model system of GLOBIOM, MAGNET and AGMEMOD for three trade scenarios. These strategies represent examples of general trade liberalization on the one hand and trade restriction on the other hand but are not directly targeted towards the cereal and oilseed markets. As expected, the economy of Ukraine and Russia benefit from trade liberalization and GDP increases. Increased tariffs by Russia, negatively affect the Russian economy but positively affect the Ukrainian.

Focusing on the cereals and oilseed sectors, the results are generally small but diverse. Liberalizing trade benefits the wheat sector in Ukraine the most, while the wheat sector in Russia is most negatively affected. The effects of increasing tariffs of the EAEU are slight price increases and minuscule shifts in production and consumption towards more cereals in Russia.

The analysis shows what would happen if tariffs and trade cost change in general. However, it omits the sensitive role of cereals and oilseeds sectors the government in Ukraine and Russia place upon them. Hence, even though general trade liberalization might occur, the cereals and oilseeds sector might still face strong export restrictions depending on price levels and domestic production as observed in the past.

The methodological approach applied here requires further research to produce consistent results between the models and could be further improved by harmonizing data (compare Section 3.3.3.2). Additionally, the exchange of trade changes from MAGNET to AGMEMOD is a weakness and needs further consideration. For example, instead of transferring trade changes from MAGNET, aggregated tariff changes could have been included as an exogenous policy in AGMEMOD and, hence, trade modelled within AGMEMOD. While this sounds like a possible alternative, it would not consider bilateral trade effects, indirect effects of changing world market prices and overall economic development. Therefore, the current application can be justified for this case study but the approach is not transferable to be applied for other markets, countries, or trade policies.

4.4 Impacts of climate change mitigation policies on cereal and oilseed markets

Several specific factors influencing future cereal and oilseed markets have been analyzed in the previous case studies. This case study focuses on the factor land use change (3) and biofuel demand (4). Here, two climate change mitigation policies are chosen to be analyzed impacting the development of cereal and oilseed markets (compare Section 2.3). The two policies are:

- Conservation of land areas with high CO_2 sequestration capacities
- Increase in biofuel demand produced from agricultural feedstocks

The first policy reduces the input land for agricultural production, while the second policy demands more agricultural production. Hence, opposing effects on cereal and oilseed production are expected. The selection of these two aspects and the applied method is motivated in the next section. Afterwards, a literature review on existing analysis regarding these two policies is presented (Section 4.4.2). In Section 4.4.3, the scenario constructions including required data updates are described, while the applied method has already been presented in Section 3.3.3. The results are presented and discussed in Section 4.4.4 and Section 4.4.5, respectively, before the last section concludes.

4.4.1 **Motivation**

Concerns about climate change are growing. The key to slow down climate change is seen to be reducing GHG emissions (UN, 2015). Hence, several goals are pursued to either save or store them and actions, in the form of policies, commitments, declarations and intentions, have been taken on local and global levels. Some of these actions directly impact the development of cereal and oilseed markets (compare Section 2.3). Two goals and their pursuits which are assumed to have an impact on the future global development on cereal and oilseed markets are selected and analyzed further.

One goal is to conserve land areas with high CO_2 sequestration capacities, e.g., forests, peatlands, and wetlands, as demanded by several initiatives such as REDD+ (compare Section 2.1.2). To end the conversion of these land types to agricultural or urban land, they could be set under protection. This results in less land potentially available for agricultural production and, hence, is a constraint on the supply side of agricultural markets. The other goal, addressed in this section, is the partial substitution of fossil fuels by biofuels in the transport sector. Increasing biofuel demand leads to an increase in cereal and oilseed production as these are the common feedstocks for biofuel production. This increased demand requires additional land for biofuel feedstock production.

Hence, both goals are land-based climate change mitigation policies and compete over the use of land. In the case of biofuel production, several studies show that the climate change goal of saving GHG emissions is not achieved if direct and indirect land use changes are accounted for (Searchinger *et al.*, 2008; Searchinger, Beringer and Strong, 2017). Additionally, the conservation of land areas with high CO_2 sequestration capacities save multiple times the amount of GHG emissions than biofuels replacing fossil fuels (Searchinger, Beringer and Strong, 2017; Righelato and Spracklen, 2007). Despite these arguments, the production of biofuels is still widely supported by policies.

One option to achieve climate change mitigation targets including both strategies could be to counterbalance biofuel production by the conservation of land areas with high CO_2 sequestration capacities to reduce the conflict between conversion and conservation. Based on regional case studies, Persson (2012) and Killeen *et al.* (2011) propose and model two options to achieve this. They envisage policies to counterbalance potential conflicts by proposing payments for forest carbon conservation (Persson, 2012) or fixed ratios between area of biofuel cultivation and area of forest conservation and reforestation (Killeen *et al.*, 2011). Reilly *et al.* (2012) propose to include all land use sectors in a global carbon tax scheme including subsidies for carbon sequestration. Yet another alternative is to actively set land areas with high CO_2 sequestration capacities under protection, i.e., forbid their conversion to agricultural land or any other form of land use and simultaneously fulfill set biofuel targets (Dixon *et al.*, 2016). This last option is explored in the current case study.

The conjoint extension of both climate change mitigation policy measures might lead to higher GHG emission savings. However, both actions, i.e., expanding protected areas and biofuel demand, increase pressure on the remaining agricultural land. Consequently, competition for land will increase and impact the agricultural production for food and feed use as well. The cereals and oilseed markets will be impacted by this land competition and the additional demand for biofuel production. Hence, the case study addresses the following research questions:

- How does a restriction on available land convertible to agricultural production and a simultaneous increase in crop-based biofuel demand impact the future development of cereal and oilseed markets?
- What are the effects of each individual policy?

These questions are best addressed with models projecting the future development of cereal and oilseed markets and including the effects of the two actions on a global scale. The developed model system of MAGNET and LandSHIFT (compare Section 3.3.3) satisfies these requirements and, hence, is applied here.

MAGNET projects agricultural market developments and simulates the effect of biofuel demand on agricultural markets. LandSHIFT simulates the effects of setting land under protection on land use change. The joined application allows analyzing both effects simultaneously and, additionally, includes the other most relevant aspects affecting cereal and oilseed markets from a bio-physical and economic perspective. Hence, changes in food and feed demand as well as technical progress over time are incorporated in the analysis to name the other most relevant aspects. The dynamic nature of the model system allows to model these policies over a defined projection period, i.e., here until 2030. Further, through the linkage of MAGNET and LandSHIFT, the modelling of land demand for agricultural production is refined (compare Section 3.3.3).

4.4.2 **Literature review**

As motivated in Chapter 3 and highlighted in the previous case studies, future development of cereal and oilseed markets are often assessed by applying economic models either stand-alone or in combination with other models. This is also the case for the analysis of climate change policies. In these models, population, income and yield developments are very important assumptions when simulating future agricultural market developments. Due to different assumptions in the models, results vary considerably.

Numerous studies concerned with the protection of land, especially forests, and the attributed saving of GHG emissions exist often focusing on very long-term projections (IPCC, 2014a). Their research aims are to provide estimates on potential savings of GHG emissions due to avoided deforestation and even afforestation or required savings to achieve certain climate change goals (Popp, Humpenöder *et al.*, 2014; Humpenöder *et al.*, 2015; IPCC, 2014a; Calvin *et al.*, 2014). The studies point to possible impacts on food security as agricultural markets are restricted in their land use options but without focusing or quantifying it. Results for agriculture markets are often reduced to required intensification increases to compensate for land expansion (Popp, Humpenöder *et al.*, 2014; Humpenöder *et al.*, 2015) or selected food price changes (Calvin *et al.*, 2014; Humpenöder, 2015)).

Some studies focus on the impact climate land use policies have on food prices and consumption (Golub *et al.*, 2013; Tabeau *et al.*, 2017). Golub *et al.* (2013) simulated subsidizing forest carbon sequestration and taxing economic wide carbon emissions by 27 USD per t CO_2eq at a global scale with a static CGE model extended by the representation of land use change, GHG emissions, and carbon sequestration. Their simulations result in reduced global agricultural area of around 10 %, reductions in food consumption of unskilled labor households of up to 15 % depending on the region, and increases in food prices of up to 40 % depending on the food and region. Tabeau *et al.* (2017) analyzed increased forest protection levels with MAGNET by setting land under protection resulting in a maximum decrease of global agricultural land by less than 10 % accompanied by a decrease of global food consumption by less than 2 % in 2030 and an increase of global agricultural prices by nearly 8 %. However, regional changes are higher especially in developing countries and, hence, compensatory payments for avoided deforestation are proposed.

The impacts of increased biofuel production on land use and agricultural markets have been analyzed in numerous studies over the years and are compared in different review papers (Muscat *et al.*, 2020; Persson, 2015; Oladosu and Msangi, 2013). The studies vary in their regional coverage, projection period, applied methods, scenario set ups, and analyzed biofuel policies. Hence, results vary widely. Examples of studies that explicitly analyze a global increase in biofuel demand as opposed to considering only a specific region are Timilsina *et al.* (2012), Wise *et al.* (2014), Banse *et al.* (2014), Prieler, Fischer and van Velthuizen (2016). All studies find increases in agricultural land and none to small effects on global food consumption. Prices for agricultural products increase the most for biofuel feedstocks, i.e., sugar crops, cereals and oilseeds, with highest increases ranging from 9 % to more than 30 % depending on the study. Recent studies even analyze the effect of a reduction of crop-based biofuel production on agricultural markets (Araujo Enciso *et al.*, 2016; Dumortier, Carriquiry and Elobeid, 2021; Delzeit *et al.*, 2018).

Several studies have analyzed the combination of increasing the use of biofuels and protecting forests at the same time on a global scale (Popp *et al.*, 2011; Reilly *et al.*, 2012; Calvin *et al.*, 2014; Dixon *et al.*, 2016; Doelman *et al.*, 2018; Klein *et al.*, 2014; Popp, Rose *et al.*, 2014). Thereby, they strongly differ in the study design (Table 26) and consequently the results (Table 27).

Table 26 Study design of papers modelling increased biofuel demand and land protection scenarios

Reference	Method	Baseline assumptions	Scenario modelling	Bioenergy	Area protection
Popp *et al.* (2011)	Iteratively linked models: global dynamic vegetation and water balance model LPJmL simulating attainable production levels, global land and water use model MAgPIE minimizing production cost, global energy-economy-climate model ReMind determining bioenergy demand	no biofuel demand and no restrictions on agricultural area expansion, growing population, increasing feed and food demand	limiting GHG emissions in the energy sector to 1100 Gt CO_2 in 2095, reduction of 74 % of suitable land for cropland expansion	cellulosic bioenergy only (miscanthus, poplar, eucalyptus) with option of carbon capture and storage (CCS)	excluding presently intact and frontier forests from possible conversion to agricultural land
Reilly *et al.* (2012)	One-way linked models: CGE model The Emissions Predictions and Policy Analysis Model (EPPA) with world economy, land conversion, and GHG emissions and Terrestrial Ecosystem Model (TEM) changing yields due to climate change and determining net carbon in ecosystem	no climate policies, continued economic growth, land productivity growth of 1 % per year	global GHG tax for all emissions with increases of 4 % per year to 730 USD/t CO_2 in 2100	2^{nd} generation cellulosic biofuels	incentive for carbon sequestration in land
Calvin *et al.* (2014)	Integrated assessment model (IAM): Global Change Assessment Model (GCAM) linking energy, climate, agriculture, land use, and economy	stabilizing total radiative forcing to 4.5 W/m2 in 2100	limiting total radiative forcing to 3.7 W/m2 in 2100 through endogenous carbon price in the energy system	endogenous demand based on competitiveness with other energy, all forms of bioenergy represented and assumed to be carbon neutral	protecting 50 % of forest area per region
Dixon *et al.* (2016)	MAGNET	biofuel policies at 2010 levels until 2030, 60 % of maximal available land for agricultural purposes cultivated at start year	biofuel mandates and protection of forest and woodland	increase of biofuel mandates (1st generation) between 0 % and 25 % for 2020 and constant to 2030 per region	reduction of maximal available land for agricultural production between 2 % and 82 % per region
Doelman *et al.* (2018)	IAM Integrated Model to Assess the Global Environment (IMAGE) covering land use, agricultural economy, the energy system, natural vegetation, hydrology, and the climate system via sub-models	middle of the road scenario according to the Shared Socio-economic Pathway (SSP2)	limiting total radiative forcing to 1.9 W/m2 in 2100 through endogenous carbon pricing	woody/ grassy bioenergy plantations with CCS, production on abandoned land and natural grassland only	protection of all area with carbon density above 100 t C/ha and reforestation of degraded forest area

Source: own compilation based on papers mentioned in reference and their supplementary material

Table 27 Selected results of papers modelling increased biofuel demand and land protection scenarios

Reference	Selected scenario[a)]	Time horizon	Land use[b)]	Agricultural productivity	Food prices[b)]	Food consumption[b)]
Popp *et al.* (2011)	M_FC	2095	cropland -250 million ha	increase of 0.8 % per year in scenario instead of 0.6 % in baseline	increase of food price index between 1 % to 82 % depending on region	exogenous
Reilly *et al.* (2012)	Energy+ Land	2100	increased area for biofuel (total 1400 million ha), forest, grassland; decreased area for crops (total 1200 million ha) and pasture	exogenous part for growth over time and endogenous climate dependent part	Indices scenario vs baseline from 2000 to 2100: Food price: +190 % vs +22 %, Crop price: +170 % vs 25 %, Livestock price: +450 % vs +80 %	reduced food consumption
Calvin *et al.* (2014)	50 % Forest	2095	6 % deforestation in scenario vs 3 % in baseline, 38 % increase in cropland in scenario (includes land for bioenergy production) vs 15 % in baseline	identical exogenous increase over time	wheat index (2005 = 1): 2050 = 1.1 and 2095 = 0.9 in scenario vs 2050 = 0.9 and 2095 = 0.9 in baseline	food crop consumption set constant, meat consumption allowed to decline but does not in current scenario
Dixon *et al.* (2016)	Biofuel & Land conservation	2030	globally -6 % agricultural land	exogenous part for technical progress in land use, endogenous part associated with different input uses	agricultural prices globally slightly below levels in 2010, consumer prices: max in Indonesia with +22 %	max reduction of 5 % in Indonesia but above levels in 2010
Doelman *et al.* (2018)	SSP2 1.9	2100	+414 million ha bioenergy plantations, -311 million ha agricultural area, +254 million ha forest	combination of various exogenous and endogenous components	food prices: +40 %	reduced food availability: 2818 kcal/cap/day in scenario compared to 2905 kcal/cap/ day in baseline

Notes: [a)]one scenario with increased biofuel demand and land protection chosen out of available scenarios; [b)]results of selected scenario compared to their baseline in last projected year if not stated otherwise

Source: own compilation based on papers mentioned in reference and their supplementary material

Climate change mitigation policies are either modelled directly by bioenergy demand and area protection or by different carbon pricing mechanisms. Klein *et al.* (2014) and Popp, Rose *et al.* (2014) focus on climate change mitigation and land use changes but only briefly mention possible impacts on agricultural markets. The other studies address the connection between climate change mitigation policies and agricultural markets via effects on food prices and food consumption.

All studies except Dixon *et al.* (2016) simulate effects of land-based climate change mitigation policies until the end of the century which requires large scale applications of technologies currently only in the research stage. The different results except Calvin *et al.* (2014) point towards conflicts with food security at least at local scales as prices increase and food consumption declines. The range of results demonstrate the magnitude of uncertainty in the projection especially if looking at side effects such as food security in this case.

Dixon *et al.* (2016) is the study most comparable to the applied approach in this dissertation as it applies MAGNET and sets up the scenarios in a similar way. This dissertation extends the research by linking MAGNET to LandSHIFT and applying updated scenario assumptions.

Additionally, none of these studies address effects on cereal and oilseed markets. Hence, the research gap of how global biofuel demand expansion and conservation of land with high CO_2 sequestration potentially influences cereal and oilseed markets is filled in this case study. The case study differs in several ways from the already existing studies as it addresses the question from a different angle, i.e., from the (narrow) perspective of cereal and oilseed markets. First, GHG emissions are not thematized here even though they are the main reason for the policy implementation. Second, a time horizon up to 2100 is too uncertain to produce meaningful results from a market perspective and, hence, the time horizon in the case study is set to 2030 which is already long-term and in itself includes large uncertainties. Third, the current case study tries to be less hypothetically by using biofuel technologies which already exist on a large scale.

4.4.3 **Data, method and scenarios**

The literature review underlines the need for a global study to analyze effects of biofuel policies and land conservation on agricultural markets in detail. The combined use of MAGNET and LandSHIFT as developed and presented in Section 3.3.3 is an appropriate tool for this analysis (compare Section 4.4.1). Before an economic analysis can be carried out, various technical specifications, namely data updates, model system setup and scenario construction, have to be made, which are presented in the following sections.

4.4.3.1 **Data update to 2015**

Several data are updated to include historically observed developments relevant for our analysis up to 2015. An update of the whole database lies beyond the capability and responsibility of the single applying modeler. The updates concern a) agricultural production, land use and yields, b) biofuel shares in transport fuel use, and c) population and GDP developments.

As the focus of this dissertation is on cereal and oilseed markets, the data on agricultural production, land use, and yields published by FAO (2020c) are updated as discussed in

Section 3.3.3.1. In MAGNET, agricultural yield changes are implemented as shock from 2007 to 2015 to incorporate the data in the projections until 2015. This is realized through using Equation 4 (page 106), which has been developed for the model link (see Section 3.3.3.1). Furthermore, the projected MAGNET outcomes on agricultural production and land are overwritten by the reported values based on FAO (2020a) and FAO (2020e). As the global land cover map applied in LandSHIFT is not available for 2015 but only for 2010, LandSHIFT allocates the FAO production data for 2015 by applying their model algorithm. The resulting land use deviates from observed values by only 1.7 % or 8 million hectares and, hence, is seen as accurate enough to replicate the situation in 2015 and start with the analysis. To ensure harmonization in 2015 between both models, the land use as projected by LandSHIFT is put into the first MAGNET iteration overwriting the results for 2015 for land use and resulting yields and the actual analysis starts in 2015.

Further, biofuel policies are analyzed and, hence, an update of the required data is necessary. The MAGNET database includes initial biofuel shares for the year 2007. These biofuel shares are updated for the year 2015 by using the same database (IEA, 2017) and approach as for the generation of the data for 2007. For the member states of the EU, biofuel shares are updated based on Eurostat (2020) and include only crop-based biofuels. The resulting biofuel shares for 2015 are shown in Table 29 below. The calculated biofuel shares for 2015 are given as an exogenous shock to the model in the same way any changes in biofuel shares are introduced in scenario analysis in MAGNET.

Besides policies and policy changes, MAGNET is driven by population and GDP development over time. Hence, these data have been updated to include historically observed data for 2015 based on UN (2017b) and USDA (2017), respectively. The resulting changes are input to MAGNET for the projections to 2015 identical to the approach as in any standard baseline.

4.4.3.2 Model system setup

The setup of the applied model system is divided in three tasks. One task is the aggregation of data from the database to an aggregation the models can solve. Another task is the decision on how to specify the individual models compared to the default model specifications as described in Woltjer *et al.* (2014) and Schaldach *et al.* (2011). The third task is the implementation of the model link between MAGNET and LandSHIFT which has been presented in Section 3.3.3. This model link is developed for the current case study but could also be used to answer other research questions concerned with the interplay between land use and agricultural markets. Task one and two are defined explicitly for this case study and their specifications are a requirement for the model linkage, especially for Step 2 Mapping and Step 4 Synchronization.

Aggregations in LandSHIFT and MAGNET

In the current case study, the database of MAGNET differentiates between 134 regions and 61 sectors. LandSHIFT differentiates 190 regions and is flexible in defining anthropogenic land use categories and land cover categories depending on available input data and study focus. However, neither of the two models produces interpretable results with this level of detail. Hence, regions and sectors are aggregated and the categories for land use and cover are limited.

The regions in MAGNET and LandSHIFT are aggregated to 35 identical regions for the model run and eight regions for the presentation of results (see Table B2 Appendix B). The 35 regions are clustered according to several criteria which ensure a balance between detail and model solving capacity (details in Table B2 in Appendix B).

First, countries with large territories, large agricultural production or specific biofuel policies should not be aggregated, e.g., Brazil, India, China, Russia, or the US. Second, countries that form a union and, hence, have common policies especially with regard to agricultural, trade and biofuel policies can be aggregated within the union but not with other countries outside of the union, e.g., the EU. Third, countries with small territories or small agricultural production should be aggregated to form larger entities. Fourth, the final aggregation should consist of no more than 40 regions. Fifth, countries within an aggregate should be neighboring countries. This last criterion is not satisfied in all aggregates as other rules were seen to be more important, e.g., the formation of the aggregate 'EFTA region' includes Norway, Switzerland, Iceland, and Liechtenstein. These criteria ensure that in the aggregation a) changes in biofuel and land demand are accurately represented, b) geographical and economic relations between regions are reflected, and c) models' limitations and requirements are considered (details in Table B2 in Appendix B).

In MAGNET the 61 sectors are aggregated to 30 sectors (details in Table B3 in Appendix B). Agricultural sectors and their processing sectors as well as sectors concerning biofuels are represented in greater detail than the other sectors which are aggregated to larger entities. This allows to model the impact of biofuel policies especially on cereal and oilseed markets. LandSHIFT adopts seven agricultural sectors from MAGNET as separate land use categories (compare Table B4 Appendix B). These land use types are further mapped in LandSHIFT to the land cover types cropland or grassland.

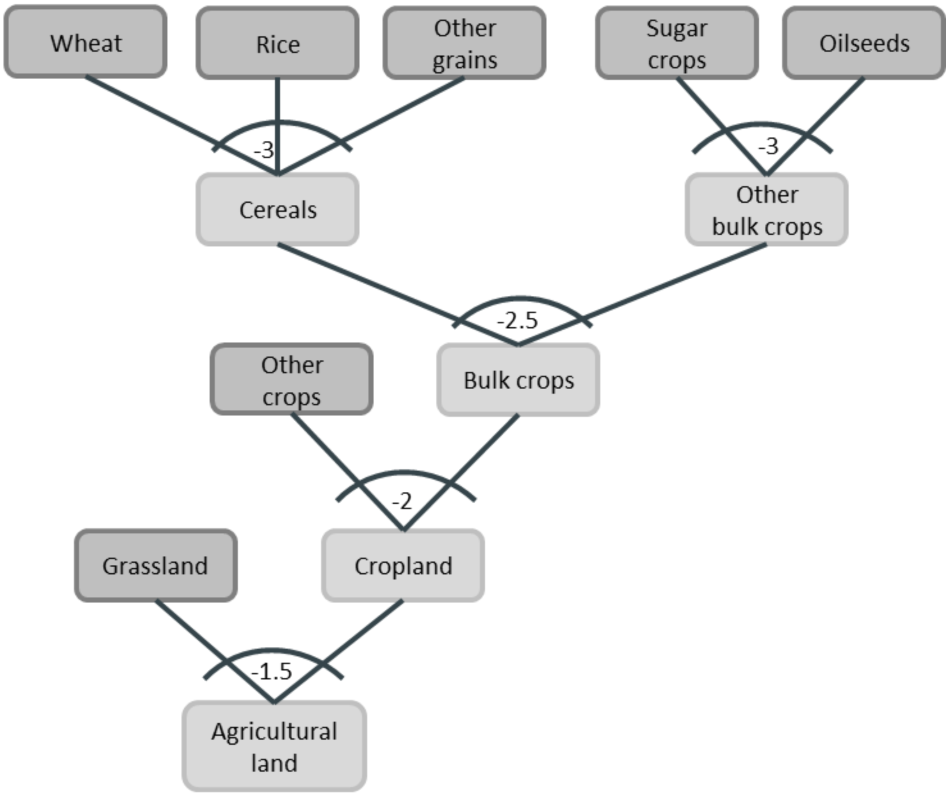
Model specifications in LandSHIFT and MAGNET

Modifications of MAGNET and LandSHIFT compared to their standard versions are implemented to a) link LandSHIFT and MAGNET and b) setting the focus on cereal and oilseed markets. The modifications only concerning the link of the two models are described in Section 3.3.3.1 above.

Applying MAGNET requires several decisions with regard to the following statements: a) which modules should be included, b) how should the modules be specified, and c) need the model or any modules to be further extended. The current case study includes nearly all modules presented in Woltjer *et al.* (2014). Specifications have been made in the production structure and the land use module, while the other modules are activated but run in the standard setting without any changes (compare Woltjer *et al.* (2014)).

