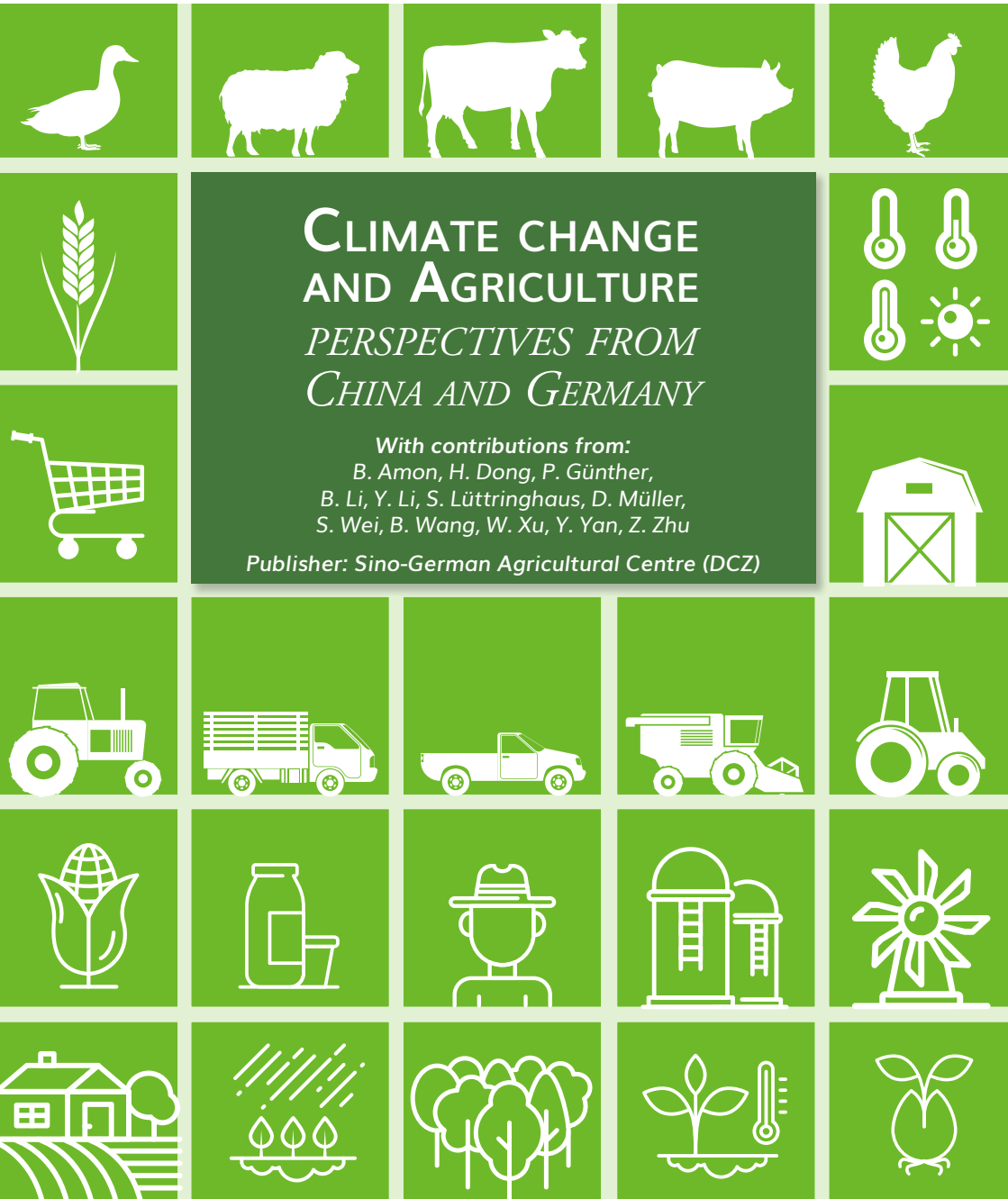
With support from

Federal Ministry of Food and Agriculture

by decision of the German Bundestag



Climate change and Agriculture

perspectives from China and Germany

With contributions from:
B. Amon, H. Dong, P. Günther, B. Li, Y. Li, S. Lüttringhaus, D. Müller, S. Wei, B. Wang, W. Xu, Y. Yan, Z. Zhu

Publisher: Sino-German Agricultural Centre (DCZ)

GFA CONSULTING GROUP

Implemented by

IAK AGRAR CONSULTING

iamo Leibniz Institute of Agricultural Development in Transition Economies

In partnership with

FECC

Climate change and Agriculture

perspectives from China and Germany

PUBLISHER:
Sino-German Agricultural Centre (DCZ)

WITH CONTRIBUTIONS FROM:
Barbara Amon, Hongmin Dong, Peggy Günther, Bo Li, Yu'e Li, Sophia Lüttringhaus, Daniel Müller, Sha Wei, Bin Wang, Wenzheng Xu, Yan Yan, Zhiping Zhu

Published by

Sino-German Agricultural Centre (DCZ)
55 Nongzhan Beilu, Chaoyang District
100125 Beijing, China

Index

Preface

by Peggy Günther (project coordinator)

Climate change and agriculture - relevance

The link between agriculture and climate change is well documented. The sector contributes to climate change in two ways: In addition to greenhouse gas emissions (namely carbon dioxide, methane and nitrous dioxide from agricultural production and land-use change), the agriculture as well as the forestry sector are the only sectors that actively contribute to carbon sequestration and thus act as greenhouse gas sinks. Significant contributions to climate protection are humus formation in arable land, the fermentation of liquid manure and peatland restoration.

The most recent IPCC report Climate change and Land (2019) once again underlined that agriculture, forestry and other land use activities account for 23% of total anthropogenic net greenhouse gas emissions. Land-based mitigation and land-use changes are needed to limit global warming to 1.5°C or well below 2°C compared to pre-industrial levels. Despite emissions from agricultural production and other land use activities, agriculture is also the sector most directly affected by its impacts.

For example, anthropogenic climate change and its consequences, such as more frequent extreme weather events, new pests and diseases, etcetera, lead to poor harvests or crop failures, threatening farmer's livelihoods and even food supplies.

While adaptation to climatic developments is becoming a necessity from a local perspective, the reduction of greenhouse gas emissions is imperative from a global perspective. It should be stressed that, from a long-term perspective, the most effective form of adaptation is mitigation. Therefore, the key question is how to produce in a climate-friendly way, i.e. with the lowest possible GHG emissions.

China and Germany are committed to an active climate policy. Both countries have adopted national climate action plans and defined their own sectoral targets for combating climate change in agriculture. Moreover, both parties have signed the Paris Agreement, which once again underlines the need for active cooperation between nations and the involvement of key stakeholders at all levels. In recognition of the strong interaction between climate change and agriculture, the respective German and Chinese ministries are tackling the issues through joint project activities.

Scope of the study

The present study outlines the findings of the German-Chinese Cooperation on Agriculture and Climate Change, which was implemented in 2019. The overall aim of the project was to establish an expert dialogue to develop policy recommendations for innovative, climate-relevant interventions in the agricultural sector in Germany and China. To this end, the project brought together renowned and experienced experts from both countries with a strong background on various aspects of the interaction between climate change and agriculture. Their work, which is presented here, was based on their own research and professional experience and was significantly complemented by the exchange and insights gained through the intensive collaboration within the project, especially during the exchange visits.

In order to cover the broad range of topics related to climate change and agriculture, this collection consists of six selected articles. In the first chapter, it introduces the current climate policy in China and Germany by providing general information, e.g. on the development of greenhouse gas emissions and the most important political measures. It focuses on policies to mitigate climate change, presenting good practices and providing further recommendations. Moreover, additional exchange on the topic is encouraged.

Chapter two presents research findings with a focus on mitigation of greenhouse gases in livestock production. In particular, the relevance of nitrogen use efficiency in livestock production and options for improvement, including livestock feeding and housing, as well as manure storage, processing and application, are discussed. The latter is explicitly addressed by providing information on the treatment and utilization modes recommended by the Chinese Ministry of Agriculture and Rural Affairs.

Chapter three focuses on how climate change is already affecting crop production in Europe and its projected future impacts. Aspects such as growing season length, water availability and increased CO_2 levels are covered. It then outlines options for adaptation and mitigation through plant breeding – and reiterates the need for international cooperation.

The final chapter deals with current global developments and their impacts on greenhouse gas emissions from agriculture. By comparing greenhouse gas emissions from pork production and feed imports in China and the European Union, it highlights the impact of the recent trade disruption between China and the United States as well as the impact of African swine fever on trade flows of pig feed, pork and related emissions.

About the project

The current study was prepared as a contribution of the German-Chinese Cooperation on Agriculture and Climate Change, a sub-project of the Sino-German Agricultural Centre (DCZ). The DCZ is part of the Bilateral Cooperation Programme (BKP) of the German Federal Ministry of Food and Agriculture (BMEL), which strengthens the German-international exchange between political and economic actors from the agricultural sector. The partner countries are emerging economies that are important in terms of agro-food policy and are also the focus of the BMEL's bilateral cooperation, which is based on the pillars of understanding, development and sustainability.

The project is being implemented by IAK Agrar Consulting GmbH (IAK) as lead company in a consortium with the Leibniz Institute of Agricultural Development in Transition Economies (IAMO).

The Sino-German Agricultural Centre is a joint initiative of the German Federal Ministry of Food and Agriculture (BMEL) and the Ministry of Agriculture and Rural Affairs of the People's Republic of China (MARA). It was established in March 2015 as a central contact and information point and for coordinating bilateral cooperation between Germany and China in the agricultural and food sector.

China is an important partner for Germany in the field of agriculture and food, both economically and politically. The BMEL has a great interest in playing a constructive role in China's transformation process. Thus, the DCZ brings together stakeholders from the public and private sector and the scientific community. It creates forums in which agricultural issues of common interest are addressed. The spectrum of Sino-German cooperation in the agricultural sector is reflected in the three components of the DCZ: Agricultural Policy Dialogue, Agri-Food Business Dialogue and Scientific Dialogue. Further information can be found on the project website.

https://dcz-china.org/en/the-project.html

Acknowledgement

The Cooperation on Agriculture and Climate Change would not have been as successful without the dedicated contribution of the experts involved. Thus, my sincere thanks go to each and every one of them, including Rita Merkle and Gerhard Rappold, who are not authors of this particular study but contributed in other ways. Further, the whole team of the Sino-German Agricultural Centre was of great support, including its backstopper. It has been a real pleasure to work with all of them.

Chapter 1:
Climate Policies in China and Germany

With contributions from:

Bo Li, Wenzheng Xu
Department of Science, Technology and Education, Ministry of Agriculture and Rural Affairs

Yan Yan
Foreign Economic Cooperation Center, Ministry of Agriculture and Rural Affairs

Hongmin Dong, Yu'e Li
Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences

Yu'e Li, Bin Wang
Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences

Abstract

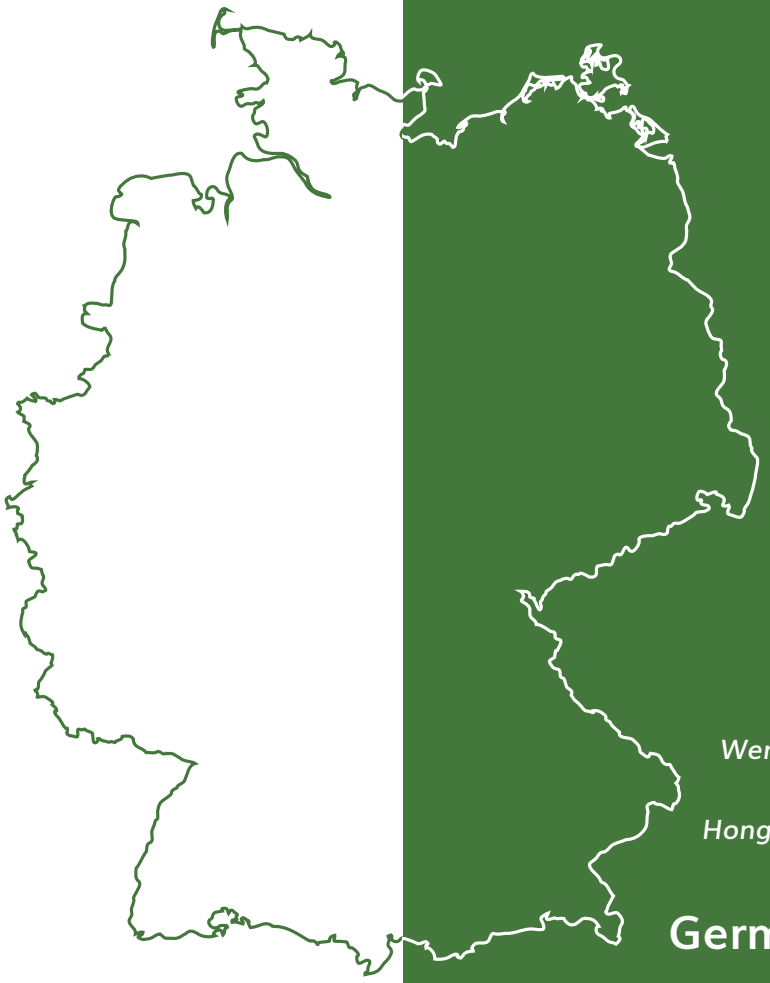
Germany is an active promoter and leader in tackling climate change. It has set targets for reducing greenhouse gas (GHG) emissions by 40% and 55% in 2020 and 2030 respectively, and a long-term goal of achieving net-zero GHG emissions in 2050. The Climate-Protection Law was approved by the German lower house of Parliament in November 2019. The agricultural sector is a main source of GHG emissions. Germany has accordingly formulated short, medium and long-term reduction targets, policy measures and good practices for agricultural GHG emissions to achieve its national reduction targets by 2020, 2030 and 2050. This paper presents German agricultural GHG emission trends, its agricultural policies and measures to address climate change, scientific research and innovation plans, best practices and potentials to reduce greenhouse gas emissions in agriculture, and finally some suggestions for China's agricultural GHG emissions reduction.

Germany's Mitigation Policies and Measures of Climate Change in Agriculture and Its Inspiration to China

Bo Li, Wenzheng Xu
Department of Science, Technology and Education, Ministry of Agriculture and Rural Affairs

Yan Yan
Foreign Economic Cooperation Center, Ministry of Agriculture and Rural Affairs

Hongmin Dong, Yu'e Li
Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences



Bo Li,
Wenzheng Xu,
Yan Yan,
Hongmin Dong,
Yu'e Li

Germany's Mitigation Policies and Measures of Climate Change in Agriculture and Its Inspiration to China

1. Introduction

In June 2019, the Chinese Minister of Agriculture and Rural Affairs (MARA) and the German Federal Minister of Food and Agriculture (BMEL) signed the *Joint Declaration of Intent on Climate Change and Agricultural Cooperation*. They agreed to carry out Sino-German cooperation activities on agriculture and climate change projects, investigate climate change issues in the agricultural sector in China and Germany, exchange climate change impact and mitigation strategies, identify best practices in adaptation and mitigation of climate change, and promote the formulation and implementation of agricultural policies to combat climate change. In order to better implement the *Joint Declaration of Intent on Climate Change and Agricultural Cooperation* signed by the two countries, Chinese experts went to Germany for an exchange visit in August 2019 and visited the BMEL, the Leibniz Institute of Agricultural Engineering and Bioeconomy, the Leibniz Institute of Plant Genetics and Crop Plant Research, the Federal Research Institute for Rural Areas, Forestry and Fisheries, Johann Heinrich von Thünen Institute and other research institutions and agricultural enterprises, in order to learn from Germany's policies and measures, best practices, scientific research and innovation plans in agriculture. This paper introduces Germany's national GHG emission trends, recent (2020), medium (2030) and long-term (2050) policy measures and good practices, and innovation plans to promote the mitigation of climate change in agriculture. Germany's policy measures, best practices, and principles to reduce agricultural GHG emissions can be of help to promote the efficient use of agricultural resources, control non-point source pollution, reduce GHG emissions and drive green agricultural development in China.

2.
Germany's GHG emissions

Germany's total GHG emissions in 2017 were 906.6 million tonnes of carbon dioxide equivalent (CO_2-eq). Germany is one of the major agricultural producers in Europe, and agricultural production activities are a significant source of GHG emissions. From 1990 to 2017, Germany's total agricultural GHG emissions accounted for 5.9-7.5% of its total GHG emissions. In 2017, its agricultural GHG emissions were 66.3 million tonnes CO_2-eq, accounting for 7.3% of its total GHG emissions. Agricultural GHG emissions are mainly CH_4 emissions from enteric fermentation and manure management, N_2O emissions from agricultural soils caused by the application of chemical and organic fertilisers, returning straw to the field, excreted faeces by animals during grazing, and CO_2 emissions from the application of limestone and urea to farmland. In 2017, N_2O emissions from agricultural soils, CH_4 emissions from enteric fermentation, and CH_4 and N_2O emissions from animal manure management accounted for 40.2%, 38.5% and 14.4% respectively of the total agricultural GHG emissions. CO_2 emissions from the application of limestone and urea to farmland accounted for 2.9% and 1.5% respectively of total agricultural GHG emissions (Figure 1).

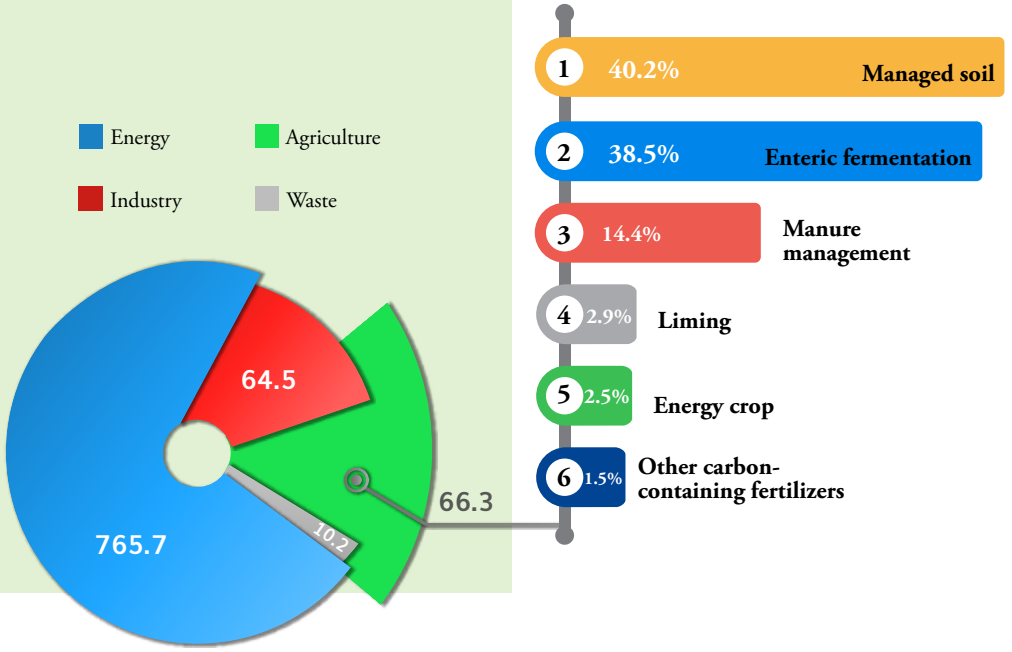


Figure 1.
Germany's GHG emissions in 2017 (million tonnes of CO_2-eq). Adapted from *Common Reporting Format (CRF) for the German Greenhouse Gas Inventory 1990 – 2017*, by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2019, retrieved from https://unfccc.int/documents/194817

From 1990 to 2017, Germany's total GHG emissions fell by 27.5%, and agricultural GHG emissions also indicated a downward trend year by year. Compared with 1990, agricultural GHG emissions in 2017 dropped by 12.923 million tonnes CO_2-eq, a decrease of 16.3%. Germany's agricultural GHG emissions are only lower than those of the Netherlands and Belgium, and slightly higher than those of Denmark, the United Kingdom, Finland, and Italy. It is worth mentioning that three major agricultural countries, including the United States, New Zealand and Canada, have witnessed an increase of their GHG emissions by 10.6%, 13.5%, and 27.8% respectively from 1990 to 2017 (United Nations Framework Convention on Climate Change [UNFCCC], 2019; Figure 2a).

The main reason for the decline in Germany's GHG emissions is that CH_4 emissions from enteric fermentation have reduced by 9.817 million tonnes CO_2-eq, a decrease of 27.8% compared to 1990; GHG emissions from manure management reduced by 2.463 million tonnes CO_2-eq, a decrease of 20.5%; N_2O emissions from agricultural soils also reduced year by year and dropped by 2.007 million tonnes CO_2-eq, a decrease of 7% (Figure 2b) compared to 1990. CO_2 emissions caused by the application of limestone to the farmland reduced by 262,000 tonnes CO_2-eq. CO_2 emissions caused by the application of urea and other carbon-containing fertilisers to the farmland were the same as in 1990. CH_4 and N_2O emissions caused by the fermentation of energy crops had increased rapidly from 390 tonnes CO_2-eq in 1990 to 1.624 million tonnes CO_2-eq in 2017. The decrease in CH_4 emissions from enteric fermentation and manure management is mainly due to the reduction in the inventory of dairy cattle, beef cattle, sheep, and pigs. In 2017, the inventory of these four types of livestock decreased by 33.9%, 38.5%, 43.0% and 13.5% respectively (Federal Environment Agency [FEA], 2019) compared with the inventory of 1990. The decrease in N_2O emissions from agricultural soils was mainly due to the decline in nitrogen input. Compared to 1990, the amount of fertiliser applied has decreased by 23.3% and the amount of manure applied in 2017 by 13.4% (FEA, 2019).