Changes in the land use module (compare Section 3.2.1.3) concern the land supply and demand side. On the land supply side, a new asymptote is introduced (compare Section 3.3.3.1 and Table B5 in Appendix B). This asymptote includes all potentially available agricultural area even if productivity is low (compare Table B1 in Appendix B). Further, the land elasticity is changed. Woltjer *et al.* (2014) proposes to set the parameter γ in the equation for the land elasticity ε to 1 (compare Equation 2 in Section 3.2.1.3). However, in the current application this leads to unrealistically high expansion of agricultural area and, hence, γ is set to 0.25. On the land demand side, the land allocation tree according to Figure 85 is implemented with CET elasticities between -1.5 and -3 which corresponds to the upper bounds proposed in Woltjer *et al.* (2014). This allows easier transformation between land for the production of bulk crops and especially potential biofuel crops as in other applied studies with MAGNET.

Figure 85 Land allocation tree and CET elasticities in MAGNET for Case Study 4



Source: own representation

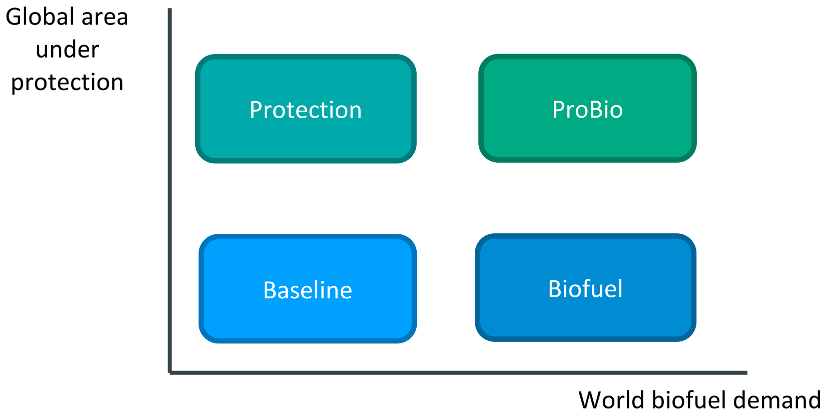
MAGNET allows to set up a fully flexible production structure based on a multilevel nested CES functional form (compare Section 3.2.1.1 and Woltjer *et al.* (2014)). This option has been used and productions structures, including elasticities, have been adjusted, e.g., to implement restrictions by the LandSHIFT model. For example, LandSHIFT does not include a substitution possibility between pasture and other feed for animal production (compare Section 3.2.4). Hence, this substitution possibility is excluded in the feed composition structure for ruminants in MAGNET.

In LandSHIFT several small adjustments are made (for details see Schüngel (forthcoming)). First, changes in crop yields over time depend on the input from MAGNET without changes due to climate change as modelled by LPJmL. Changes in crop yields in MAGNET are based on an endogenous and an exogenous part which implicitly includes parts of climate change and, hence, including changes in yields due to climate change from the LPJmL model would have been a double counting if added here. Further, the time horizon in the case study is only till 2030 which justifies the neglection of modelling the influence of climate change on crop production in detail (compare Section 2.3). Second, livestock grazing is updated to include technical change and the allocation to grazing in a similar fashion as crop cultivation. Additionally, feed use in livestock production does not change in its composition, i.e., fixed feed shares between land directly used for feed, e.g., as pasture, and feed from crops are assumed. Consequently, neither intensification nor extensification in the livestock sector is modelled here. Third, areas with yields below 10 % of the regional average for each form of agricultural production compared to the initialization, are separately reported and excluded from being able to be convert to agricultural land.

4.4.3.3 **Scenario construction**

Having set up the model system, the scenarios are constructed to analyze the influence of biofuel policies and land conservation on cereal and oilseed markets. First, a business-as-usual scenario, i.e., baseline, is set up which represents a future pathway given current trends and policies. Second, three additional scenarios representing alternative future pathways are set up as summarized graphically in Figure 86. From the baseline, these scenarios differ in the level of protected area resulting in constraints on agricultural land supply and biofuel policies resulting in increased biofuel demand. The 'ProBio' scenario is the scenario which models the joined application of both policies which represents one option to reduce negative effects of biofuel production through undesired land use change as motivated in Section 4.4.1. The 'Protection' and 'Biofuel' scenario are run to quantify the effects of changes in one policy.

Figure 86 Graphical representation of the relationship between the scenarios



Source: own representation

The scenarios are set up from 2015 to 2030 in five-year periods, i.e., the model system produces results for 2015, 2020, 2025 and 2030. General assumptions in the scenarios are population development, GDP development, and technical change. Specific assumptions regard biofuel policies and land protection.

General assumptions

All scenarios include identical assumptions for population development based on UN (2017b). The assumed GDP projections are based on USDA (2017). In the baseline these GDP projections are exogenously given, while in the scenarios GDP adjust to changes in policies. These two assumptions are the main drivers for changes over time in the MAGNET model. Their development is summarized in Table 28 which shows that population growth is assumed to be strongest in Africa between 2015 to 2030 and GDP per capita growth in percentage is strongest in South & East Asia.

Table 28 Assumptions on population and GDP development in the baseline

Region	Population					GDP per capita				
	2015	2030	2015 - 2030			2015	2030	2015 - 2030		
	Million persons		Δ%/ a	Δ%	Δ absolute	USD per person at constant prices 2007		Δ%/ a	Δ%	Δ absolute
Africa	1194	1703	2.4%	43%	509	1464	1690	1.0%	15%	226
Europe	542	548	0.1%	1%	6	34507	42901	1.5%	24%	8394
Former Soviet Union	287	294	0.2%	2%	7	6586	8412	1.6%	28%	1826
Middle East	320	394	1.4%	23%	74	8648	11498	1.9%	33%	2851
North America	482	543	0.8%	13%	61	37961	45956	1.3%	21%	7994
South & East Asia	4014	4452	0.7%	11%	438	4435	7688	3.7%	73%	3253
South & Central America	506	570	0.8%	13%	64	6729	8741	1.8%	30%	2013
Australia	40	48	1.2%	20%	8	31425	38073	1.3%	21%	6648
World	7383	8551	1.0%	16%	1168	8922	11622	1.8%	30%	2700

Source: MAGNET database based on UN (2017b) for population and USDA (2017) for GDP

In MAGNET, land productivity has an exogenous and an endogenous component. The endogenous component represents efficiency gains, i.e., producing the same amount with less input or substituting inputs. The exogenous component represents technical change for the endowment land, e.g., higher yields through plant breeding. In the current case study, this technical change is set to 0.5 % per year, 0.75 % per year or 1 % per year depending on the countries or regions (compare Table B5 in Appendix B). Developed economies are attributed a low growth rate arguing that yield growth as occurred in the past might slow down due to environmental restrictions and fewer advances in breeding techniques, while developing countries are attributed higher growth rates arguing that improved management practices and access to new crop varieties could increase yields. In LandSHIFT, exogenous land productivity includes yield changes over time except the change in yields due to reallocation of production to different grid cells. Therefore, the exogenous land productivity in LandSHIFT is defined as the changes in total yields from the initial MAGNET runs. These annual growth rates in yields differ per region, per crop, per period, and per scenario ranging from 0.3 % to 1.9 %. Their range is within historically observed growth rates (Section 2.1.1).

Specific assumptions

Areas that have the potential to sequester large amounts of CO_2, i.e., forest, wetland, and peatland, are set under increased protection in the 'Protection' and 'ProBio' scenario to simulate their preservation. While global protection of these lands is desirable, the realization is currently not achievable. For example, deforestation occurs in several regions either legally or illegally and depends on the economic and political stability as well as the level of corruption. Hence, LandSHIFT simulates the protection of these areas depending on the level of corruption in a region. Therefore, any grid cells with the land cover category forest, wetland or peatland is not allowed to be converted to any other use if the CPI (Transparancy International, 2020), i.e., a measure for the level of corruption, in a region is above a defined criterion (compare Section 3.2.4 and Table B5 in Appendix B). In detail, forests are not allowed to be converted if the CPI is above 50 for a region in the baseline and 'Biofuel' scenario, while the conversion of area is not allowed if the CPI is above 25 for forests and 50 for wetlands and peatlands as of 2025 in the 'Protection' and 'ProBio' scenarios.

These assumptions are roughly transferred from LandSHIFT to MAGNET by recalculating the maximal available area for agricultural production, i.e., the asymptote (see Table B5 in Appendix B). This approach simulates a tightening land market in MAGNET differentiated between regions. In total, 2,328 million hectares of land are put under additional protection in 2025 for the scenarios 'Protection' and 'ProBio'. Most of this area lies in Russia (972 million hectares) and Brazil (340 million hectares). In the scenarios, the maximal available area for agricultural production in a region is further reduced over time due to urbanization and the lack of suitable agricultural area in LandSHIFT to allocate the given agricultural production from MAGNET (compare Section 3.3.3.1 and Section 4.4.4).

Biofuel policies are incorporated in all scenarios as blending mandates, i.e., the share of biofuel in transport fuel demand. These mandates are realized by crop-based biofuel production only. Hence, all biofuel from any form of advanced biofuels are not incorporated as these are assumed not to be realized on a large scale until the end of the projection, i.e., 2030. The baseline and 'Protection' scenario include a conservative demand of crop-based biofuels which is oriented toward mandated and realized targets in the different regions, while the 'Biofuel' and 'ProBio' scenario simulate an increased demand of crop-based biofuels which are oriented toward loosely declared targets by governments. In general, biofuel mandates are either constant at latest observed levels or increase until 2030. Table 29 shows the specific mandates within MANGET for historically observed values in 2015 and the assumed mandates for 2030 in the different scenarios.

Table 29 Biofuel mandates as biofuel share in transport fuel for 2015 (historical) and 2030 (scenario dependent), in %

Region	2015	2030		
	historical	Baseline, Protection	Biofuel, ProBio	Justifications
Canada	3.7	5.2	7.5	d)
United States	5.3	5.3	7.0	d), e)
Central America	0.2	1.0	5.0	a), c)
Brazil	25.1	27.0	30.0	a)
Rest of Latin America	2.9	15.0	20.0	b), c)
Western Europe	3.7	5.6	7.0	d), e)
Central Europe	4.1	5.4	7.0	d), e)
Southern Europe	1.4	5.1	7.0	d), e)
Scandinavia	4.9	5.9	7.0	d), e)
Baltics	2.7	4.4	7.0	d), e)
EFTA region	2.2	2.2	5.0	d), f)
Ukraine Belarus Moldova	0.4	3.0	5.0	b)
Turkey	0.5	0.5	3.0	b), f)
Rest of Europe	0.6	0.6	2.0	c), f)
Eastern Africa	0.1	0.8	5.0	c)
Rest of Southern Africa	0.5	2.0	10.0	b), c)
China	0.9	1.0	7.5	c), d)
Japan and Korea	0.4	1.0	3.0	b), f)
India	0.5	5.0	11.0	c)
Malaysia Philippines Thailand	4.8	11.5	20.0	c)
Indonesia	2.6	12.0	25.0	c)
Australia New Zealand Oceania	0.8	0.7	1.5	f)

Notes: a) generally supportive, b) new increased targets under discussion, c) further expansion proclaimed but previous targets not always met, d) increased focus on overall GHG emission savings or non-crop-based feedstocks, e) cap on some crop-based biofuels implemented or under discussion, f) support limited

Source: 2015 based on IEA (2017) and calculated within MAGNET, 2030 own compilation based on USDA FAS (2017-2020), Biofuel Digest (2019) and IEA (2020), for the EU own calculations based on Eurostat (2020) and European Parliament and Council (2015)

4.4.4 **Results**

Analyzing effects of biofuel policies and land protection on cereal and oilseed[8] markets requires the inclusion of biofuel sectors as well as land markets in the analysis. This justifies that the scenarios are run with the joined model system of MAGNET and LandSHIFT as described in Section 3.3.3. The results presented here are the final results, i.e., after iteration is successfully completed. Additionally, the results are presented for eight aggregated regions even though the scenario analysis is conducted with 35 separate regions (for mapping see Table B2 in Appendix B).

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[8] Oilseeds include in the definition of the joined system of MAGNET and LandSHIFT also oil crops such as palm or coconut

4.4.4.1 **Baseline results**

The baseline shows a development of cereal and oilseed markets until 2030 under the specified assumptions representing a business-as-usual development. Table 30 to Table 32 summarize the development for cereal and oilseed markets from 2015 to 2030. Given the increase in population and income (compare Table 28) as well as slight increase in biofuel demand, cereal and oilseed production increases in all regions with strongest growth of cereals in Africa and South & East Asia and strongest growth of oilseeds in South & East Asia and South & Central America (compare Table 30 and Table 31). The production growth is accompanied by yield growth in all regions and in most regions by area expansion. This area expansion is strongest in Africa for cereal production and in South & Central America for oilseed production.

Table 30 Development of production and area of cereals and oilseeds from 2015 to 2030 in absolute terms

	Production in million tons			Area in million hectares		
Region	2015	2030	Δ 2015 -2030	2015	2030	Δ 2015-2030
Cereals						
Africa	187	288	101	120	152	32
Europe	333	353	20	66	64	-2
Former Soviet Union	219	242	24	145	142	-3
Middle East	66	80	14	30	32	2
North America	551	616	65	104	107	2
South & East Asia	1284	1506	222	224	232	8
South & Central America	193	220	26	40	40	0
Australia	38	42	4	25	24	-1
World	2870	3346	476	754	793	39
Oilseeds						
Africa	47	74	27	30	36	6
Europe	35	46	10	13	16	3
Former Soviet Union	38	46	9	41	42	1
Middle East	4	6	2	1	2	0
North America	147	184	36	59	66	7
South & East Asia	354	504	149	54	65	11
South & Central America	193	288	95	51	67	16
Australia	7	8	1	6	6	0
World	826	1155	329	256	299	43

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table 31 Development of production, area, yield and producer prices of cereals and oilseeds in percentage change in 2030 relative to 2015

	Cereals				Oilseeds			
Region	Production	Area	Yield	Price	Production	Area	Yield	Price
Africa	54	27	21	-4	65	22	31	-4
Europe	6	-2	9	-13	28	20	8	-13
Former Soviet Union	11	-2	13	-7	27	3	20	-7
Middle East	21	7	14	-9	30	20	15	-10
North America	12	2	9	-11	23	11	12	-10
South & East Asia	15	3	13	13	37	20	19	12
South & Central America	15	1	13	-8	49	30	14	-6
Australia	10	-3	12	0	10	-1	11	7
World	18	5	11	-3	38	17	20	-3

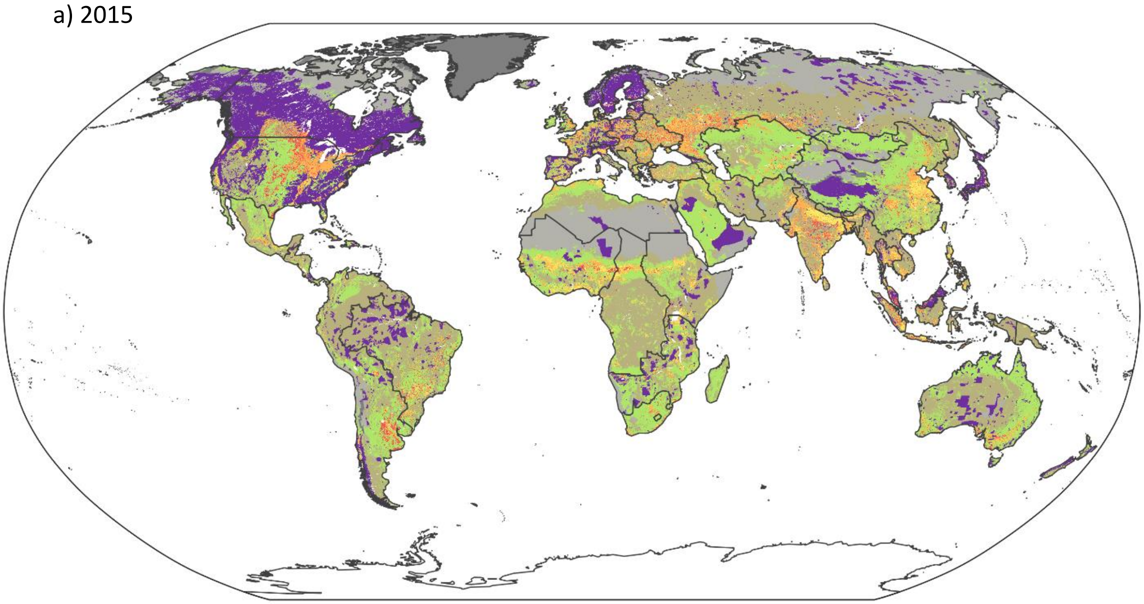
Note: Percentage changes in production are based on the production volumes in MAGNET with the basis expressed in value of 2007 with constant USD. Using FAO production volume in tons of 2015 results in slightly different figures due to aggregation reasons.

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

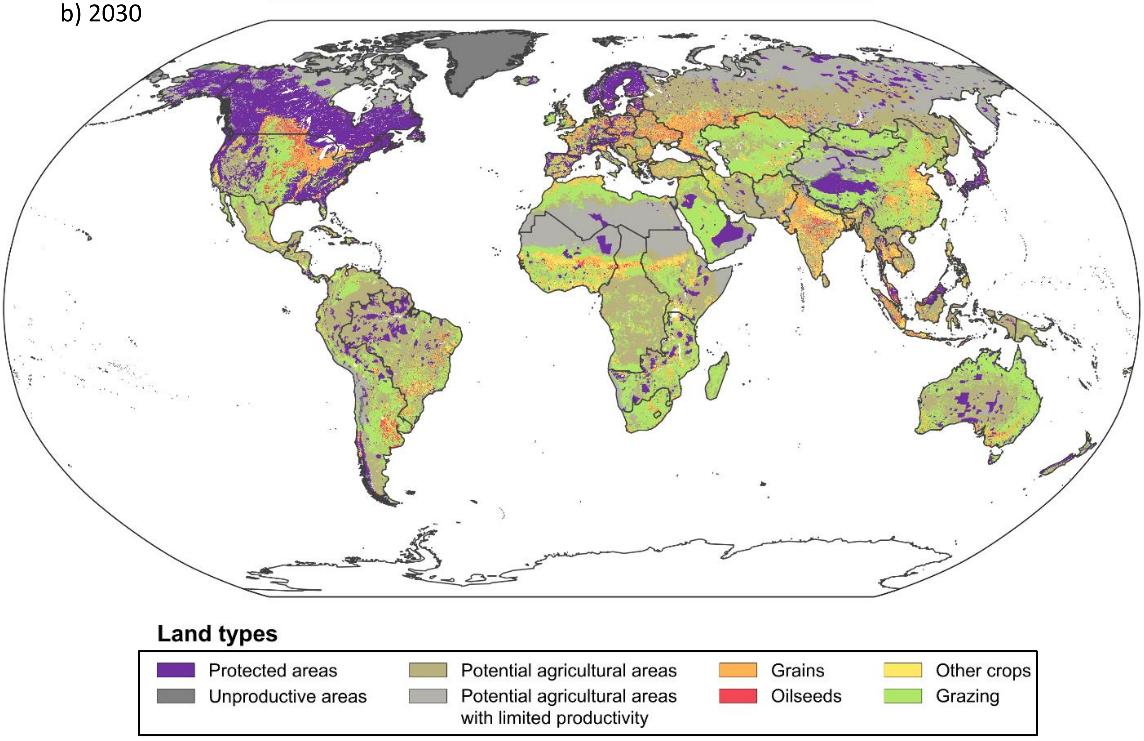
Compared to historical developments between 2000 and 2015, overall global growth of cereal and oilseed production from 2015 to 2030 slows down as well as the accompanying global area expansion and global yield growth (FAO, 2020a). However, total agricultural area expands by 11 % globally, corresponding to an additional 504 million hectares from 2015 to 2030 which is mainly caused by livestock expansion, i.e., grazing expands by 339 million hectares. Figure 87 shows the land use and cover as simulated by LandSHIFT for 2015 and 2030. The potential agricultural area includes all area that is bio-physically suitable for the cultivation of at least one agricultural crop or for grazing if not protected (compare Section 3.3.3.1 and Table B1 in Appendix B). Agricultural area, especially grazing, expands most in the northern parts of Africa but also in South America, Asia except Russia and Australia. The increased grazing area is due to increased demand for livestock products which is due to rising incomes especially in Africa and South & East Asia. This development is in contrast to historical development where agricultural area including grazing decreased by 2 % from 2000 to 2015 (FAO, 2020e).

Figure 87 Land use and cover in the baseline for a) 2015 and b) 2030

a) 2015



b) 2030



Note: Land types are described Table B1 in Appendix B
Source: results from LandSHIFT by Jan Schüngel generated by the joined use of MAGNET and LandSHIFT

Demand for cereals and oilseeds grows in all regions (Table 32). Increases in cereal demand are mainly caused by increasing population while changes in oilseed demand is also caused by increased incomes. As GDP increases in all regions but population growth slows down in the projections, oilseeds increase more than cereals. Further, the increased production of biofuel demands more cereals and vegetable oil as feedstocks. The difference in the development of production and demand in a region result in increased trade (Table 32) and price changes (Table 31). For example, the Former Soviet Union, a region with high export shares of production, increases production in cereals and oilseeds more than demand resulting in increased exports and slightly reduced production prices. South & East Asia shows a contrary development with demand increasing more than production resulting in increased prices and slight increases in net import shares of consumption.

Table 32 Development of demand in percentage change from 2015 to 2030 and trade shares of cereals and oilseeds for 2015 and 2030

	Cereals					Oilseeds				
	Demand Δ% 2015	Net exports / production		Net imports / demand		Demand Δ% 2015	Net exports / production		Net imports / demand	
Region	-30	2015	2030	2015	2030	-30	2015	2030	2015	2030
Africa	47			15	11	60	1	4		
Europe	2		1	2		23			19	16
Former Soviet Union	5	17	21			21	19	23		
Middle East	27			31	34	29			52	51
North America	12	23	23			16	36	40		
South & East Asia	16			8	9	46			31	34
South & Central America	14	1	2			47	39	40		
Australia	15	14	10			15			4	8

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Real production prices for cereals and oilseeds decline in all regions except for South & East Asia (Table 31). This results from the fact that productivity in production grows in most regions faster than demand. However, focusing on the more disaggregated regional level, real cereal and oilseed production prices increase also in South Africa as well as the regions Rest of Southern Africa, Middle Eastern, and Central Asia (Table B12 and Table B13 in Appendix B). In these regions demand growth is larger than supply growth leading to possible worsening of the economic situation for poor consumers as additional imports cannot compensate the gap between demand and supply and, hence, prices rise. The differences in the availability and cost of input factors, e.g., land and labor, are an additional reason for the different production price developments between regions.