3. Germany's mitigation policies and measures of climate change in agriculture

In order to achieve the 2020 GHG reduction targets, the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) issued the *Climate Action Programme 2020* in 2014, which put forward priority emission reduction measures and contributions of various industries (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety [BMUB], 2014). The government updated the *German Sustainable Development Strategy* in 2018, which explicitly stated to increase the proportion of organic agriculture areas from 6.3% in 2014 to 20% in 2030 (The Federal Government [FGG], 2018). In November 2016, the BMUB passed the *Climate Action Plan 2050*, which proposed medium and long-term targets for the mitigation of climate change, clarified emission reduction targets and development paths for various industries, and listed all technical measures for reducing GHG emissions. Its medium-term target is to reduce Germany's total GHG emissions by 55% by 2030 in comparison to 1990, and the long-term target is to achieve net-zero emissions by 2050 (BMUB, 2016). The Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) published the *Climate Action Plan 2030* in October 2019, reaffirming its national and industrial emission reduction targets for 2030, and identifying technical measures and actions for industrial emission reductions (Federal Ministry of Food and Agriculture [BMEL], 2019).

The German lower house of Parliament approved the Climate-Protection Law in November 2019, which set its medium and long-term GHG reduction targets into law for the first time. Also, the BMEL issued directives on the promotion of innovation in animal husbandry (BMEL, 2016a), in crop production (BMEL, 2016b), in the soil sector (BMEL, 2016c), a temporary call for proposals in the area of raw material plant production for material and energy use (BMEL, 2016d), the *German Fertiliser Ordinance* (Kuhn, 2017), the *Livestock Husbandry Strategy* (BMEL, 2018), and other GHG emission reduction policies (Figure 3).

The *Climate Action Programme 2020*, issued by the BMU in 2014, puts forward two priority actions in the agriculture sector: 1) amending the German Fertiliser Ordinance and calculating fertiliser demands, banning fertilisation in autumn and winter, increasing the capacity of farm manure storage, and improving fertilisation techniques. In addition, the improvement of fertiliser management through an amendment to the German Fertiliser Ordinance to reduce farmland N2O emissions by 3.3 million tonnes CO2-eq and CO2 emissions from fertiliser production by 2.5 million tonnes CO2-eq was addressed. Another priority was to 2) increase the proportion of organic agriculture areas and reduce GHG emissions during the production of fertilisers and pesticides. The additional emission reductions were 250,000 tonnes CO2-eq (BMUB, 2014).

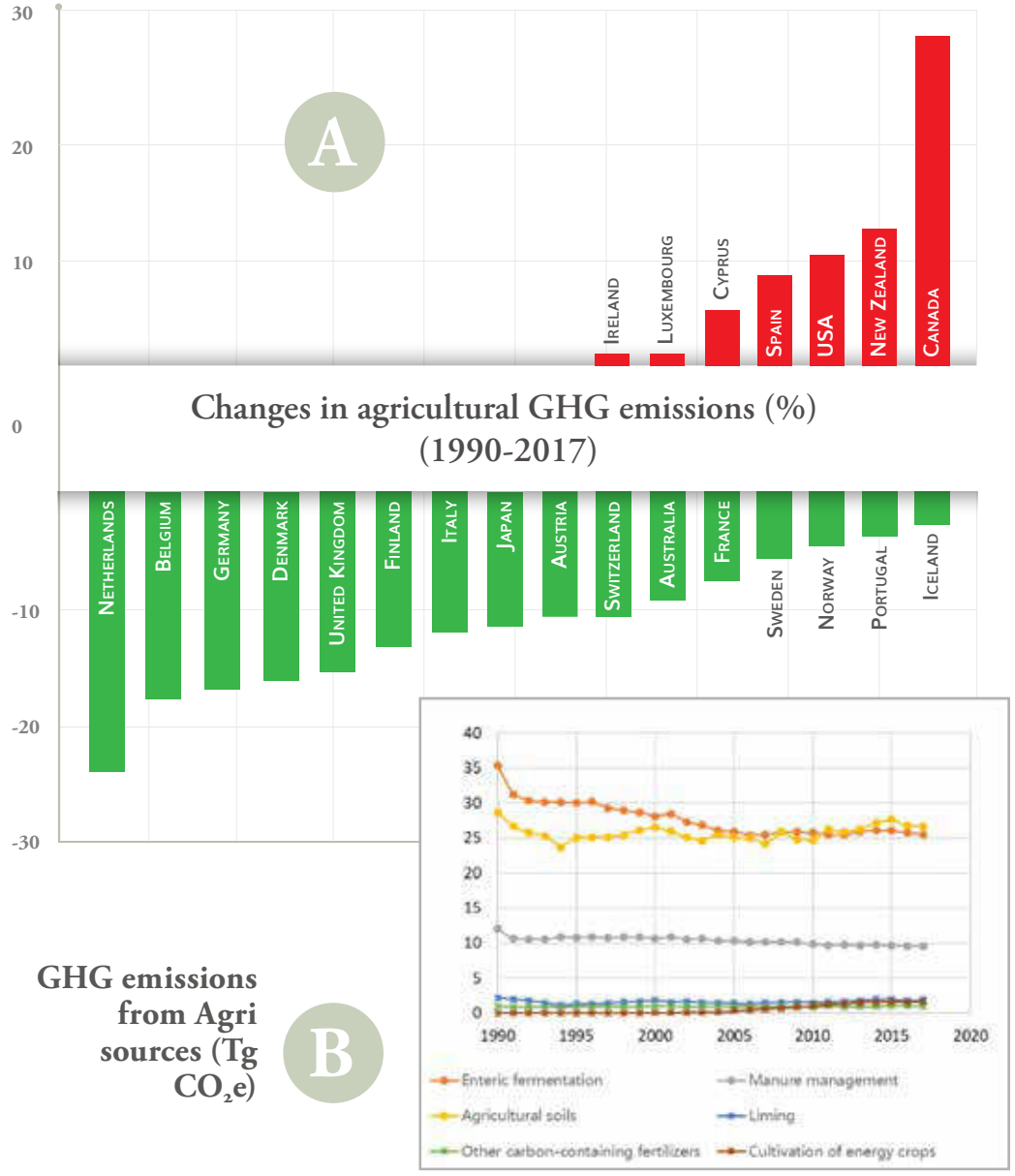


Figure 2. **Trends in agricultural GHG emissions,** a) changes in total agricultural GHG emissions in developed countries from 1990 to 2017; b) changing trends in Germany's primary agricultural GHG emission sources. Adapted from *National Inventory Submissions in 2019 from Annex I Parties,* by United Nations Framework Convention on Climate Change, 2019, retrieved from https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2019

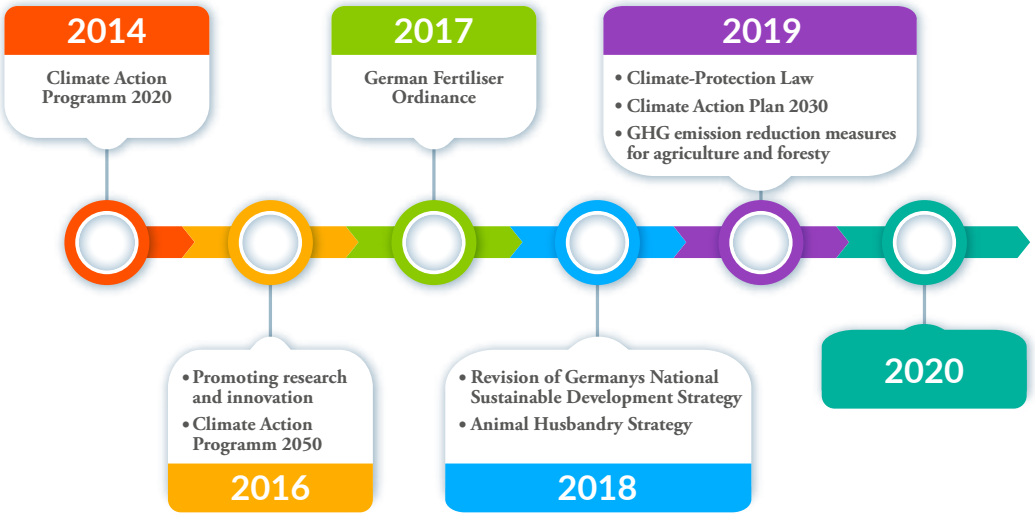


Figure 3. Germany's main policy measures to address climate change and their release dates. Data from BMU (2019), BMUB (2014, 2016), BMEL (2016a, 2016b, 2016c, 2016d, 2018, 2019), FGG (2018), Kuhn (2017).

The *Climate Action Plan 2050* proposed to control agricultural GHG emissions at 58-61 million tonnes CO_2-eq in 2030, which will be 31-34% lower than in 1990, nitrogen surplus within 70 kgN/ha in 2028-2032 and increase organic agriculture areas to 20% in 2030. Work in the agriculture sector focuses on reducing GHG emissions and improving resource efficiency. Emission reduction measures mainly include promoting the implementation of agricultural policies and measures; carrying out the *German Fertiliser Ordinance*, developing technical measures for reducing nitrogen, and supporting farmers to promote gasification of straw and manure by implementing the Common Agricultural Policy (CAP) and the Improvement of the Agricultural Structure and Coastal Protection (GAK); studying climate-friendly livestock breeding and variety selection technologies, formulating livestock husbandry development strategies, and reducing GHG emissions in livestock husbandry; reducing food waste; strengthening scientific research on agricultural GHG emissions reduction (BMUB, 2016).

The *Climate Action Plan 2030* once again puts forward the reduction target of agricultural GHG emissions that must not exceed 58-61 million tonnes CO_2-eq in 2030 (BMU, 2019b). However, against the backdrop of existing policy measures, it is estimated that Germany's agricultural GHG emissions will be 67 million tonnes CO_2-eq in 2030.

Therefore, the *Climate Action Plan 2030* puts forward a set of enhanced emission reduction measures and actions, clarifies actions to be performed for each measure, proposes not to restrict agricultural production and to reduce agricultural competitiveness while simultaneously carrying out emission reduction measures, improving resource utilisation efficiency, taking mitigation and adaptation activities, and meeting the targets of other policy measures (such as sustainable development strategies, agricultural development wars, and air pollution control). Emission reduction measures and actions include:

1. reducing nitrogen surplus, NH_3 and N_2O. From 2021 on, all farms will be required to calculate their nitrogen balance. If the allowable surplus is exceeded, farm owners will be interviewed, facing a potential penalty; other possible measures are adjusting the fertilisation time, improving crop residue management, using low-emission fertilisation technology, increasing the sealed storage ratio of cattle and pig manure (up to 70%), and reducing agricultural NH_3 and N_2O emissions;

2. promoting the production of biogas from manure and straw, biogasification of manure and gas-tight storage of biogas slurry;

3. promotion of organic agriculture, providing financial support and research funding for its development, and implementing organic agriculture strategies;

4. reducing GHG emissions from livestock husbandry. Guided by the protection of animal welfare and taking into account environmental impacts, appropriate actions could include supporting farms with no more than two animal units/ha, promoting the animal welfare labelling system for livestock products, improving the standards of livestock housing, collecting the assessment results of feed production, consumption and demands, formulating overall strategies for the development of livestock husbandry, drawing up binding qualitative animal welfare targets and quantitative environmental targets, and incorporating national livestock husbandry strategies into the overall strategies for reducing livestock emissions;

5. improving energy efficiency and further enhancing agricultural energy-saving technology as well as the use of renewable energy;

6. promoting the energy efficiency of agricultural production and the use of renewable energies (such as geothermal energy and waste heat), regularly checking the sealing of biogas digesters, improving the efficiency of biogas digesters, and carrying out farm energy conservation training and consultation;

7. increasing soil organic carbon storage: advocating crop rotation, building windbreaks and compliance systems for agriculture and forestry, making voluntary accreditation of management measures to increase soil carbon storage and obtaining financial support, and developing tools to accurately assess soil carbon storage in order to increase organic carbon storage, improve soil quality, reduce CO_2 emissions and prevent pollution;

8. protecting permanent grassland, increasing grassland soil carbon storage, continuing to implement regulations for permanent grassland protection and developing grassland strategies to ensure and enhance sustainable grassland use; implementing the Common Agricultural Policy (direct payments to farmers); continuing and improving support for farms adopting low-nitrogen fertiliser inputs, reduced tillage and grassland renewal; carrying on to adopt agricultural and environmental protection measures to promote grassland protection and utilisation, and implementing the LFA subsidy policy under the second pillar of the CAP, which makes permanent grassland maintenance more economically attractive;

9. improving existing policies and measures for peat soil protection, providing necessary financial support for wetland protection, and increasing research and the development of peat soil protection; strengthening research on peat soil substitutes and reducing the use of peat soil for horticultural planting;

10. drawing up a national strategy to reduce and avoid food waste.

The Climate-Protection Law stipulates that the total GHG emissions shall be reduced by at least 55% by 2030 compared to 1990 and realise net-zero emissions by 2050. It specifies the emissions allowed in different sectors, such as energy, industry, construction, transportation, agriculture and forestry, and waste. It also points out requirements and procedures for the monitoring, reporting and verification of GHG emissions in various industries. The federal government is obliged to monitor GHG emissions reduction targets in all industries. Once one sector fails to achieve the emissions reduction target, its competent authority must submit an emergency plan within three months, and the federal government will take relevant measures to meet this emission reduction target by means of consulting relevant expert committees. Detailed carbon emissions data for different sectors will be measured annually by the German Federal Environment Agency and published in March of the following year. An independent expert committee, composed of experts in climate, social, economic, and environmental sectors will evaluate the annual data released by the Federal Environment Agency and report to the lower house of Parliament and the government.

The revised version of the G*erman Fertiliser Ordinance* came into effect at the end of May 2017. The regulation stipulates that the amount of organic fertiliser applied to agricultural land must not exceed 170 kg N/ha; it also requires to calculate the amount of organic nitrogen in manure and straw returning to the field and the formulation of a fertilisation plan based on the output. Further, it stipulates that the nitrogen surplus must not exceed 50 kg N/ha/yr, the phosphate fertiliser surplus must not exceed 10 kg P/ha/yr, and phosphorus-rich soil must not exceed 0 kg P/ha/yr; the time in winter when fertilisation is banned is delayed; a limit of applied fertiliser for catch crop (ammonia nitrogen <30 kg and total nitrogen <60 kg) is set; the requirement that land must be ploughed within 4 hours after fertilisers are applied to the soil surface is stated, as is banning surface fertilisation on farmland in 2020 and surface fertilisation on grassland in 2025 (Kuhn, 2017).

Compared to the *German Fertiliser Ordinance*, the revised version has stricter restrictions on nitrogen surplus, fertilisation time, and soil surface fertilisation, which can significantly improve nitrogen fertiliser utilisation, reduce N_2O and NH_3 emissions into farmland and reduce losses such as the leaching of fertilisers.

In January 2018, the BMEL released the *Livestock Husbandry Strategy* (BMEL, 2018), which aims to improve animal welfare in the livestock industry and to reduce adverse effects on the environment. Simultaneously, the economic foundation for agricultural enterprises and the supply of sustainably produced meat to consumers must be secured. Main measures include improving livestock housing and animal health, popularising animal welfare food certification, supporting the development of farming enterprises with sufficient pastures, and restricting the use of antibiotics. CAP funds are mainly used to support small and medium-sized farming enterprises so that they can meet increasing demands for animal welfare, environment and climate protection. The BMEL is developing a grassland strategy to increase grassland productivity and fulfil its ecological functions.

The Cabinet of Germany approved the ten climate change mitigation measures in the agriculture and forestry sectors in September 2019 to ensure that these climate goals are met (BMEL, 2019). The nine agriculture-related measures will reduce annual emissions by 12.3-34.1 million tonnes CO_2-eq (Table 1).

No	Agricultural measures for carbon emissions reduction and carbon fixation	Estimated emissions reduction (10,000 tonnes CO_2-eq per year)
1	Reducing nitrogen surplus, promoting sealed storage of biogas slurry, using nitrification inhibitors, and taking crop variety improvement and management measures	190-750
2	Producing biogas by using livestock manure and straw, and promoting sealed storage of biogas slurry	200-240
3	Developing organic agriculture and reducing the use of chemical fertilisers	40-120
4	Improving animal welfare, developing livestock housing which can reduce GHG emissions, advocating precision feeding technology and reducing feed waste	30-100
5	Improving energy-saving technologies for agricultural production and promote the use of renewable energies	90-150
6	Increasing soil organic carbon storage through measures such as reducing cultivation, adopting no-tillage, planting catch crops, developing organic agriculture and strengthening grassland protection	100-300
7	Promoting permanent grassland protection and formulating a grassland strategy to ensure and strengthen the innovative management of grassland	-
8	Formulating peat soil protection policies and reduction of the use of peat soil for gardening	300-850
9	Preservation and sustainable management of forests and utilization of wood	-
10	Implementing the National Strategy for Food Waste Reduction and Germany's National Sustainable Development Strategy to increase the supplies of climate-friendly and healthy food in public catering	300-790
	Total	**1250-3300**

Table 1.
Note: Adapted from *Klimakabinett morgen: Klimaschutzmaßnahmen des Bundesagrarministeriums*, by Federal Ministry of Food and Agriculture, retrieved from https://www.bmel.de/SharedDocs/Pressemitteilungen/2019/190919-Klimakabinett.html Copyright 2019 by BMEL.

4. Science and technology innovation support for agricultural mitigation of climate change

In 2015, the United Nations Climate Change Conference (COP 21) reached the Paris Agreement. In order to implement the agreement and promote the reduction of GHG emissions in the agricultural sector and adapt to climate change, the BMEL launched four research projects to encourage industry-research cooperation, innovation in practical and economical mitigation and adaptation technologies, and promote synergies between climate protection and food security, climate change mitigation and adaptation, climate protection and other environmental protection.

The *Directive on the promotion of innovation in animal husbandry* (BMEL, 2016a) aims to improve and develop technical measures to reduce emissions and adapt to various production stages of livestock husbandry, to formulate feed strategies and exploit the potential of variety cultivation in addressing climate change. Further, the directive targets the sustainable and stable development of livestock husbandry, significantly reducing emissions during its development and enhancing the adaptation to climate change. In terms of the mitigation of GHG emissions, support measures include: 1) improving animal nutrition, optimising feed management to reduce GHG emissions and enhancing its input/output ratio; 2) enhancing animal breeding and reducing methane emissions, such as reducing GHG emissions by increasing feed digestibility or increasing adaptive capacity; 3) improving official management; 4) perfecting the environmental conditions inside livestock housing; 5) optimising manure management in the farms (manure management in houses and during storage and processing); 6) encouraging the implementation of new technologies and knowledge transfer for energy and nutrient recovery; 7) developing an evaluation index system; etcetera (BMEL, 2016a).

The *Directive on the promotion of innovation in crop production* (BMEL, 2016b) aims to significantly reduce GHG emissions in crop production through the development of emissions reduction and adaptation technologies, to increase crop resistance to biotic and abiotic stress, and enhance climate change adaptation. Support measures include: 1) drawing up technical measures to reduce NH_3 and N_2O emissions; 2) planting catch crops specifically with roots and/or nitrate/nitrogen leaching; 3) promoting agricultural knowledge transfer and providing decision-making support, providing effective GHG emission reduction programmes, and improving the farmers' management capacity in terms of emissions reduction; 4) establishing an evaluation index system for emissions reduction; 5) setting up an effective market mechanism and incentive system (BMEL, 2016b).

The *Directive on the promotion of innovation in the soil sector* (BMEL, 2016c) aims to reduce GHG emissions and promote soil carbon sinks through the development of innovative soil management and fertilisation technologies as well as to maintain soil productivity and improve adaptation to climate change. Support measures include: 1) optimising the application of chemical fertilisers, such as reducing GHG emissions in the industrial chain during fertiliser transportation and application, before, during and after application and improving fertiliser use efficiency; 2) reducing and eliminating soil compaction; 3) optimising biotic and abiotic soil characteristics to reduce GHG emissions; 4) identifying, protecting and promoting soil carbon sinks, developing optimised management technologies to protect and enhance soil organic matter for an extended period, monitoring carbon content, and analysing organic carbon reserves and changes under different management options (BMEL, 2016c).

The *Measures to reduce greenhouse gas emissions in the area of raw material plant production for material and energy use* (BMEL, 2016d) aims to reduce GHG emissions in the production of renewable raw materials and energy crops through technology research and development and avoiding land-use changes caused by the production of biomass raw materials.

Support measures include: 1) Research and development of technologies for the production of renewable raw materials and energy crops in different soil-climate zones, including the selection of crops, design of crop rotation systems, efficient use of inorganic and organic fertilisers and other resources, use of by-products, production of GHG emissions and microbial processes for carbon storage, and investigation and analysis of farmland management measures and crucial technologies on reducing GHG emissions; 2) adopting comprehensive measures for the production of renewable raw materials to protect soils with high organic carbon content (such as permanent grasslands and swamps after flooding); 3) evaluation and promotion of emission reduction technology and measures, including analysis and optimisation of the overall economic and environmental efficiency, models and calculation methods of GHG emission reduction measures, and consideration of these measures' impacts on other resources (such as water and biodiversity), contributions to climate protection, suggestions and consultation on GHG emission measures (BMEL, 2016d).

5. Good practices in agricultural mitigation of climate change

Germany has explored a lot of good practices in reducing GHG emissions in livestock husbandry, manure management, crop planting, and management, which have been widely promoted and applied as summarised in Table 2.

Emissions reduction measures	Best practice
Reducing animal CH_4 emissions	• Improving control over the environment of livestock housing, enhancing animal welfare and health, and reducing the emissions of animal products per unit • Promoting low protein feed to reduce the N content in animal manure • Increasing the milk production and reducing methane emissions from cows • Ensuring that farms have adequate pastures, and reduce GHG emissions during feed production and transportation
Reducing GHG emissions from manure management and promoting biogas recycling	• Encouraging manure anaerobic fermentation and biogas recovery • Storing animal manure outside the facility to reduce methane emissions • Covering liquid faeces to reduce CH_4 and N_2O emissions • Promoting the sealed storage of liquid faeces to reduce CH_4 and NH_3 emissions • Reducing the solid content of liquid faeces to reduce CH_4 emissions • Increasing the nitrogen content of biogas slurry and using it as a substitute for fertiliser • Reducing ammonia emissions by using acidified manure • Carrying out the deep application of biogas slurry fertiliser or covering it after fertilisation to reduce N_2O and NH_3 emissions
Reducing N_2O emissions from agricultural soils	• Calculating fertiliser application based on soil and historical yield to reduce nitrogen surplus in the soil • Applying slow release fertilisers and adding nitrification inhibitors into fertilisers in order to improve their utilisation efficiency • Promoting tillage after surface fertiliser application or deep fertiliser application to reduce nitrogen loss • Avoiding fertilisation in autumn and winter and improving the nitrogen fertiliser utilisation rate • Reduction of cultivation, introduction of no-tillage and promotion of strip farming and crop cover in order to reduce soil erosion • Increasing soil carbon storage through crop rotation, planting catch crops and applying green manure • Enhancing the large-scale utilisation of crop straws to increase soil organic carbon storage • Planting legumes and reducing the application of nitrogen fertilisers • Promoting organic agriculture, cutting down nitrogen fertiliser application and increasing soil organic carbon storage
Protecting wetland grassland	• Avoiding wetland drainage, protecting and restoring wetlands, and reducing soil CO_2 emissions • Prohibition of recultivation of grassland as farmland and increase of organic carbon storage in the soil • Reducing the use of peat soil as a horticultural substrate
Reducing GHG emissions by changing the consumption methods	• Purchasing food based on the intake of animal products recommended by the German Nutrition Society • Encouraging dietary changes, climate protection, and reducing the consumption of animal products • Reduction of food waste • Reduction of the consumption of bottled water • Controlling air cargo • Exploring climate labels

Table 2. **Best practices in agricultural mitigation of climate change**
Note: Adapted from Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection & Scientific Advisory Board on Forest Policy, 2016; Naumann & Frelih-Larsen, 2010; BMUB, 2017; Yi et al., 2018

6. Comparison of Chinese and German agricultural emission reduction policies and some suggestions

Through exchange, we believe that German agricultural policies and technologies in response to climate change have played a vital role in reducing carbon dioxide emissions, mitigating and adapting to climate change, and thus can be helpful for China.

Germany has formulated a series of policies and measures for tackling climate change in the agriculture sector, set the targets for reducing national net GHG emissions by 2020, 2030, and 2050 by 40%, 55%, and 100% respectively in comparison to 1990 levels, proposed policy measures, emission reduction targets and potential for each specific measure to reduce GHG emissions (BMUB, 2014, 2016; BMEL, 2019), and also put forward medium and long-term emission reduction targets in the form of legislation. China's National Climate Change Programme (National Development and Reform Commission [NRDC], 2007), released in 2007, is China's first policy to address climate change, including agricultural mitigation and adaptation measures.

China's 12th Five-Year Plan (National People's Congress [NPC], 2011) and 13th Five-Year Plan (NPC, 2016) for controlling GHG emissions, and the report *Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions*, submitted to the United Nations by China (NDRC, 2015), have proposed different GHG control targets at different times. CO_2 emission intensity in 2020 and 2030 is to be reduced by 40-45% and 60-65% respectively in comparison to 2005. In these policy documents, guidelines and relevant targets for reducing GHG emissions in the agriculture sector are also explicitly stipulated. The determination and efforts of China and Germany in combating climate change are clearly reflected in the integrity, coherence and operability of the above-mentioned policy measures.

In the *Climate Protection Programme 2030* issued by the German government, the principle of adopting measures to reduce GHG emissions in the agriculture sector (BMU, 2019b) is proposed, that is, without restricting agricultural competition or reducing agricultural competitiveness, creating synergies between mitigation and adaptation strategies, improving resource utilisation and meeting the goals of other policies and measures. China is a country with a large population, minimal cultivated land and water resources, and a fragile ecosystem. Ensuring food security, eliminating poverty, protecting the environment, and promoting sustainable agricultural development are top priorities for China.

All emission reduction policies and measures formulated and implemented by the government should increase food production capacity, the farmers' income, enhance the farmers' adaptive capacity, and improve the utilisation efficiency of pesticides, fertilisers, and irrigation water while reducing agricultural GHG emissions and promoting agricultural soil carbon sinks. Also, the agricultural sector's principles for combating climate change in both countries are consistent, and both strive to reduce agricultural GHG emissions on the premise of promoting sustainable agricultural development and ensuring the interests of farmers.

At present, China has issued policy documents such as the *Opinions of the General Office of the State Council on Accelerating the Resource Utilization of Livestock and Poultry Manure and the Opinions of the General Office of the State Council on Innovative System Mechanisms to Promote the Green Development of Agriculture* to carry out particular actions such as zero growth in the consumption of chemical fertilisers and pesticides, and the utilisation of livestock and poultry manure resources, which have contributed to treating agricultural non-point source pollution, while some GHG emission reduction policies can also increase the farmers' savings and income. However, some emission reduction measures may require increased investments, such as the use of highly efficient fertilisers and returning straw to the field. The Chinese government should continue to strengthen the existing policy support and explore the formulation of regulations on the limited use of fertilisers, the application of high-efficiency and low-emission fertilisers, the utilisation of low-emission fertilisation technology, and the recycling of agricultural waste such as crop straw and livestock manure; further, relevant policies for consumers on climate change should be explored and China's agricultural climate mitigation strategies to promote green agricultural development should be formulated.

In the past 30 years, China has researched controlling CH_4 emissions from paddy fields, N_2O emissions from cropland, strengthening the prevention and control of grassland disasters and farmland conservation, and improving soil carbon storage capacity. However, there are still some deficiencies in fundamental and applied research. China should continue to systematically review technical measures and introduce advanced technologies and practices to reduce GHG emissions and increase carbon sequestration in soil, carry out demonstrations, clarify technical measures and best practices for emission reduction applicable to different planting systems and climate zones, formulate technical regulations for emission reduction, explore carbon labelling for agricultural products grown in modern agricultural demonstration zones and projects, enhance consumers' awareness of their contribution to climate change and climate change mitigation, and improve climate change mitigation technologies, knowledge dissemination, and science popularisation.

References:

BMEL (Federal Ministry of Food and Agriculture) (2016a). *Richtlinie über die Förderung von Innovationen in der Tierhaltung als Beitrag zum Klimaschutz gemäß Pariser Abkommen (COP 21) und zur Anpassung an Klimaänderungen im Rahmen des Programms zur Innovationsförderung.* Retrieved from https://www.bmel.de/SharedDocs/Downloads/Landwirtschaft/Klima-und-Umwelt/Klimaschutz/Foerderbekannmachung-COP21-Klimaschutz-Tier.pdf?__blob=publicationFile

BMEL (Federal Ministry of Food and Agriculture) (2016b). *Richtlinie über die Förderung von Innovationen in der Pflanzenproduktion als Beitrag zum Klimaschutz gemäß Pariser Abkommen (COP 21) und zur Anpassung an Klimaänderungen im Rahmen des Programms zur Innovationsförderung.* Retrieved from https://www.bmel.de/SharedDocs/Downloads/Landwirtschaft/Klima-und-Umwelt/Klimaschutz/Foerderbekannmachung-COP21-Klimaschutz-Pflanze.html

BMEL (Federal Ministry of Food and Agriculture) (2016c). *Richtlinie über die Förderung von Innovationen im Themenbereich Boden als Beitrag zum Klimaschutz gemäß Pariser Abkommen (COP 21) und zur Anpassung an Klimaänderungen im Rahmen des Programms zur Innovationsförderung.* Retrieved from https://www.bmel.de/SharedDocs/Downloads/Landwirtschaft/Klima-und-Umwelt/Klimaschutz/Foerderbekannmachung-COP21-Klimaschutz-Boden.html

BMEL (Federal Ministry of Food and Agriculture) (2018). *Livestock Husbandry Strategy.* Retrieved from https://www.bmel.de/SharedDocs/Downloads/EN/Animals/Summary_Nutztierhaltungsstrategie.pdf?__blob=publicationFile

BMEL (Federal Ministry of Food and Agriculture) (2016d). B*efristeter Aufruf über die Förderung von "Maßnahmen zur Minderung von Treibhausgasemissionen im Bereich der Rohstoff-pflanzenproduktion für die stoffliche und energetische Nutzung" als Beitrag zum Klimaschutz gemäß Übereinkommen von Paris (COP 21) im Rahmen des Förderprogramms Nachwachsende Rohstoffe.* Retrieved from https://www.bmel.de/SharedDocs/Downloads/Landwirtschaft/Klima-und-Umwelt/Klimaschutz/Foerderbekannmachung-FPNR-COP21-THG-Minderung-FPN.pdf?__blob=publicationFile

BMEL (Federal Ministry of Food and Agriculture) (2019). *Klimakabinett morgen: Klimaschutz-maßnahmen des Bundesagrarministeriums.* Retrieved from https://www.bmel.de/SharedDocs/Pressemitteilungen/2019/190919-Klimakabinett.html

BMUB (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety) (2014). *The German Government's Climate Action Programme 2020: Cabinet decision of 3 December 2014.* Retrieved from https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/aktionsprogramm_klimaschutz_2020_broschuere_en_bf.pdf

BMUB (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety) (2016). *Klimaschutzplan 2050: Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung*. Retrieved from https://www.bmu.de/en/publication/klimaschutzplan-2050/

BMUB (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety) (2017). *Germany's Seventh National Communication on Climate Change: A report under the United Nations Framework Convention on Climate Change 2017.* Retrieved from https://unfccc.int/documents/198253

BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) (2019a). *Common Reporting Format (CRF) for the German Greenhouse Gas Inventory 1990 – 2017.* Retrieved from https://unfccc.int/documents/194817

BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) (2019b). *Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050*. Retrieved from https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzprogramm_2030_umsetzung_klimaschutzplan.pdf

FEA (Federal Environment Agency) (2019). *National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2017: Federal Environment Agency.* Retrieved from https://unfccc.int/documents/194930

FGG (The Federal Government) (2018). *German Sustainable Development Strategy: 2018 Update.* Retrieved from https://www.bundesregierung.de/resource/blob/975274/1588964/1b24acbed2b-731744c2ffa4ca9f3a6fc/2019-03-13-dns-aktualisierung-2018-englisch-data.pdf?download=1

Kuhn, T. (2017). The revision of the German Fertiliser Ordinance in 2017. In T, Heckelei (Ed.). *Agricultural and Resource Economics, Discussion Paper* (2017:2, 1-26). Bonn, Germany: Institute for Food and Resource Economics. Retrieved from http://www.ilr.uni-bonn.de/agpo/publ/dispap/download/dispap17_02.pdf

Naumann, S., & Frelih-Larsen, A. (2010). *Klimaschutz in der Landwirtschaft: Ziele und Anforderungen zur Senkung von Treibhausgasemissionen*. Berlin, Germany: NABU-Bundesverband. Retrieved from https://www.nabu.de/imperia/md/content/nabude/landwirtschaft/klimaschutz-landwirtschaft-web.pdf

NDRC (National Development and Reform Commission) (2007). *China's National Climate Change Programme.* Retrieved from https://www.greengrowthknowledge.org/sites/default/files/downloads/policy-database/%20China%27s%20National%20Climate%20Change%20Programme%20%282007%29.pdf

NDRC (National Development and Reform Commission) (2015). *The Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions.* Retrieved from https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/China/1/China's%20INDC%20-%20on%2030%20June%202015.pdf

National People's Congress (2011). *China's 12th Five-Year Plan (2011-2015) for National Economic and Social Development.* Retrieved from http://www.gov.cn/2011lh/content_1825838.htm (in Chinese)

National People's Congress (2016). *China's 13th Five-Year Plan (2016-2020) for National Economic and Social Development.* Retrieved from http://www.gov.cn/xinwen/2016-03/17/content_5054992.htm (in Chinese)

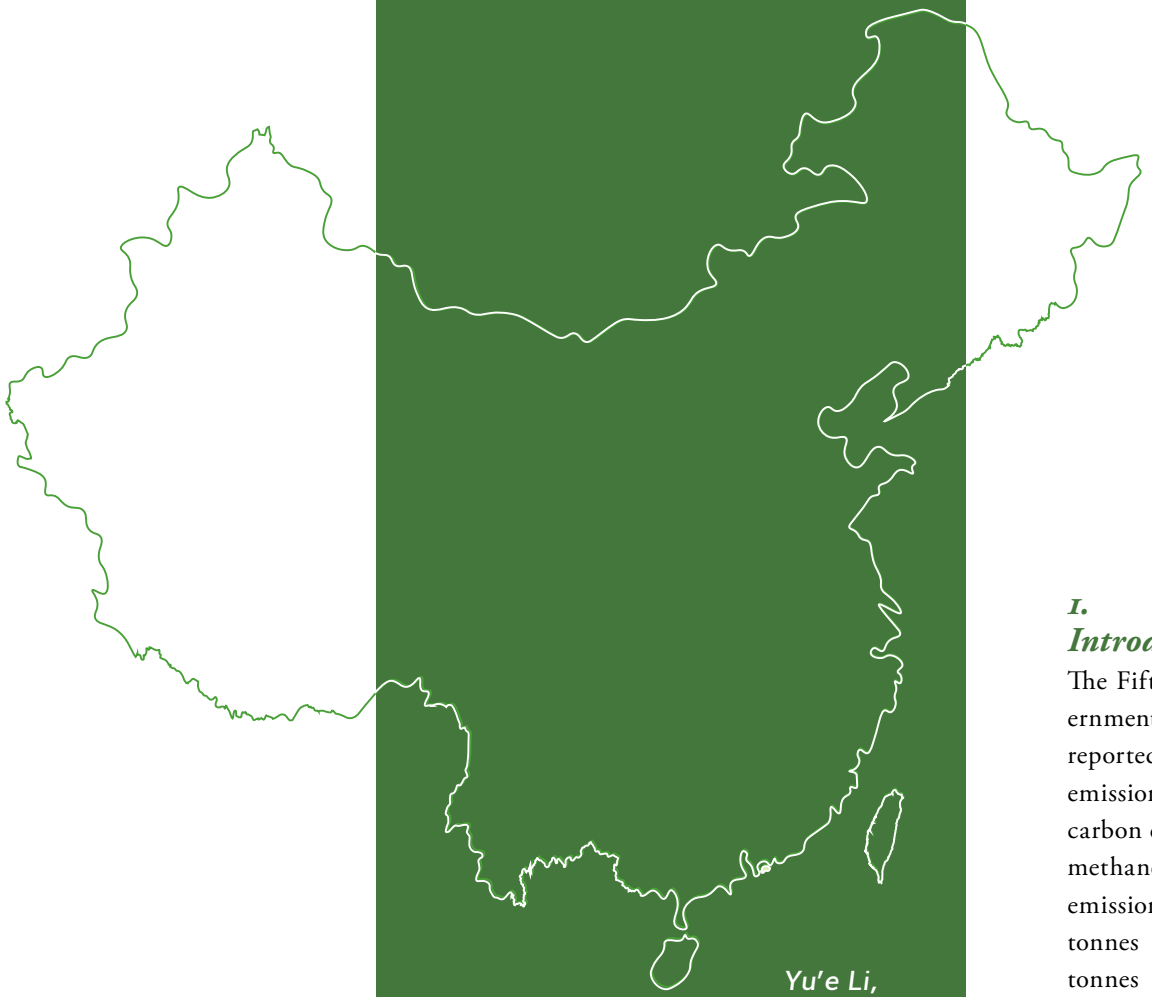
Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection & Scientific Advisory Board on Forest Policy (2016). *Climate change mitigation in agriculture and forestry and in the downstream sectors of food and timber use: Executive Summary.* Bonn, Germany: BMEL. Retrieved from https://buel.bmel.de/index.php/buel/article/view/175/KlimaschutzGutachten%20engl.

UNFCCC (United Nations Framework Convention on Climate Change) (2019). *2019 Annex I Party GHG Inventory Submissions.* Retrieved from https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2019

Yi, X., Chen, Z., Chen, S., Yin, C., You, F., & Yuan, M. (2018). Practice of the sustainable utilization of farmland resources in Germany and its implications to China under the framework of EU common agricultural policy. *Research of Agricultural Modernization*, 39(1), 65-70.

Mitigation Policies, Measures, and Recommendations for the Agricultural Sector of China

Yu'e Li, Bin Wang
Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences



Yu'e Li,
Bin Wang

Mitigation Policies, Measures, and Recommendations for the Agricultural Sector of China

1. Introduction

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) reported that global greenhouse gas (GHG) emissions in 2010 were 49 ± 4.5 billion tonnes of carbon dioxide equivalent (CO_2-eq), of which methane (CH_4) and nitrous oxide (N_2O) emissions accounted for 16% (7.8 ± 1.6 billion tonnes CO_2-eq) and 6.2% (3.1± 1.9 billion tonnes CO_2-eq) respectively of total GHG emissions. Agriculture is the primary source of CH_4 and N_2O emissions, and those from crop cultivation and the livestock sector (CH_4 and N_2O) account for about 10-12% of total global GHG emissions (Smith et al., 2014). China's total GHG emissions in 2014 were 12.3 billion tonnes CO_2-eq, with agricultural production activities being a significant contributor to these GHG emissions. Agricultural GHG emissions accounted for 6.7% of total emissions, with 41.5% and 59.5% respectively of China's total CH_4 and N_2O emissions (People's Republic of China [PRC], 2018). China attaches immense importance to combating climate change and has therefore introduced and implemented a number of policies and measures to reduce GHG emissions and integrated mitigation policies into the *12th Five-Year Plan (2011-2015)* and *13th Five-Year Plan (2016-2020) for National Economic and Social Development.* In 2009 and 2015, China made commitments on GHG control targets for 2020 and 2030. The agricultural sector has also formulated relevant measures to control agricultural non-point source pollution and GHG emissions and to promote the green development of agriculture.

2. China's agricultural production status and GHG emissions

2.1 China's agricultural production status

During 1980-2018, China's total grain production increased significantly by 105%. In particular, rice (52%), wheat (138%) and maize (311%) showed remarkable increases. Between 1982 and 2018, meat and milk production increased by 4.4 and 26 times respectively and egg production 10.2 times (National Bureau of Statistics of China [NBS], 1985, 2019). The rapid development of China's agricultural production is closely related to high input use. In 2018, China's chemical fertilisers consumption was 56.53 million tonnes (equivalent to pure quantity), of which 20.65 million tonnes were nitrogen fertilisers and 22.69 million tonnes compound fertilisers. In China, the application of nitrogen and phosphorus (P_2O_5) fertilisers increased by 57.4% and 102.5% respectively; the application of potassium (K_2O) and compound fertilisers increased by 6.6 and 11.6 times respectively during 1986-2018 (NBS 1987, 2019). In 2017, the amounts of nitrogen, phosphorus (P_2O_5) and potassium (K_2O) application per unit of cropland in China was much higher than the global average. It was 3.1, 3.2 and 3.3 times the world average and 1.8, 5.2 and 2.4 times the average German application (Statistics | Food and Agriculture Organization of the United Nations [FAOSTAT], 2019). Due to excessive fertilisation and the rapid development of animal husbandry, water, air and soil pollution are severe, and a large amount of GHGs was emitted.

2.2 GHG emissions from agricultural activities

China has submitted five national inventories to the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). Greenhouse gas emissions are gradually increasing, but the growth rate was decreasing in 2012-2014. Without considering the carbon removal in *Land Use, Land-Use Change and Forestry (LULUCF)*, China's total GHG emissions in 2014 were 12.3 billion tonnes CO_2-eq. Agriculture is an essential source of GHG emissions. GHG emissions from the agricultural sector in China for the years 1994, 2005, 2010, 2012 and 2014 accounted for 14.9%, 9.8%, 7.9%, 7.9% and 6.7% of total national GHG emissions respectively (Figure 1a). GHG emissions from the agricultural sector (938 million tonnes of CO_2-eq) were highest in 2012 during the period of 1994-2014 and were reduced to 830 million tonnes of CO_2-eq in 2014 (Fig. 1b). The reduction in GHG emissions from agriculture in 2014 is mainly due to reduced livestock numbers. Fertilisation, livestock breeding, rice cultivation, and manure management are the main sources of agricultural GHG emissions. In 2014, the four emission sources (energy, industry, agriculture, and waste) accounted for 43%, 26%, 20%, and 10% of total agricultural GHG emissions respectively (PRC, 2018). Reducing farmland fertilisation and increasing fertiliser use efficiency, improving animal management, and improving water and fertiliser management of paddy field are the leading measures to reduce GHG emissions from the agricultural sector in China.