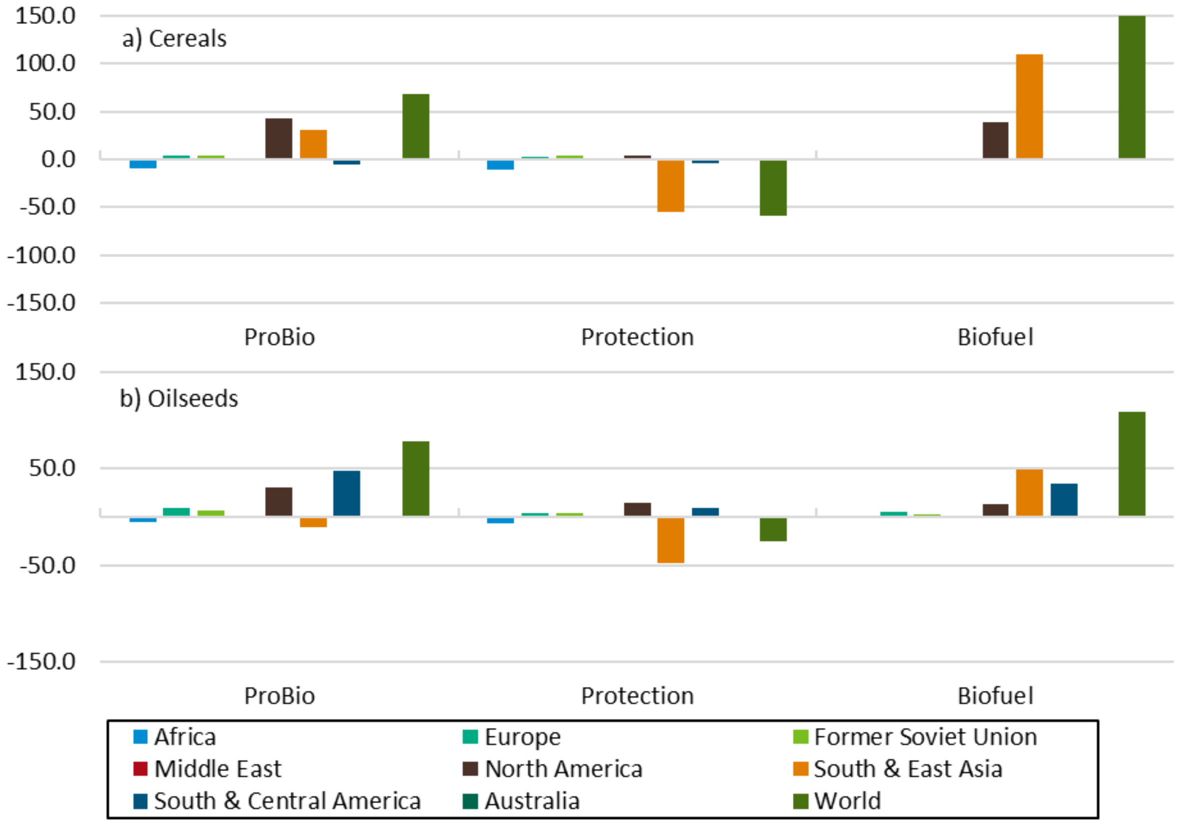
4.4.4.2 Scenario results and discussion

The results of the baseline are the basis on which the scenarios built upon. Hence, comparing the outcomes of the scenarios to the baseline quantify the effects of a restriction on available land convertible to agricultural production and an increase in crop-based biofuel demand on cereal and oilseed markets. In the following, the scenario results are presented for 2030 relative to the baseline in 2030, if not stated otherwise. The focus of the analysis is laid on the 'ProBio' scenario as it ensures GHG emission savings due to the combination of the two land-based climate change mitigation policies. Possible negative climate change effects from the expansion of biofuel demand are counterbalanced by simultaneously protecting areas which sequester large amounts of CO_2 to reduce GHG emissions from land use change. The other two scenarios simulate the implementation of one of the climate change mitigation policies. Hence, their results quantify the single effect of the respective policy.

Production

Global production of cereals and oilseeds expands compared to the baseline as shown in Figure 88. In the scenario 'ProBio' and 'Biofuel', an increased demand for crop-based biofuels is simulated by increasing biofuel blending targets in MAGNET according to Table 29. This increase leads to a global increase of crop-based biofuel production of around 65 % in both scenarios in 2030 compared to the baseline with largest absolute increases in South & East Asia and North America. In the 'ProBio' scenario, this results in additional global cereals and oilseeds production of 68 million tons (+2 %) and 79 million tons (+7 %), respectively. South & East Asia and North America show the largest absolute production increases in cereals, while main increases in the oilseed sector occur in America. In South & Central America a shift from cereals towards oilseed production can be observed in all scenarios. In the absence of area protection, cereal and oilseed production would increase stronger due to increased biofuel demand, especially in South & East Asia which is strongly restrained in area expansion if forests, wetlands, and peatlands are protected. Production is the product of changes in land and yields, which are both affected by the implemented policies.

Figure 88 Changes of cereals and oilseeds production, changes in million tons in the scenarios compared to the baseline in 2030

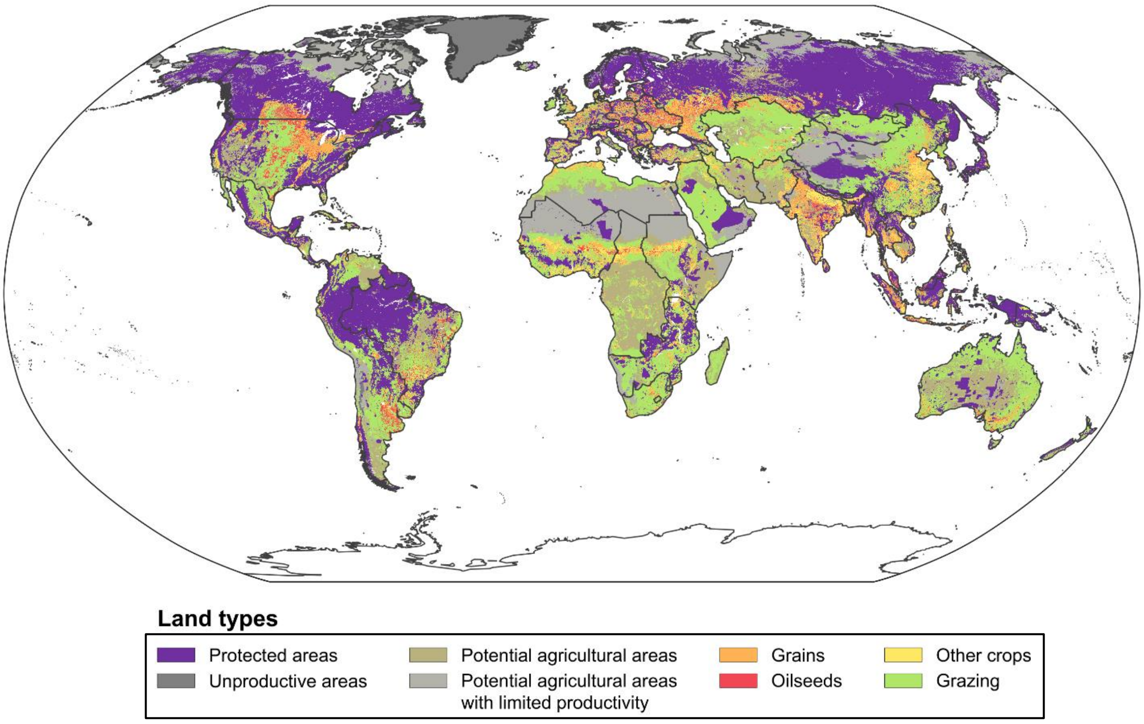


Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Land

In the scenarios 'ProBio' and 'Protection', the conservation of land with high CO_2 sequestration potential is simulated by not allowing 2,328 million hectares of land deserving protection to be converted to other land uses as of 2025 (compare Table B5 in Appendix B and Figure 89). While in each region additional area is protected, the most of the protected area lies in the Former Soviet Union, South & Central America and South & East Asia (compare protected area, i.e., purple color, in Figure 87 and Figure 89).

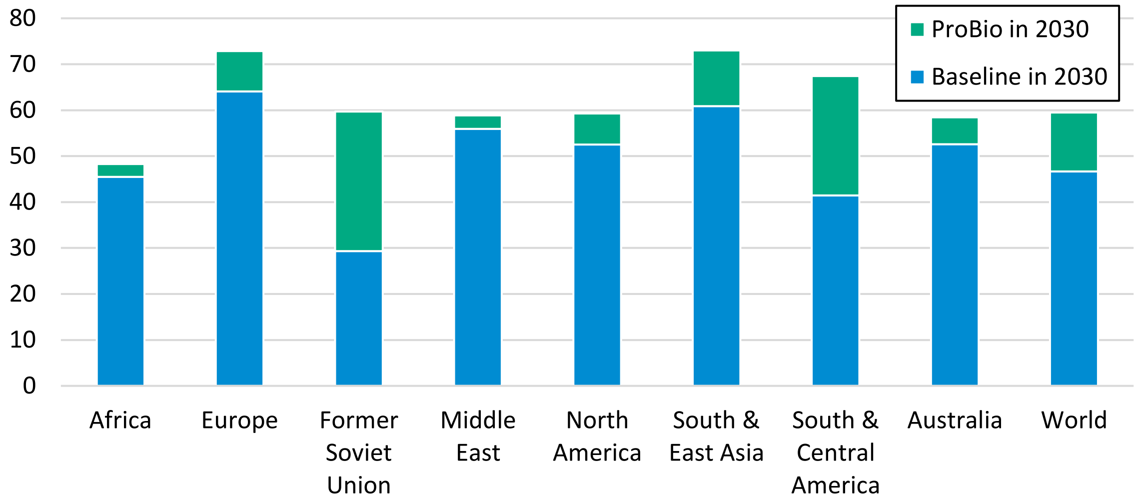
Figure 89 Land use and cover in the 'ProBio' scenario in 2030



Note: Land types are described in Table B1 in Appendix B
Source: results from LandSHIFT by Jan Schüngel generated by the joined use of MAGNET and LandSHIFT

The pressure on land markets through a reduced availability of additional land for agricultural production is demonstrated in Figure 90. While most of the additionally protected area lies in the Former Soviet Union, the used agricultural land share of potentially available agricultural area is still below the share for South & Central America and South & East Asia. Hence, expansion of agricultural land in the Former Soviet Union is less restricted. This fact does not necessarily imply an expansion of agricultural area but a comparative advantage as the input factor land is less expensive. Further, the additionally protected area in the Former Soviet Union lies mostly in remote areas of Russia with low bio-physical production potential, socio-economic constraints, and poor market accessibility (Meyfroidt *et al.*, 2016). In contrast, the additionally protected area in South & Central America and South & East Asia show higher suitability for agricultural production at least from a bio-physical point of view than the area in the Former Soviet Union (Zabel, Putzenlechner and Mauser, 2014). Hence, the Former Soviet Union becomes relatively more competitive on world agricultural markets as the potential for area expansions is still larger than in other regions and their now protected areas are less suitable for agricultural production anyway.

Figure 90 Pressure on land use, used agricultural land share on potentially available agricultural area, percentage



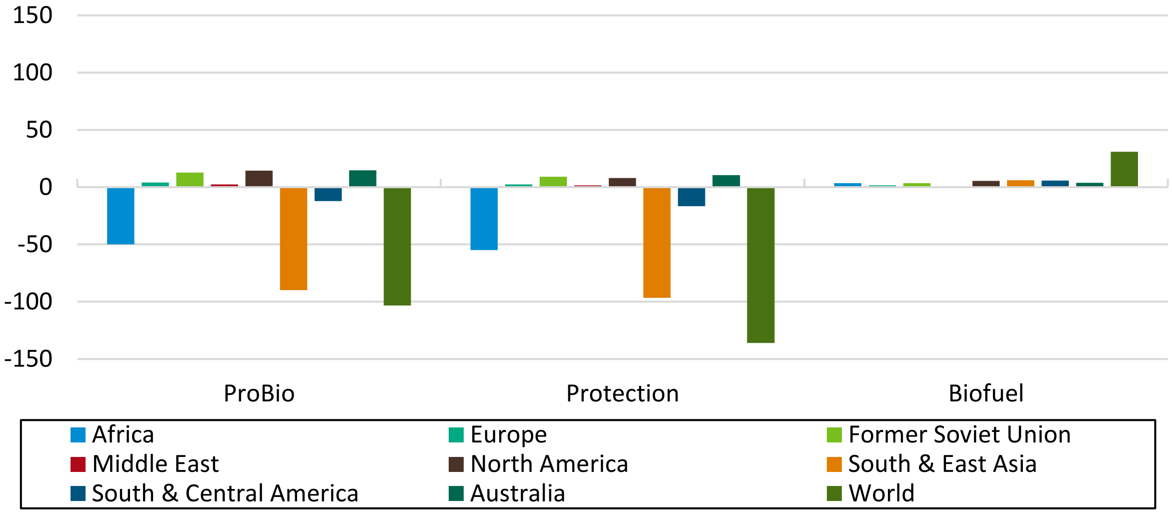
Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Through the restriction on agricultural area expansion, the increase in production over time is restricted in both the 'ProBio' and 'Protection' scenario compared to the baseline. Consequently, the projected production cannot be produced on the available land in all regions as demonstrated by the joined use of MAGNET and LandSHIFT. In Western Africa, China and South Africa, there is not enough suitable land available to produce the necessary amount of agricultural production because LandSHIFT was unable to allocate all projected agricultural production from MAGNET during the first iterative model run. Hence, a protection of land with high CO_2 sequestration potential restricts these regions directly in their decision to expand agricultural production as they would have done without the restriction. This tightens the land market further in these regions and is simulated in MAGNET during the next iterations by a reduction of the asymptote (see Section 3.3.3). This adjustment leads to additional decreases in the potentially available area for agricultural production (compared to the numbers presented in Table B5 in Appendix B) of 19 %, 13 %, and 3 % for Western Africa, China and South Africa, respectively. The applied approach results in reduced production levels which might overstate economic reactions if the reduction of the asymptote is high as pointed out by Dixon *et al.* (2016). Hence, the effect especially in Western Africa might be too high and results should be taken with caution (compare Table B6 to Table B15 in Appendix B). However, this does not change the general message of the case study and a negative impact in Western Africa is expected even though it might be less extreme as in the simulation.

Figure 89 shows the land use and cover as simulated by LandSHIFT for the 'ProBio' scenario in 2030. Agricultural area decreases by 104 million hectares (2 %) in 2030 compared to the baseline. Despite this, cereal and oilseed area increase globally by 1.4 and 23.5 million hectares, respectively, while pasture area decreases by 111 million hectares. This can be attributed to the additional demand for biofuels and the higher productivity of cereals and oilseeds compared to pasture.

The protection of area reduces agricultural land use mostly in tropical areas, i.e., South & East Asia, Africa, and South & Central America, while in temperate areas, i.e., the Former Soviet Union, North America, and Australia, agricultural land use slightly increases compared to the baseline (Figure 91). Hence, some regions partly compensate for the reduction in other regions. In other words, the agricultural sector even gains from such a climate change policy in the Former Soviet Union, North America, and Australia. The increased demand of biofuels slightly increases agricultural area in all regions resulting in a global increase of 31 million hectares.

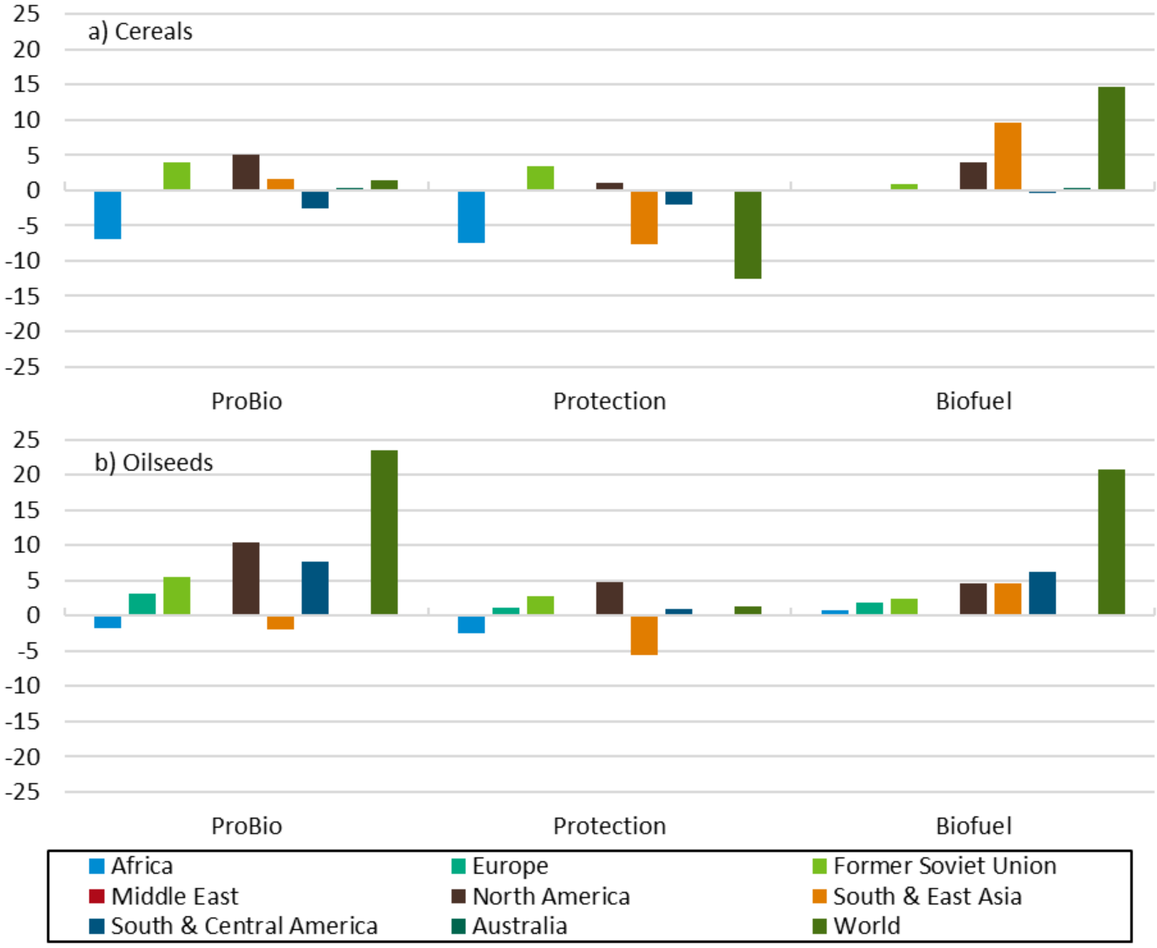
Figure 91 Changes of agricultural area in the scenarios compared to the baseline in 2030, million hectares



Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

The increases in the oilseed area are larger than the increases in the cereal area with variations as shown in Figure 92. Areas increase in the Former Soviet Union and North America in all scenarios. Hence, they have the highest competitive advantage with respect to land. The increase in biofuel demand results in a shift in land use patterns in South & Central America with reduced land for cereal production but strongly increased land for oilseed production. The decreased land availability in Africa mostly affects land use for cereal production, while the decreased land availability in South & East Asia affects both crops.

Figure 92 Changes of cereals and oilseeds area, changes in million hectares in the scenarios compared to the baseline in 2030



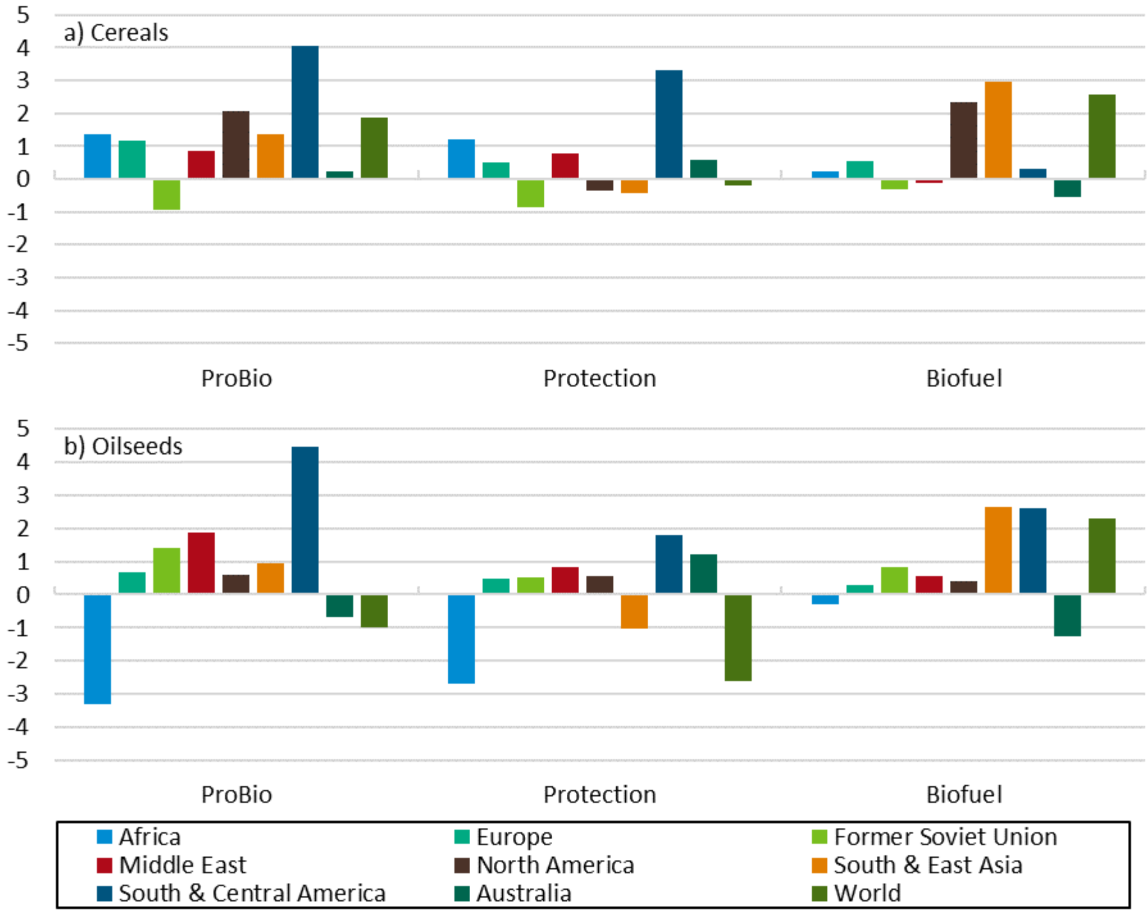
Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Yields

In the current analysis, yield changes can be distinguished in three separate components. First, an exogenous shift over time representing technical progress which is identical in all scenarios. Second, changes in the composition of input factors. Most importantly the substitution between land and other inputs which can lead to intensification, if less land relative to other inputs is used, or extensification, if more land relative to other inputs is used. Third, changes of land use on a small scale due to the link with LandSHIFT, which allocates agricultural production per grid cell of 5 minutes of arc. Each grid cell has a crop specific yield and through changes in allocation and production patterns the yields change. Thereby, average yields can increase, if production is allocated to more productive crop cells, or decrease, if production is allocated to less productive crop cells. A production increase in one crop can lead to reduced yields, if the additional production is produced on less productive area. Additionally, the production increase of one crop can lead to a yield decrease in another crop, if the other crop is relocated to less productive areas. Also, a decrease in production can lead to higher yields, if the most productive area is cultivated.

This effect can also happen if yields increase due to changes in input use. In general, increased demand of a specific crop or a strict restriction of area expansion stimulates intensification and, hence, yield increases can be expected in all scenarios. Additionally, the regions mostly affected by the increased demand or the decreased land availability are expected to intensify agricultural land use. This can be observed in most regions as depicted in Figure 93. For example, yields increase compared to the baseline in 2030 in South & Central America due to increased demand for biofuels triggering increased oilseed production and the conservation of land with high CO_2 sequestration potential triggering reduced area for cereals production.