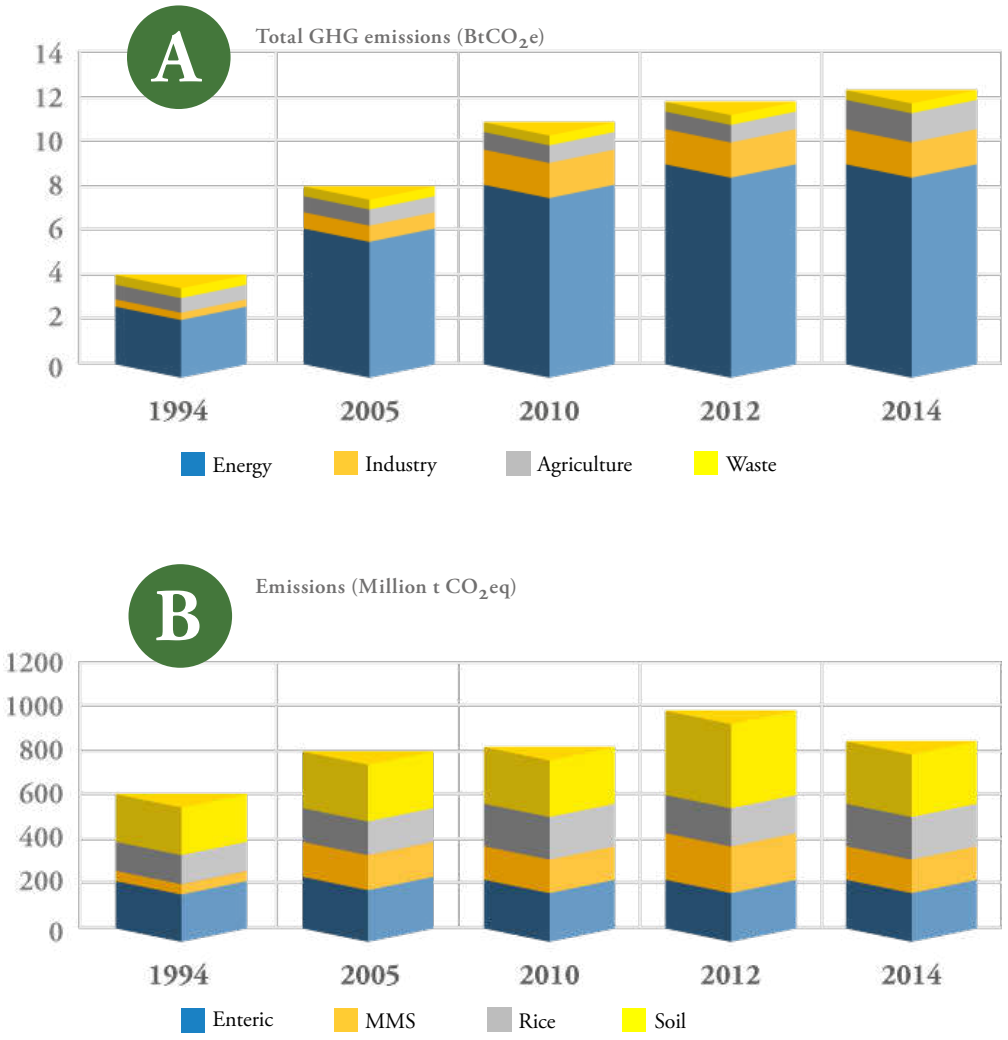


Figure 1. **1. GHG emissions from different sectors in China,**

a) composition of the GHG emissions in China;
b) composition of the GHG emissions from the agricultural sector in China.

Adapted from *The People's Republic of China Second Biennial Update Report on Climate Change*, by People's Republic of China (PRC), 2018, retrieved from http://english.mee.gov.cn/Resources/Reports/reports/201907/P020190702568751604320.pdf

3. Policies and measures to mitigate climate change in China

3.1 Climate change policies and measures at the national level

In 2007, it was the first time that China formulated *China's National Climate Change Programme* (National Development and Reform Commission of China [NDRC], 2007). Work plans on greenhouse gas emission control were issued in the 12*th Five-Year Plan* 2011 and the *13th Five-Year Plan* 2016. The *National Plan on Climate Change 2014-2020* was issued in 2014 (NDRC, 2014). China submitted their *intended nationally determined contributions (INDCs)* to the UNFCCC in 2015 and committed to the emission reduction targets for 2030 (Table 1; NDRC, 2015). In each of these policies, mitigation actions in the agricultural sector are important components. Significant measures to mitigate climate change in agriculture include 1) improving water and fertiliser management and reducing CH4 emissions from rice paddies; 2) improving fertilisation technology to reduce chemical fertiliser use and N2O emissions from cropland; 3) promoting the utilisation of agricultural waste resources, reducing GHG emissions and fossil fuel utilisation; 4) enhancing protection of cropland and grassland from degradation, and soil organic carbon sequestration of farmland and grassland; 5) encouraging energy-saving agricultural and fishery machinery, fishing boats, and reducing fossil fuel consumption and CO2 emissions during agricultural production; and 6) enhancing research base and management techniques for intensive livestock farming to develop excellent ruminant breeds (Table 1). The Opinions on Adopting Innovative Systems and Mechanisms and Promoting Green Agricultural Development not only emphasise the comprehensive utilisation of agricultural waste in the agricultural production process, but also focus on the green production of inputs, green circulation of processing and distribution, low consumption and low carbon emission in marketing and packaging, and finally highlight rational food consumption (General Office of the CPC Central Committee and General Office of the State Council [CPCCC and State Council], 2017). This process promotes a low-carbon recycling lifestyle, such as saving and reducing food waste.

3.2 Policies and measures to mitigate climate change in the agricultural sector

In the past five years, a series of policies and measures have been formulated for agricultural non-point pollution control, overall utilisation of agricultural waste, and the improvement of cropland productivity. The development goals and actions were proposed simultaneously (Table 2). Actions to reduce agricultural GHG emissions and promote soil carbon storage include increasing the quality of arable land, applying scientific fertilisation and methods, and promoting the comprehensive utilisation of livestock, poultry waste and straw. The implementation of these measures will improve soil carbon storage and reduce GHG emissions from the management of cropland and livestock manure.

4. Progress on the mitigation of climate change

Since 2015, the Ministry of Agriculture (renamed to the Ministry of Agriculture and Rural Affairs in 2018) has been implementing zero growth measures for fertilisers in accordance with central government guidelines. Significant progress on the reduction of fertilisation application has been achieved. The efficiency of fertilisers was significantly improved. In 2019, the nitrogen use efficiency of chemical fertilisers for rice, corn and wheat in China was 39.2%, showing an increase of 4 percentage points compared to the 2015 level. The main reasons for the increase in fertiliser utilisation efficiency are: 1) chemical fertiliser reduction and efficiency improvement have become critical practices for promoting the green development of agriculture in various regions; 2) the extension of fertiliser-saving technologies. Soil testing and formula fertilisation, fertigation, deep application of fertiliser using machinery, and organic fertiliser replacement have been widely adopted. In 2019, the application area of soil testing and formula fertilisation technology in China was 129 million ha, and the technical coverage rate reached 89.3%; 3) green and highly efficient products were widely used. The application area of new fertilisers such as slow released fertilisers and water-soluble fertilisers reached 16.3 million ha, and organic fertiliser application areas exceeded 36.7 million ha (Ministry of Agriculture and Rural Affairs [MARA], 2019). According to the *China Statistical Yearbook 2019,* fertiliser output in 2018 was 56.53 million tonnes (NBS, 2019), a decrease of 2.06 million tonnes from 2017. According to the estimates on CO2 emission factors for nitrogen fertiliser production, 2.116 t CE/t N (Chen et al., 2015), the zero-growth action on chemical fertilisers reduced CO2 emissions from fertiliser production by 11.7 million tonnes CO2-eq.

Policies	Year of issue	Targets	Measures
China's National Climate Change Programme [a]	*2007*	20% reduction of energy consumption per unit of GDP (carbon intensity) by 2010 compared to 2005 levels	• Selecting and breeding high-yield and low-emission varieties, improving water and fertiliser management, and controlling farmland methane emissions [a, b, c, e] • Promoting soil testing and formula fertilisation, replacement of chemical fertiliser with organic fertiliser, implementing zero growth of chemical fertiliser use, and reducing nitrous oxide emissions from cropland [a, b, c, d, e, g] • Developing energy-saving agricultural and fishing machinery, and fishing boats [b, c] • Strengthening farmland conservation, promoting the return of straw to field and reduced tillage, improving soil quality, and increasing soil organic carbon storage [a, b, c, e, g] • Establishing a long-term mechanism for grassland ecological compensation, implementing the return of grazing land to grassland, promoting grass-animal balance, curbing grassland degradation, and enhancing grassland soil organic carbon storage [b, c, d, e, g;] • Researching and developing livestock breeding management technologies [a] • Establishing a circular agricultural system, promoting the comprehensive utilisation of livestock waste and crop straw, and improving the mechanism for a comprehensive recycling system for straw and animal waste [a, b, c, d, e, f, g] • Carrying out pilot demonstrations of low-carbon agriculture projects [c, e] • Establishing a mechanism for a green and low-carbon agricultural production system, establishing a low-carbon, low-consumption, circular, and efficient processing and distribution system [g]
Work Plan for the Control of Greenhouse Gas Emissions during the 12th Five-Year Plan Period (2011-2015) [b]	*2011*	17% reduction in carbon intensity by 2015 compared to 2010 levels	
The National Plan on Climate Change 2014-2020 was issued in 2014 [c]	*2014*	40-45% reduction in carbon intensity by 2020 compared to 2005 levels	
Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions [d]	*2015*	Reaching the peak of carbon dioxide emissions around 2030 and efforts to reach the peak early; reduction of CO_2 emission intensity by 60-65% compared to 2005 levels	
Work Plan for the Control of Greenhouse Gas Emissions during the 13th Five-Year Plan Period (2016-2020) [e]	*2016*	Lowering carbon intensity by 18% by 2020 compared to 2015 levels	
Opinions of the general office of the state council on accelerating the resource utilization of livestock and poultry breeding wastes [f]	*2017*	Achieving a comprehensive utilisation rate of livestock and poultry manure of more than 75% by 2020	
Opinions on Adopting Innovative Systems and Mechanisms and Promoting Green Agricultural Development [g]	*2017*	By 2020, total grain production capacity will be stable at more than 550 million tonnes; the quality of cultivated land will increase nationwide by an average of 0.5 grades compared to 2015; the use of fertilisers and pesticides for major crops will achieve zero growth, and the utilisation rate of fertilisers and pesticides will reach 40%. The overall utilisation rate of straw and animal waste will reach 85% and 75% respectively. By 2030, the utilisation rate of chemical fertilisers and pesticides will continue to decline, and agricultural waste will be fully recycled.	

Table 1. **Policies and measures to address climate change in China**

Note: Data retrieved from

a http://www.china.com.cn/policy/txt/2007-06/04/content_8340931.htm (2007);
b http://www.gov.cn/zhengce/content/2012-01/13/content_1294.htm (2012);
c http://www.cec.org.cn/huanbao/xingyexinxi/qihoubianhua/2014-11-17/130019.html (2014);
d http://www.china.org.cn/china/Off_the_Wire/2015-06/30/content_35947874.htm;
e http://www.gov.cn/zhengce/content/2016-11/04/content_5128619.htm (2016);
f http://www.gov.cn/zhengce/content/2017-06/12/content_5201790.htm (2017);
g http://www.gov.cn/zhengce/2017-09/30/content_5228960.htm (2017).

Table 2. **Policies and actions to mitigate climate change in the agricultural sector**

Note: Data retrieved from **a** http://www.gov.cn/xinwen/2015-05/28/content_2869902.htm (2015); **b** http://www.moa.gov.cn/nybgb/2015/shiyiqi/201712/t20171219_6103894.htm (2015); **c** http://www.moa.gov.cn/nybgb/2015/san/201711/t20171129_5923401.htm (2015); **d** http://www.china-nengyuan.com/news/101942.html (2016); **e** http://www.moa.gov.cn/nybgb/2017/dbq/201801/t20180103_6134011.htm (2017)

Policies	Year of issue	Targets and Actions
National Sustainable Agricultural Development Plan (2015-2030) [a]	*2015*	Improving the quality of cultivated land; by 2020, the basic fertility of cultivated land across the country will improve by 0.5 grade a, b; the organic matter content of cultivated land in the country will increase by 0.2 percentage points on average b; raising the country's cultivated land foundation fertility by more than 1 level in 2030 [a];
Action Plan for the Protection and Improvement of Cultivated Land Quality [b]	*2015*	Scientific and rational use of agricultural inputs to improve the input use efficiency. By 2020, the coverage rate of national soil testing and formula fertilisation practice will reach more than 90%, and the utilisation rate of chemical fertilisers will be increased to 40% [a, b, c.] Striving to achieve a zero growth rate of fertiliser application a (including a zero growth rate of fertiliser application for main crops [b, c])
The Action Plan for Zero Growth in Fertilizer Use by 2020 [c]	*2016*	Improving the utilisation level of organic fertiliser resources. By 2020, the rate of returning nutrients from livestock manure and crop stalks to the field will reach more than 60% [b, c] Improving fertilisation methods. Mechanical fertilisation accounts for more than 40% of the main crop area. The fertigation area will reach 10 million ha [b, c] Promoting the overall utilisation of livestock and poultry waste; by 2020 and 2030, the overall utilisation rate of manure will reach 75% and 90% respectively. Almost all livestock and poultry waste from large farms is utilised [a].
Guiding Opinions on Formulation of the Implementation Plan of Comprehensive Utilization of Straw during the 13th Five-Year Plan [d]	*2016*	Promotion of straw utilisation as fertiliser, feed, energy and raw materials. The overall straw utilisation rate will be over 85% by 2020
Action Plan for the Utilization of Livestock and Poultry Waste (2017-2020) [e]	*2017*	Determining the scale of livestock and poultry farms based on land carrying capacity; accelerating the transformation and upgrading of animal husbandry, precise management of large-scale farms; developing 200 demonstration counties during 2016-2020 to promote comprehensive waste utilisation across the country; building a circular development mechanism, promoting energy production using livestock and poultry manure, and applying biogas residues and sludge to the farmland.

Pilot projects of straw utilisation have been implemented in 100 counties of ten provinces. The overall national utilisation rate of straw reached 83%, and the overall utilisation level was significantly improved (Ministry of Ecology and Environment [MEE], 2019). In 2018, the country's straw utilisation amounted to 700 million tonnes, of which 56.5% straw was returned to the cropland, 23.3% straw was used as livestock feed, and 15.2% straw was burned as energy source. The area of straw returned to cropland increased from 30 million ha in 2009 to 50 million ha in 2017 (ECYAM, 2011, 2019). Based on the carbon sequestration factor of the cropland soil for returning straw to the field (0.44 Mg C/ha/yr), calculated using data from long-term experiments (Li et al., 2018), it is estimated that soil organic carbon storage could increase by 80.6 million tonnes CO2-eq in 2017 due to straw return to the field.

Since 2016, China has vigorously developed biomass energy and promoted the transformation and upgrading of rural biogas production. At the end of 2017, the number of household biogas digesters was 40.58 million, of which 26.74 million household biogas digesters were in operation. The quantities of biogas produced by the household biogas digesters amounted to 9.75 billion m^3. Agricultural biogas plants produced 2.15 billion m^3 of biogas. The total number of biogas users was 28.61 million (Table 3). Assuming that the thermal value of biogas is 5,500 kcal/m3, biogas produced using agricultural waste can replace nearly 9.35 million tonnes of standard coal each year. Considering the reduction of CH4 emissions from lagoon treatment of manure changed to anaerobic biogas digesters, power generation through biogas instead of fossil fuels, and according to calculation methods for different scale projects of the Clean Development Mechanism under the Kyoto Protocol (United Nations Framework Convention on Climate Change [UNFCCC], 2013, 2012, 2017) and China's cases (Dong & Li, 2011, 2012; Li & Dong, 2013), the greenhouse gas emission reduction of household biogas digesters and agricultural biogas plants in China was about 54 million tonnes CO2-eq. In addition, the agricultural biogas plants treated 185.60 million tonnes of animal manure and 5.61 million tonnes of straw in 2017. 8.43 million tonnes of commercial biogas slurry and biogas residues were produced. One hundred and seventy-eight million tonnes of biogas slurry and biogas residues were directly returned to the cropland (4.63 million ha), effectively reducing the amount of chemical fertilisation and increasing soil organic carbon storage.

	Biogas projectcs (1000 projects)	Biogas production (Mm^3)	Households use of biogas (1000 households)	Electricity generation (MWh)
Very large biogas plants	0.066	266.56	24.40	210510
Large-scale biogas plants	7.565	1206.91	641.20	482140
Medi-um-scale biogas plants	10.516	381.89	265.90	51500
Small-scale biogas plants	91.585	515.23	926.20	7190
Household biogas digesters	26773.50	9757.95	26773.50	-
Total	**-**	**11909.20**	**2860.68**	**75134**

Table 3. **Agricultural biogas plants, household biogas digesters and emission reduction**
Note: : Adapted from National Rural Renewable Energy Statistics, 2017

5. Policy recommendations

5.1 Reducing farmland nitrogen surplus

Excessive fertilisation is severe in China. From 2000 to 2016, the average N surplus of farmland was 18.10-21.60 million tonnes N per year (Liu, 2018). At 156-204 kg N/ha/yr, the nitrogen surplus was well above the target of the German *Fertiliser Ordinance* for 2030, i.e. the annual nitrogen surplus of arable land must not exceed 50 kg N/ha/yr (Kuhn, 2017). It is recommended that China calculates the amount of organic nitrogen in manure and straw that is returned to farmland, formulates a nutrient management plan based on soil fertility and crop yield potential in different regions, limits the fertiliser application rate for each area and each crop, increases nitrogen fertiliser utilisation, and reduces the farmland nitrogen surplus, thereby reducing N2O and NH3 emissions from farmland and N losses such as leaching and run-off.

5.2 Providing subsidies for measures to reduce emissions and increase carbon sequestration in soil

A large number of experiments have proven that the application of controlled-release fertilisers, fertilisers with nitrification inhibitors, and deep application of fertilisers can effectively reduce N2O emissions from cropland. Returning straw to the field and applying organic fertilisers can significantly increase soil carbon storage and reduce CO2 emissions from fertiliser production. It is recommended that the government formulate policies, improve subsidy methods, and provide subsidies to farmers taking action to reduce emissions and increase carbon sequestration in soil. This can encourage farmers to participate in the fight against climate change.

5.3 Development of monitoring and evaluation tools

The Chinese government attaches great importance to addressing climate change in the agricultural sector. It has formulated and implemented a series of policies and actions to reduce emissions and increase carbon sequestration. Accounting methods for agricultural GHG emissions and assessment tools for emission reduction were developed. Unfortunately, there are no monitoring, reporting and verification tools in China to evaluate the progress of mitigation actions and their effects. It is recommended that China assess the impact of technologies on emission reductions and develop monitoring, reporting and verification guidelines for individual or integrated technologies in order to track the progress of emission reduction measures and increase the transparency of emission reduction effects in order to better implement the Paris Agreement.

5.4
Mitigation activities in the agricultural sector should be a priority to be included in the voluntary carbon emission reduction market in China

Agricultural projects for GHG emission reduction have the potential to reduce water, soil, and atmospheric pollution. Some projects can simultaneously reduce farmers' cost of inputs and increase farmers' income. Agricultural soil fertility enhancement projects can increase soil productivity, soil health, and biodiversity. Therefore, it is recommended that priority be given to agricultural emission reduction and soil carbon sequestration projects in the voluntary carbon emission reduction market to enable farmers to achieve environmental benefits, which can also raise farmers' awareness of climate change.

5.5
Improving GHG mitigation measures for the processing, storage, transport and consumption of agricultural products

Currently, policies, measures and actions to reduce emissions and increase soil organic carbon are mainly focused on the agricultural production process. It is necessary to formulate low-carbon, low-consumption, circular, and efficient policies and measures for the systems of processing, storage, and distribution of agricultural products. Reducing post-harvest losses and food consumption waste are also important ways to reduce GHG emissions. It is recommended that specific measures be taken to reduce losses during harvesting, grain purchasing, storage, transport, processing and consumption, and to promote the resource use of food waste.

References

Chen, S., Lu, F., & Wang, X.K. (2015). Estimation of greenhouse gases emission factors for China's nitrogen, phosphate, and potash fertilizers. *Acta Ecologica Sinica*, 35(19), 6371-6383. DOI:10.5846/stxb201402210304

CPCCC and State Council (General Office of the CPC Central Committee and General Office of the State Council) (2017). *The Opinions on Adopting Innovative Systems and Mechanisms and Promoting Green Agricultural Development.* Retrieved from http://www.gov.cn/zhengce/2017-09/30/content_5228960.htm (in Chinese)

Dong, H., & Li, Y. (2011). *Animal Manure Management System (AMMS) GHG Mitigation Project.* Retrieved from https://cdm.unfccc.int/Projects/DB/TUEV-SUED1214574673.61/view

Dong, H., & Li, Y. (2012). *Hubei Eco-Farming Biogas Project Phase I.* Retrieved from https://cdm.unfccc.int/Projects/DB/TUEV-SUED1218669721.67/view

ECYAM (Editorial Committee of the Yearbook of Agricultural Mechanization in China) (2019). *The Yearbook of Agricultural Mechanization in China 2018.* Beijing, PRC: Press of Agricultural Science and Technology

ECYAM (Editorial Committee of the Yearbook of Agricultural Mechanization in China) (2011). *The Yearbook of Agricultural Mechanization in China 2011.* Beijing, PRC: Press of Agricultural Science and Technology

Kuhn, T. (2017). The revision of the German Fertiliser Ordinance in 2017. In T, Heckelei (Ed.). *Agricultural and Resource Economics, Discussion Paper* (2017:2, 1-26). Bonn, Germany: Institute for Food and Resource Economics. Retrieved from http://www.ilr.uni-bonn.de/agpo/publ/dispap/download/dispap17_02.pdf

Li, Y., & Dong, H. (2013). *Hebei Animal Manure Management System (AMMS) GHG Mitigation Programme (POA).* Retrieved from https://cdm.unfccc.int/ProgrammeOfActivities/poa_db/N9JHWZPGXCYQMRB34IV5OKT7EA8L2F/view

Li, Y., Shi, S., Waqas, M.A., Zhou, X., Li, J., Wan, Y., Qin, X., Gao, Q., Liu, S., & Wilkes, A. (2018). Long-term (≥20 years) application of fertilizers and straw return enhances soil carbon storage: A meta-analysis. *Mitigation and Adaptation Strategies for Global Change*, 23, 603-619. DOI:10.1007/s11027-017-9751-2

Liu, X. (2018). *Study on nutrient balance and requirement in agricultural production in China* [D]. Beijing, PRC: Chinese Academy of Agricultural Sciences. Retrieved from https://kns.cnki.net/KCMS/detail/detail.aspx?dbcode=CDFD&dbname=CDFDLAST2018&filename=1018151824.nh&uid=WEEvREcwSlJHSldRa1FhdXNzY2Z1OVZoU1BjdthYTFkTHpwK29ZWU9HVT0=$9A4hF_YAuvQ5obgVAqNKPCYcEjKensW4IQMovwHtwkF4VYPoHbKxJw!!&v=MzAzODV4WVM3RGgxVDNxVHJXTTFGckNVUjdxZlp1ZHVGeXZrVnIvTlZGMjZGcks5SDluT3E1RWJQSVI4ZVgxTHU= (in Chinese)

MARA (Ministry of Agriculture and Rural Affairs) (2019). *Steady increase in the utilization efficiency of fertilizer and pesticides.* Retrieved from http://www.moa.gov.cn/xw/zwdt/201912/t20191218_6333443.htm (in Chinese)