Figure 93 Changes of cereals and oilseeds yields, % changes in the scenarios compared to the baseline in 2030



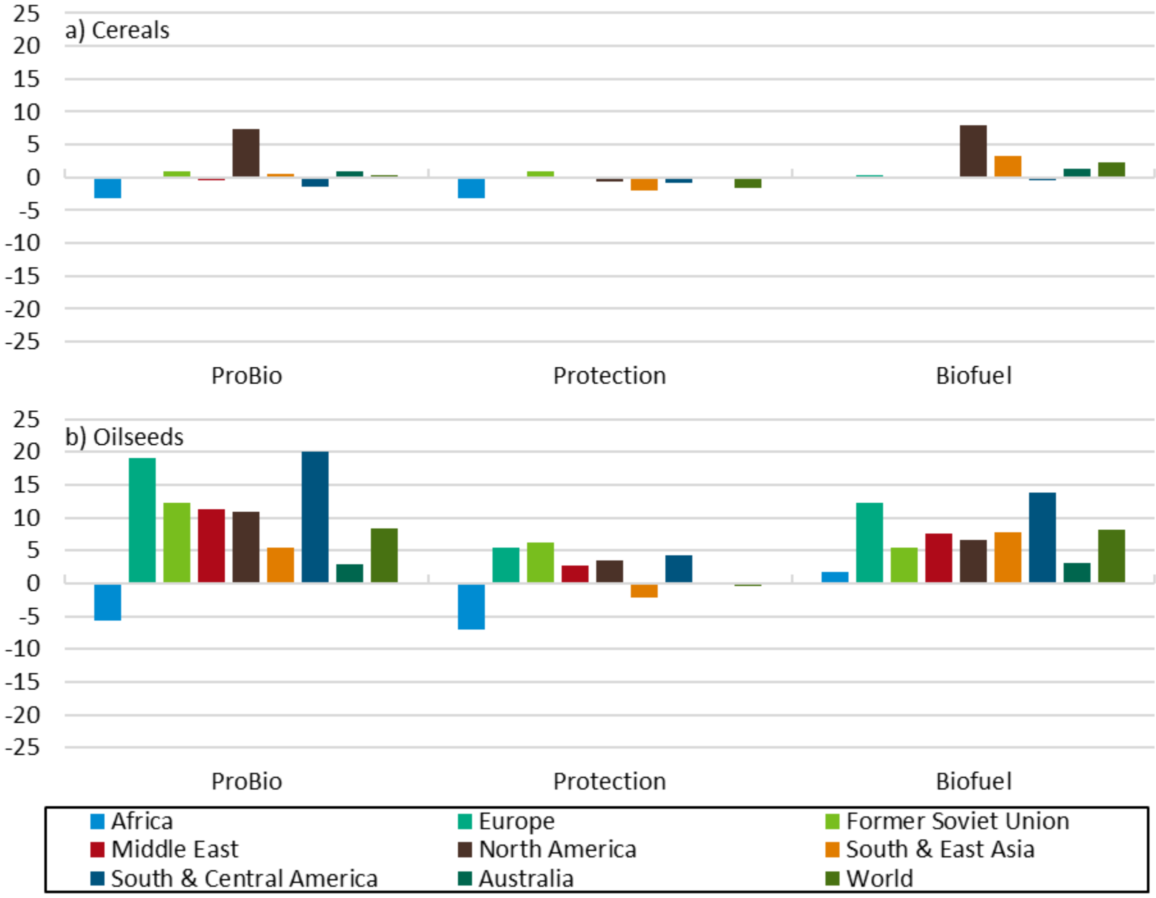
Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

One exception to be highlighted is the development in South & East Asia if land is protected (see ‘Protection’ scenario). The area protection policy sets fertile land under protection which was used for production in the baseline. Due to the restriction, this land is not available anymore and production and area declines. The additional decline in yields is counterintuitive and only explainable with a shift in used area towards less productive area for cereals and oilseeds. The increased demand due to increased biofuel policies results in intensification increases which partly compensate for the loss due to area reallocation (see ‘ProBio’ scenario). Following the same argumentation, the yield declines of cereals in the Former Soviet Union and of oilseeds in Africa and Australia are explainable as land use change, i.e., cultivation on less productive land for the specific crop, dominates the intensification effect.

Demand

The demand for cereals and oilseeds increases with increased demand for biofuels and decreases with restrictions on agricultural area (Figure 94). The former Soviet Union is the only region increasing their demand for cereals slightly in the 'Protection' scenario due to their increased relative competitiveness in production. The strongest declines are observable in Africa which is an indicator that food security might be threatened in the region as cereals are important staple crops. In the case of oilseeds, global demand of the raw material decreases slightly in the 'Protection' scenario. However, shifts between regions are observable. These shifts represent not only changes in demand but are also a result of production changes because the processed products of oilseeds are often traded instead of the raw material (compare also Section 2.2.2).

Figure 94 Changes of cereals and oilseeds demand, % changes in the scenarios compared to the baseline in 2030



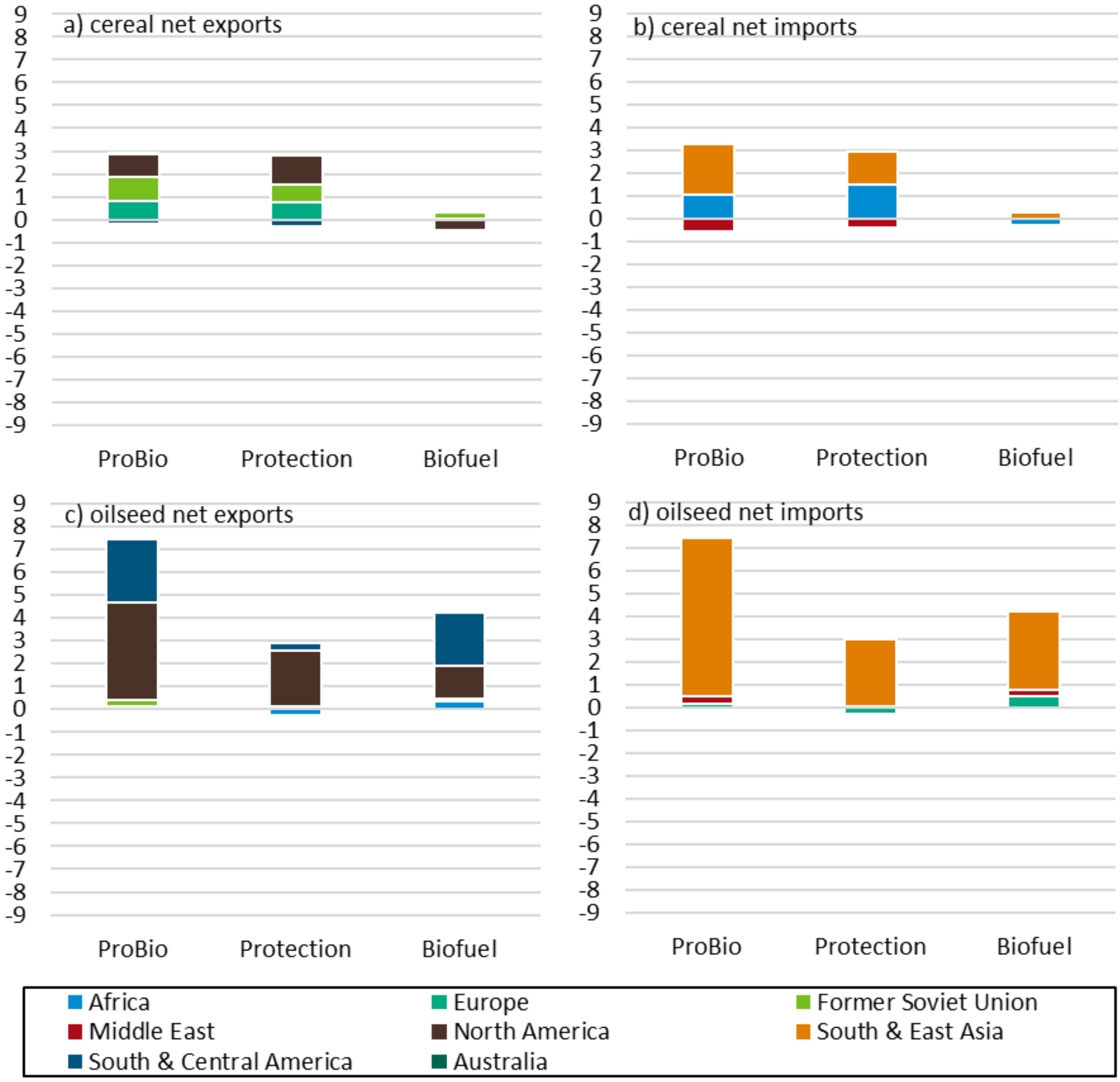
Note: Demand = Production volume + Import volume – Export volume based on the GTAP database and as defined in MAGNET, i.e., not in physical tons as production is.
Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Trade

As a result of the analyzed policies, trade changes between the different regions (Figure 95). For cereals, the protection of area results in higher exports from North America, the Former Soviet Union and Europe to South & East Asia and Africa, while the biofuel policy increases trade only marginally. In the oilseed sector, both policies stimulate trade. South & Central America increases trade due to increased biofuel policies, while

North Americas’ exports would increase more from the protection of area. Especially for South & East Asia and Africa trade contributes to compensate for reduced production, though that the decrease in demand stays relatively low.

Figure 95 Changes of cereals and oilseeds net trade, volume changes in billion USD 2007 in the scenarios compared to the baseline in 2030



Note: Net trade calculated based on Export volumes at world prices based on the GTAP database and as defined in MAGNET, i.e., not in physical tons as production is.

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

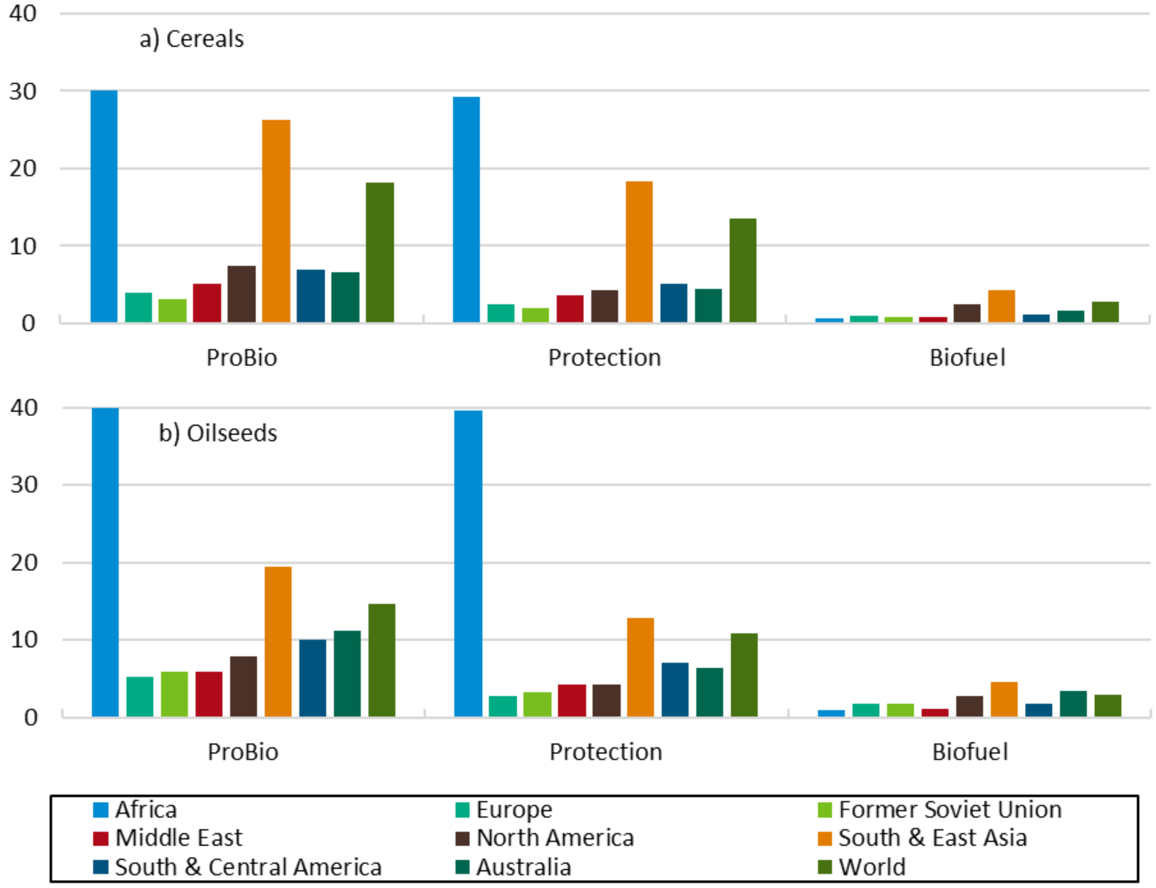
Prices

The changes in prices as presented in Figure 96 are the results of the new market situation due to the changes in policies. Both policies lead to a price increase. The price increases due to an increase in biofuel demand are less than the protection of areas. Increases in cereal and oilseed prices coming from increased demand makes producers better off and stimulate production. Consequently, yields increase due to intensification and technical change and area expands. These adjustments lower prices in turn. As a result, only moderate price increases are observed.

In the ‘Protection’ scenario, the option to extend agricultural area is limited. This also results in reduced yields in some area where production needs to take place on less productive land. As food demand is relatively inelastic, prices strongly increase, especially in the regions where area expansion is a strong driver for production growth over time, i.e., Africa and South & East Asia (compare Table 30, page 194). It is important to note here, that these two areas are not the areas with highest increases of pressure on land (compare Figure 90, page 200). Due to the strong increase in prices, demand in these two regions also declined as imports can only partially compensate for the reduced production. These strong price increases result in threats to food security as the poor might not be able to afford enough food.

The combination of both policies results in even higher prices as shown in the 'ProBio' scenario. Especially in South & East Asia, the combination of both effects exceeds the price effect if the individual price affects would simply be added up. This can be explained by the fact, that the region has ambitious biofuel policies but lacks the resource land especially if environmental protection policies are in place.

Figure 96 Changes of cereals and oilseeds prices, percentage changes in the scenarios compared to the baseline in 2030



Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

4.4.5 Discussion

The two analyzed climate change policies most negatively impact the cereal and oilseed markets in Africa and South & East Asia because production is restricted, demand reduced, and prices strongly increase. For Africa, the strongest impact occurs due to area protection because production increases in Africa are dominated by area expansion which is now restricted.

In the case of South & East Asia, both policies play a crucial role in the market developments. In this region, two countries are identified to shoulder the largest burden in the 'ProBio' scenario, namely China and Indonesia (compare Table B6 to Table B15 Appendix B). In China and Indonesia, maximal potential available area for agricultural production is reduced by 13 and 58 %, respectively (Table B5 in Appendix B), combined with a strong increase in biofuel demand though their envisaged biofuel polices (Table 29, page 193). This results in increases of production prices between 28 % and 40 % for cereal and oilseeds in both countries (Table B12 and Table B13 in Appendix B). Chinas production shifts towards cereal production and cereal imports increase to satisfy the demand for biofuel production, while in Indonesia cereal and oilseed production decreases in 2030 compared to the baseline and imports of oilseeds strongly expand to satisfy the additional biofuel demand (Table B6 to Table B15 in Appendix B).

Biofuel targets have often not been met and are under revision and regularly adjusted. China has already proclaimed to switch from crop-based ethanol to cellulosic ethanol with transition complete in 2025 (USDA FAS, 2019a). Indonesia aims to further increase its palm oil based biodiesel consumption through policies while ethanol targets have not been enforced (USDA FAS, 2019b). Further policy changes regarding biofuels have been observed in the EU and the US from supporting to limiting certain feedstock uses in the production of biofuels. Several countries aim at producing biofuels from so-called advanced or 2nd, 3rd and even 4th generation biofuels. A change in fuel consumption patterns might reduce the need for biofuels, e.g., if the use of electrical vehicles increase as pointed out by Dumortier, Carriquiry and Elobeid (2021). Given these arguments, the assumed biofuel demand in the 'Biofuel' and 'ProBio' scenario can be considered to be on the upper bound. However, even the policies limiting certain feedstocks leave room for further expansion of crop-based biofuels until 2030. Additionally, the technologies for advanced biofuel production are not yet available for large scale production and will only emerge in the coming years. Further, their expansion is limited due to a restriction in the available feedstocks, e.g., used cooking oil. Hence, crops, including cereals and oilseeds, might stay the dominant input for biofuel production for the next years.

The preservation of land sequestering CO_2, increase cereal and oilseed prices strongly, especially in Africa and South & East Asia. Here, significantly less area is used for agricultural production. Hence, countries in these regions might oppose to any policies or commitments to conserve these lands. China and Indonesia are two examples, especially if they stick to currently proclaimed biofuel targets. Despite the large area protection in South & Central America, agricultural area is only slightly reduced. However, production patterns change towards more oilseeds and less cereal production.

Even more intriguing is the situation in the Former Soviet Union where most of the additionally protected area is located. Here, area even expands under the simulated climate change mitigation policies because the protected area is located in less well-suited areas for agricultural production, mostly in areas in the Asian part of Russia (Figure 89, page 199). Additionally, a relatively low percentage of maximal available area for agricultural production is cultivated (Figure 90, page 200). Hence, the policy does not restrict agricultural area expansion there in the current setting. Also, Australia, Europe, and North America are less affected by conserving these lands as less than 8 % of the total land put additionally under protection is located in the regions (Table B5 in Appendix B). As the results show, their agricultural area increases in all scenarios compared to the baseline. Hence, these regions might support policies or commitments to conserve forests, peatlands and wetlands.

Global efforts to protect land with high CO_2 sequestration potential effects the regions where the land is located if agricultural production is restricted, i.e., Africa, South & East Asia and South & Central America, while the whole world profits from it from an environmental point of view, i.e., mitigation of climate change. Hence, the conservation of this land needs to be rewarded through global efforts, i.e., every country contributing to it and not only the ones that actively restrain from converting this land to other uses. Policy instruments might be a global carbon tax system including the land use sector or direct compensatory payments for land conservation. However, both options pose challenges in implementation and leakage effects might offset the intended positive effects of the policy (Popp, Humpenöder *et al.*, 2014).

4.4.6 **Conclusion**

This case study provides a global projection of the development of cereal and oilseed markets till 2030. Possible changes due to a restriction on available land convertible to agricultural production and an increased demand for crop-based biofuels are analyzed with the newly developed joined model system of MAGNET and LandSHIFT. Therefore, four scenarios are constructed representing a baseline, a scenario with increased area protection, a scenario with increased biofuel demand and a scenario combining increased area protection and biofuel demand. Given the time span until 2030, the modelled effects of a restriction on available land convertible to agricultural production and an increase in crop-based biofuel demand can be seen as exaggerated compared to what might be possible to implement in reality. This is the case as land is currently not protected according to their capacity to sequester CO_2 and a global consensus on the subject might not be reached in the near future. Additionally, the political support for cereals and oilseeds as feedstocks in biofuel production in major producing and consuming countries is reduced. Hence, the results present a maximum impact of these two effects on cereal and oilseed markets.

From 2015 to 2030, the development of cereal and oilseed markets are dominantly influenced by the baseline development, i.e., the underlying factors of population, income growth, and productivity growth. This results in increased cereal and oilseed production and demand in all regions and scenarios from 2015 to 2030. The growing demand is met by sufficiently increased production in nearly all regions as real production prices for cereals and oilseeds decrease from 2015 to 2030 for most regions except South & East Asia in the baseline (compare also Table 31). Price increases are an indicator that demand for a product grows faster than supply. Especially cereal price increases affect poor consumers most negatively as the affordability of buying staple foods is reduced. Consequently, South & East Asia is a region of concern regarding food security under baseline assumptions.

The simulated climate change mitigation policies significantly affect cereal and oilseed markets. Increases in cereal and oilseed prices coming from increased demand, here biofuel demand, makes producers better off and stimulate production. However, the restricted availability or scarcity of inputs, e.g., land, hinders production expansion. Regions with price increases in the baseline experience further price increases in the scenarios, i.e., a tense market becomes even more tense. Regions with price decreases in the baseline over time mostly still experience price decreases over time in the scenarios with the exception of Africa. Hence, besides South & East Asia, Africa will become an additional region of concern regarding food security especially if land is protected.

Some regions profit from the increased demand by expanding production and exports, especially if the two factors do not play a large role in the region, namely the Former Soviet Union. Shifts within agricultural markets occur in other regions, e.g., South & Central America expands oilseed production at the expanse of cereal and other agricultural production. This shift is not only triggered by local restrictions and demands but also through increased export opportunities for oilseeds and its processed products.

Other regions are negatively affected resulting in strong price increases, namely South & East Asia and Africa. Specifically, two countries of concern, i.e., China and Indonesia, are identified which are most strongly affected by the analyzed policies. In both countries a restriction on area expansion would hinder the domestic production of biofuel feedstocks. Hence, these two counties need special attention if global area protection for climate change mitigation becomes reality. Solutions need to be found to reduce local negative effects, especially if they are not generated locally.

Concluding, the effects of conserving land with high CO_2 sequestration potential and increased biofuel demand is lower than the effect of population and income growth. However, additional pressure is put on regions which experience pressure already in the baseline, i.e., increase in real prices for cereals and oilseeds. Further, the effect of land with high CO_2 sequestration potential has larger impacts than the expansion of biofuels on cereal and oilseed markets. Combining both factors leads to increased production with oilseeds increasing more than cereals. The case study shows that climate change mitigation policies might lead to lower food security in regions which already face problems regarding food security today. Hence, their implementations need to be combined with some policy instruments which reduce this negative effect.

4.5 Conclusion out of the four case studies with respect to cereal and oilseed markets

The four case studies project the development of cereal and oilseed markets until 2030 under given assumptions and changes in important factors impacting their development. The most important factors driving cereal and oilseed markets over time are changes in population, income, and productivity as demonstrated by the case studies. In general, the demand for cereals and oilseeds will continue to grow globally as well as in the specifically studied regions, i.e., Ukraine and Russia. Given historical trends, production is able to satisfy this demand by increasing productivity and input use. Consequently, moderate price changes occur in the baseline scenarios with mostly declining real prices. However, deviations from this general rule can be observed for products and regions, e.g., the corn price in Russia or the price increases in South & East Asia for cereals and oilseeds.

Changes in policies or other factors can significantly change cereal and oilseed markets in ways and magnitudes not previously anticipated. Therefore, it is important to conduct analyses with a detailed product and regional representation, but in a global context. The case studies meet these requirements with the application of the developed model systems.

The conducted scenarios addressed four factors impacting cereal and oilseed markets, namely closing of yield gaps (1), trade policies (2), land use change (3), and biofuel demand (4). All of these factors can be regulated or supported by policies. The scenarios cover a range of possible developments of these factors and show their long-term effects on cereal and oilseed markets. The results need to be interpreted in the context of the underlying assumptions and methods applied. Nevertheless, several general conclusions are drawn from the case studies as presented in the following.

Closing of yield gap

A large part of production increases in cereals and oilseeds was, is, and will be realized by technical progress and intensification. The potential to close yield gaps from a bio-physical but also from an economic point of view is considerable in many regions. However, multiple restrictions and circumstances contribute to the fact that the achieved yields, and even the economically optimal yields, are below the 'maximal economic feasible yield' (compare Section 4.2.3).

Ukraine and Russia are two regions which have shown strong yield increases in the last decades but still have the potential to increase yields even further if the political and economic environment improves, as highlighted in Case Study 2. The strong increase in intensification levels in Russia during the most recent years (compare Section 4.1.7) shows that this is not only a theoretical concept.

The closing of yield gaps will not only result in overall increased production but in a shift of production patterns as shown in Case Study 2. The most prominent example in the case study is the disproportionally high expansion of barley production in Ukraine. Barley yields increase more than wheat yields in Ukraine which leads to higher competitiveness of barley and increased production levels despite a stronger reduction in domestic barley prices.

Despite higher yields, area expansion is limited and even declines in some cases. This is mainly caused by the fact that the higher yields are partly due to increased input use. Consequently, some areas with low yield potential are less profitable for cultivation given the global decline in prices even if this decline is small. In case of increased prices at the global level, area expansion might additionally occur as demonstrated by Case Study 4 for the region of the Former Soviet Union.

The projected small decline in global prices might come as a surprise given that more is being produced. However, the additional production from Ukraine and Russia is still relatively small compared to global production levels. Furthermore, additional production at lower prices leads to increased global demand. This demand is primarily for feed use, because food use is more inelastic, the demand for biofuel production is regulate nearly exclusively by policies, and other uses are minimal.

The probability of closing yield gaps in Ukraine and Russia is not part of the dissertation. The high variability in weather conditions and the attributed risk of harvest failures might hinder a closing of the yield gap. Hence, the economically optimal yields might be below the ‘maximal economic feasible yields’. Additionally, given the most recent developments, i.e., the Russian invasion of Ukraine, a closing of yield gaps in the time frame until 2030 became less likely. The main reasons are the uncertain situation, economic disruptions, and the more difficult access to inputs in both regions.

Trade and trade policies

The analysis of different long-term trade strategies (Case Study 3) has shown only small impacts on cereal and oilseed markets for Ukraine and Russia in general. However, even small changes in the markets lead to changes in production patterns as observed for the less intuitive decline in Russian wheat production if markets are liberalized.

Trade policies have not changed in the other case studies. However, the changes in trade patterns are worthy of further attention. Trade in general increased over time and with changes in markets. Hence, the different countries or regions focused on the production of products with a comparative advantage and the increased trade reduced negative impacts with regard to lower availability or surging prices.

In the case of Ukraine and Russia, short-term trade policies are much more disruptive than long-term trade strategies. These policies are frequently implemented if global markets are tight. This contributes to a further tightening of the markets on global levels and results in increased prices. The current war by Russia against Ukraine very strongly disrupted global trade arrangements and its effects are stronger than any scenarios envisaged here. On the one hand, Russia, being the largest exporter of wheat, could use its market position as a geopolitical weapon (von Cramon-Taubadel, 2022). On the other hand, agricultural and food products, especially staple foods, might be exempted from trade restrictions to ensure food security in import dependent countries. Any long-term trade relationships are highly speculative at the moment.

Land use

Theoretically, the bio-physical potential for agricultural area expansion is high, especially in Russia. However, the projections show that area expands only slightly, with the exception of Africa. Compared to other options to satisfy growing demand, area expansion is often economically less attractive. Historically, the area for cereals and oilseeds expanded in Ukraine, Russia, and globally. A further, more moderate, expansion is projected in most case studies to satisfy the increased demand over time, resulting in shifts in agricultural area use, but also slight agricultural area expansion.

Closing of yield gaps (Case Study 2) and the protection of land with high CO_2 sequestration potential (Case Study 4) cause reduced and shifted area expansion compared to their baselines. Intensification and technology adaptation in the cereals and oilseeds sector results in less area used, as some areas are not attractive for recultivation and are not required to satisfy the demand. Hence, cereal and oilseed prices decline due to more efficient input use. This effect can be observed more strongly at local scales, i.e., in Ukraine and Russia, than at the global scale.

Area protection results in a shift of cultivated area towards less suitable area and an increase in intensification levels. Both reactions contribute to an increase in cereal and oilseed prices because the input mix becomes less efficient and more expensive. Depending on the region, one of the effects dominate. In general, regions in the tropical zones are most restricted in their land expansion, while regions in temperate zones even increase their area to compensate for the losses in other part of the world.

Biofuel demand

Increased demand for crop-based biofuels results in moderate price increases for cereals and oilseeds. Prices rise mostly in regions with increased demand but spillover effects to all other regions are observed. However, biofuel use is still small compared to food and feed use and, consequently, the effects are small. The ambitious targets in Indonesia and China change this relationship locally. Hence, price increases are higher, and ensuring that food security is not threatened by increased biofuel demand might become one challenge in these regions. For cereal and oilseed producers, the slightly higher prices make production more attractive and results in slightly increased area used and increased yields at global scale.

Overall conclusion

The four case studies projected dynamic developments for cereal and oilseed markets until 2030 under specific assumptions and variations in the identified four most relevant factors. This timespan was chosen to analyze the impact of long-term factors and their possible changes. The case studies incorporate assumptions judged as realistic at the time of their set-up. Nonetheless, they are highly speculative. Consequently, a wide range of possibilities was analyzed to show the variations in developments that might occur.

The simulated changes in cereal and oilseed markets demonstrate the resilience and adaptability of cereal and oilseed markets. The baseline projections confirm that production can keep pace with increased demand until 2030. Prices rise only in South & East Asia which shows that markets become tighter and the region will depend even more on imports in the future. Additionally, the various scenarios demonstrate the possibilities of increasing production without reaching bio-physical boundaries. Again, regional exceptions exist. Hence, regional conditions play an important role in the development of cereal and oilseed markets. The favorable conditions in Ukraine and Russia with possibilities to expand agricultural land and increase yields have positive domestic but also global effects, i.e., larger amounts are available to the world market at lower prices. In contrast, regions which cannot expand agricultural land or increase yields but have a strong demand growth will face increasing prices, e.g., China and Indonesia if they adhere to their biofuel policies. Trade can only partially compensate this and leads to production growth in other regions with more favorable conditions.

Limitations

Results need to be interpreted with caution and within their produced context. The analysis focuses on long-term effects which implicitly assumes a smooth transition towards the new market situation. However, short-term effects, such as war, a crop failure, or export bans, might impact markets more strongly, at least in the short-term and can result in severe market disruptions. These are not considered in the current analysis.

The development of the underlying assumptions will differ from their observed future development. Consequently, if strong discrepancies occur, the gap between model outcome and actual developments will be large. However, the simulated effects of changes in the four analyzed factors are still valid but might be overshadowed by strong changes in other factors.

Variations of long-term factors relevant to the development of cereal and oilseed markets have been analyzed in the current case studies by including all long-term factors judged most relevant for the development of cereal and oilseed markets. However, the relevancy of these factors might change over time. Additionally, new factors might gain a stronger relevancy. For example, the European Commission puts higher emphasis on environmental concerns. In the Green Deal, the European Commission has set targets to reduce fertilizer and crop protection until 2030. Depending on the implementation, this might significantly reduce production of cereals and oilseeds in the EU.

Data from up until 2016 was used in the case studies. The relevancy of the updated work used in this study was high. However, the timeliness of data is not as relevant as the statistical coverage of the data depending on the research questions. Consequently, the case studies sought a balance between data coverage, relying on existing databases such as the GTAP database, and most recent data, updating specific and important data such as agricultural production statistics. Similarly, a balance between detail in product and country representation and coverage, i.e., global vs. regional and whole economy vs. agricultural sector vs. individual crop, was found in the different case studies depending on the research question, data availability, and capacities of the model systems. Hence, compromises between timeliness, coverage, and detail must be made for each case study. These compromises leave room for further research.

5 Discussion of the applied methods

In this dissertation, large-scale economic, bio-physical, and land use change models are linked to each other (Chapter 3) and the two resulting model systems are applied in the four case studies (Chapter 4). Following the five steps of model linkage (Section 3.3), a one-way linkage between GLOBIOM, MAGNET, and AGMEMOD and a two-way iterative linkage between MAGNET and LandSHIFT are developed.

From a methodological point of view, a model linkage should be realized by a two-way iterative linkage with converging results. Its successful realization requires a clear definition of the intersection (Step 1), mapping of the common coverage (Step 2), harmonization of common data and starting point (Step 3), synchronization of assumptions and scenarios (Step 4) as well as a manageable implementation of the linkage through (semi-)automated iterative model runs (Step 5). The development and applications are challenging, time consuming, and often not realizable.

Consequently, from a practical point of view, data exchange in the form of a one-way linkage is sometimes preferable. While the five steps of model linkage should be followed, a looser interpretation is possible. The defined intersection (Step 1) is not necessarily the only intersection. The mapping (Step 2) can deviate from a one-to-one mapping and include aggregations. The harmonization of common data (Step 3) can be left out if not feasible, e.g., due to different data sources, aggregation levels, units, or even definitions. However, this restricts the data transfer and results in transferring only approximate effects such as percentage changes instead of absolute values. This increases the inaccuracy of the projections. The synchronization of assumptions and scenarios (Step 4) and the implementation of the link (Step 5) is of the same importance as with a two-way iterative linkage. This one-way linkage improves the projection outcome of the last model in the chain compared to an application with the stand-alone version of that model because factors are depicted in more detail and more relevant factors are considered. Further, new scenario analyses that are not possible with the stand-alone models can be conducted with the resulting model systems.

A model linkage builds upon already existing models which were developed for different aims and purposes than the developed model system. Each single model abstracts from reality and relies on data, assumptions, and theories, all of which can be improved. For example, the data in the models originate from different sources and need to be modified to fit to the underlying theoretical framework. These modifications require data adjustments such as replacing the reported value in the database by a calculation so that the market balance closes. More accurate data would help to improve projections. Similarly, models rely on specific theoretical specifications such as a Leontief production structure, which restricts the possible reactions in the models to a specific shock. Consequently, improving each model before developing the model link, improves the outcome of the model system as well, or in the absence of single model improvements restricts the successful linkage. In this dissertation, the models have been taken as given without improving their structural or methodological representations. However, considerable work on data and equation updates has been made as well as some improvements to specifically depict certain features.

Besides the improvements done within the single model, the model linkage further requires model adjustments so that the link can be implemented. These adjustments are specific to the model link and should interfere as little as possible with the stand-alone model logic. For example, the link between MAGNET and LandSHIFT required that MAGNET does not allow for substitution between the inputs land, i.e., pasture, and concentrated feed for livestock production as the ratio between pasture and concentrated feed in LandSHIFT is fixed.

As a consequence of the above elaboration, neither the accurateness of a stand-alone model nor a model system should be overrated. Each model is imprecise and the link to other models might reduce a specific imprecision but could also increase others as modifications are necessary so that the model link can be established. For example, the oilseed sector in MAGNET consists only of the aggregate for oilseeds, while the oilseed sector is disaggregated in AGMEMOD and depicts soybeans, rapeseed, and sunflower seed as single commodities. Consequently, identical world market price changes from MAGNET to AGMEMOD have been transferred for the three products. As these prices often show similar developments (compare Section 2.2.2), the specific reactions within the markets to changes in supply and demand are neglected in the transfer. Hence, an inaccuracy occurs but is justifiable as the prices correlate strongly.

The applications of the model system in the case studies have shown that deviations from the developed model link are sometimes necessary to avoid increasing imprecision. Staying with the example of the oilseed sector, the sunflower sector in Ukraine behaves differently than the rapeseed sector, which cannot be depicted by MAGNET, but is depicted in AGMEMOD. Consequently, changes in trade were transferred from MAGNET to AGMEMOD for the sunflower sector, but not the rapeseed sector in Ukraine (compare Case Study 3). This flexibility is only possible with a one-way link and requires market expert judgment to justify the deviation from the theoretical approach. Another solution to avoid such up- and downscaling because of different aggregations would have been to disaggregate the oilseed sector in MAGNET into soybeans, rapeseed, sunflower seed, and other oilseeds. However, this would have meant considerable work within the MAGNET model and was beyond the scope of this dissertation.

Different economic models have been developed for ex-ante long-term market analysis. These models compete against each other. Each model originated from a defined research question and within a specific context. Having set up such a model, a reuse for other research questions is beneficial as it builds upon already existing work. This saves time and resources compared to building a model from scratch. However, a new research question might require large extension of the model. Consequently, a linkage to other models covering the required extension is an option to reuse already existing work. Hence, the models can also complement each other, which is underlined by the developments of the model systems in the dissertation.

For example, the analysis of closing of yield gaps (Case Study 2) and changes in trade polices (Case Study 3) would not have been possible with the stand-alone AGMEMOD model. However, the analysis is enabled with the model system, and the advantages of AGMEMOD for depicting the agricultural sector of Russia and Ukraine in detail and using the most recent data could be included.

An additional advantage of a model system compared to a stand-alone model are the inclusion of different research disciplines and, hence, more relevant aspects are considered for the development of the market. In the current applications, especially the bio-physical information transferred from GLOBIOM and LandSHIFT to the economic models made it possible to model yield developments and land use changes more accurately.

However, the practical development of the two model systems revealed several disadvantages when linking models. First, the development of the link required the cooperation of different research teams from different disciplines and locations. Each research team had different expectations regarding a link between the models, so that a fully automatized two-way iterative link was suspended at the early beginning of the projects. The most important factors for this are the time constraints of the involved researchers, the reluctance to alter the own model, the questioning of a value added by the link, and the lack of an appropriate tool to facilitate the linkage.

Second, the knowledge of a model is higher for one's own model than for the others. Consequently, the trust in one's own model might be higher than in the other models. This leads to a reluctance to adopt features from other models, to change the structure of the own model, and a tendency to question the results of the other models more harshly than own model results. This might be the most important aspect for why the implementation of a two-way model link fails, is reduced to a one-way link, or even abandoned altogether.

Third, the results of one model are validated within each research team. Consequently, these are either used by the other models without questioning, e.g., as in the case of potential barley yield developments in Ukraine (Case Study 2), or are not considered, e.g., trade developments for rapeseed in Ukraine (Case Study 3). However, a change in the models to depict certain features more realistically might have been more appropriate but was beyond the scope of the dissertation.

Fourth, each model has its own boundaries in, e.g., data coverage, aggregation levels, method, projection capacity, and scenario set-ups. In the linked model system all of them apply and, hence, the results are hard to interpret for the research team itself. Results might be misinterpreted and put into the wrong context due to a limited knowledge of all models involved. This complicates the transfer of results to the scientific and the non-scientific community.

Keeping the advantages and disadvantages of a model system in mind, several recommendations for further research can be made. First, the logic of the models and the practical implementation of the model needs to be understood by each modelling team involved. This is especially true for the identified intersection(s) between the models. Given that the models come from different research disciplines this is neither an easy nor straight forward undertaking. However, the better the knowledge of each model is the more likely a successful link can be developed which might overcome the reluctance to adapt parts of the own model.

Second, the models in the model link should be in one location, e.g., one server, and be linked through a tool which fully automates the communication between the models. The development of the MOJITO tool is a step into that direction. MOJITO facilitates the data exchange between the models and prevents copy and paste errors. Additionally, results are easily comparable. The tool needs further development so that the model systems can run by pressing one button instead of the multiple manual steps in between. This would save even more time and is a first step to reusing the developed systems for other applications. Additionally, sensitivity analysis could be more easily conducted for the whole system.

Third, the developed links between the models could be further improved, especially for the model system of GLOBIOM, MAGNET, and AGMEMOD. The link should ensure that the results of the models go into similar directions or even converge. Further, the link should be built so that the model system can run flexibly by using only selected models of the model system depending on the research question.

Finally, it is important that multiple models and model systems exist which try to answer similar research questions to underline the uncertainty or inaccuracy of results. A comparison of results from different model or model system shows the range of outcomes given similar assumptions. However, the comparison is often challenging as each model or model system is applied for different scenario analyses or in different contexts. Therefore, several initiatives exist which apply different models or model system to answer the same research question and decipher the reasons for different model behavior (Lampe *et al.*, 2014; M'barek and Delincé, 2015). Such comparisons also help to improve the individual model or model system and should be further encouraged.

6 Discussion of the future of cereal and oilseed markets

This dissertation elaborates on the historical development of cereal and oilseed markets and highlights the relationship of factors impacting these markets (Chapter 2). Globally, the demand for cereals and oilseeds has been growing, driven by increases in population and income. However, population and income growth are slowing down. Production has kept pace with increased demand, predominantly through productivity increases, and to a lesser extent area expansion. The productivity increase results from higher input use and technical progress. These drivers are classified as 'long-term important persistent underlying factors' and will impact cereal and oilseed markets in the future.

The dominating uses of cereals and oilseeds are food and feed use. However, they can also be used for energy production or various other industrial uses. The most important example is the expansion of biofuel use which has been strongly supported by policies. These uses are relatively low compared to food and feed use with regional exceptions. Over time, trade increased with a few countries dominating the export side, while imports are less concentrated. Nevertheless, new countries and shifting importance of countries in cereal and oilseed markets are observable over time. These general historical developments are likely to continue in the future resulting in higher production concentration, increased trade, but also shifts of importance between countries.

Cereal markets are dominated by four main cereals, i.e., corn, wheat, rice, and barley. Rice is not analyzed in detail here despite it being an important staple food. However, rice production differs in terms of production requirements and systems from the other cereals and is strongly concentrated in Asia, which is not a focus of this dissertation. Additionally, the substitution between rice and the other three cereals is less than that between corn, wheat, and barley. These three cereals are highly substitutable in feed rations.

Of them, corn markets have shown the strongest growth. Corn is predominantly used as feedstuff, except in Africa where it also plays a major role as food and the US where its use for bioethanol production dominates. The main trade flows of corn occur from US, Brazil, Argentina, and Ukraine to the European Union, Mexico, and Asia. In contrast to corn, wheat is a staple food all over the world. Consequently, wheat is important for food security reasons resulting in a) higher stocks-to-use ratios than for other crops, b) policies in several countries to ensure self-sufficiency, and c) higher price spikes if production is expected not to meet demand. Despite this, wheat is the most traded cereal with approximate one quarter of production being internationally traded. The main exporters of wheat are Russia, the US, Canada, the European Union, Ukraine, Argentina, and Australia. Barley is the least attractive of the main cereals as its yields and feed quality are lower compared to the other two cereals. Consequently, the market has shown little to no growth. However, China has increased its imports in recent years.

Oilseed markets are dominated by soybeans, rapeseed, and sunflower seed. Their growth has been stronger over time than for cereals with the exception of corn which showed similar growth. However, the size of the oilseed market in terms of production volumes is less than a quarter of the size of the cereal market. The demand for vegetable oil, but also meal in the case of soybeans, are the main drivers for the increase in production. They and their processed products are traded even more than cereals. Of oilseeds, soybeans show the highest export share of production with 45 %, while sunflower oil has the highest export share of production with over 55 % of the processed products. On the production and export side, the markets are dominated by a few countries which vary depending on the oilseed. For soybeans, these countries are the US, Brazil, and Argentina. Canada is the main producer and exporter of rapeseed and its processed products, while Ukraine and Russia dominate the sunflower seed and processed products markets.

The US, the EU, and Argentina are traditionally large producers and exporters of several crops. However, they have not increased, and in some cases have even decreased, their production and exports most recently. In the US, for example, a shift away from wheat towards corn has been observed, driven by stronger domestic demand for corn to produce ethanol. In the EU, intensive production systems dominate and yields are close to their 'maximal economic feasible yield'. Additionally, recent EU policies, such as restrictions on planting genetically modified crops or on applying fertilizers and specific crop protection products, restrict yield growth. This has led to a low yield growth and in some cases even a stagnation in yields in the last years. In Argentina, the instable institutional environment as well as the frequent and volatile levy of export taxes are important factors which hinder production expansion. The mentioned policies are examples of 'strong market-interfering factors' subject to possible change in the future.

Contrary to the large traditional producing countries, Brazil, Ukraine, and Russia have shown large production and export increases becoming major exporters in several markets. In all three countries, higher potentials for yield growth and area expansion exist than in the large traditional producing countries. If the institutional environment in these countries improve, and policies do not restrict production, production could continue growing. For Ukraine and Russia, this is confirmed by Case Study 2 (Section 4.2). The scenario of closing of yield gaps shows that Ukraine and Russia have high potentials to increase production. Additionally, the projections show a shift in production patterns between cereals in the two countries. Wheat production will increase more than other cereals in Russia, while it even declines in Ukraine. The war of Russia against Ukraine has rendered such a scenario impossible as the institutional environment worsened in both countries. In Africa, several regions have large potentials to increase yields from a bio-physical point of view. However, due to the weak political and economic environment, it is less likely that any progress will occur in this direction in the next years.

Domestic developments impact international markets through trade relationships. Consequently, long-term trade strategies, but also ad hoc trade policies, are also 'strong market-interfering factors'. In the case of Ukraine and Russia, ad hoc trade policies in the form of export taxes, quotas, and bans play a more important role than long-term trade strategies. Case Study 3 (Section 4.3) confirms this observation by analyzing changes in trade strategies of these two countries and finding that they will have only minor impacts on cereal and oilseed markets. Most striking, the Russian wheat market does not gain from global trade liberalization as it profits from the existing trade barriers of Ukraine towards the rest of the world. This demonstrates that trade policies of one country impact third countries. Historically, one important example is China because it is a main producer and importer of cereals and oilseeds. The dynamic development in the Chinese markets has strongly steered international markets in the short- and long-term and might continue to do so in the future. The increased soybean demand has been satisfied by strongly increasing imports over time, so that China is now by far the largest importer of soybeans. The fast build-up of pig herds after the outbreak of African swine fever in China resulted in large cereal imports, especially corn, which had not been observed before (OECD and FAO, 2021a). It is yet to be seen if this development is of short- or long-term nature.

Environmental and climate change mitigation policies have gained importance on a global scale and particularly in developed countries. Of these, biofuel policies impact cereal and oilseed markets most strongly as both are feedstocks to their production. Due to the fuel vs. food and the indirect land use change debate, several countries have changed or adjusted their policies to limit the use of specific feedstocks in the future. However, this does not reduce the current demand and multiple other countries have set ambitious targets for the use of biofuels. Case Study 4 (Section 4.4) analyzes the effects of increased biofuel demand and finds that cereal and oilseed production would grow most in North America and South & East Asia. With the increased demand, prices for cereals and oilseeds slightly increase. Consequently, a real price decline for cereals and oilseeds is still observed as in the baseline over time with the exception of South & East Asia. However, they already experience real price increases in the baseline over time. Historically, the biofuel market has been purely driven by policies in most countries as they have not been competitive with fossil fuels. However, with rising energy prices, this could change not only as observed in the US and Brazil but also in other countries. Furthermore, the use of biofuels in aviation might cause additional demand for agricultural feedstocks. Consequently, more ambitious biofuel policies need to adequately address the competition for other demands, in particular food, and the limitations of resources, in particular land.

Another climate change mitigation policy is the conservation of land with high CO_2 sequestration capacities. From an agricultural perspective, this results in the restriction of expanding agricultural area and has also been analyzed in Case Study 4 (Section 4.4). The protection of area as simulated would result in lower cereal and oilseed production and strongly rising prices, mostly in Africa and South & East Asia. In these regions, countries would expand area strongly without the restriction in the future. In the joined analysis of area protection and increased biofuel demand, the results showed that in most cases the impacts added up. However, over-proportionally large changes due to the joined application of both policies occurred especially in regions where land is scarce and biofuel demand increases most, i.e., China and Indonesia show high price increases. Consequently, these regions might not support global climate change mitigation policies if they lack a solution to ensure food security.

Environmental policies, such as, restricting the use of fertilizers and crop protection products as well as fostering organic farming, would reduce the production of cereal and oilseeds if enforced or extended. Additional ‘potential market-interfering factors’, such as, constraints in input markets, climate change, and changing diets towards less meat, might also reduce production. However, their impact on cereal and oilseed markets until 2030 is evaluated to be less pronounced than the factors discussed above.

Other ‘potential market-interfering factors’, such as increased industrial uses, might increase demand for cereals and oilseeds. This would be especially the case if a transformation of the currently largely fossil based economy towards a circular bioeconomy is pursued. However, conflicting policy aims, resource constraints, and yet to be developed efficient technology might hinder a fast expansion so that few impacts will be observed until 2030.

Besides impacts on the size of cereal and oilseed markets, ‘potential market-interfering factors’ can also change the structure of the markets. These are changes in preferences towards certain product attributes accompanied with certification schemes which lead to market segmentations. These product attributes are, e.g., regional, GMO-free, organic, deforestation-free, fair trade, and sustainable. Currently, these certified products have small shares in the global market but do play significant roles in specific countries, e.g., GMO-free feeding of poultry and dairy cows in Germany. In general, preference changes are, however, slow as they happen more over generations than over years.

It is important to stress here again, that the focus of the dissertation is placed on long-term factors, and short-term factors such as extreme weather events and sudden disruptions of markets are neglected. However, short-term factors play a large role in the developments of cereal and oilseed markets on a year by year basis.

The most important short-term factor is weather as it is a persistent underlying factor impacting supply. Good weather conditions result in above average harvests and declining prices, while bad weather conditions result in below average harvest and increasing prices. The increase in prices also depends largely on the level of stocks in the specific year. With high stocks, prices are not increasing as much as with low stocks. The global markets have learned to cope with this change in supply with trade being the most important option to absorb local supply shocks.

The most recent short-term shock to cereal and oilseed markets is the aggression of Russia against Ukraine. With the Russian invasion of Ukraine, starting February 24, 2022, a war broke out which impacts global cereal and oilseed markets. These global impacts are due to the fact that both Ukraine and Russia are large exporters of cereal and oilseed products. Consequently, cereal and oilseed markets in the region and globally have to adjust to a new reality. A discussion of the multiple impacts is beyond the scope of this dissertation. Further, the impacts depend largely on the duration of the war and the related policies. However, markets will adjust in the long-term with prices being the main driver towards balanced markets.

Nevertheless, the war has several implications for the interpretation of the results of this dissertation. All analyzed factors are impacted. First, the prerequisite for closing gaps, i.e., a stable economic and institutional environment in Ukraine and Russia, is not given anymore. Consequently, the results in Case Study 2 might not be achieved until 2030 but delayed for several years or even longer.

Second, trade is not only hindered by changing trade policies but severely disrupted by destroyed infrastructure, closed ports, and mines in the Black Sea. Additionally, sanctions against Russia increase trade costs. Russia is the main exporter of wheat. Export destinations are often poor countries which largely depend on wheat to ensure domestic food consumption. These countries might not be able to afford the currently record high wheat prices and a food crisis could occur with spillover effects as seen in 2007/08.

Third, land use is restricted, mainly in Ukraine, by the ongoing war and remnants of war left on the fields. Depending on the spread and duration of the war, this results in destroyed harvests, lower sown area, and increased abandoned area in the short-term. In the long-term, abandoned area might increase depending on the possibilities to remove the explosive remnants of war in Ukraine but also the ability of exporting production which is currently strongly reduced. However, global area might expand to compensate for the lost production in Ukraine.

Fourth, biofuel policies might change more radically than anticipated. These can go in two directions. On the one hand, biofuel mandates could be suspended or production of biofuels from crop-based feedstock could be limited. This would result in higher supply of cereals and oilseeds for other purposes and act as buffer against high prices. On the other hand, biofuel production might be expanded as it becomes more competitive given high energy prices. This is observable for corn-based ethanol in the US which additionally has gotten political support from the US government by allowing gasoline with higher ethanol blends to be sold also in summer, i.e., E15 instead of only E10 (EPA, 2022).