MEE (Ministry of Ecology and Environment) (2019). *China's Policies and Actions for Addressing Climate Change.* Retrieved from http://english.mee.gov.cn/Resources/Reports/reports/201912/P020191204495763994956.pdf

NBS (National Bureau of Statistics of China) (1985). *China Statistical Yearbook 1985.* Beijing, People's Republic of China: Statistics Press

NBS (National Bureau of Statistics of China) (1987). *China Statistical Yearbook 1987*. Beijing, People's Republic of China: Statistics Press

NBS (National Bureau of Statistics of China) (2019). *China Statistical Yearbook 2019*. Beijing, People's Republic of China: Statistics Press

NDRC (National Development and Reform Commission of China) (2007). *China's National Climate Change Programme.* Retrieved from https://www.greengrowthknowledge.org/sites/default/files/downloads/policy-database/%20China%27s%20National%20Climate%20Change%20Programme%20%282007%29.pdf

NDRC (National Development and Reform Commission of China) (2014). *National Plan on Climate Change 2014-2020*. Retrieved from http://www.cec.org.cn/huanbao/xingyexinxi/qihoubianhua/2014-11-17/130019.html

NDRC (National Development and Reform Commission of China) (2015). *Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions.* Retrieved from https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/China/1/China's%20INDC%20-%20on%2030%20June%202015.pdf

PRC (People's Republic of China) (2018). *The People's Republic of China Second Biennial Update Report on Climate Change.* Retrieved from http://english.mee.gov.cn/Resources/Reports/reports/201907/P020190702568751604320.pdf

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E.A., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N.H., Rice, C.W., Robledo Abad, C., Romanovskaya, A., Sperling, F., & Tubiello, F. (2014). Agriculture, Forestry and Other Land Use (AFOLU). In O, Edenhofer, R, Pichs-Madruga, Y, Sokona, E, Farahani, S, Kadner, K, Seyboth, A, Adler, I, Baum, S, Brunner, P, Eickemeier, B, Kriemann, J, Savolainen, S, Schlömer, C, von Stechow, T, Zwickel, & J.C, Minx (Eds.). *Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 811-922). New York, NY, USA: Cambridge University Press

Statistics | Food and Agriculture Organization of the United Nations (2019, January 06). *Fertilizers by Nutrient.* Retrieved from http://www.fao.org/faostat/en/#data/RFN

UNFCCC (United Nations Framework Convention on Climate Change) (2012). *Methane recovery in agricultural activities at household/small farm level --- Version 3.0.* Retrieved from https://cdm.unfccc.int/methodologies/DB/QHRMGL23TWZ081T6G7G1RZ63GM1BZ

UNFCCC (United Nations Framework Convention on Climate Change) (2013). *GHG emission reductions from manure management systems --- Version 8.0.* Retrieved from https://cdm.unfccc.int/methodologies/DB/99QRTE6N5QJEBOV2XP374B25SSIXBB

UNFCCC (United Nations Framework Convention on Climate Change) (2017). *Methane recovery in animal manure management systems --- Version 21.0.* Retrieved from https://cdm.unfccc.int/methodologies/DB/H9DVSB24O7GEZQYLYNWUX23YS6G4RC

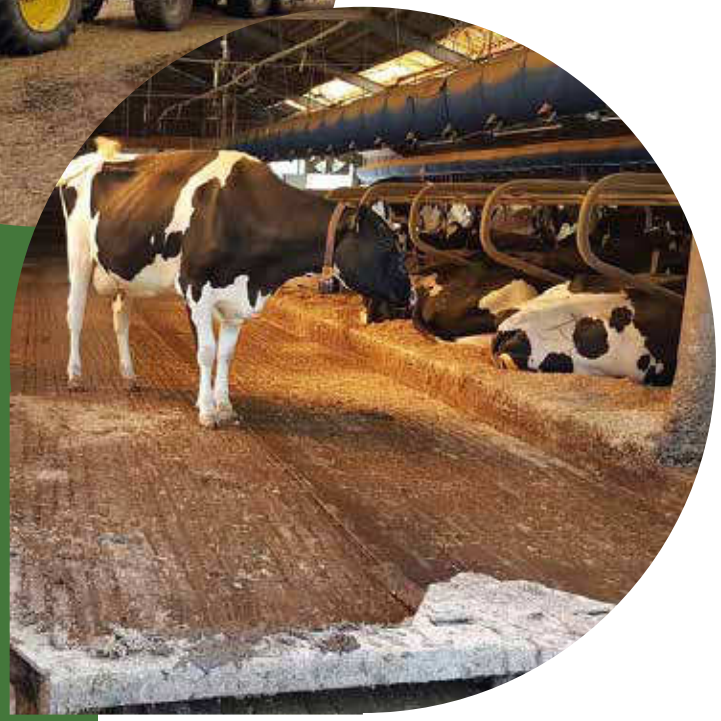
Chapter 2:
Livestock Production

With contributions from:

Barbara Amon
Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB)

Faculty of Civil Engineering, Architecture and Environmental Engineering, University of Zielona Góra, Poland

Sha Wei,
Hongmin Dong,
Zhiping Zhu
Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agriculture Sciences



Nitrogen Use Efficiency in Livestock Production: Relevance and Options for Improvement

Barbara Amon
Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB)

Faculty of Civil Engineering, Architecture and Environmental Engineering, University of Zielona Góra, Poland

Barbara Amon

Nitrogen Use Efficiency in Livestock Production: Relevance and Options for Improvement

1. Nitrogen use efficiency and GHG emissions from livestock production - relevance

The current agricultural practice contributes significantly to environmental damage, resulting in adverse effects on health and health-related costs: air pollution, particulate matter pollution, nitrates in groundwater, climate change, loss of biodiversity, and much more. The current way of doing agriculture creates enormous costs and health hazards, the burden of which is, at present, externalised to society. A large share of the deleterious effects of agricultural activities on the environment and health are due to high losses of nutrients, inefficient nitrogen use efficiency, and open material cycles.

For nearly a century, humankind has caused unprecedented changes to the nitrogen cycle by more than doubling the transformation of non-reactive atmospheric di-nitrogen (N_2) into reactive nitrogen (N_r) forms, which cascade through the environment (Galloway et al., 2003). Already now, large parts of food, feed and fibre production rely on mineral fertiliser input with a substantial worldwide increase in the demand for agricultural products due to population growth, changes in human diets and the need for renewable materials. Agricultural production and productivity must heavily increase to meet this demand (Hunter et al., 2017; FAO, 2018b), opening up enormous business opportunities for the agricultural industry.

At the same time, the high N_r input leads to high N_r losses to the environment and the environmental and health burdens associated with these losses. As a result of human activities (Steffen et al., 2015), N_r is one of the three surpassed *planetary boundaries*. Several thresholds for human and ecosystems health have been exceeded due to excess N_r emitted to the environment (Lelieveld et al., 2015; Pozzer et al., 2017; EEA, 2017; Ward et al., 2018).

In contrast with many other pollutants, nitrogen can change form and go a long way once released into the environment. As it moves through the biogeochemical pathways, the same nitrogen atom can cause a sequence of adverse effects. This phenomenon is called nitrogen cascade (OECD, 2018). Nitrogen management requires strategies that do not result in unintended nitrogen impacts in other areas (*pollution swapping*), and – if possible - seize opportunities to reduce other nitrogen impacts (*synergy effects*). There is an urgent need for research to deliver strategies for solving the *nitrogen dilemma*: secure high N inputs required by the increased demand for food, feed and fibre and at the same time reduce N losses to the environment. Despite the massive importance of solving this N dilemma, N has received less attention than climate change so far. Sustainable livestock production must aim at low GHG and low nitrogen emissions.

Agricultural production is currently at the cusp of unimagined new opportunities. Progress in technology, robotics, sensor technology, digitisation, data science and communication opens up highly promising prospects. These novel technologies offer high potentials for solving the dilemma of increasing agricultural production while decreasing environmental burdens. Currently, nitrogen use efficiency (NUE) is only about 20%, with the remaining 80% contributing to pollution problems (Sutton et al., 2013).

The factors that lead to low NUE in the agri-food chain include:

1) lack of market-ready precision farming technologies that increase productivity while reducing N losses, 2) lack of adoption of best management practices of already existing technologies, associated with a lack of a holistic perspective that integrates the different aspects of N_r management practices, 3) human choices for unbalanced diets, especially with too much livestock protein and excessive food waste across the developed world, and 4) the lack of comprehensive and easy to use guidelines in all domains of human N_r management. Therefore, a key strategy to mitigating N_r losses to the environment is to focus on improving and maximising NUE at multiple levels.

2.
Nitrogen use efficiency and GHG emissions from livestock production – options for improvement

Livestock feeding.

Ammonia emissions result from the degradation of urea by the ubiquitary enzyme urease, which results in NH_4^+ formation. Urea is mainly excreted in the urine and is much more prone to ammonia losses than organic nitrogen excreted in the faeces. N_2O emissions from manure directly correlate with N excretion. Crude protein content and composition in the animal diet is the primary driver of urine excretion. Excess crude protein is excreted and can be lost in the manure management chain. Adaptation of crude protein in the diet to the animals´ needs is, therefore, the first and most efficient measure to mitigate nitrogen emissions.

Livestock housing.

Mitigation options for livestock housing can be grouped into the following types: (i) Floor based systems and related management techniques (including scrapers and cleaning robots); (ii) Litter based systems (use of alternative organic material); (iii) Slurry management techniques at pit level; (iv) Indoor climate control techniques; (v) End-of-pipe techniques (hybrid ventilation + air-cleaning techniques). There are several pathways to optimise existing and develop new mitigation techniques. Emission reduction techniques at animal housing level should aim to affect one or more of the following critical factors or driving forces of the emission processes: draining capacity of the floor for direct transportation of urine to the manure storage; residence time of open urine/manure sources; emitting surface area of open urine/manure sources; urease activity in urine puddles; urine/manure pH and temperature; indoor air temperature; air velocities at emitting surfaces (urine puddles and manure surface in the pit); air exchange between pit headspace and indoor air; exhaust of indoor air.

Manure storage and processing.

Sustainable agriculture must aim at optimal use of manure nutrients. Nutrients may be lost via nitrate leaching and via gaseous emissions (NH_3, N_2O, NO_x, N_2). Besides nutrient losses, methane emissions to the atmosphere must be reduced as far as possible. Slurry composition is not ideal with regard to fertiliser properties and low emission handling. In particular, the high dry matter and carbon content pose several problems during storage, and during and after slurry application. Manure shall be stored in outdoor, covered storage tanks. Storage capacity depends upon the length of the vegetation and must enable storage up to the time when crops have nitrogen demand. Slurry separation can be a useful tool to reduce dry matter content and increase the content of readily available nitrogen in the manure. Anaerobic digestion improves the fertiliser value of manure and sharply decreases methane emissions during slurry storage.

Manure application.

There has been considerable research and development of slurry application methods associated with lower ammonia emissions. The use of trailing shoe and injection technology can dramatically reduce ammonia emissions and odour and thus reduces indirect nitrous oxide emissions. Slurry acidification as a means of reducing ammonia emissions is also very effective and in recent years has been demonstrated to be a practical option with significant implementation in Denmark. Pre-processing, such as slurry separation, may also improve the ability to use the slurry nutrients more efficiently, but impacts on N flows will depend on the subsequent use of the liquid and solid fractions. Rapid soil incorporation of manures by tillage significantly reduces ammonia emission. Nitrification inhibitors can be used to reduce direct N_2O emissions and nitrate leaching associated with manure application to land, but have the potential to increase ammonia emissions, and positive effects on yield or crop N uptake are small if seen at all. Anaerobic digestion of manures enhances the proportion of readily available N in the manure, which enhances crop N uptake and reduces N leaching. However, anaerobic digestion also results in higher slurry pH, which may increase ammonia volatilisation during storage and after application. It is therefore essential to store anaerobically digested slurry in covered stores and apply it with low trajectory technologies. NUE can be maximised through the development of a nutrient management plan including fertiliser use depending on crop requirements, considering application rate, timing and method according to local soil and environmental conditions.

3. Summary of key publications on nitrogen use efficiency and GHG emissions from livestock production

This summary includes the following publications:

- *Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen*
- *Agriculture and Forestry, Water, Ecosystems and Biodiversity. Austrian Assessment Report, Needs and Opportunities for Adaptation and Mitigation*
- *Evaluating the potential of dietary crude protein manipulation in reducing ammonia emissions from cattle and pig manure: A meta-analysis*
- *Greenhouse Gas and Ammonia Emissions from Different Stages of Liquid Manure Management Chains: Abatement Options and Emission*
- *Nutrient flows and associated environmental impacts in livestock supply chains: Guidelines for assessment*
- *Comparison of ammonia emissions related to nitrogen use efficiency of livestock production in Europe*
- *The value of manure - Manure as co-product in life cycle assessment*

Bittman et al. (2014): Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen

The purpose of this document is to guide the Parties to the Convention in identifying ammonia (NH_3) control measures for reducing emissions from agricultural sources, taking account of the whole nitrogen cycle, and focusing on livestock feeding strategies. This guidance will facilitate the implementation of the basic obligations of the Protocol mentioned in chapter 3, as regards NH_3 emission, and more specifically will contribute to the effective implementation of the measures listed in Annex IX, and to achieving the national NH_3 emission ceilings listed in Table 3 (amended version of December 2005).

The document addresses the abatement of NH_3 emissions produced by agricultural sources. Agriculture is the primary source of NH_3, chiefly from livestock excreta in livestock housing, during manure storage, processing, treatment and application to land, and from excreta from animals at pasture. Emissions also occur from inorganic nitrogen (N) fertilisers following their application to land and from crops and crop residues, including grass silage. Emissions can be reduced through abatement measures in all the above areas.

The first version of the guidance document (EB.AIR/1999/2) provided general guidance on the abatement of NH_3 emissions. This version was revised in 2007 (ECE/EB.AIR/WG.5/2007/13). The current version is further revised and addresses the provisions in the proposal for revision of Annex IX of the 1999 Protocol to *Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol)*. Following a brief introduction to livestock production and development, this guidance document follows the order of the provisions in the proposal for revision of Annex IX.

This document groups strategies and techniques for the abatement of NH_3 emissions and N losses into three categories:

a. ***Category 1 strategies:***
These are well researched, considered to be practical, and there are quantitative data on their abatement efficiency, at least on the experimental scale.

b. ***Category 2 strategies:***
These are promising, but research on them is at present inadequate, or it will always be difficult to quantify their abatement efficiency. That does not mean that they cannot be used as part of an NH3 abatement strategy, depending on local circumstances.

c. ***Category 3 strategies:***
These are ineffective or are likely to be excluded on practical grounds.

Based on the available research, Category 1 techniques can be considered as already verified for use in abatement strategies. Category 2 and Category 3 techniques may also be used in abatement strategies. However, for these categories, independent verification should be provided by Parties using them in order to demonstrate the reductions in NH_3 emissions that they report. It should be noted that the cost of a technique is not part of the definition of these categories. If a particular technique is well researched and effective, it may be classed as category 1. Information on costs is provided to support decisions on the use of the techniques.

Separate guidance has also been prepared under the *Integrated pollution prevention and control (IPPC) Directive to reduce a range of polluting emissions from large pig and poultry units. The Reference Document on Best Available Techniques (BAT) for Intensive Rearing of Poultry and Pigs*, the BREF (BAT reference) document, may be found at http://eippcb.jrc.es/reference/irpp.html. There is an only partial overlap between the BATs and the present guidance document, since they have only been defined for the pig and poultry sectors, and have not been defined for cattle, sheep or other livestock, nor the land application of manure or fertilisers.

Options for NH_3 reduction at the various stages of livestock manure production and handling are interdependent, and combinations of measures are not merely additive in terms of their combined emission reduction. Controlling emissions from applications of manures to land is particularly important, because these are generally a significant component of total livestock emissions and because the land application is the last stage of manure handling. Without abatement at this stage, much of the benefit of abating during housing and storage may be lost. Because of this interdependency, Parties should as far as possible exploit models with an assessed overall mass-flow of ammonia nitrogen, such as *GAINS*, in order to optimise their abatement strategies.

The costs of the techniques will vary from country to country. Due to economies of scale, some of the abatement techniques may be more cost-effective on large farms than on small farms, which is particularly the case when an abatement technique requires the purchase of capital equipment, e.g., reduced-emission slurry applicators. In such cases, the unit costs increase as the volumes of manure decrease. A higher cost burden for smaller farms may also be the case for immediate incorporation of manures. Both for slurry application and manure incorporation, the costs for small farms will often be reduced by hiring a contractor with access to suitable equipment.

Many measures may incur both capital and annual costs. In addition to theoretical calculations based on capital and operating expenditure, actual data on costs (e.g., as charged by contractors) should be used where available. In addition to calculating the direct costs, the benefits of measures should be calculated as far as possible. In many cases, the benefits to the farmer (e.g., reduced mineral fertiliser need, improved agronomic flexibility, reduced emissions of other pollutants, fewer complaints due to odour) will outweigh the costs. A summary of the main interacting factors affecting net costs and benefits of ammonia mitigation has been provided in the *Informal note from the Task Force on Reactive Nitrogen (No. 11) to the 46th Session of the Working Group on Strategies and Review.* Comparison of the net cost to the farmer (i.e., cost minus benefit) with other environmental benefits (e.g., improved air, water quality and soil quality, reduced biodiversity loss, reduced perturbation of climate) is beyond the scope of this document.

Wherever possible, the techniques listed in this document are clearly defined and assessed against a 'reference' or unabated situation. The 'reference' situation, against which percentage emission reduction is calculated, is defined at the beginning of each chapter. In most cases, the 'reference' used to construct baseline inventories is the most commonly practised technique or design presently found on commercial farms.

The livestock sector is an essential contributor to the global food and agricultural economy, accounting for 40% of the value of world agricultural output and providing 10-15% of total food calories and one-quarter of dietary protein. In most of the developing country regions, it is the fastest-growing segment of the agricultural sector. The livestock sector is increasingly expected to provide safe and plentiful food and fibre for growing urban populations, livelihoods for almost one billion poor producers as well as global public goods related to food security, environmental sustainability and public health.

While livestock provides various useful functions to society and the global demand for dairy, meat and egg products is expected to continually increase for the next decades, there is also increasing pressure on (intensive) livestock production systems to produce more environmentally friendly. The livestock sector is a major land user globally and has been implicated for deforestation and biodiversity loss. It is also the main user of freshwater, mainly through animal feed production, while freshwater resources become scarce in some areas. Livestock production is the primary source of atmospheric ammonia (NH_3) and the greenhouse gases methane (CH_4) and nitrous oxide (N_2O). The emissions mainly originate from the nitrogen in the manure of animals. Emissions of NH_3 from livestock production are related to the type, number and genetic potential of the animals, the feeding and management of the animals, and to the technology of animal housing and manure management.

Livestock production systems can broadly be classified in (i) grazing systems, (ii) mixed systems and (iii) landless or industrial systems. Grazing systems are entirely land-based systems, with stocking rates less than one livestock unit per ha. In mixed systems, a significant part of the value of production comes from other activities than animal production while part of the animal feed is often imported. Industrial systems have stocking rates higher than ten livestock units per ha, and they depend primarily on external supplies of feed, energy and other inputs. Less than 10% of the dry matter fed to animals is produced on the farm. Relevant indicators for livestock production systems are animal density in animals per ha (AU/ha) and kg milk/ha/year. A common and useful indicator for the pressure on the environment is the total N or P excretion of the livestock per ha per year.

In each livestock category, a distinction can be made between conventional and organic farming. Further, there is often a distinction between intensive and extensive systems, which may coincide with the distinction between conventional and organic farming, but not necessarily. Intensive livestock production systems are characterised by a high output of meat, milk, and eggs per unit of agricultural land and unit of stock (i.e., livestock unit), which usually coincides with a high stocking density per unit of agricultural land. This is generally achieved by high efficiency in converting animal feed into animal products.

Because of their capacity to rapidly respond to a growing demand, intensive livestock production systems now account for a dominant share of the global pork, poultry meat and egg production (respectively 56, 72 and 61%) and a significant share of milk production.

Traditionally, most animal products consumed by humans were produced locally on the basis on locally produced animal feeds. Increasingly, many animal products consumed by humans in urban areas are produced based on animal feeds imported from elsewhere, which holds especially true for pig and poultry products. Thereby, areas of animal feed production and pig and poultry production become increasingly disconnected from the site of animal product consumption. This disconnection has been made possible through the development of transport infrastructure and the relatively low price of fossil energy; the shipment of concentrated feed is cheap relative to other production costs. Transportation of meat and egg products has also become cheaper. However, the uncoupling of animal feed production from animal production has significant consequences for the proper disposal and management of animal manure.

Increasingly, production chains are organised and regionally clustered in order to minimise production and delivery costs. Animal feed is the primary input to livestock production, followed by labour, energy, water and services. Input costs vary substantially from place to place within countries as well as across continents. Access to technology and know-how is also unevenly distributed, as is the ability to respond to changing environments and to market changes. There are also institutional and cultural patterns that further affect production costs, access to technologies and transaction costs. The combination of these factors determines that livestock production systems become larger, specialised, and intensive.

Livestock production systems are dynamic systems because of continuous developments and changes in technology, markets, transport and logistics. Such developments lead to changes in livestock production systems and its institutional organisation and geographical locations. Increasingly, livestock products become 'global commodities', and livestock production systems are producing in an 'open', highly competitive, global market. These developments are facilitated by the increasing demand for animal products because of the increasing urban population and the increasing consumption of animal products per capita, although there are substantial regional and continental differences. The additional demand for livestock products concentrates in urban centres. With high rates of consumption, rapid growth rates and a shift towards animal-derived foods, urban centres increasingly drive the sector. The retail, processing industry and suppliers of animal feed and technology greatly influence the sector, while the farmers, the livestock producers, become increasingly dependent on the organisation within the whole food chain.