Another short-term shock which recently occurred was the outbreak of the COVID-19 pandemic and the disruptions of supply chains. This unexpected event has shown how important the functioning of global supply chains is and how a disruption can have negative short-term effects. Nevertheless, the resilience of the cereal and oilseed supply chains has also been demonstrated as impacts due to COVID-19 hit the market later than other markets and were less severe.

Short-term effects can result in lasting long-term effect. These lasting long-term effects are less pronounced than the immediate sudden shock because the markets will adjust in the long-term to the new situation and might even move back to historically observed trends. High prices will reduce demand and give incentives to increase production. For example, other suppliers of cereals and oilseeds will fill the void the Ukraine is leaving. In the short-term, this might only be possible by reducing stocks but in the medium-term production expansion will occur. Consequently, prices will fall again. In the long-term even the supply from Ukraine to levels above observed levels might be possible.

7 Summary and conclusion

Agricultural crop production is dominated by cereals and oilseeds. The global markets of cereals and oilseeds are dominated by a few products which are studied in more depth in the dissertation. Specifically, this dissertation addresses three research questions (Chapter 1):

1) What are factors that have impacted and might still impact cereal and oilseed markets?
2) How did cereal and oilseed markets develop in the past and which factors caused the development?
3) How will cereal and oilseed markets be impacted by the different long-term factors in the future?

Research Question 1

The first research question is answered by identifying and categorizing the factors which had, have, and will have an impact on cereal and oilseed markets (Chapter 2). The factors are identified by conducting literature reviews and market monitoring. They are categorized in ‘important persistent underlying factors’, ‘strong market-interfering factors’, ‘potential market-interfering factors’, and ‘other underlying factors’ (compare Table 1, page 9).

The markets have been constantly growing with population and income increases being the main driver of growth on the demand side. On the supply side, productivity growth and increased input use have been the main drivers of growth. In general, these drivers will persist in playing a significant role in the future development of cereal and oilseed markets. However, population growth is slowing down and income levels in high income countries have reached levels where the demand for certain foods, i.e., staple foods, is saturated or even declining. Productivity growth seems to be a factor constantly increasing with new technologies and higher adaptation levels around the world. Although, the use of inputs in many regions is below potential and optimal levels.

Various policies are identified as ‘strong market-interfering factors’. These range from domestic agricultural policies over trade policies to climate change mitigation policies including biofuel policies. The policies vary strongly between regions and in their impact on cereal and oilseed markets.

Besides these important long-term factors, short-term factors, such as weather, stock holding, and multiple unexpected events, e.g., an economic crisis or war, play significant roles in cereal and oilseed markets and cause annual regional or global variabilities. These short-term factors have typically a severe impact at the time of occurrence but no or only small impacts on the long-term development after the market has adjusted to the shock. Other factors have been judged to have a potential market-interfering effect if they change considerably from their long-term trend, e.g., food loss and waste, livestock sector, or dietary preferences. However, large global changes which would indicate a change in long-term developments have not yet been observed.

Research Question 2

To answer the second research question, the historical development of global corn, wheat, barley, soybeans, rapeseed, and sunflower seed markets from 2004/05 to 2018/19 are presented in detail (Section 2.2). Corn and oilseed markets have been growing strongly with yield and area expansion, while wheat markets increased mostly by yield growth and barley markets stagnated. Hence, the main drivers on the supply side were intensification, factor productivity growth, and only in specific cases land expansion.

In general, population and income growth have been the main drivers for increased demand. Specifically, the shift in China towards more meat-based diets has resulted in increased global production of corn and soybeans. Additionally, the supporting policies for biofuels have increased demand for cereals, especially corn in the US, and oilseeds, especially rape seed in the EU as well as soybean oil in the US, Brazil, and Argentina.

Further, several countries became important players in the different markets by showing high increases in production and exports. These are a) Brazil for corn and soybeans, b) Ukraine for corn, wheat, rapeseed, sunflower oil, and sunflower meal, and c) Russia for wheat and sunflower oil. Despite unfavorable trade policies for cereals and oilseeds in Ukraine and Russia, their production expanded remarkably but has not yet reached levels observed during Soviet times. This expansion was mainly caused by the emergence of large private agroholdings which raised productivity and intensified production. Additionally, the cereal and oilseed area expanded strongly in Ukraine.

In contrast, the production growth of traditional exporters, such as the US, the EU, and Argentina, grew less or even declined, e.g., wheat in the US. The US and the EU are large crop producers with intensive production systems and limited possibilities to expand area. Hence, their possibilities to increase production depends mostly on technical progress.

The import markets of cereals are traditionally less concentrated than the export markets. However, China has become a major importer for soybeans and barley to satisfy its feed demand, while ensuring self-sufficiency in wheat for food security reasons.

Research Question 3

The third research question is addressed by selecting four factors in the categories 'important persistent underlying factors' and 'strong market-interfering factors' to be analyzed in more depth by case studies (Chapter 4). These four factors are: the closing of yield gaps (1) at the example of Ukraine and Russia, changes in global trade policies (2) with a focus on Ukraine and Russia, land use changes (3) in the form of possible recultivation of abandoned land in Ukraine and Russia and global conservation of areas which have the potential to sequester large amounts of CO_2 and policy induced global biofuel demand from crop-based feedstocks (4).

To answer the third research question, an adequate method had to be selected for analyzing long-term ex-ante impacts of variations in the four chosen factors on cereal and oilseed markets. Large scale agricultural economic models are well suited for market analysis. However, several important aspects regarding bio-physical factors which impact yields and area use can be explicitly depicted by models which represent these in more detail. Hence, existing models from different research disciplines have been linked to each other to form model systems.

Two model systems have been developed (Chapter 3). First, a one-way link between the models GLOBIOM, MAGNET, and AGMEMOD has been established to analyze: closing of yield gaps (1), trade policies (2), and land use change (3) in Ukraine and Russia. The model link improved the outcome of AGMEMOD, i.e., the last model in the chain. Second, a two-way iterative link between LandSHIFT and MAGNET has been successfully implemented to address changes in land use (3) and biofuel demand (4). The model system of GLOBIOM, MAGNET, and AGMEMOD is applied in the Case Studies 1 to 3, while Case Study 4 uses the model system of LandSHIFT and MAGNET.

Case study 1 projects the development of cereal and oilseed markets in Ukraine and Russia until 2030 (Section 4.1). Hence, a baseline is developed which acts as starting point for the analysis in Case Study 2 and 3 (Section 4.2 and 4.3, respectively). Both countries have expanded their cereal production strongly in recent years with a focus on corn expansion in Ukraine and wheat expansion in Russia. While Ukrainian cereal expansion is projected to continue growing, Russian cereal expansion is projected to slow down. The increased production is mainly exported. In the oilseed sector, sunflower seed dominates in both countries. Strong growth rates have been observed here as well and are projected to continue in Russia, while slowing down in Ukraine.

The bio-physical potentials to increase yields by intensification and technology adaptation in Ukraine and Russia are large. The ‘maximal economic feasible yield’, i.e., approximately 80 % of maximal bio-physical potential yield, could be reached if the institutional environment improves in the countries. This would lead to higher investments in the agricultural sector. Case Study 2 simulates this yield increase for cereals and oilseeds. Together, Ukraine and Russia could increase their cereal and oilseed production by nearly 100 % in 2030 compared to 2015 or 50 % compared to the baseline in 2030. This expansion occurs without expanding cropland area. The Russian invasion of Ukraine since February 24, 2022, has destroyed the hope for an improved institutional environment in Ukraine and Russia. Consequently, the simulated increases in yields, if ever realized, will be delayed for several or even more years.

Case Study 3 simulates changes in general trade policy strategies by reducing tariffs and NTMs of Ukraine and Russia in the two scenarios liberalizing trade, and increasing tariffs in Russia in the scenario with increased border protection for all products. The changes of these trade policies have only small effects on the cereal and oilseed sector in the two countries. However, cereal and oilseed exports are often regulated by short-term ad hoc policies in both countries restricting exports if production levels are low or prices are high. These could not be incorporated in the analysis but will influence the markets to a larger extent than the simulated changes. Additionally, trade relationships have changed massively after the Russian invasion of Ukraine. A world after this war will most probably not fall back to the trade relations observed before, especially with regard to Russia. However, trade in agricultural products is often exempted from sanctions as it is essential for global food security. Consequently, trade in cereals and oilseeds might be less affected in the long-term than other products, i.e., when trade via the Black Sea is again unrestricted.

The last case study (Section 4.2) takes a global perspective and analyzes an increase in biofuel demand from crop-based feedstock as well as the protection of area with a high potential to sequester CO_2. These two climate change mitigation policies affect China and Indonesia the most as they are restricted in their agricultural area expansion in addition to their aim to increase biofuel use. There, real prices increase over time for cereals and oilseeds, while in most other parts of the world real prices still decline in the scenarios.

Considering the results of the four case studies, the following conclusions can be drawn. First, closing of yield gaps can lead to substantial increases in production. Ukraine and Russia have been increasing yields in recent years and are projected to increase them further. However, their potential for yield increases is much larger than is realized in the baseline. Also, it might not be economically optimal to aim for highest yields which require high input use. For example, high volatility in weather which frequently leads to crop failures can result in an economically optimal extensive production strategy. Satisfying global demand for cereals and oilseeds even with increased crop-based biofuel production, does not require a higher increase in yields as historically observed. This is shown in Case Study 4 which simulates growth rates similar or even lower to historical growth rates.

Second, trade policies, especially a change in general trade policy strategies as simulated in Case Study 3, have small effects on cereal and oilseed markets in Ukraine and Russia despite both sectors being export oriented. Specific trade changes in the markets such as the frequently applied, export restricting, ad hoc policies have larger effects. A closer and more detailed look into these and their effect on domestic as well as global cereal and oilseed markets was beyond the scope of this dissertation. At the moment, trade from Ukraine and Russia has been disrupted due to the Russian invasion of Ukraine in a way not foreseen. The hope is that this disruption is only short-term as market participants already start searching for solutions. However, the future developments are very uncertain.

Third, land use and specifically changes in cereal and oilseed area is addressed in all case studies. In Russia, large amounts of formerly cultivated land are abandoned. However, its recultivation is economically not profitable in the simulated scenarios. Consequently, only small agricultural area expansion occurs if any. In Ukraine, most of the formerly abandoned land is already under production with only slight additional possibilities of extension. In Case Study 4, highest absolute and relative area expansion occurs in Africa, while other regions increase their production predominantly by yield increases. Nevertheless, the restriction of agricultural area expansion puts pressure on cereal and oilseed markets which results in local price increases as the demand cannot be satisfied. In the intensification and adaptation scenario (Case Study 2), area expansion is also reduced compared to the baseline. In that case, the increased yields make it unattractive to cultivate areas with low yield potentials as prices decline due to more efficient input use.

Fourth, additional demand from biofuels can be met without large increases in cereal and oilseed prices. Case Study 4 cannot confirm the fear that food availability and affordability is threatened due to biofuel production, as biofuel use still has a small share in overall use of cereal and oilseeds. However, too ambitious targets might result in locally high prices especially if area expansion is restricted as shown for Indonesia and China.

Limitations

Overall, the dissertation gives an overview of cereal and oilseed markets (Research Question 2), highlights the main factors impacting the markets (Research Question 1), and contributes to a better understanding of the development of cereal and oilseed markets under certain assumptions (Research Question 3). However, several limitations exist as discussed in the different chapters.

The main limitations originate from the methodological approach. Even though multiple large-scale models have been used, their abstraction from reality remains large. The links between the models partly compensate for the less detailed representation of important factors impacting cereal and oilseed markets in the individual models, but additionally add own inaccuracy to the projections. Nevertheless, these models are the best tools available to ex-ante quantify the effects of the simulated policy changes. The linked model systems could be improved in several ways and their projection capacity validated by additional sensitivity analysis. However, this was beyond the scope of this dissertation due to the absence of appropriate tools, time, and resources.

The long-term factors impacting cereal and oilseed markets are often overlaid by short-term factors. The cumulation of the most recent short-term events, i.e., the disruption of the supply chains due to the COVID-19 pandemic, unfavorable weather conditions in several large production regions, and the raging war of Russia against Ukraine, have disrupted cereal and oilseed markets strongly with prices at record levels. These short-term effects cannot be adequately addressed with economic equilibrium models nor the developed model systems. Their applications to such problems would be a misuse of the model and bound to produce false results. Here, more emphasis needs to be put on market expert judgment, preferably stakeholders directly involved in the markets and of all levels in the supply chain to analyze the short-term effects. Additionally, only ex-post analysis of these short-term effects might be possible. Consequently, it is important to distinguish between these short-term and long-term factors. Hence, the impact of the analyzed long-term factors on cereal and oilseed markets are still valid.

Further research

The dissertation selected four important long-term factors to be analyzed. One important long-term factor, i.e., domestic agricultural policies, has not been specifically addressed. This gives room for further research. However, model and model system adjustments might be necessary depending on the specific policy to be studied. For example, the EU has announced in its Green Deal to become climate neutral and more environmentally friendly (European Commission, 2019b). For the agricultural sector, various targets have been set in the Farm to Fork Strategy such as a reduction in fertilizer use, an increase in area cultivated organically, and a reduction of crop protection products (European Commission, 2020a). The analysis of these targets or policies which aim to contribute to these targets require other models or large extension of the current models.

Other long-term factors which might potentially impact cereal and oilseed markets such as changes in diets towards less meat consumption, reduced livestock production, fertilizer shortages, and environmental policies have not been focused on in the analysis. Nevertheless, it is worth analyzing these with economic models or model systems as a more forward looking or pioneering exercise. However, this would require modifications to the developed model systems and was beyond the scope of this dissertation.

Another field which has not been addressed here specifically is sustainable development which has become a top priority at the global scale by the establishment of the SDGs of the United Nations with their specific targets (UN, 2021b). Cereal and oilseed markets can contribute or might be impacted by the SDG targets ‘2 Zero Hunger’, ’12 Responsible Consumption and Production’, ’13 Climate Action’, and ’15 Life on Land’.

In order to analyze this, environmental and social aspects of cereal and oilseed markets need to be addressed in addition to economic aspects. Furthermore, conflicting aims between the three aspects of sustainability need to be included. Therefore, models or model systems can be developed or extended to include the three aspects of sustainability and put weights upon their importance to achieve a best solution. Again, this is beyond the scope of this dissertation. However, the knowledge gained by establishing the model systems and the MOJITO tool are a first step in the direction of building more complex model systems and addressing new research questions in the field of cereal and oilseed markets or even beyond.

Policy recommendations

From an economic perspective, several policy recommendations can be derived from this dissertation to improve the functioning of cereal and oilseed markets. In general, cereal and oilseed markets are globally well-integrated markets. However, interference by policies often distort cereal and oilseed markets directly and indirectly. These interferences in the market or in other markets with spillover effects to cereal and oilseed markets might be accompanied by negative side effects, high costs, or a reduction of the effectiveness of other policies which have a different policy aim.

Consequently, politics should not interfere in a well-functioning market. However, multiple policies are in place that impact cereal and oilseed markets as presented in this dissertation. The most important policies are domestic agricultural policies, agricultural trade policies, climate change mitigation policies, and environmental policies. Of these, some have been analyzed in more detail in the case studies. Hence, specific policy recommendations concerning the studied factors in Chapter 4 are made in the following.

First, an increase in yields is important to satisfy the growing future cereal and oilseed demand and keep prices for cereals and oilseeds low. Hence, support for research to increase yields is necessary so that technical progress continues to grow. Additionally, research aiming to reduce the volatility in yields should be supported. Sustainable intensification should be ensured so that enough fertilizer and crop protection products are applied but not as much that the environment is harmed. Here, other research disciplines can contribute to find the accurate amount.

In a situation with high yield gaps, policies can contribute to a closing of yield gaps by supporting and fostering knowledge transfer, the availability and affordability of inputs, the access to markets and a secure environment for investments. If a market is functioning, direct interference in a market, e.g., via input subsidies, should be avoided because they might lead to an overuse of inputs.

High intensification levels can harm the environment. If this is the case and it is not monetized in the market, targeted local restrictions on the application of inputs could improve the situation. However, they need to be correctly quantified and closely monitored and if necessary adjusted so that effects do not unnecessarily restrict production. General reductions or restrictions of fertilizer and crop protection are not effective in this case. Supporting organic farming or banning GMO crop production reduces yields and, hence, the costs and benefits in terms of economic, social, and environmental aspects as well as global spillover effects should be closely considered and weighed before these policies are implemented. Additionally, regular assessments are necessary to adjust implemented policies.

Second, increased yields can also reduce the amount of land needed for production. As land is limited and used for multiple purposes, yield growth contributes to reducing the pressure on land. The forced conservation of specific areas will lead to increased prices in hot spot regions and threatened food security in parts of Africa and South & East Asia as shown in Case Study 4. Hence, their implementation needs to be combined with policies that ensure food security in these regions.

Third, biofuel policies are one example where adjustments to current policies are necessary. The often proclaimed aims for biofuel policies are a) reducing GHG emissions, b) supporting domestic production, and c) decreasing energy dependencies. These aims are only partly achieved because a) environmental benefits can be reduced due to land use change, b) feedstocks, such as cereals and oilseeds, and biofuels need not be produced domestically as both markets are globally integrated, and c) the possible amount of biofuel replacing fossil fuels is small compared to overall fossil fuel consumption.

Additionally, negative effects are the competition for resources, such as land, reduced food security due to rising prices, and a more intensive link to the energy market. The latter would be problematic, if higher feedstock prices can be paid to produce biofuels than if these feedstocks are used as food or feed. This can happen due to the implemented policy, high energy prices, improved competitiveness of biofuels with fossil fuels, or a combination of these factors.

Consequently, policy support to the biofuel sector should be accompanied with additional policy measures that reduce the competition with food and feed production. Furthermore, if biofuels are competitive with fossil fuels, policies would need to ensure that the food and feed use of feedstocks have a priority over the use as biofuel feedstock. For example, in times of a shortage of supply, biofuel feedstocks might be used as food and feed. Hence, the biofuel industry could act as a buffer to ensure food security. Another positive effect is that the additional demand for cereals and oilseeds for biofuel production contributes to increase productivity which in turn ensures larger supply.

Fourth, trade policies are often implemented to protect a specific group in a market, e.g., domestic producers or consumers. However, liberalizing trade benefits the overall economy the most. Consequently, trade policies should be avoided if a market is functioning well. Especially ad hoc export taxes, quotas, or bans in times of high world market prices should not be implemented as it increases global prices even more. Additionally, these policies or even the threat of implementing these policies contribute to a higher risk and insecurity of a market which in turn results in higher prices.

In a market with negative external effects, trade policies could be an addition to policies combating the negative external effect so that leakage effects are avoided. However, these general message needs to be analyzed case by case and is beyond the scope of this dissertation.

In conclusion, a policy or multiple policies need to be carefully designed to guarantee a political aim is met with few negative effects. Therefore, policy makers should listen to all stakeholders including various disciplines of science. This ensures that most aspects and interlinkages of a policy or multiple policies are known and preferably quantified, so that policy makers can make the most informed decisions. This also includes the weighing up of the envisioned policies with other policy aims, the associated costs, and the negative external effects arising from the policy implementation.

Policies directly distorting cereal and oilseed markets should be removed. Additionally, climate change mitigation and environmental policies should be designed so that other policy aims, such as ensuring food security, are not negatively impacted. Furthermore, technical progress and productivity growth should be supported to ensure the growing demand for cereals and oilseeds is met without large increases in prices.

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Appendix A

This section contains additional information with regard to the applied model system of AGMEMOD, MAGNET, and GLOBIOM. These are mappings of regions, sectors, variables, and parameters as well as additional results of Case Study 3.

Table A1 Regional structure and mapping of AGMEMOD, MAGNET, and GLOBIOM for Case Studies 1 to 3

Descriptive name	Common mnemonics		AGMEMOD		MAGNET		GLOBIOM	
	Abb.	Agg.	Abb.	Agg.	Abb.	Agg.	Abb.	Agg.
Belgium	bel	EMW	BE	EMW				
Netherlands	nld	EMW	NL	EMW				
Germany	deu	EMW	DE	EMW				
France	fra	EMW	FR	EMW				
United Kingdom	gbr	ENO	UK	ENO				
Italy	ita	ESO	IT	ESO				
Cyprus	cyp	ESO						
Malta	mlt	ESO						
Greece	grc	ESO	GR	ESO				
Czech Republic	cze	ECE	CZ	ECE				
Hungary	hun	ECE	HU	ECE				
Slovakia	svk	ECE	SK	ECE				
Slovenia	svn	ECE	SI	ECE				
Poland	pol	ECE	PL	ECE				
Austria	aut	EMW	AT	EMW				
Ireland	irl	ENO	IE	ENO				
Bulgaria	bgr	ECE	BG	ECE				
Romania	rou	ECE	RO	ECE				
Denmark	dnk	ENO	DK	ENO				
Estonia	est	EBA	EE	EBA				
Finland	fin	ENO	FI	ENO				
Latvia	lva	EBA	LV	EBA				
Lithuania	ltu	EBA	LT	EBA				
Sweden	swe	ENO	SE	ENO				
Portugal	prt	ESO	PT	ESO				
Spain	esp	ESO	ES	ESO				
Croatia	hrv	ECE	HR	ECE				
Russian Federation	rus	rus	RU		rus		RussiaReg	
Kazakhstan	kaz	kaz	KZ		kaz		KazakReg	
Belarus	blr	blr			blr		BelarusReg	
Ukraine	ukr	ukr	UA		ukr		UkraineReg	
Moldova Republic of	xee	CIS			mda	FSU		
Armenia	arm	CIS			arm	FSU		

Descriptive name	Common mnemonics		AGMEMOD		MAGNET		GLOBIOM	
	Abb.	Agg.	Abb.	Agg.	Abb.	Agg.	Abb.	Agg.
Azerbaijan	aze	CIS			aze	FSU		
Georgia	geo	CIS			geo	FSU		
Australia	aus	OCE						
China	chn	CHN			CHN		ChinaReg	
India	ind	ind			ind		IndiaReg	
Japan	jpn	jpn			jpn		JapanReg	
Korea	kor	kor			kor		SouthKoreaReg	
Turkey	tur	TUR	TR		tur		TurkeyReg	
United States	usa	USC					USAReg	NAM
Canada	can	USC					CanadaReg	NAM
Mexico	mex	XAM					MexicoReg	OSA
Brazil	bra	bra			bra		BrazilReg	
EU_MidWest	EMW	TEU	EMW	TEU	EMW	TEU	EU_MidWestReg	TEU
EU_North	ENO	TEU	ENO	TEU	ENO	TEU	EU_NorthReg	TEU
EU_South	ESO	TEU	ESO	TEU	ESO	TEU	EU_SouthReg	TEU
EU_CentralEast	ECE	TEU	ECE	TEU	ECE	TEU	EU_CentralEastReg	TEU
EU_Baltic	EBA	TEU	EBA	TEU	EBA	TEU	EU_BalticReg	TEU
Rest of Europe and World	XER				XER		XER	
Rest of former USSR countries MAGNET	cisMagnet				CIS	FSU		
Rest of former USSR countries	CIS				FSU		Former_USSRReg	
Total EU 28	TEU		TEU		TEU		TEU	
Rest of America	XAM				XAM		OSA	
Rest of Asia	XAS				XAS		XAS	
Rest of Africa	AFR				AFR		SSA	
Oceania	OCE				OCE		OCE	
Middle East and North Africa	MEN				MEN		MidEastNorthAfrReg	
USA and Canada	USC				USC		NAM	
CongoBasin	CongoBasinReg	AFR					CongoBasinReg	SSA
SouthAfrReg	SouthAfrReg	AFR					SouthAfrReg	SSA
EasternAf	EasternAfreg	AFR					EasternAfreg	SSA

Descriptive name	Common mnemonics		AGMEMOD		MAGNET		GLOBIOM	
	Abb.	Agg.	Abb.	Agg.	Abb.	Agg.	Abb.	Agg.
SouthernAf	SouthernAfreg	AFR					SouthernAfreg	SSA
WesternAf	WesternAfreg	AFR					WesternAfreg	SSA
RSAM	RSAMreg	XAM					RSAMreg	OSA
RCAM	RCAMreg	XAM					RCAMreg	OSA
RCEU	RCEUReg	XER					RCEUReg	XER
ROWE	ROWEReg	XER					ROWEReg	XER
RSAS	RSASReg	XAS					RSASReg	XAS
RSEA_PAC	RSEA_PACReg	XAS					RSEA_PACReg	XAS
RSEA_OPA	RSEA_OPAReg	XAS					RSEA_OPAReg	XAS
Australia and Newzealand	ANZ	OCE					ANZ	OCE
Pacific_ Islands	Pacific_ IslandsReg	OCE					Pacific_Islands Reg	OCE

Notes: Abb. = abbreviation, Agg. = aggregation

Source: own representation based upon the agreement between the modelers in the AGRICISTRADE project

Table A2 Sectoral structure and mapping of AGMEMOD, MAGNET, and GLOBIOM for Case Studies 1 to 3

Descriptive name[a)]	Common mnemonics	AGMEMOD		MAGNET		GLOBIOM	
		Abb.	Agg.	Abb.	Agg.	Abb.	Agg.
wheat	WHT	wht	GRAIN	wht	allGRAIN	WHT	GRAIN
barley	BAR	ba	othG			Barl	othGrain
corn	COR	co	othG			Corn	othGrain
rice	RIC	re	GRAIN	pdr	allGRAIN	RIC	GRAIN
soft wheat	ws	ws	wht				
durum wheat	wd	wd	wht				
oats	oa	oa	othG				
rye	ry	ry	othG				
triticale	tr	tr	othG				
other grains AGMEMOD	og	og	othG				
millet	Mill					Mill	othGrain
sorghum	Srgh					Srgh	othGrain
other grains GLOBIOM and AGMEMOD to MAGNET	ogr	othG	GRAIN	grain	allGRAIN	othGrain	GRAIN
Grains	GRAIN	GRAIN		allGRAIN		GRAIN	
rapeseed	RPS	rs	osd3			Rape	OSD

Descriptive name[a)]	Common mnemonics	AGMEMOD		MAGNET		GLOBIOM	
		Abb.	Agg.	Abb.	Agg.	Abb.	Agg.
sunflower seed	SFS	uf	osd3			Sunf	OSD
soybeans	SBS	sb	osd3			Soya	OSD
oilseeds	OSD	osd3		oils		OSD	
rape meal	rl	rl	cake				
sun meal	um	um	cake				
soya meal	sm	sm	cake				
oil cakes	CAKE	cake		oilcake			
rape oil	ro	ro	vof				
sun oil	uo	uo	vof				
soya oil	so	so	vof				
vegetable oil	VOF	vof		vol			
Milk	MLK	WM		milk		ALMILK	
Ruminants	RUM_L	RUM		rum			
other animals than ruminants	NRM_L	HP		pigpoul			
Sugar beet and cane	sug	st		sug			
Cattle Meat	RUM_M	BV_LM		cmt		RUM	
Other Meat	RRM_M	o_meat		omt		NRM	
Dairy Products	dairy			dairy		DRY	
Sugar and Molasse	sugar	SU		sugar			
potato	PT	PT				Pota	
Cattle	CC	CC	RUM				
Beef and veal (meat)	BV	BV	BV_LM			BVMEAT	RUM
Pork (Pig meat)	PK	PK	o_meat			PGMEAT	NRM
Sheep total	SH	SH	RUM				
Mutton and Lamb (meat)	LM	LM	BV_LM			SGMEAT	RUM
Poultry meat	PO	PO	o_meat			PTMEAT	NRM
Cow's Milk	CM	CM	WM				
Other milk	OM	OM	WM				
eggs	EG	EG				PTEGGS	NRM
cotton	Cott					Cott	OSD
groundnut	Gnut					Gnut	OSD

Descriptive name[a)]	Common mnemonics	AGMEMOD		MAGNET		GLOBIOM	
		Abb.	Agg.	Abb.	Agg.	Abb.	Agg.
oil palm	OPAL					OPAL	OSD
Grassland	GrsLnd	GL				GrsLnd	
Cropland	CrpLnd	CR				CrpLnd	
Forest/ wood land	Forest	AF				Forest	
Short rotation plantations	PltFor					PltFor	XL
ohter natural vegetation	NatLnd					NatLnd	XL
Abandoned land	Abn Land					AbnLand	XL
other land	XL	XL				XL	

Notes: [a)]only sectors existing in at least two models are shown, Abb. = abbreviation, Agg. = aggregation
Source: own representation based upon the agreement between the modelers in the AGRICISTRADE project

Table A3 Comparable variables and parameters[1)] between AGMEMOD, MAGNET, and GLOBIOM for Case Studies 1 to 3

Descriptive name[1)]	Common mnemonics	AGMEMOD Abb.	MAGNET Abb.	GLOBIOM Abb.
area harvested	AREA	aha	AREA	AREA
yield	YILD	yha	YILD	YILD
production	PROD	spr	PROD	PROD
net exports	NETT	uxn	NETT	NETT
domestic use	CONS	udc	CONS	CONS
feed use	FEED	ufe	FEED	FEED
food use	FOOD	ufd	FOOD	FOOD
biofuel use	BFSU	uod	BFSU	
sum of other uses	OTHU	OTHU	OTHU	OTHU
population	POPT	pop	POPT	POPT
total GDP	GDPT	rgdpd	GDPT	GDPT
real production market price MAGNET	XPPR_M		XPPR	
nominal producer price AGMEMOD	pfn_A	pfn		
World price (base year=1)	XPRR		XPRR	XPRR
World merchandise exports prices	XPRX		XPRX	XPRX
world price, AGMEMOD	wmp	wmp		
Weighted average producer price GLOBIOM	XPRP_G		XPRP	XPRP
exogenous shifter on yields/ technical progress related to use of land	YEXO		YEXO	YEXO
Imports (with intra-trade)	IMP1	smt	IMP1	
Imports (without intra-trade)	IMP2		IMP2	IMPO
Exports (with intra-trade)	EXP1	uxt	EXP1	
Exports (without intra-trade)	EXP2		EXP2	EXPO

Notes: [1)]only variables existing in at least two models are shown, Abb. = abbreviation

Source: own representation based upon the information provided by the modelers in the AGRICISTRADE project

Table A4 Market developments for cereals and the oilseed complex in Russia and Ukraine in Case Study 3, absolute differences trade scenarios to baseline in 2030

	Ukraine				Russia			
	Prod	Cons	Net exports	P price	Prod	Cons	Net exports	P price
	Δ thousand tons			Δ x$^{1)}$	Δ thousand tons			Δ x$^{1)}$
Towards EU integration								
Corn	-69.7	-381.6	310.8	-2.7	-69.8	-257.0	188.4	-19.1
Wheat	387.0	364.3	22.7	-1.1	-774.2	-877.8	106.7	-6.5
Barley	-10.2	-51.5	41.3	-3.5	609.5	406.3	192.9	-12.3
Sunflower seed	-28.8	-25.9	-1.7	-9.0	43.1	48.5	-5.4	-25.3
Soybeans	-116.2	-103.5	-12.7	-9.0	7.1	194.2	-187.2	-30.2
Rapeseed	-19.7	-0.1	-19.6	-8.7	3.5	-1.6	5.1	-22.6
Vegetable oil	-29.2	8.3	-29.5	-9.7	53.4	21.5	31.9	-38.5
Meals	-85.3	-0.1	-85.2	-1.4	170.9	108.9	62.0	9.7
of which soybean meal	-74.1	-0.1	-74.0	9.5	151.4	43.8	107.6	11.7
Global liberalization								
Corn	-45.6	-356.8	309.8	-3.0	-73.4	-252.2	179.6	-19.2
Wheat	432.5	-283.3	715.8	-2.8	-744.7	-142.8	-599.6	-5.2
Barley	-15.3	-53.6	38.2	-3.9	598.6	404.4	184.5	-13.7
Sunflower seed	-20.9	-18.3	-1.8	-10.4	37.0	39.2	-2.2	-29.4
Soybeans	-147.5	-124.9	-22.6	-10.4	4.3	137.4	-133.1	-36.0
Rapeseed	-24.3	-0.1	-24.1	-10.1	2.9	-3.3	6.2	-26.2
Vegetable oil	-29.5	11.6	-29.3	-11.7	39.1	17.6	21.5	1.0
Meals	-97.2	-0.1	-97.1	-4.4	121.6	92.9	28.7	5.8
of which soybean meal	-89.1	-0.1	-89.0	6.1	107.1	31.3	75.8	7.6
Increased protection								
Corn	-33.0	60.1	-93.1	0.1	84.6	258.0	-176.0	16.2
Wheat	79.7	243.0	-163.3	0.4	71.2	321.2	-250.4	0.4
Barley	-7.9	8.6	-16.6	0.2	-71.6	113.4	-183.7	3.7
Sunflower seed	8.3	8.8	-0.7	0.5	-13.4	-19.2	5.8	1.1
Soybeans	-26.4	-11.8	-14.6	0.5	-4.1	-83.8	79.6	0.7
Rapeseed	-3.5	0.0	-3.5	0.5	-1.2	-4.7	3.5	0.5
Vegetable oil	1.9	4.1	-2.2	-0.1	-24.2	-7.9	-16.4	1.0
Meals	-4.1	-0.1	-4.0	0.5	-76.2	-42.6	-33.7	6.7
of which soybean meal	-7.7	-0.1	-7.6	2.3	-65.3	-22.3	-43.0	2.8

Notes: $^{1)}$x=national currency per 100kg, Prod = production, Cons = domestic use, P price = producer price

Source: own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Table A5 Market developments for cereals and the oilseed complex in Russia and Ukraine in Case Study 3, % differences trade scenarios to baseline in 2030

	Ukraine				Russia			
	Prod	Cons	Net exports	P price	Prod	Cons	Net exports	P price
Towards EU integration								
Corn	-0.1	-1.5	1.3	-0.9	-0.4	-2.0	3.8	-1.6
Wheat	1.5	2.6	0.2	-0.3	-1.1	-2.2	0.4	-0.5
Barley	-0.1	-0.6	0.9	-1.0	3.5	3.2	3.8	-1.1
Sunflower seed	-0.2	-0.2	-4.0	-1.2	0.3	0.3	11.0	-1.1
Soybeans	-2.4	-3.8	-0.6	-1.1	0.1	2.9	10.4	-1.0
Rapeseed	-1.1	0.0	-1.4	-1.1	0.3	-0.1	9.6	-0.9
Vegetable oil	-0.4	1.0	-0.5	-0.5	0.7	0.6	0.8	-0.5
Meals	-1.3	0.0	-1.6	-0.2	1.4	1.3	1.7	0.5
of which soybean meal	-25.5	0.0	15.0	0.8	3.0	1.0	21.1	0.8
Global liberalization								
Corn	-0.1	-1.4	1.3	-1.0	-0.4	-1.9	3.7	-1.6
Wheat	1.6	-2.0	5.8	-0.8	-1.1	-0.4	-2.0	-0.4
Barley	-0.1	-0.6	0.8	-1.1	3.4	3.2	3.6	-1.2
Sunflower seed	-0.1	-0.1	-4.3	-1.3	0.3	0.3	4.5	-1.3
Soybeans	-3.0	-4.5	-1.1	-1.3	0.1	2.1	7.4	-1.2
Rapeseed	-1.4	0.0	-1.7	-1.3	0.2	-0.3	11.8	-1.1
Vegetable oil	-0.5	1.4	-0.5	-0.6	0.5	0.5	0.5	0.0
Meals	-1.5	0.0	-1.8	-0.7	1.0	1.1	0.8	0.3
of which soybean meal	-30.6	0.0	18.1	0.5	2.1	0.7	14.9	0.5
Increased protection								
Corn	-0.1	0.2	-0.4	0.0	0.5	2.0	-3.6	1.3
Wheat	0.3	1.7	-1.3	0.1	0.1	0.8	-0.8	0.0
Barley	-0.1	0.1	-0.4	0.1	-0.4	0.9	-3.6	0.3
Sunflower seed	0.1	0.1	-1.7	0.1	-0.1	-0.1	-11.9	0.0
Soybeans	-0.5	-0.4	-0.7	0.1	-0.1	-1.3	-4.4	0.0
Rapeseed	-0.2	0.0	-0.2	0.1	-0.1	-0.4	6.6	0.0
Vegetable oil	0.0	0.5	0.0	0.0	-0.3	-0.2	-0.4	0.0
Meals	-0.1	0.0	-0.1	0.1	-0.6	-0.5	-0.9	0.3
of which soybean meal	-2.6	0.0	1.5	0.2	-1.3	-0.5	-8.4	0.2

Notes: Prod = production, Cons = domestic use, P price = producer price

Source: own projections based on the model system of AGMEMOD, GLOBIOM, and MAGNET

Appendix B

This section contains additional information with regard to the applied model system of MAGNET and LandSHIFT. These are a) detailed information about the land cover types in LandSHIFT, b) sectoral and regional aggregations, c) mappings of regions, sectors, and land between MAGNET and LandSHIFT as well as d) detailed assumptions and results of Case Study 4.

Table B1 Land cover types in LandSHIFT

Name of aggregate Name	Abbreviation	land cover types of CCI[a)] Label (Value) in initialization	Description
Protected areas			Areas under protection or conservation
Protected forest	Forest_protected	Forest (50,60,70,80,90,100) + Wetland Forest (160,170)	Forest Areas that are protect by Conservation (see below)
Protected other area	Conservation	any possible except forest	all area currently under protection according to all WDPA[b)] classes and additional protected area (depending on CPI, year and scenario)
Unproductive areas			Areas not usable for agricultural production
Unproductive land	YieldLow	any possible	Land where all yields of crops and grass are below a threshold of 10 % of the mean in the initialization year. Land is therefore not usable for any agriculture activity.
Urban areas	Urban	Urban areas (190)	Land with high populated settlements and artificial surface. Corresponds to land use type settlements
Other land	NotUseable Static	Water (210), Snow/ Ice (220)	Land that is mostly static
Potential agricultural areas			
Forests	Forest	Forest (50,60,70,80,90,100) + Wetland Forest (160,170)	Forest areas that are not protected (such areas are in the categorie protected forest)
Nature	Nature	Shrubland (120), Grassland (110, 130 ,140), Wetland (180)	All nature vegetation and not protected in any form
Fallow land	Set-aside	former cropland	Areas which are not cropland anymore but have been previously (LandSHIFT internal result)

Name of aggregate Name	Abbreviation	land cover types of CCI[a)] Label (Value) in initialization	Description
Potential agricultural areas with limited productivity			
Low productive land		Any possible, mostly Bare areas (200) and Sparse Vegetation (150)	Land where yields of at least one agricultural activity but not all are above the threshold of 10 % of the corresponding mean yield in the initialization year. Land is therefore potentially usable for at least one agriculture activity.
Cropland		Cropland (10, 20, 30, 40)	Corresponds to land use type crop cultivation
Cereals			Wheat, Rice, Coarse grains
Oilseeds			Oilseeds
Other crops			Sugar beet and cane, other crops
Grazing		Grassland (110, 130, 140)	Corresponds to land use type livestock grazing
Grazing			all used grassland for feeding animals
Protected grazing			as grazing but not convertible to another land cover type

Notes: [a)]as in Defourny *et al.* (2017), [b)]WDPA= World Database on Protected Areas as in IUCN and UNEP (2016)
Source: own representation based on sources in notes, mapping by Jan Schüngel and author

Table B2 Regional aggregation in MAGNET and LandSHIFT for Case Study 4

Regions in results	Regions in models Name	Abb.	Country ISO Codes	Rule	Reason
North America	Canada	CAN	CAN	1	a)
	United States	USA	USA	1	a)
	Mexico	MEX	MEX	1	a), b)
South & Central America	Central America	CAM	ATG, BHS, BRB, BLZ, VGB, CYM, CRI, CUB, DMA, DOM, SLV, GRD, GTM, HTI, HND, JAM, MSR, ANT, ABW, NIC, PAN, PRI, KNA, AIA, LCA, VCT, TTO, TCA, VIR	3, 4	b), c)
	Brazil	BRA	BRA	1	a)
	Rest of Latin America	XLA	ARG, BOL, CHL, COL, ECU, FLK, SGS, GUF, GUY, PRY, PER, SUR, URY, VEN	3, 4	b), c)
Europe	Western Europe	WEU	AUT, BEL, FRA, DEU, GLP, IRL, LUX, MTQ, NLD, REU, GBR	2, 4	a), b)
	Central Europe	CEU	BGR, HRV, CZE, HUN, POL, ROU, SVK, SVN	2, 4	a), b)
	Southern Europe	SEU	CYP, GRC, ITA, MLT, PRT, ESP	2, 3	a), b)
	Scandinavia	SCA	DNK, FIN, ALA, SWE	2, 3	a), b)
	Baltics	BAL	EST, LVA, LTU	2, 3	a), b)
	EFTA region	EFT	ISL, LIE, NOR, SJM, CHE	3, 5	b), c)
	Rest of Europe	XEU	FRO, ATF, GIB, GRL, VAT, MCO, MNE, SPM, SMR, SRB, MKD, GGY, JEY, IMN	3, 5	c)

Regions in results	Regions in models Name	 Abb.	Country ISO Codes	Rule	Reason
Former Soviet Union	Ukraine Belarus Moldova	UKB	BLR, MDA, UKR	4	c)
	Russia	RUS	RUS	1	a), b)
	Central Asia	CAS	KAZ, KGZ, TJK, TKM, UZB	3	b), c)
	Armenia Azerbaijan Georgia	XSU	AZE, ARM, GEO	3	c)
Middle East	Turkey	TUR	TUR	1	b)
	Middle East	WAS	BHR, PSE, IRQ, ISR, JOR, KWT, LBN, OMN, QAT, SAU, SYR, ARE, YEM	3	b), c)
	Iran	IRN	IRN	1	b)
Africa	Northern Africa	NAF	DZA, LBY, MAR, ESH, TUN, EGY	3	b), c)
	Western Africa	WAF	CPV, BEN, GMB, GHA, GIN, CIV, LBR, MLI, MRT, NER, NGA, GNB, SHN, SEN, SLE, TGO, BFA	3	b), c)
	Central Africa	CAF	AGO, CMR, CAF, TCD, COG, COD, GNQ, GAB, STP	3	b), c)
	Eastern Africa	EAF	BDI, COM, MYT, ETH, ERI, DJI, KEN, RWA, SYC, SOM, SDN, SSD, UGA	3	b), c)
	South Africa	ZAF	ZAF		b)
	Rest of Southern Africa	SAF	BWA, LSO, MDG, MWI, MUS, MOZ, NAM, ZWE, SWZ, TZA, ZMB	3	b), c)
South & East Asia	Japan and Korea	JKO	JPN, KOR	3	c)
	China	CHN	CHN, TWN, HKG	1, 2, 3, 4	a), c)
	Mongolia	XCH	PRK, MAC, MNG	3, 5	c)
	India	IND	IND	1	a)
	Malaysia Philippines Thailand	SEA	MYS, PHL, THA	3, 4	a), b)
	Indonesia	IDN	IDN	1	a)
	Rest of Southern Asia	XSA	AFG, BGD, BTN, LKA, MDV, NPL, PAK	3, 5	b), c)
	Rest of Southeastern Asia	XEA	BRN, MMR, KHM, LAO, TLS, SGP, VNM	3, 5	b), c)
Australia	Australia New Zealand Oceania	OCE	ASM, AUS, SLB, CXR, CCK, COK, FJI, PYF, KIR, GUM, HMD, NRU, NCL, VUT, NZL, NIU, NFK, MNP, UMI, FSM, MHL, PLW, PNG, PCN, TKL, TON, TUV, WLF, WSM	3, 5	b), c)

Note: Abb. = Abbreviation; Rules: 1 = county with large territories, large agricultural production, specific biofuel policies or strongly different economic situation than neighbors, 2 = countries that form a union and have common policies especially with regard to agricultural, trade and biofuel policies, 3 = countries with small territories or small agricultural production, 4 = aggregation because of geographical neighborhood, 5 = aggregation so that final aggregation is below 40 regions violating 4; Reason: a) research question, b) geographical and economic relations, c) model limitations and requirements

Source: Mapping by Jan Schüngel and author based on regions in MAGNET and LandSHIFT and ISO country codes (ISO, 2018)

Table B3 Aggregation and mapping of sectors in MAGNET in Case Study 4

Sector names in Results	sectors in MAGNET		
	Name	Code	MAGNET codes
Cereals	Wheat	wht	wht
	Rice	pdr	pdr
	Other grains	gro	gro
Oilseeds	Oilseeds and oilcrops	osd	osd
other Crops	Sugar crops	c_b	c_b
	Other Crops	O_CR	v_f, pfb, ocr
Grazing	Ruminants (live animals, raw product)	CATT	ctl, rmk, wol
Biofuel	Biodiesel	biod	biod
	Ethanol	biog	biog
not presented	Non-ruminant animal products	ANI	oap, omt
	Forestry	frs	frs
	Ruminant animal products	MEMI	cmt, mil
	Sugar and by-product	SGR	sgr, mola
	Crude vegetable oil	cvol	cvol
	Vegetable oils and fats	vol	vol
	Processed rice	pcr	pcr
	Fish, Beverages, Tobacco	O_FO	fsh, b_t
	Other food products	ofd	ofd
	Oilcake	oilcake	oilcake
	Distiller's dried grains and solubles	ddgs	ddgs
	Animal feed	feed	feed
	Crude oil	c_oil	c_oil
	Petroleum, coal products	petro	petro
	Gas mining, production, distribution	gas	gas
	Coal	coa	coa
	Electricity	ely	ely
	Chemical industry	crp	crp
	Other Industry	INDU	omn, tex, wap, lea, lum, ppp, nmm, i_s, nfm, fmp, mvh, otn, ele, ome, omf, cns
	Services (except transport)	SERV	gdt, wtr, trd, cmn, ofi, isr, obs, ros, osg, dwe
	Transprot sector	TRSP	otp, wtp, atp

Source: own mapping based on sectors in MAGNET

Table B4 Mapping of sectors in MAGNET to land use and cover categories in LandSHIFT in Case Study 4

	MAGNET sectors		LandSHIFT land use types		LandSHIFT categories	
Names in Results	Name	Code	Name	Code	land use	land cover
Cereals	Wheat	wht	Wheat	wht	Crop cultivation	Cropland
	Rice	pdr	Rice	pdr		
	Other grains	gro	Other grains	gro		
Oilseeds	Oilseeds and oilcrops	osd	Oilseeds and oilcrops	osd		
other Crops	Sugar crops	c_b	Sugar crops	cnb		
	Other Crops	O_CR	Other Crops	ocr		
Grazing	Ruminants (live animals, raw product)	CATT	Grazing	grazing	Livestock grazing	Grassland

Source: Mapping by Jan Schüngel and author based on sectors in MAGNET and land use categories in LandSHIFT

Table B5 Assumptions of Case Study 4 on land productivity, CPI and the asymptote

Region	land productivity %/a	CPI Classification	Asymp-tote all scenarios in 2015 million hectares	asymptote after area protection in 2025 million hectares	Δ% asymp-tote 2015-2025
Canada	0.50	A	327	319	-3
United States	0.50	A	527	509	-3
Mexico	0.75	B	186	115	-38
Central America	1.00	B	55	38	-32
Brazil	0.50	B	723	383	-47
Rest of Latin America	0.75	B	806	535	-34
Western Europe	0.50	A	94	92	-2
Central Europe	0.50	A	76	62	-19
Southern Europe	0.50	A	68	64	-5
Scandinavia	0.50	A	12	12	-3
Baltics	0.50	A	7	7	-1
EFTA region	0.50	A	19	19	-2
Rest of Europe	0.75	B	20	10	-49
Ukraine Belarus Moldova	0.75	B	80	66	-18
Russia	0.75	B	1507	535	-65
Central Asia	0.75	B	382	382	0
Armenia Azerbaijan Georgia	0.50	B	14	13	-7
Turkey	0.75	B	75	56	-25
Middle East	0.50	B	288	284	-1
Iran	0.75	B	152	152	0
Northern Africa	1.00	B	557	556	0
Western Africa	1.00	B	562	510	-9
Central Africa	1.00	C	650	649	0
Eastern Africa	1.00	C	496	467	-6
South Africa	0.75	B	117	111	-5
Rest of Southern Africa	1.00	B	428	346	-19
Japan and Korea	0.50	A	11	11	0
China	0.50	B	785	686	-13
Mongolia	1.00	B	147	147	0
India	0.75	B	293	238	-19
Malaysia Philippines Thailand	0.50	B	77	65	-16
Indonesia	0.50	B	171	72	-58
Rest of Southern Asia	0.75	B	177	161	-9
Rest of Southeastern Asia	0.75	B	130	74	-44
Australia New Zealand Oceania	0.50	A	742	689	-7