The rapid developments in livestock production systems have a strong effect on the emissions of NH_3, N_2O and CH_4 from these systems into the atmosphere and the leaching of N to waters. Emission abatement strategies have to take such developments into account and should anticipate them in order to make these strategies effective and efficient.

Management is commonly defined as a coherent set of activities to achieve objectives. This definition applies to all sectors of the economy, including agriculture. Nitrogen management can be outlined as a coherent set of activities related to nitrogen use in agriculture to achieve agronomic and environmental/ecological objectives. The agronomic objectives relate to crop yield and quality and animal performance. The environmental/ecological objectives relate to nitrogen losses from agriculture. Taking account of the whole nitrogen cycle emphasises the need to consider all aspects of nitrogen cycling, also in NH_3 emissions abatement, to be able to consider all objectives in a balanced way and to circumvent pollution swapping.

Nitrogen is a constituent of proteins (and enzymes) and involved in photosynthesis, eutrophication, acidification, and various oxidation-reduction processes. Through these processes, nitrogen changes in form (compounds), reactivity and mobility. Primary mobile forms are the gaseous forms di-nitrogen (N_2), ammonia (NH_3), nitrogen oxides (NO and NO_2), nitrous oxide (N_2O) and the water-soluble forms nitrate (NO_3^-), ammonium (NH_4^+) and dissolved organically bound nitrogen (DON). In organic matter, most nitrogen is in the form of amides, linked to organic carbon ($R\text{-}NH_2$). Because of the mobility in both air and water, reactive nitrogen is also called *double mobile*.

Depending on the type of farming systems, N management at farm level involves a series of management activities in an integrated way, including:

- Fertilisation of crops
- Crop growth and crop residue management
- Growth of catch crops
- Grassland management
- Soil cultivation, drainage and irrigation
- Animal feeding
- Herd management, including animal housing
- Manure management, including manure storage and application
- Ammonia emissions abatement measures
- Nitrate leaching and runoff abatement measures
- Nitrous oxide emissions abatement measures
- Denitrification abatement measures

In order to be able to achieve high crop and animal production with minimal N losses, all activities have to be considered in an integrated and balanced way.

Nitrogen is essential for plant growth. In crop production, it is often the most limiting nutrient, and therefore must be available in sufficient amount and in a plant-available form in the soil to achieve optimum crop yields. To avoid excess or untimely N applications, guidelines for site-specific best nutrient management practices should be adhered to, including:

- Nutrient management planning and record-keeping, for all essential nutrients

- Calculation of the total N requirement by the crop based on realistic estimates of yield goals, N content in the crop and N uptake efficiency by the crop

- Estimation of the total N supply from indigenous sources, using accredited methods

  - mineral N in the upper soil layers at the planting stage (by a soil test)
  - mineralisation of residues from previous crops
  - net mineralisation of soil organic matter, including the residual effects of livestock manures, applied over several years and, on pastures, droppings from grazing animals
  - deposition of N from the atmosphere
  - biological N_2 fixation by leguminous plants

- Computation of the needed N appli-cation, taking account of the N requirement of the crop and the supply by indigenous N sources

- Calculation of the amount of nutrients in livestock manure applications that will become available for crop uptake. The application rate of manure will depend on

  - he availability of livestock manure
  - the demands for nitrogen, phosphorus and potassium by the crops
  - the immediately-available nitrogen, phosphorus and potassium content in the manure
  - the rate of release of slowly-available nutrients from the manure
  - the nutrient sufficiently supplied at the lowest application rate (to ensure no nutrient is oversupplied)
  - Estimation of the needed fertiliser N and other nutrients, taking account of the N requirement of the crop and the supply of N by indigenous sources and livestock manure

- Application of livestock manure and/ or N fertiliser shortly before the onset of rapid crop growth, using methods and techniques that prevent ammonia emissions

- Where possible, application of N fertiliser in multiple portions (split dressings) with in-crop testing, where appropriate

Nitrogen management which takes account of the whole nitrogen cycle aims at identifying measures for reducing all unwanted N emissions, including NH_3 emissions, cost-effectively, i.e., to a level where the value of marginal damages to human health and biodiversity is (approximately) equal to the marginal cost of achieving further reductions. Preferred measures for reducing NH_3 emissions are those that decrease other unwanted N emissions simultaneously while maintaining or enhancing agricultural productivity (measures with synergistic effects). Conversely, measures aimed at reducing NH_3 emissions, which increase other unwanted emissions (antagonistic effects) should be modified to such extent that the antagonistic effects are nullified. Similarly, abatement measures avoid to increase other types of farm pollution (e.g., P losses, pathogens, soil erosion) or resource use (e.g., fuel), reduce the quality of food (e.g., increased antibiotics, hormones or pesticides) or the health and welfare of farms (e.g., by limiting barn size).

The effectiveness of nitrogen management can be evaluated in terms of (i) decreases of nitrogen losses, and (ii) increases of N use efficiency. Nitrogen use efficiency (NUE) indicators provide a measure for the amount of N retained in crop or animal products, relative to the amount of nitrogen applied or supplied. Management has a large effect on nitrogen use efficiency.

Austrian Assessment Report 2014 (AAR14), Eitzinger et al. (2014): Agriculture and Forestry, Water, Ecosystems & Biodiversity. Austrian Assessment Report, Volume 3, Needs and Opportunities for Adaptation and Mitigation

Climate change represents a substantial challenge for the management, use and protection of terrestrial and aquatic ecosystems as well as the sustainable use of key water resources. Numerous feedbacks exist between agriculture, forestry, and water management sectors as well as the conservation of ecosystems and biodiversity. Almost all options to reduce greenhouse gas (GHG) emissions or to adapt to climate change in these sectors also have other socioeconomic or ecological consequences than the intended ones. Such feedbacks can also affect the GHG reduction potentials of climate change mitigation measures. One example is the GHG emission reductions associated with a substitution of bioenergy for fossil fuels, which are substantially influenced by direct and indirect systemic feedbacks in land use, such as changes in forest areas that may result from changes in cultivated areas.

A multitude of options exists in the agricultural sector to reduce GHG emissions, in particular in ruminant feeding, manure management, reduction of nitrogen losses and increased nitrogen efficiency. Increased production of agricultural bioenergy can help to reduce GHG emissions, especially when implemented following an integrated optimisation of food and energy production as well as a cascadic use of biomass. Short-term adaptation options include changes in soil management such as mulching or reduced tillage; selection of heat- or drought-tolerant breeds or cultivars; or changes in the timing of sowing or soil management measures; as well as improved crop rotation schemes. Medium-term options include improved irrigation infrastructures and technologies; breeding of drought or heat resistant cultivars; development of monitoring systems for pests or infectious diseases; increased storage capacities; and other risk minimisation strategies.

Due to the high carbon stocks in forests, the forestry sector is a crucial factor for land-use related GHG mitigation strategies. Forestry can contribute to climate change mitigation through carbon sequestration as well as through the provision of low-carbon resources (e. g., materials, energy). Systemic interdependencies between the forest's production and sequestration functions, as well as its delivery of other ecosystem services, need to be considered. Socioeconomic, as well as ecological and climate effects, can be improved through an integrated optimisation of forest production and biomass use cascades. For forestry, adaption to climate change is a particular challenge due to the long lifespan of trees and the long-term legacies of forest management measures. Changes in mean values of precipitation and temperature, including their effects on forest pathogens, as well as extreme events such as drought or storms, need to be considered.

Few options exist to reduce GHG emissions in water management. Adaption to climate change can help to address a multitude of challenges in that sector, which is most efficient if based on integrated, interdisciplinary concepts. These include land-use changes in watersheds; protection against low and high water runoff in rivers; rubble and sediment management; as well as measures for drinking water supply and wastewater treatment.

Climate change increases the pressures on ecosystems and biodiversity, which are already affected by a multitude of factors such as land-use change or toxic chemicals. Removal of migration barriers, e.g., through the creation of a habitat network, is a adaptation option. Many nature conservation measures can also help to increase carbon sequestration, e. g., through the protection or restoration of bogs and wetlands or a reduction of land-use intensity in suitable forest or wetland areas.

Demand-side options, e. g., changes in food consumption or reductions of food wastes, can help to reduce GHG emissions substantially. In particular, a reduction of the share of animal products in diets, as well as an increased share of regional and seasonal products as well as preferred use of low-GHG products, can contribute to demand-side related GHG mitigation.

Sajeev et al. (2018): Evaluating the potential of dietary crude protein manipulation in reducing ammonia emissions from cattle and pig manure: A meta-analysis

Dietary manipulation of animal diets by reducing crude protein (CP) intake is a strategic NH_3 abatement option as it reduces the overall nitrogen input at the very beginning of the manure management chain. This study presents a comprehensive meta-analysis of scientific literature on NH_3 reductions following a reduction of CP in cattle and pig diets. Results indicate higher mean NH_3 reductions of 17 ± 6% per % point CP reduction for cattle as compared to 11 ± 6% for pigs. Variability in NH_3 emission reduction estimates reported for different manure management stages and pig categories did not indicate a significant influence. Statistically significant relationships exist between CP reduction, NH_3 emissions and total ammoniacal nitrogen content in manure for both pigs and cattle, with cattle revealing higher NH_3 reductions and a more evident trend in relationships. This is attributed to the greater attention given to feed optimisation in pigs relative to cattle and also due to the specific physiology of ruminants to efficiently recycle nitrogen in situations of low protein intake. The higher NH_3 reductions in cattle highlight the opportunity to extend concepts of feed optimisation from pigs and poultry to cattle production systems to further reduce NH_3 emissions from livestock manure. The results presented help to accurately quantify the effects of NH_3 abatement following reduced CP levels in animal diets distinguishing between animal types and other physiological factors. This accurate quantification is useful in the development of emission factors associated with reduced CP as an NH_3 abatement option.

Sajeev et al. (2018): Greenhouse Gas and Ammonia Emissions from Different Stages of Liquid Manure Management Chains: Abatement Options and Emission Interactions

Farm livestock manure is an essential source of ammonia and greenhouse gases. Concerns over the environmental impact of emissions from manure management have resulted in research efforts focusing on emission abatement. However, questions regarding the successful abatement of manure-related emissions remain. This study uses a meta-analytical approach comprising 89 peer-reviewed studies to quantify emission reduction potentials of abatement options for liquid manure management chains from cattle and pigs. Analyses of emission reductions highlight the importance of accounting for interactions between emissions. Only three out of the eight abatement options considered (frequent removal of manure, anaerobic digesters, and manure acidification) reduced ammonia (3–60%), nitrous oxide (21–55%), and methane (29–74%) emissions simultaneously, whereas in all other cases, trade-offs were identified. The results demonstrate that a shift from single-stage emission abatement options towards a whole-chain perspective is vital in reducing overall emissions along the manure management chain.

The study also identifies some key elements like proper clustering, reporting of influencing factors, and explicitly describing assumptions associated with abatement options that can reduce variability in emission reduction estimates. Prioritisation of abatement options according to their functioning can help to determine low-risk emission reduction options, in particular options that alter manure characteristics (e.g., reduced protein diets, anaerobic digestion, or slurry acidification). These insights supported by comprehensive emission measurement studies can help improve the effectiveness of emission abatement and harmonise strategies aimed at reducing air pollution and climate change simultaneously.

FAO (2018): Nutrient flows and associated environmental impacts in livestock supply chains: Guidelines for assessment

The methodology in these guidelines aims to introduce an internationally harmonised approach to assess the potential environmental impacts associated with nutrient use in livestock supply chains while considering the different nutrient flows in the various production systems involved. These guidelines aim to increase the understanding of nutrient flows in livestock supply chains and their impact assessment concerning eutrophication and acidification. These guidelines are a joint effort of the *Livestock Environmental Assessment and Performance (LEAP) Partnership*, a multi-stakeholder initiative committed to improving the environmental performance of livestock supply chains while ensuring its economic and social viability. LEAP builds up consensus on comprehensive guidance and methodology for understanding the environmental performance of livestock supply chains in order to shape evidence-based policy measures and business strategies.

Leip et al. (2019): The value of manure - Manure as co-product in life cycle assessment

Livestock production is vital for food security, nutrition, and landscape maintenance, but it is associated with several environmental impacts. In order to assess the risk and benefits arising from livestock production, transparent and robust indicators are required, such as those offered by life cycle assessment. A central question in such approaches is how the environmental burden is allocated to livestock products and to re-used manure for agricultural production. In order to create an incentive for its sustainable use, manure should be considered as a co-product as long as it is not disposed of, wasted, or applied in excess of crop nutrient needs, in which case it should be treated as waste. This paper proposes a theoretical approach to define nutrient requirements based on nutrient response curves to economic and physical optima and a pragmatic approach based on crop nutrient yield adjusted for nutrient losses to atmosphere and water. The allocation of the environmental burden to manure and other livestock products is then based on the nutrient value from manure for crop production using the price of fertiliser nutrients. Leip et al. (2019) illustrate and discuss the proposed method with two case studies.

Groenestein et al. (2019): Comparison of ammonia emissions related to nitrogen use efficiency of livestock production in Europe

Both the increasing global demand for food and the environmental effects of reactive nitrogen losses in the food production chain amplify the need for efficient use of nitrogen (N). Of all N harvested in agricultural plant products, 80% is used to feed livestock. Because the most significant atmospheric loss of reactive nitrogen from livestock production systems is ammonia (NH_3), the focus of this paper is on N lost as NH_3 during the production of animal protein. The focus of this paper is to understand the key factors explaining differences in nitrogen use efficiency (NUE) of animal production among various European countries. Therefore Groenestein et al. (2019) developed a conceptual framework to describe the NUE defined as the amount of animal-protein N per N in feed and NH_3N losses in the production of milk, beef, pork, chicken meat and eggs in The Netherlands, Switzerland, the United Kingdom, Germany, Austria and Denmark. The framework describes how manure management and animal-related parameters (feed, metabolism) relate to NH_3 emissions and NUE.

The results illustrate that the animal product with the lowest NUE has the largest NH_3 emissions and vice versa, which agrees with the reciprocal relationship between NUE and NH_3 within the conceptual framework. Across animal products for the countries considered, about 20% of the N in feed is lost as NH_3. The significant smallest proportion (12%) of NH_3N per unit of N feed is from chicken production. The proportions for other products are 17%, 19%, 20% and 22% for milk, pork, eggs and beef respectively. These differences do not significantly vary due to the differences among countries. For all countries, NUE was lowest for beef and highest for chicken. The production of 1 kg N in beef required about 5 kg N in feed, of which 1 kg N was lost as NH_3N. For the production of 1 kg N in chicken meat, 2 kg N in feed was required, and 0.2 kg was lost as NH_3. The production of 1 kg N in milk required 4 kg N in feed with 0.6 kg NH_3N loss, the same as pork and eggs, but those needed 3 and 3.5 kg N in feed per kg N in product respectively. Except for beef, the differences among these European countries were mainly caused by differences in manure management practices and their emission factors rather than animal-related factors, including feed and digestibility influencing the excreted amount of ammoniacal N (TAN). For beef, both aspects caused essential differences. Based on the results, we encourage the expression of N losses as per N in feed or per N in the product in addition to per animal place when comparing production efficiency and NUE. We consider that disaggregating emission factors into a diet/animal effect and a manure management effect would improve the basis for comparing national NH_3 emission inventories.

References:

Amon, B., Blamauer, B., Essl, F., Gaube, V., Habersack, H., Jandl, R., Klik, A., Lexer, M., Rauch, W., Tappeiner, U., & Zechmeister-Boltenstern, S. (2014). Agriculture and Forestry, Water, Ecosystems and Biodiversity. In J, Eitzinger & H, Haberl (Eds.). *Austrian Assessment Report 2014 (AAR14)* (Volume 3, Needs and Opportunities for Adaptation and Mitigation, pp. 772-799). Retrieved from http://austriaca.at/0xc1aa500e_0x0031144af.pdf

Bittman, S., Dedina, M., Howard C.M., Oenema, O., & Sutton, M.A. (Eds.). (2014). *Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen.* Edinburgh, UK: Centre for Ecology and Hydrology. Retrieved from http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/AGD_final_file.pdf

European Environment Agency (2017). *Air quality in Europe* — 2017 report. Copenhagen, Denmark: EEA. Retrieved from https://www.eea.europa.eu/publications/air-quality-in-europe-2017

Food and Agriculture Organization of the United Nations (2018a). *Nutrient flows and associated environmental impacts in livestock supply chains: Guidelines for assessment.* Rome, Italy: FAO. Retrieved from http://www.fao.org/3/CA1328EN/ca1328en.pdf

Food and Agriculture Organization of the United Nations (2018b). *The future of food and agriculture – Alternative pathways to 2050. Summary version.* Rome, Italy: FAO. Retrieved from http://www.fao.org/3/CA1553EN/ca1553en.pdf

Galloway, J.N., Aber, J.D., Erisman, J.W., Seitzinger, S.P., Howarth, R.W., Cowling, E.B., & Cosby, B.J. (2003). The Nitrogen Cascade. *BioScience*, 53(4), 341–356. Retrieved from https://doi.org/10.1641/0006-3568(2003)053[0341:TNC]2.0.CO;2

Groenestein, C.M., Hutchings, N.J., Haenel, H.D., Amon, B., Menzi, H., Mikkelsen, M.H., Misselbrook, T.H., van Bruggen, C., Kupper, T., & Webb, J. (2019). Comparison of ammonia emissions related to nitrogen use efficiency of livestock production in Europe. *Journal of Cleaner Production*, 211, 1162-1170. Retrieved from https://doi.org/10.1016/j.jclepro.2018.11.143

Hunter, M.C., Smith, R.G., Schipanski, M.E., Atwood, L.W., & Mortensen, D.A. (2017). Agriculture in 2050: Recalibrating targets for sustainable intensification. *BioScience* 67(4), 386–391. Retrieved from https://doi.org/10.1093/biosci/bix010

Leip, A., Ledgard, S., Uwizeye, A., Palhares, J.C.P., Aller, M.F., Amon, B., Binder, M., M.d.S. Cordovil, C., De Camillis, C., Dong, H., Fusi, A., Helin, J., Hörtenhuber, S., Hristov, A.N., Koelsch, R., Liu, C., Masso, C., Nkongolo, N.V., Patra, A.K., Redding, M.R., Rufino, M.C., Sakrabani, R., Thoma, G., Vertès, F., & Wang, Y. (2019). The value of manure - Manure as co-product in life cycle assessment. *Journal of Environmental Management*, 241, 293-304. Retrieved from https://doi.org/10.1016/j.jenvman.2019.03.059

Lelieveld, J., Evans, J., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, 525, 367–371. DOI:10.1038/nature15371

OECD Policy Highlights (2018). *Human Acceleration of the Nitrogen Cycle: Managing Risks and Uncertainty*. Retrieved from https://doi.org/10.1787/9789264307438-en

Pozzer, A., Tsimpidi, A.P., Karydis, V.A., de Meij, A., & Lelieveld, J. (2017). Impact of agricultural emission reductions on fine-particulate matter and public health. *Atmospheric Chemistry and Physics*, 17, 12813–12826. Retrieved from https://doi.org/10.5194/acp-17-12813-2017

Sajeev, E.P.M., Amon, B., Ammon, C., Zollitsch, W., & Winiwarter, W. (2018). Evaluating the potential of dietary crude protein manipulation in reducing ammonia emissions from cattle and pig manure: A meta-analysis. *Nutrient Cycling in Agroecosystems*, 110(1), 161-175. Retrieved from https://doi.org/10.1007/s10705-017-9893-3

Sajeev, E.P.M., Winiwarter, W., & Amon, B. (2018). Greenhouse Gas and Ammonia Emissions from Different Stages of Liquid Manure Management Chains: Abatement Options and Emission Interactions. *Journal of Environmental Quality*, 47(1), 30-41. Retrieved from https://dx.doi.org/10.2134/jeq2017.05.0199

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. Science 347, 1259855. DOI:10.1126/science.1259855

Ward, M.H., Jones, R.R., Brender, J.D., Kok, T.M., Weyer, P.J., Nolan, B.T., Villanueva, C.M., & van Breda, S.G. (2018). Drinking Water Nitrate and Human Health: An Updated Review. *International Journal of Environmental Research and Public Health*, 15(7), 1557. DOI:10.3390/ijerph15071557

Sutton, M.A., Bleeker, A., Howard, C.M., Bekunda, M., Grizzetti, B., de Vries, W., van Grinsven, H.J.M., Abrol, Y.P., Adhya, T.K., Billen, G., Davidson, E.A., Datta, A., Diaz, R., Erisman, J.W., Liu, X.J., Oenema, O., Palm, C., Raghuram, N., Reis, S., Scholz, R.W., Sims, T., Westhoek, H., & Zhang, F.S. (2013). Our nutrient world: *The challenge to produce more food and energy with less pollution.* Edinburgh, UK: NERC/Centre for Ecology & Hydrology

Abstract

With the rapid development of large-scale livestock production in recent years, manure production is large and concentrated, and the sustainable development of livestock production has become a global focus. The Chinese *Ministry of Agriculture and Rural Affairs* (MARA) recommends seven treatment and utilisation modes and encourages the application of cost-effective modes according to the resource and environmental characteristics of different regions. However, there are different views on the selection of manure treatment and application options, especially in sensitive areas with limited land for manure (slurry) recycling. This paper analyses the characteristics and applicability of the main approaches to livestock manure treatment and utilisation in China. Subsequently, it recommends establishing a mechanism of integrated crop and livestock production based on nutrient balance and the strength of third-party services, and to promote mechanisation and smart systems for manure land application towards a sustainable development of livestock production in China.