Note: CPI (= Corruption perception index) with A: CPI ≥ 50, B: 25 < CPI <50, C: CPI ≤ 25 implementation in LandSHIFT at the level of 134 regions, land productivity (= exogenous technical change for the endowment land in MAGNET), asymptote (= maximal available potential agricultural area in MAGNET)

Source: land productivity: own assumption; CPI classification own aggregation based on Transparancy International (2020); Asymptotes based on LandSHIFT using Transparancy International (2020) and Defourny and ESA Land Cover CCI project team (2017)

Table B6 Case Study 4 – cereal production, million tons

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	54.7	67.6	71.2	69.6	73.5
United States of America	459.4	504.3	538.7	507.7	542.1
Mexico	36.6	44.2	44.6	42.8	43.0
Central America	7.2	8.7	8.7	9.1	9.3
Brazil	97.2	104.5	103.5	102.9	101.7
Rest of Latin America	88.6	106.3	106.4	103.3	103.2
Western Europe	151.7	160.9	161.4	162.6	163.0
Central Europe	92.5	98.2	98.2	98.6	98.3
Southern Europe	45.5	46.5	46.7	46.5	46.8
Scandinavia	19.3	21.0	21.4	21.3	21.7
Baltics	9.3	10.6	10.8	10.8	11.0
EFTA region	2.2	2.4	2.5	2.5	2.6
Ukraine Belarus Moldova	73.5	78.5	77.9	77.7	76.8
Turkey	35.5	43.0	43.0	42.8	42.9
Russia	107.8	123.8	125.2	128.8	130.4
Armenia Azerbaijan Georgia	3.7	4.4	4.4	4.4	4.4
Rest of Europe	12.7	13.0	12.9	13.2	13.0
Northern Africa	36.2	53.8	54.1	55.1	55.6
Western Africa	60.0	94.2	94.3	82.7	82.8
Central Africa	11.7	18.5	18.5	19.3	19.6
Eastern Africa	42.0	70.7	70.9	70.9	71.3
South Africa	12.9	15.2	15.2	15.1	15.1
Rest of Southern Africa	23.8	35.3	35.4	34.0	34.1
Middle East	10.7	12.7	12.9	12.8	12.9
Iran	19.4	24.3	24.3	24.4	24.5
Central Asia	33.6	35.5	35.5	35.3	35.2
China	600.2	719.5	830.0	666.7	754.3
Mongolia	5.6	6.5	6.5	6.8	6.9
Japan and Korea	17.2	16.1	16.1	16.3	16.3
India	292.7	338.3	337.9	334.4	333.8
Rest of Southern Asia	116.3	143.3	143.6	146.1	146.7
Malaysia Philippines Thailand	61.9	64.7	63.7	64.5	63.5
Indonesia	95.9	104.3	103.5	101.0	99.5
Rest of Southeastern Asia	94.0	113.0	113.5	114.4	115.7
Australia	38.1	41.6	42.1	41.7	42.3

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B7 Case Study 4 – oilseed production, million tons

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	25.5	36.7	39.8	40.2	44.2
United States of America	120.0	144.0	154.1	154.9	166.9
Mexico	1.8	2.9	3.1	2.6	2.7
Central America	5.8	8.5	9.1	8.6	9.3
Brazil	98.3	140.9	154.8	146.0	161.3
Rest of Latin America	89.2	138.7	159.2	142.6	165.2
Western Europe	15.1	19.0	21.3	20.4	22.9
Central Europe	13.7	18.4	20.4	19.6	21.7
Southern Europe	3.2	4.0	4.5	4.3	4.9
Scandinavia	1.1	1.5	1.7	1.7	2.0
Baltics	0.9	1.3	1.4	1.4	1.6
EFTA region	0.1	0.1	0.1	0.1	0.1
Ukraine Belarus Moldova	18.7	26.4	28.8	28.5	31.1
Turkey	3.5	4.9	5.5	5.2	5.8
Russia	14.3	15.7	16.3	16.7	17.5
Armenia Azerbaijan Georgia	0.1	0.2	0.2	0.2	0.2
Rest of Europe	1.1	1.3	1.9	1.4	1.9
Northern Africa	0.5	0.9	0.9	1.0	1.0
Western Africa	25.7	41.0	41.7	34.2	34.3
Central Africa	7.4	11.5	11.6	11.5	11.6
Eastern Africa	4.7	9.0	9.5	9.4	10.0
South Africa	1.9	2.1	2.1	2.1	2.2
Rest of Southern Africa	6.4	9.5	9.8	9.0	9.2
Middle East	0.2	0.2	0.3	0.3	0.3
Iran	0.5	0.6	0.6	0.6	0.6
Central Asia	4.4	4.1	4.2	4.2	4.4
China	61.7	67.3	70.6	52.7	57.6
Mongolia	0.4	0.3	0.4	0.4	0.5
Japan and Korea	0.4	0.5	0.5	0.5	0.5
India	39.2	56.0	57.2	55.2	56.6
Rest of Southern Asia	5.8	12.7	13.4	13.1	14.0
Malaysia Philippines Thailand	106.2	143.6	152.1	135.9	142.5
Indonesia	136.3	216.9	251.9	191.5	215.0
Rest of Southeastern Asia	4.4	6.5	7.0	6.0	6.4
Australia	7.0	7.7	7.9	7.7	7.9

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B8 Case Study 4 – land demand of cereals, million hectares

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	15.2	18.0	18.6	18.7	19.5
United States of America	77.9	76.7	80.0	77.5	80.7
Mexico	11.1	11.8	11.9	11.4	11.4
Central America	3.5	3.5	3.5	3.5	3.5
Brazil	17.3	16.8	16.5	15.7	15.3
Rest of Latin America	18.7	19.6	19.7	18.7	18.6
Western Europe	22.5	21.9	21.8	22.0	21.9
Central Europe	22.2	21.6	21.5	21.6	21.4
Southern Europe	11.1	10.7	10.7	10.7	10.7
Scandinavia	4.7	4.7	4.7	4.7	4.7
Baltics	2.6	2.7	2.7	2.8	2.8
EFTA region	0.5	0.5	0.5	0.5	0.5
Ukraine Belarus Moldova	23.5	22.2	21.7	21.5	20.9
Turkey	12.7	13.4	13.4	13.2	13.2
Russia	88.9	90.6	91.9	95.0	96.2
Armenia Azerbaijan Georgia	2.0	2.1	2.1	2.1	2.1
Rest of Europe	2.6	2.3	2.3	2.4	2.3
Northern Africa	13.2	16.8	16.9	16.8	16.9
Western Africa	45.3	56.5	56.4	49.4	49.3
Central Africa	16.7	20.7	20.7	21.7	22.0
Eastern Africa	21.1	30.6	30.7	30.7	30.9
South Africa	7.1	7.2	7.2	7.1	7.1
Rest of Southern Africa	16.7	20.5	20.4	19.2	19.2
Middle East	8.3	8.8	8.9	8.8	8.9
Iran	8.5	9.5	9.5	9.4	9.4
Central Asia	30.9	27.2	27.2	27.0	27.0
China	71.5	76.8	86.9	70.7	80.5
Mongolia	1.7	1.6	1.6	1.7	1.7
Japan and Korea	2.5	2.2	2.2	2.2	2.2
India	72.0	73.1	72.9	71.8	71.5
Rest of Southern Asia	21.4	23.7	23.8	24.0	24.1
Malaysia Philippines Thailand	18.2	17.3	17.0	17.2	16.9
Indonesia	20.1	19.7	19.6	19.0	18.7
Rest of Southeastern Asia	17.0	17.9	18.0	18.1	18.2
Australia	24.6	24.0	24.4	23.9	24.3

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B9 Case Study 4 – land demand of oilseeds, million hectares

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	11.9	15.4	17.0	17.2	19.4
United States of America	46.9	50.0	52.9	52.9	56.5
Mexico	0.6	0.8	0.8	0.7	0.7
Central America	0.6	0.8	0.8	0.8	0.8
Brazil	25.9	34.2	36.9	34.7	37.7
Rest of Latin America	24.7	31.8	35.3	32.2	36.0
Western Europe	4.9	5.5	6.1	5.8	6.5
Central Europe	5.8	7.2	8.0	7.7	8.5
Southern Europe	1.4	1.7	2.0	1.9	2.1
Scandinavia	0.4	0.5	0.5	0.5	0.6
Baltics	0.4	0.5	0.5	0.5	0.6
EFTA region	0.0	0.0	0.0	0.0	0.0
Ukraine Belarus Moldova	12.4	16.1	17.6	17.4	18.9
Turkey	1.0	1.2	1.4	1.3	1.4
Russia	22.6	22.2	23.0	23.5	24.5
Armenia Azerbaijan Georgia	0.0	0.0	0.0	0.0	0.0
Rest of Europe	0.4	0.5	0.6	0.5	0.7
Northern Africa	0.2	0.2	0.2	0.2	0.2
Western Africa	10.9	13.4	13.6	11.0	11.1
Central Africa	3.5	4.7	4.7	4.6	4.6
Eastern Africa	4.2	6.5	6.8	6.8	7.3
South Africa	3.4	3.1	3.3	3.1	3.2
Rest of Southern Africa	7.6	8.3	8.4	8.0	8.1
Middle East	0.1	0.1	0.1	0.1	0.1
Iran	0.3	0.3	0.3	0.3	0.3
Central Asia	5.6	3.7	3.8	3.9	4.1
China	14.9	14.7	15.8	11.7	12.7
Mongolia	0.3	0.2	0.2	0.2	0.3
Japan and Korea	0.3	0.3	0.4	0.4	0.4
India	18.4	21.9	22.3	21.6	22.1
Rest of Southern Asia	0.9	1.5	1.6	1.6	1.8
Malaysia Philippines Thailand	6.6	8.0	8.4	7.6	7.9
Indonesia	10.0	14.4	16.6	12.6	14.1
Rest of Southeastern Asia	2.7	3.6	3.8	3.4	3.5
Australia	5.9	5.9	6.1	5.8	6.0

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B10 Case Study 4 – cereal demand, billion USD 2007

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	4.5	5.4	6.0	5.5	6.1
United States of America	57.7	63.9	69.9	63.5	69.5
Mexico	11.3	13.1	13.1	12.9	12.9
Central America	8.2	9.5	9.5	9.5	9.5
Brazil	14.9	15.7	15.6	15.5	15.3
Rest of Latin America	17.8	21.6	21.5	21.3	21.3
Western Europe	33.6	35.1	35.1	35.1	35.0
Central Europe	14.3	14.4	14.4	14.4	14.4
Southern Europe	20.7	20.5	20.7	20.5	20.6
Scandinavia	4.2	4.6	4.6	4.6	4.7
Baltics	1.0	1.0	1.0	1.0	1.0
EFTA region	1.5	1.6	1.7	1.6	1.7
Ukraine Belarus Moldova	7.3	7.3	7.3	7.3	7.2
Turkey	9.9	11.4	11.4	11.4	11.4
Russia	26.8	27.4	27.5	27.8	27.9
Armenia Azerbaijan Georgia	2.4	2.7	2.7	2.7	2.7
Rest of Europe	1.6	1.6	1.6	1.6	1.6
Northern Africa	30.1	41.0	41.0	41.0	40.9
Western Africa	30.7	46.8	46.7	43.3	43.3
Central Africa	3.9	6.0	6.0	6.0	6.0
Eastern Africa	11.2	18.6	18.6	18.5	18.6
South Africa	3.9	4.5	4.5	4.5	4.5
Rest of Southern Africa	6.7	10.2	10.2	9.9	9.9
Middle East	12.7	18.3	18.3	18.3	18.3
Iran	8.9	10.2	10.2	10.1	10.1
Central Asia	4.4	5.4	5.4	5.3	5.3
China	78.4	96.7	105.3	92.8	100.1
Mongolia	0.4	0.5	0.5	0.5	0.5
Japan and Korea	33.7	31.5	31.4	31.7	31.7
India	49.2	60.2	60.1	59.6	59.5
Rest of Southern Asia	17.9	21.8	21.7	21.8	21.8
Malaysia Philippines Thailand	13.2	14.3	14.1	14.2	14.0
Indonesia	18.4	20.4	20.2	19.9	19.6
Rest of Southeastern Asia	8.3	9.8	9.8	9.6	9.7
Australia	6.7	7.6	7.7	7.6	7.7

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B11 Case Study 4 – oilseed demand, billion USD 2007

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	1.1	1.3	1.3	1.4	1.4
United States of America	18.6	21.6	23.2	22.4	24.2
Mexico	2.5	3.1	3.1	3.1	3.1
Central America	1.3	1.8	1.8	1.8	1.8
Brazil	9.8	12.8	13.9	13.3	14.6
Rest of Latin America	13.6	21.7	25.5	22.7	27.0
Western Europe	12.4	15.4	17.0	16.1	17.8
Central Europe	4.2	5.2	5.7	5.3	5.9
Southern Europe	11.5	14.0	15.7	14.9	17.0
Scandinavia	0.8	1.1	1.3	1.2	1.5
Baltics	0.2	0.2	0.2	0.2	0.2
EFTA region	0.4	0.5	0.6	0.5	0.6
Ukraine Belarus Moldova	1.2	1.6	1.8	1.7	1.9
Turkey	1.8	2.1	2.4	2.2	2.5
Russia	1.9	2.0	2.0	2.1	2.1
Armenia Azerbaijan Georgia	0.2	0.4	0.4	0.4	0.4
Rest of Europe	0.5	0.7	1.0	0.7	1.0
Northern Africa	2.6	4.0	4.1	4.1	4.2
Western Africa	10.3	16.3	16.5	14.0	14.1
Central Africa	1.0	1.5	1.5	1.5	1.5
Eastern Africa	3.6	6.2	6.4	6.3	6.5
South Africa	0.4	0.5	0.5	0.5	0.5
Rest of Southern Africa	1.2	1.9	1.9	1.8	1.9
Middle East	1.7	2.6	2.8	2.8	3.0
Iran	1.4	1.7	1.7	1.7	1.7
Central Asia	0.1	0.2	0.2	0.2	0.2
China	33.9	48.2	51.8	47.9	52.2
Mongolia	0.0	0.0	0.0	0.0	0.0
Japan and Korea	5.0	5.3	6.0	5.4	6.1
India	23.5	34.4	35.1	34.0	34.7
Rest of Southern Asia	2.1	4.7	5.0	5.1	5.4
Malaysia Philippines Thailand	12.3	17.1	18.2	16.3	17.2
Indonesia	13.9	22.4	26.4	20.3	23.4
Rest of Southeastern Asia	0.6	0.8	0.8	0.8	0.8
Australia	1.4	1.6	1.6	1.6	1.6

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B12 Case Study 4 – cereal prices, index with 2007=1

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	0.99	0.91	0.92	0.94	0.95
United States of America	1.01	0.90	0.93	0.94	0.97
Mexico	1.07	0.99	1.00	1.05	1.07
Central America	0.98	0.85	0.85	0.89	0.90
Brazil	0.93	0.81	0.82	0.84	0.85
Rest of Latin America	1.01	1.00	1.02	1.06	1.09
Western Europe	0.98	0.87	0.88	0.89	0.90
Central Europe	0.88	0.76	0.77	0.77	0.79
Southern Europe	1.00	0.86	0.87	0.88	0.90
Scandinavia	0.98	0.85	0.86	0.87	0.88
Baltics	0.84	0.68	0.69	0.69	0.70
EFTA region	1.00	0.92	0.93	0.92	0.93
Ukraine Belarus Moldova	0.89	0.77	0.77	0.79	0.80
Turkey	0.84	0.69	0.69	0.71	0.71
Russia	0.92	0.84	0.85	0.86	0.87
Armenia Azerbaijan Georgia	0.93	0.90	0.91	0.93	0.94
Rest of Europe	0.94	0.71	0.72	0.72	0.73
Northern Africa	1.00	0.94	0.94	0.96	0.97
Western Africa	0.93	0.91	0.92	1.49	1.50
Central Africa	0.94	0.90	0.90	0.93	0.94
Eastern Africa	0.91	0.81	0.82	0.84	0.84
South Africa	1.08	1.09	1.10	1.17	1.18
Rest of Southern Africa	1.03	1.22	1.23	1.37	1.38
Middle East	1.07	1.18	1.19	1.21	1.23
Iran	1.06	0.97	0.98	1.02	1.03
Central Asia	1.01	1.13	1.13	1.15	1.16
China	1.43	1.87	1.94	2.43	2.61
Mongolia	1.01	1.13	1.13	1.16	1.17
Japan and Korea	0.99	0.79	0.80	0.81	0.82
India	0.99	1.04	1.05	1.12	1.13
Rest of Southern Asia	0.91	0.81	0.81	0.84	0.85
Malaysia Philippines Thailand	1.10	1.18	1.21	1.29	1.34
Indonesia	0.91	0.90	0.93	1.07	1.15
Rest of Southeastern Asia	1.01	0.95	0.96	1.06	1.08
Australia	1.06	1.06	1.08	1.11	1.13

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B13 Case Study 4 – oilseed prices, index with 2007=1

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	0.99	0.91	0.93	0.95	0.97
United States of America	1.02	0.92	0.95	0.96	1.00
Mexico	1.11	0.98	0.98	1.07	1.08
Central America	0.99	0.87	0.87	0.92	0.92
Brazil	0.96	0.86	0.87	0.91	0.93
Rest of Latin America	1.04	1.04	1.06	1.12	1.15
Western Europe	0.98	0.87	0.89	0.90	0.92
Central Europe	0.89	0.76	0.78	0.79	0.81
Southern Europe	1.00	0.87	0.88	0.89	0.90
Scandinavia	0.97	0.83	0.84	0.85	0.86
Baltics	0.83	0.67	0.68	0.68	0.70
EFTA region	0.98	0.92	0.94	0.95	0.98
Ukraine Belarus Moldova	0.89	0.77	0.78	0.80	0.82
Turkey	0.86	0.72	0.73	0.75	0.76
Russia	0.93	0.85	0.86	0.86	0.88
Armenia Azerbaijan Georgia	0.88	0.83	0.86	0.85	0.89
Rest of Europe	0.96	0.74	0.78	0.75	0.81
Northern Africa	1.05	1.05	1.06	1.06	1.08
Western Africa	0.94	0.93	0.94	1.54	1.55
Central Africa	0.94	0.90	0.91	0.93	0.94
Eastern Africa	0.92	0.82	0.83	0.84	0.85
South Africa	1.14	1.14	1.17	1.23	1.27
Rest of Southern Africa	1.03	1.15	1.15	1.32	1.33
Middle East	1.28	1.55	1.57	1.63	1.66
Iran	1.06	0.97	0.98	1.01	1.03
Central Asia	1.39	1.73	1.79	1.85	1.94
China	1.45	1.86	2.01	2.33	2.50
Mongolia	1.10	1.24	1.24	1.29	1.30
Japan and Korea	1.00	0.83	0.86	0.88	0.88
India	1.05	1.23	1.25	1.34	1.37
Rest of Southern Asia	0.94	0.86	0.87	0.93	0.95
Malaysia Philippines Thailand	1.17	1.34	1.40	1.46	1.54
Indonesia	1.02	1.13	1.22	1.34	1.48
Rest of Southeastern Asia	1.05	1.06	1.07	1.18	1.22
Australia	1.24	1.33	1.38	1.42	1.48

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B14 Case Study 4 – cereal net-export volumes at world market prices, million USD 2007

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	6439	8110	8247	8441	8628
United States of America	18639	19800	19108	20832	20283
Mexico	-3168	-3405	-3339	-3474	-3417
Central America	-1847	-1792	-1703	-1554	-1438
Brazil	1041	1261	1286	1237	1267
Rest of Latin America	2300	2415	2381	1917	1849
Western Europe	1805	2443	2594	2923	3084
Central Europe	3227	4302	4250	4369	4277
Southern Europe	-6175	-5768	-5811	-5675	-5705
Scandinavia	347	393	405	437	457
Baltics	336	562	561	585	586
EFTA region	-247	-271	-284	-240	-243
Ukraine Belarus Moldova	1562	2134	2098	2076	2026
Turkey	-454	-115	-98	-114	-95
Russia	6112	9498	9755	10343	10657
Armenia Azerbaijan Georgia	-469	-459	-458	-468	-466
Rest of Europe	-168	-132	-131	-117	-124
Northern Africa	-7791	-8336	-8192	-7576	-7231
Western Africa	-1271	-433	-331	-2756	-2726
Central Africa	-247	-325	-308	-273	-248
Eastern Africa	-417	-397	-396	-320	-302
South Africa	-525	-567	-557	-573	-558
Rest of Southern Africa	-513	-1057	-1060	-1104	-1100
Middle East	-6995	-11097	-11032	-11072	-10994
Iran	-750	-426	-400	-68	13
Central Asia	1012	386	394	381	387
China	-1789	-5352	-5767	-7346	-8362
Mongolia	-31	-87	-87	-88	-88
Japan and Korea	-6868	-6369	-6327	-6341	-6292
India	-162	-823	-816	-992	-983
Rest of Southern Asia	-608	-768	-674	-370	-204
Malaysia Philippines Thailand	-1412	-1892	-1902	-1850	-1852
Indonesia	-1420	-1724	-1726	-1803	-1816
Rest of Southeastern Asia	-554	-557	-541	-241	-173
Australia	1060	852	863	878	902

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Table B15 Case Study 4 – oilseed net-export volumes at world market prices, million USD 2007

	2015	2030			
Region	all Scenarios	Baseline	Biofuel	Protection	ProBio
Canada	3892	5903	6483	6535	7277
United States of America	10615	13525	14350	15361	16447
Mexico	-2034	-2432	-2427	-2455	-2453
Central America	-93	11	79	30	113
Brazil	9987	15534	17176	16013	17799
Rest of Latin America	5688	8265	8871	8091	8648
Western Europe	-3869	-4692	-5088	-4706	-5105
Central Europe	1889	3033	3363	3384	3764
Southern Europe	-2388	-2735	-3044	-2784	-3108
Scandinavia	-243	-312	-362	-340	-401
Baltics	197	330	380	374	439
EFTA region	-190	-232	-275	-231	-274
Ukraine Belarus Moldova	930	1337	1437	1441	1550
Turkey	-638	-479	-588	-439	-545
Russia	-48	33	66	86	136
Armenia Azerbaijan Georgia	-10	-12	-13	-12	-12
Rest of Europe	-75	-96	-192	-96	-193
Northern Africa	-696	-944	-931	-910	-890
Western Africa	277	501	580	-8	3
Central Africa	2	10	13	12	16
Eastern Africa	693	1868	2108	2137	2463
South Africa	-62	-69	-70	-67	-69
Rest of Southern Africa	149	133	160	90	113
Middle East	-1183	-1984	-2118	-2094	-2274
Iran	-278	-232	-225	-222	-213
Central Asia	-51	-98	-110	-122	-142
China	-17143	-27791	-30087	-29924	-32597
Mongolia	-15	-22	-22	-22	-23
Japan and Korea	-3240	-3486	-4005	-3579	-4087
India	562	155	249	107	207
Rest of Southern Asia	-763	-1806	-1876	-2058	-2190
Malaysia Philippines Thailand	-1185	-1920	-2089	-1964	-2128
Indonesia	-734	-1343	-1868	-1625	-2276
Rest of Southeastern Asia	97	152	185	103	121
Australia	-38	-99	-106	-99	-110

Source: own results from MAGNET generated by the joined use of MAGNET and LandSHIFT

Annex 1 List of publications related to the dissertation

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Annex 2 Eidesstattliche Erklärung

Hiermit versichere ich, dass ich die vorliegende schriftliche wissenschaftliche Abhandlung (Dissertation) selbständig verfasst habe und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Es wurde keine Hilfe Dritter in einer dem Prüfungsrecht und wissenschaftlicher Redlichkeit widersprechenden Weise in Anspruch genommen. Hilfe Dritter wurde nur in wissenschaftlich vertretbarem und prüfungsrechtlich zulässigem Ausmaß in Anspruch genommen. Insbesondere sind alle Teile der Dissertation selbst angefertigt und fremde Hilfe habe ich dazu weder unentgeltlich noch entgeltlich entgegengenommen. Weiter versichere ich, dass anderweitig keine entsprechende Promotion beantragt wurde und hierbei die eingereichte Dissertation oder Teile daraus vorgelegt worden sind.

Braunschweig, 30. September 2022,

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