How to Make Use of Livestock Manure? Standard Discharge or Land Application Use

Sha Wei,
Hongmin Dong,
Zhiping Zhu
Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agriculture Sciences

Sha Wei,
Hongmin Dong,
Zhiping Zhu

How to Make Use of Livestock Manure? Standard Discharge or Land Application Use

1. Introduction

Livestock manure has been the primary source of organic fertiliser in China's agricultural production. However, with the rapid development of large-scale livestock production in recent years and as a result of the large and concentrated amount of manure, inhibited by seasonal restrictions, inconvenient application and other factors, many manure resources have become significant sources of pollution, such as odours and fine dust particles (PM2.5) (Menzi et al., 2010; Basset-Mens et al., 2007; Steinfeld et al., 2010; Herrero & Thornton, 2013). Meanwhile, nitrogen in livestock manure is discharged into the atmosphere through ammonia (NH_3), nitrous oxide (N_2O), and nitrogen oxides (NOX), and leached into the water through soluble forms of nitrate. These emissions contribute to the greenhouse effect, eutrophication, acidification and loss of biodiversity (Guo et al., 2010; Liu et al., 2011; Herrero et al., 2013; Bai, 2015; Wei, 2016; Dangal et al., 2017).

In recent years, the Chinese government has attached great importance to the resource utilisation of livestock manure and proposed a series of regulations and activities.

In 2017, the central government invested in a county-wide project to recycle livestock manure. Currently, 585 major livestock counties in China have promoted livestock manure recycling (General Office of the State Council [GOSC], 2017). In addition, the *Ministry of Agriculture and Rural Affairs* (MARA) has also promoted a campaign to replace chemical fertilisers with organic fertilisers in 150 large fruit, vegetable, and tea counties (Ministry of Agriculture [MOA], 2017b). In 2017, the overall utilisation rate of livestock manure in China reached 70%.

However, there are still some challenges in manure treatment and utilisation selection, especially in sensitive areas with limited land for manure (slurry) recycling, which will result in severe nutrient losses. The objectives of this study are: (1) to analyse the characteristics and applicability of the main manure treatment and utilisation modes in China, (2) to clarify the critical issues and links of treatment and utilisation of livestock manure in China, (3) to put forward suggestions for key problems, providing a reference for the rapid scale development of livestock in developing countries like China.

2. Manure treatment model of Chinese livestock farms

The *Ministry of Agriculture and Rural Affairs* has summarised seven main modes of manure treatment and utilisation in China, including full manure collection and land application, specialised biogas plants, composting of solid manure, high-rise manure fermentation bedding, litter recycling, wastewater fertilisation and up-to-standard discharge of wastewater (Figure 1).

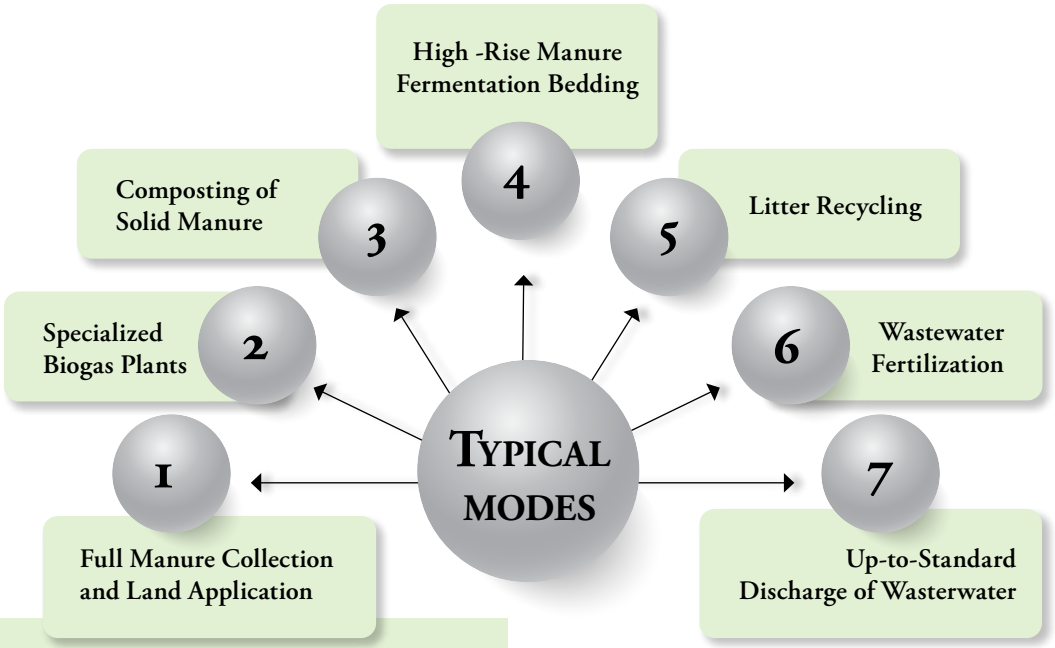


Figure 1.
Seven modes of manure treatment and utilisation. Adapted from *Action plan for the utilization of livestock manure (2017-2020)*, by Ministry of Agriculture of the People's Republic of China, July 7 2017, retrieved from http://www.moa.gov.cn/nybgb/2017/dbq/201801/t20180103_6134011.htm (in Chinese)

3. Characteristics of standard discharge and manure land application

The treatment modes are generally divided into two categories: in category one, the requirements of fertiliser utilisation are achieved through fermentation and composition of manure; in category two, the requirements of environmental discharge are achieved through the advanced treatment of manure. Each mode has its characteristics and must meet and comply with the applicable conditions.

3.1 Characteristics of standard discharge

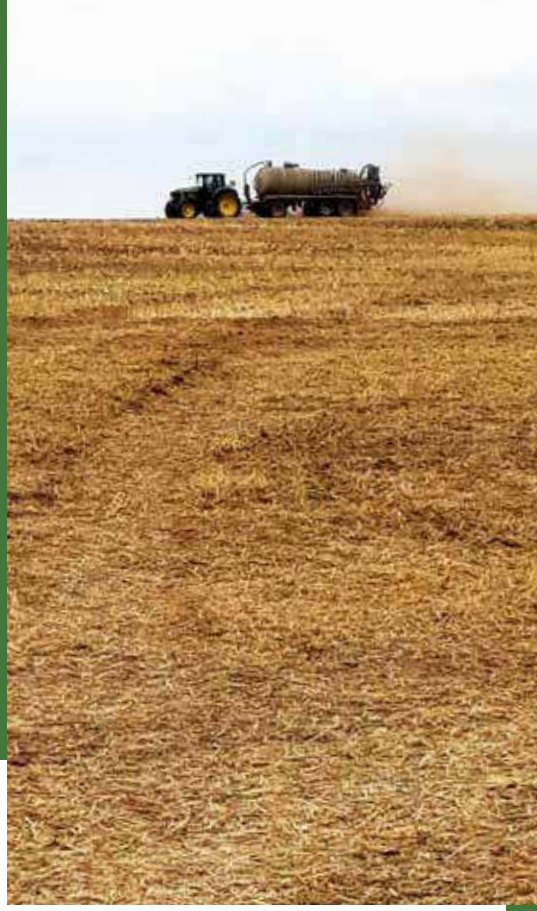
In the process of anaerobic and aerobic treatment of liquid manure, most nitrogen is converted to a form that cannot be reused as fertiliser (N_2) due to nitrification and denitrification. Although N_2, as a component of the air, will not cause pollution to the atmospheric environment, N_2 emissions into the air do not produce recycling benefits, which is a waste of resources to some extent. At the same time, studies have shown that during these processes, most of the carbon in faeces and urine is also lost, thus reducing the input of soil organic matter (Hou et al., 2017). In the process of standard discharge anaerobic treatment and aerobic treatment, gas collection or transformation facilities are equipped to collect nitrogen-containing gas to achieve the purpose of nitrogenous fertilisation and recycling.

3.2 Characteristics of manure land application

The challenge of the 'last kilometre' regarding manure land application remains to be solved. In the short term, there is no comparative advantage between manure and chemical fertiliser due to the low fertiliser efficiency, slow effect, peculiar smell and unstable nutrient content of manure. In particular, the transport and application of liquid manure is inconvenient, which results in much lower competitiveness of liquid manure compared to chemical fertilisers.

On the other hand, the separation of crop and livestock production restricts the utilisation of manure (slurry). At present, the separation of crop and livestock production is prevalent in China and other countries. Solid waste is relatively easy to handle, while liquid manure is the main problem for a large part of landless farming. These farms can only separate solid-liquid manure and then deep-treat the separated liquid fraction to irrigation water standard before application in the field, which not only increases costs but also leads to nutrient losses.

Besides, there are still some restricting factors on the path of returning manure (slurry) to the field, which mainly manifests in the slow development of social service organisations, such as the limited ability for effectively connecting crop and livestock production and its small quantity. Meanwhile, facilities and equipment are not adapted to land application, and there is no operation guide for integrated crop and livestock production in different regions and crops.



To promote manure land application, the MARA has formulated relevant documents, which firstly recommend controlling heavy metals and the use of antibiotics from the feed source (MOA, 2017c; Ministry of Agriculture and Rural Affairs [MARA], 2018). The second recommendation is process control: Aerobic composting and anaerobic fermentation can significantly reduce the content of antibiotics in the manure (Wang et al., 2013; Yin et al., 2019a, 2019b). The third is scientific use. Manure land application should be carried out following the *Technical guide for measuring the land carrying capacity of livestock and poultry manure* issued by the MARA (MOA, 2018).

4. Suggestions for manure utilisation

4.1 Determining the manure treatment model based on regional characteristics

The recycling use mode of livestock manure should be chosen based on local and natural features, agricultural practices, and economic development level. Through representative demonstration, a typical pattern of manure treatment and utilisation with regional characteristics took shape. At present, China is still in traditional breeding production. For small and medium-sized farm households in concentration areas with a low economic level and enough farmland, manure land application should be the first choice to fully make use of nitrogen, phosphorus and other nutrients and organic matter resources in the animal manure. This can improve the physical and chemical properties of the soil, increase its productivity, and thus increase crop yields. For farms located in the suburbs of some economically developed cities without enough farmland to absorb livestock manure, the standard discharge mode can compensate for the lack of land created by the manure land application mode.

4.2 Promoting integrated crop and livestock production based on nutrient balance management

The utilisation of livestock manure is a green link connecting the two industries of livestock and crop. The model of integrated livestock and crop production for achieving recycling has become a social consensus. It is thus suggested to learn from the comprehensive European and American nutrient management plans to promote the implementation of nutrient management systems. According to the requirements of the *Technical guide for measuring the land carrying capacity of livestock and poultry manure*, the livestock farms are required to be equipped with sufficient farmland. Meanwhile, a standing account for the utilisation of livestock manure has been established. The *Ministry of Agriculture and Rural Affairs* (MARA) and the *Ministry of Ecology and Environment* (MEE) jointly established a service and supervision system based on nutrient balance management to achieve the *three appropriate* (the right amount, the right application time and the right fertilisation method), which can improve the use efficiency of manure and ensure the yield and quality of crop and environmental safety.

4.3 Strengthening third-party services and promoting mechanisation and informatisation of manure land application

At present, the difficulty of the implementation of integrated crop and livestock production based on nutrient balance is to carry out the feasible mechanism, technology and facilities. As an efficient organisational model, third-party services have achieved excellent results in some regions of China, playing a decisive role in reducing non-point source pollution and improving soil fertility. In farming areas with suitable conditions for recycling and dense regions of livestock production, regional organisations for livestock manure application services were set up, and the government can conduct guiding subsidies on transport vehicles, fertilisation machinery, service fees, etcetera to reduce the farmers' fertiliser costs. By doing so, farmers can be free from heavy manure application, which might increase their enthusiasm for using livestock manure. In order to improve the efficiency of manure land application, it is necessary to study and popularise the equipment for transportation and land application of manure suitable for different areas and types of fields. Through carrying out the information management of manure land application, the whole process is recorded in order to ensure the scientific and accurate utilisation amount of manure.

References

Bai, Z.H. (2015). *The resources requirement, nitrogen and phosphorus use and losses in the main livestock production system in China* [D]. Beijing, PRC: China Agricultural University (in Chinese)

Basset-Mens, C., van der Werf, H.M.G., Robin, P., Morvan, Th., Hassouna, M., Paillat, J.-M., & Vertès, F. (2007). Methods and data for the environmental inventory of contrasting pig production systems. *Journal of Cleaner Production*, 15(15), 1395-1405

Dangal, S.R.S., Tian, H., Zhang, B., Pan, S., Lu, C., & Yang, J. (2017). Methane emission from global livestock sector during 1890–2014: Magnitude, trends and spatiotemporal patterns. *Global Change Biology*, 23(10), 4147-4161. Retrieved from https://doi.org/10.1111/gcb.13709

Food and Agriculture Organization of the United Nations (2006). *Livestock's long shadow: Environmental issues and options*. Rome, Italy: FAO. Retrieved from http://www.fao.org/3/a0701e/a0701e.pdf

General Office of the State Council (2017). *Opinions of the general office of the state council on accelerating the utilization of livestock and poultry waste resources*. Retrieved from http://www.gov.cn/zhengce/content/2017-06/12/content_5201790.htm (in Chinese)

Guo, J.H., Liu, X.J., Zhang, Y., Shen, J.L., Han, W.X., Zhang, W.F., Christie, P., Goulding, K.W.T., Vitousek P.M., & Zhang, F.S. (2010). Significant Acidification in Major Chinese Croplands. *Science*, 327(5968), 1008-1010. DOI:10.1126/science.1182570

Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M.C., Thornton, P.K., Blümmel, M., Weiss, F., Grace, D., & Obersteiner, M. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences of the United States of America* (PNAS), 110(52), 20888–20893. Retrieved from https://doi.org/10.1073/pnas.1308149110

Hou, Y., Velthof, G.L., Lesschen, J.P., Staritsky, I.G., & Oenema, O. (2017). Nutrient Recovery and Emissions of Ammonia, Nitrous Oxide, and Methane from Animal Manure in Europe: Effects of Manure Treatment Technologies. *Environmental Science & Technology*, 51(1), 375-383. DOI:10.1021/acs.est.6b04524

Liu, X., Duan, L., Mo, J., Du, E., Shen, J., Lu, X., Zhang, Y., Zhou, X., He, C., & Zhang, F. (2011). Nitrogen deposition and its ecological impact in China: An overview. *Environmental Pollution*, 159(10), 2251-2264. Retrieved from https://doi.org/10.1016/j.envpol.2010.08.002

Menzi, H., Oenema, O., Burton, C., Shipin, O., Gerber, P., Robinson, T., & Franceschini, G. (2010). Impacts of Intensive Livestock Production and Manure Management on the Environment. In H, Steinfeld, H, Mooney, F, Schneider, & L.E, Neville (Eds.). *Livestock in a Changing Landscape: Drivers, Consequences and Responses* (Vol. 1, pp.139-163). Washington, DC, U.S.A.: Island Press

Ministry of Agriculture (2017a). *Action plan for the utilization of livestock manure (2017-2020)*. Retrieved from http://www.moa.gov.cn/nybgb/2017/dbq/201801/t20180103_6134011.htm (in Chinese)

Ministry of Agriculture (2017b). *Notice of the ministry of agriculture on printing and distributing the action plan of carrying out the replacement of organic fertilizer with fruit, vegetable and tea*. Retrieved from http://www.moa.gov.cn/govpublic/ZZYGLS/201702/t20170210_5472878.htm (in Chinese)

Ministry of Agriculture (2017c). *Notice of the ministry of agriculture on soliciting opinions on the revision of the code for the safe use of feed additives.*

Ministry of Agriculture (2018). *Notice of the general office of the ministry of agriculture on printing and distributing technical guide for measuring the land carrying capacity of livestock and poultry manure*. Retrieved from http://www.moa.gov.cn/gk/tzgg_1/tfw/201801/t20180122_6135486.htm (in Chinese)

Ministry of Agriculture and Rural Affairs (2018). *Notice of the General Office of the Ministry of Agriculture and Rural Affairs on the Pilot Work of Veterinary Antimicrobial Use Reduction*. Retrieved from http://www.moa.gov.cn/govpublic/SYJ/201804/t20180420_6140711.htm (in Chinese)

Steinfeld, H., Mooney, H.A., Schneider, F., & Neville, L.E. (Eds.). (2010). *Livestock in a Changing Landscape: Drivers, Consequences and Responses* (Vol. 1). Washington, DC, U.S.A.: Island Press

Wang, R &Wei, Y.S. (2013). Pollution and Control of Tetracyclines and Heavy Metals Residues in Animal Manure. *Journal of Agro-Environment Science*, 32(9), 1705-1719. (in Chinese)

Wei, S. (2016). *Nutrient cycling, environment losses and sustainability assessment of livestock production in peri-urban areas of Beijing* [D]. Beijing, PRC: China Agricultural University (in Chinese)

Wei, S., Bai, Z.H., Qin, W., Xia, L.J., Oenema, O., Jiang, R.F., & Ma, L. (2016). Environmental, economic and social analysis of peri-urban pig production. *Journal of Cleaner Production*, 129, 596-607. Retrieved from https://doi.org/10.1016/j.jclepro.2016.03.133

Yin, F., Dong, H., Zhang, W., Zhu, Z., Shang, B., & Wang, Y. (2019a). Removal of combined antibiotic (florfenicol, tylosin and tilmicosin) during anaerobic digestion and their relative effect. *Renewable energy*, 139, 895-903. Retrieved from https://doi.org/10.1016/j.renene.2019.03.001

Yin, F., Dong, H., Zhang, W., Zhu, Z., & Shang, B. (2019b). Additional function of pasteurisation pretreatment in combination with anaerobic digestion on antibiotic removal. *Bioresource Technology*, 297, 122414. Retrieved from https://doi.org/10.1016/j.biortech.2019.122414

Chapter 3:
Crop Production

With a contribution from:

Sophia Lüttringhaus
HFFA Research GmbH

Division Sustainable Land Use and Climate Change, Department of Agricultural Economics, Humboldt-Universität zu Berlin

Climate Change Impacts on Crop Production in Europe and Opportunities for Adaptation and Mitigation by Plant Breeding

Sophia Lüttringhaus
HFFA Research GmbH

Division Sustainable Land Use and Climate Change, Department of Agricultural Economics, Humboldt-Universität zu Berlin

Sophia Lüttringhaus

Climate Change Impacts on Crop Production in Europe and Opportunities for Adaptation and Mitigation by Plant Breeding

1. Introduction

Climate change manifests itself both in rising temperatures and in structural changes in precipitation patterns and overall water availability. The climate has already changed in Europe and worldwide, and the consequences are manifold effects in time and space. The global annual near-surface temperature has increased in recent decades by almost 1°C above pre-industrial levels. The last decade has been the warmest on record due to anthropogenic climate change. One approach to describing these climate shifts is the concept of climate analogues, which compares the projected future climate of a city with the current climate of another city. For example, with unabated climate change in 2071-2100, Berlin is likely to have the climate of Zaragoza today. As a rule, one can say that precipitation levels will increase in Northern Europe and decrease in the South. Another effect of climate change is the increasing probability and intensity of extreme weather events. Thus, such weather extremes as the drought in Germany and other European regions will be more probable and last longer in the future.

The quantity and quality of crop production depends on many factors, such as climate, weather, specific location, farmer management, available inputs and technologies used. One technology that can increase crop production without expanding agricultural land, hence decreasing land-use change that has adverse effects on the environment, is plant breeding. This technology can have several benefits for food security, in particular by increasing the yield potential and improving the quality and bioavailability of crops.

In this article, I first provide an overview of the effects of climate change impacts already observed and predicted in Germany and Europe (Chapter 2).[1] Then, I look at how plant breeding can help to adapt crop production to these changes and thus stabilise or increase food security (Chapter 3). The article closes with a conclusion and policy recommendations (Chapter 4).

1 Please note that this part of the article is based on Lüttringhaus et al. (2019).

2.
Climate change impacts on crop production in Europe

The global annual near-surface (land and ocean) temperature has increased by about 0.9°C in the decade from 2008 to 2017 compared to pre-industrial levels in the mid-19th to early 20th century (NASA's Goddard Institute for Space Studies [NASA/GISS], 2019). In the same period, land temperatures in Europe increased by 1.6 to 1.7°C (European Environment Agency [EEA], 2018). Along with rising temperatures, climate change increases the probability of occurrence and the intensity of extreme weather events such as droughts and floods (Otto et al., 2012, 2018). In particular, high-temperature climate-related extremes such as heatwaves have become more frequent and intense (EEA, 2017a; Kovats et al., 2014). However, due to changes in global climate circulation patterns (e.g., blocked weather conditions due to a slower jet stream), low-temperature extremes may also occur more frequently and for longer periods (Kornhuber et al., 2017; Rahmstorf & Coumou, 2011; Kretschmer et al., 2018; Pfleiderer et al., 2019).

Precipitation patterns have also changed due to climate change. These effects are very heterogeneous across space (EEA, 2017a). For Europe, these are the most striking points:

- Annual precipitation levels in Northern Europe have increased by up to 70 mm per decade since the 1960s as winters have become wetter and summer rains have also increased by up to 18 mm per decade
- In contrast, annual precipitation levels in Southern Europe have decreased by up to 90 mm per decade. In this region, the mean precipitation during the summer months has decreased by up to 20 mm per decade

In addition, it is predicted that climate change will continue without effective measures to reduce emissions and that the changes already observed would continue. Figure 1 gives an overview of how annual temperatures and precipitation patterns will most likely change in Europe. It shows the projected changes for the years from 2071 to 2100, compared with the period one hundred years earlier[2].

2 These projections are a model ensemble: they represent the mean value of several models under a high emission scenario, using the so-called Representative Concentration Pathway (RCP) 8.5 high emissions scenario. This scenario projects an increase in global mean temperature of 1.4 to 2.6°C (mean 2.0°C) between 2046 and 2065 (see EEA, 2015).

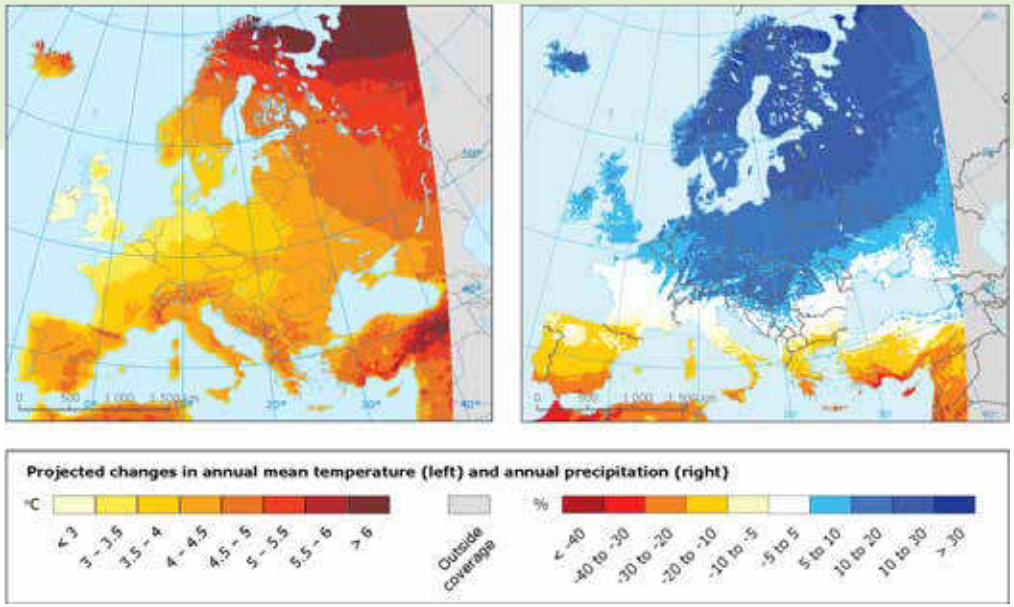


Figure 1.
Projected changes in annual mean temperature (left) and annual precipitation (right) for 2071-2100 (assuming RCP8.5) compared to 1971-2000.

Reprinted from European Environment Agency (EEA), 2015, retrieved from https://www.eea.europa.eu/data-and-maps/figures/projected-change-in-annual-mean

It is clear that the annual mean temperature will rise everywhere in Europe; and as far as precipitation is concerned, the rule of thumb is that the North will become wetter and the South drier. In general, longer dry periods are projected in Europe, too (EEA, 2017b). Heat waves will particularly impact Southern Europe, increasing the likelihood of systemic failures, as multiple sectors will be affected (e.g., health and agriculture). Thus, economic activity will be more adversely impacted in these regions than in other parts of Europe. Furthermore, there is great confidence in model projections that the decline in all ecosystem services will be particularly pronounced in Southern Europe.

Considering the above-mentioned wide range of changes, it is evident that climate change has significant repercussions on agriculture. Figure 2 illustrates the effects of climate change on crop yields by 2080 compared to the period from 1961-1990 and shows their heterogeneity within Europe. It compares two climate simulation models that drive a crop model. The crop model forecasts yield increases in the green shaded areas, while red and orange coloured areas symbolise expected yield declines.[3] Depending on the climate model[4], yield declines are projected to be very high in the far West of the continent, the Iberian Peninsula, Italy, and the Balkans, whereas yield increases are forecasted mainly for Scandinavia and some parts of Central and Eastern Europe.

In the following, I will explain the impacts of climate change on agricultural crop production systems according to their practical relevance for farmers and other sectoral stakeholders.

3 For a more detailed view on how projected wheat yields under climate change vary between different combinations of specific climate and crop models, please see chapter 4 of Lüttringhaus et al. (2019).

4 Depending on the climate model used, climate change and subsequent impact findings may differ. See also chapter 4 in Lüttringhaus et al. (2019), which provides insights concerning this still given 'uncertainty'.

2.1
Growing season length, crop life cycle timing and habitat shift

An important aspect that has already been – and will continue to be – altered by climate change is the length of the growing season, which is a limiting factor especially in Northern Europe. Recent developments show that the thermal growing season of crops is expanding with rising temperatures and fewer frost days due to global warming. Since 1992, this period has increased by more than ten days, with the delay of the senescence being more pronounced than the advance of its onset (Jeong et al., 2011). This expansion will continue, and by 2050, the date of the last spring frost is projected to have advanced by 5 to 10 days (Trnka et al., 2011). This so-called spring advance is more present in parts of Northern and Eastern Europe. Olesen et al. (2007) predict that net primary plant production may steeply increase by 35-54% in Europe's Northern regions due to a longer vegetative period (and also due to higher CO_2 concentration).

A change in the growing season modifies the phenology of the plants, i.e. the timing of the crops' life cycle, which is shown, for example, by earlier flowering dates. During the past 50 years, the flowering of several crops has advanced by about ten days (EEA, 2017a). This development is counteracted, however, by an earlier maturation of crops due to increased temperatures.

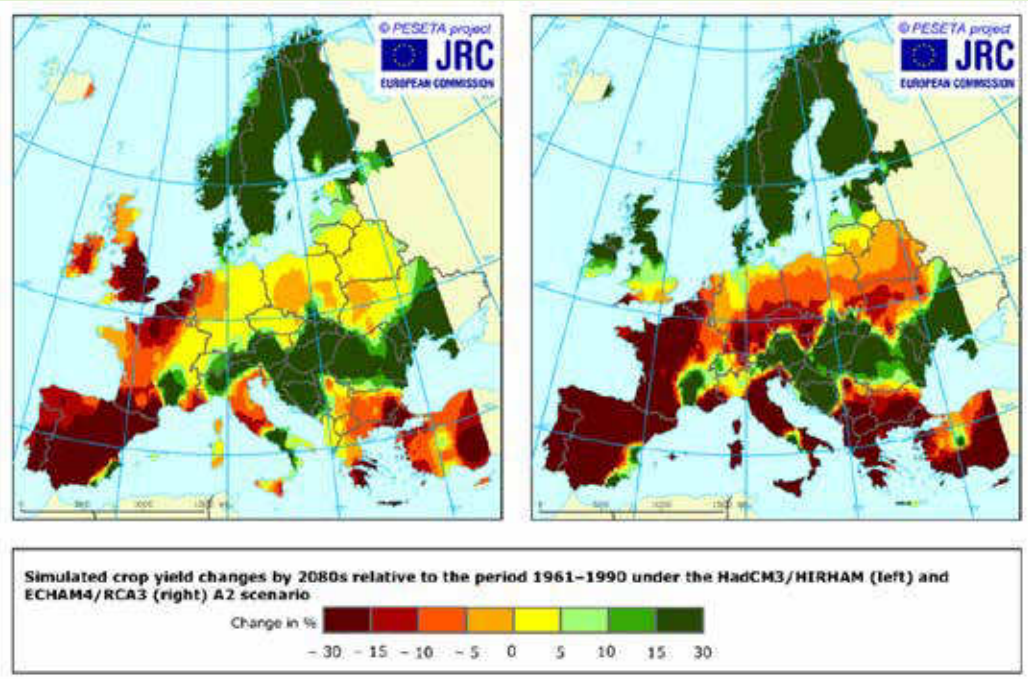


Figure 2. **Simulated crop yield changes by 2080.**

Reprinted from Climate change, impacts and vulnerability in Europe 2016: An indicator-based report, by European Environment Agency (EEA), 2017. Copyright 2016 by European Environment Agency.

Thus, the growth phases (e.g., the grain-filling phase) are shortened, and possible yield-enhancing effects of earlier planting dates are jeopardised. This results in lower biomass production and/or harvest indices (EEA, 2017a). To take advantage of the potential benefits of these changes, farmers could grow other crops or varieties with higher thermal requirements or postpone planting dates to create longer growth periods overall.

Another adverse effect of climate change on plant growth and health is the higher probability of extreme weather events, especially during critical growing stages of a crop such as the flowering stage. This trend is expected to continue particularly in Central and Southern Europe (see e.g., Powell & Reinhard, 2016; Rahmstorf & Coumou, 2011; Rosenzweig et al., 2001; Rötter & van de Geijn, 1999).

Another aspect of climate change is the so-called habitat shift or habitat expansion of crops. This means that warmer temperatures and fewer frost days will allow thermophile crops to expand northwards or to higher altitudes. For example, farmers can grow maize in northern parts of Europe, where the growing period is currently too short and temperatures are too low for these thermophilic crops. A similar agronomic change induced by climate change is that, for instance, farmers in parts of Southern Europe can shift some of their cultivation activities into the winter months to avoid heat waves and droughts in summer (EEA, 2017a). In other European regions, however, such as western France and parts of South-Eastern Europe, this shift will be difficult because the time horizon in which plants can be optimally planted is more limited. In consequence, these regions' vulnerability is predicted to increase. Moreover, the negative effects of climate change cannot be overcome by this adaptation option if farmers grow two crops per year on one field.

These phenomena are also observed in pests and diseases, which in turn has enormous repercussions on the interaction between crops and on pests and diseases. Studies suggest that the regional composition, distribution, density, phenology, and plant structure (e.g., the increasing plant height) of damaging weeds will change significantly due to climate change (McDonald et al., 2009; Peters et al., 2014; Kovats et al., 2014).

As crops, but also pests and diseases, change in the wake of climate change, the damage niche also changes. The damage niche describes the area in which both the crops and the infested pests and diseases predominate and the pests and diseases also damage plant production. Farmers must therefore apply new management strategies and technologies in order to grow the most suitable crops or varieties, and also follow the latest developments in integrated plant protection[5].

2.2 Water availability and irrigation demand

Globally, climate change will put further pressure on agricultural water management, which is already under pressure from population growth, economic development and environmental concerns (Iglesias & Garrote, 2015; Field et al., 2014; Jeong et al., 2011). Kovats et al. (2014) estimate that by mid-century irrigation will not be sufficient in some European regions to compensate for the damage caused to crops by water stress. However, too much water – induced regionally by extreme weather events (such as heavy precipitation) and, in addition, locally by sea-level rise – also tends to threaten agricultural production. These impacts lead to waterlogging and salinisation in particular, which are often very site-specific (Iglesias & Garrote, 2015)[6]. Due to changes in overall water availability in the soil, it is very likely that the need for irrigation will also increase.

When talking about climate change impacts on crop production, it is of particular interest to understand how precipitation patterns, i.e. the timely and regional distribution of rainfall, change throughout the year. The same can be said for the occurrence of extreme weather events. In this context, it is necessary to consider the total water availability, consisting of precipitation, evapotranspiration and soil moisture. As scientists agree that the global mean temperature has risen, and will continue to rise, evapotranspiration is also expected to increase. This in turn reduces the total near-surface water availability (i.e. the hydrological balance) for crops (Solomon et al., 2007); and this water balance will deteriorate further if total precipitation decreases in certain regions. Again, this interrelation underlines the dramatic consequences climate change will have on water availability, even though it is very challenging to predict single precipitation events accurately.

Another vital aspect is the spatiotemporal interaction between groundwater and climate. The hydraulic memory of groundwater systems varies, and it is therefore difficult to estimate the effects of climate change on them (Cuthbert et al., 2019). Furthermore, it is challenging to measure the effectiveness of certain mitigation activities, as the response time might be longer than a human lifespan (i.e. about 100 years). The authors conclude that in arid regions, groundwater systems are less responsive than in humid regions. Hence, water scarcity is likely to last longer and with greater intensity in drier regions.

5 Integrated plant protection describes a holistic approach that includes preventive measures as well as various non-chemical (e.g., mechanic procedures), and chemical plant protection measures (Freier et al., 2017).

6 Another important point is water quality, which might diminish due to rising temperatures and environmental degradation.

To highlight this aspect, the following case study findings are added. Deike (2018) explains the effects of climate change on water availability in the agricultural life cycle with a focus on Germany. According to the author, precipitation in the first half of the year will decrease on average in many regions of Germany:

- More persistent aridity from January to March rarely impacts yield development, as crops do not need much water at this time because of their low evapotranspiration and growth stage. Nevertheless, water reservoirs cannot be filled, so that future droughts or aridity cannot be compensated as well

- If aridity coincides with an early start of vegetation in spring, weakened crops cannot recover very well because weeds also start to compete for water resources

- Early summer aridity, especially in April and May, is of particular importance for the yield development of the crops, which is mainly determined in the early development phase of the plants

- On the contrary – and again on average – more precipitation falls in the second half of the year. They make harvesting more difficult, e.g. of oilseed rape, but crops harvested later (e.g., maize) can benefit from this.

2.3
Elevated CO_2 levels

Despite the predominantly negative effects of global warming (especially in the long term), some changes could be beneficial for crop production. One of these is a rising atmospheric CO_2 content, which can increase yields under certain conditions due to the CO_2 fertilisation effect. Figure 3 shows the steadily increasing concentration of this greenhouse gas.

More particularly, there is much evidence that higher CO_2 concentrations increase photosynthesis processes in C3 plants but less in C4 plants[7] (Van Meijl et al., 2017; Ramesh et al., 2017; Fuhrer, 2003). In C3 crops, higher CO_2 levels improve water use efficiency and cause plants to transpire less (Kruijt et al., 2008), which can translate into a lower water demand. Other authors conclude that water use efficiency is increased in both carbon pathways, but not necessarily photosynthesis (Keenan et al., 2013).

This alone shows that there is still much uncertainty about the yield effects of CO_2 fertilisation. One reason for this is the limited understanding of how plants will respond in the long term. The CO_2 concentration influences several – possibly counteracting – plant physiological processes (Van Meijl et al., 2017). Nevertheless, Tubiello et al. (2007) summarise that crop yields will increase by 10-20% for C3 and by up to 10% for C4 plants by 2100 compared to CO_2 concentrations in 2007.

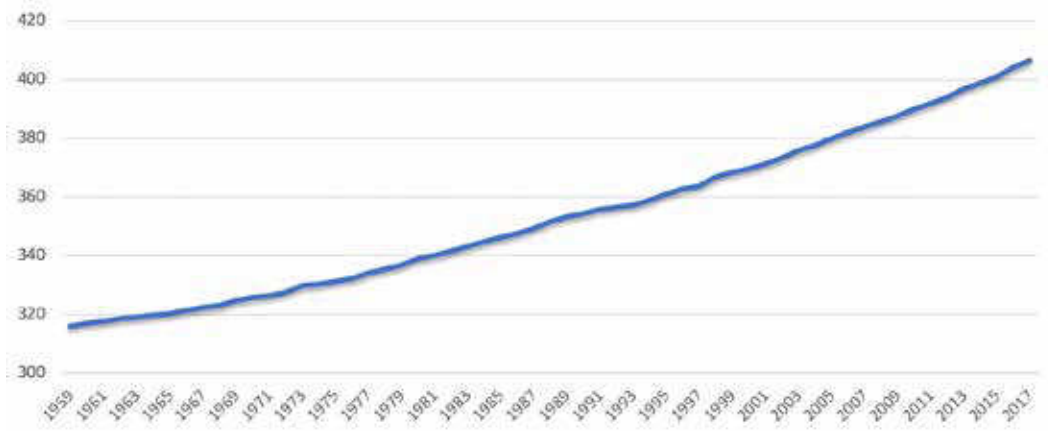


Figure 3. **Annual mean CO_2 concentration (in parts per million).**

ReprintedAdapted from Trends in Atmospheric Carbon Dioxide.
Mauna Loa CO_2 annual mean data, by Tans & Keeling, 2020,
retrieved from https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html

Ribeiro et al. (2012) conclude that even desired traits such as dwarf varieties for better agronomic properties could be reversed with increased CO_2 content due to the changed hormonal growth control. As mentioned above, it is difficult to separate the different effects on plant growth and interactions from other effects of climate change. For example, the potential positive effects of CO_2 fertilisation can be significantly hampered if adverse weather conditions such as heat hinder proper plant development (Tubiello et al., 2007), and thus net effects are uncertain or could be harmful.

7 C3 and C4 plants have different paths of photosynthesis. C3 plants are the most common and have a very efficient photosynthesis under cool and humid climate. Examples of this group are wheat, rice, soya, sunflower, oilseed rape, potato, sugar beet and dry bean. In opposite to that, C4 plants, such as maize, sugar cane and sorghum are most efficient under hot and sunny climate (see van Meijl et al., 2017; Jaggard et al., 2010).

2.4 Erosion

Following the increased occurrence and intensity of weather extremes, the impacts of climate change (e.g., heavy rains and/or droughts) may also increase soil erosion and reduce soil fertility (Kovats et al., 2014). Indeed, the model results of Panagos et al. (2017) show that soil erosion caused by rainfall in Europe will increase by 18% by 2050 and that 81% of European territory will experience increased erosion. Especially for the Western Alps, parts of the French Atlantic coast, Eastern Croatia, parts of Slovakia, and Southern Germany, such an increase is predicted due to higher rainfall intensity and other erosive events. As far as wind erosion is concerned, Mediterranean countries are expected to have the least impacts, while areas around the North Sea will be more affected by wind erosion (Borrelli et al., 2014); and in regions such as the Mediterranean and Central-Eastern Europe, which are already – currently – centres of desertification, extreme weather conditions such as droughts and forest fires will further increase the risk of desertification (EEA, 2017a).

3. Possible adaptation and mitigation pathways created by plant breeding

According to the Mbow et al. (2019), one option for more productive use of land, water, nutrients and other resources is the genetic improvement of crops for high yields, tolerance and adaptation to climate change. Therefore, plant breeding and the new technologies implemented in this sector can help to reduce pressure on the soil and also contribute to mitigating climate change (Mbow et al., 2019; Matthews, 2019).

In the following, possible ways in which plant breeders can contribute to climate adaptation and mitigation are outlined. Please note that all of these pathways are highly interconnected and influence each other. Furthermore, the extent to which these breeding-induced benefits can be exploited depends on general plant care and local conditions.

Closing the yield gap – this means reducing the gap between the yields achievable under comprehensive management and the actual farm yields achieved by an average farmer. On the one hand, side plant breeding has increased the genetic yield maximum of the plants – and still has potential to increase it further. On the other hand, plant breeding can create varieties that produce high yields under various environments and limited input use (Voss-Fels et al., 2019). Furthermore, new traits facilitating crop production (e.g., dwarf varieties or the synchronisation of ripening times) have helped farmers to achieve higher yields. For example, the Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs (2011) analysed that German wheat breeding increased the achievable yields by 0.34-0.38 dt/ha/yr between 1966 and 2007. This is equivalent to about 0.5% of the average yield attained in 2010 in Germany (Statista, 2018). Increasing land productivity through improved yields can reduce global land-use changes and thus contribute to climate change mitigation.

Breeding for crop production under climate change conditions – as explained in chapter 1, climate change will alter plant production systems. Plant breeding contributes to adapting crop plants to these changes. Increased drought and heat tolerance are, for example, achieved by creating crops with larger root systems (Mbow et al., 2019). This improves the water uptake of the plants, as they can reach lower water reservoirs and draw water from a larger area. Thereby, also more nutrients might be absorbed. However, plant breeding is not only helpful under adverse climate conditions. Another field of work is the selection and creation of varieties that are well adapted to new environments, such as maize varieties that produce well in areas that used to be too cold for cultivation (see chapter 2a). Furthermore, plant breeding can optimise the life cycle of crops under new climatic conditions, which ultimately results in higher and more stable yields. Depending on a region's climate, a variety's growing period can also be shortened to avoid water stress events during crucial stages of plant growth, or a variety could even be bred to allow for several harvests per year.

Improving nutrient and water use efficiency – these breeding objectives contribute to both climate change adaptation and mitigation. For example, genetic improvements pursued in Germany since the 1960s on winter wheat achieved a reduced demand for fertiliser and water (Voss-Fels et al., 2019). Fertiliser emissions to the environment can also be reduced through increasing the nitrogen use efficiency.

Enhancing nutrition and food security - breeding has improved the quantity and quality of crop production. As yields increase, food security is improved through greater availability of food. In addition, plant breeding can stabilise or even increase the micronutrient content of crops under unfavourable climate change conditions. This is done, for example, by reducing the sensitivity of crops to atmospheric CO_2, since research has shown that increased CO_2 levels reduce the micronutrient content of crops (Mbow et al., 2019). Consequently, breeding can improve food security and global health by providing inputs that ensure high-quality food production under climate change conditions. Another aspect is the proliferation of local protein crops, a strategy that is supported by the German government. In order to reduce protein imports and adverse climate change effects by the clearing of land, e.g. for soya plantations, plant breeding can improve the agronomic qualities of protein crops such as legumes.

In order to maximise these potential breeding-induced benefits for climate change mitigation and adaptation, it is necessary to harness the vast global genetic material available and also to include landraces, wild relatives of crops, and orphaned and neglected crops (e.g., millet, beans, cassava) in breeding programs (WRR, 2019; Searchinger, 2014) in search for desired traits such as increased resistance to biotic stresses or heat tolerance.

The speed and quality of future genetic improvements will also depend on existing breeding technologies. For example, the application of hybrid and CRISPR/Cas breeding in wheat has produced wheat varieties that are resistant to powdery mildew and have higher and more stable yields (Zhao et al., 2015). The CRISPR/Cas technique made it possible to introduce the powdery mildew resistance found in barley into wheat. Without the new technique, i.e. with conventional breeding, this would probably have taken 10-20 years longer (Wang et al., 2014; Acevedo-Garcia et al., 2016).

As climate change is a rapidly evolving phenomenon, plant breeding must also be accelerated, but due to its complexity and the need to test new varieties under real field conditions, this is a challenging undertaking. So far, other technologies such as high-throughput phenotyping and genomic markers have already reduced breeding time and costs.

4. Conclusion

The current and future effects of climate change make it clear that agricultural systems must adapt and reduce emissions. Climate change has led to systematic problems such as irreversible environmental degradation and will continue to do so in the future. The impacts vary regionally and are very complex, as many climate systems are interlinked and influence each other. Therefore, the entire climate system must be taken into account when projecting the effects of climate change on plant production. Regardless of the region- and crop-specific projections of climate change impacts, it is clear that crop production will be confronted with many more extreme weather events in the future. Such extremes as the rainfall deficit in Germany in 2018 and 2019 will occur more frequently and with greater impact. Moreover, the persistence of these events will increase. This means that crop production will be more volatile in the future. Furthermore, climate change will influence the growing season length and the life cycle of crops. Since 1992, the thermal growing season has already been extended by ten days, and this trend is continuing. The phenology of crops has also changed, as can be seen for example in earlier flowering dates. Additionally, habitat shifts or habitat expansions occur when thermophilically growing crops move northwards. One example is the expansion of the ecological niche of maize due to rising average temperatures.

Farmers' management, political regulations and the quality and quantity of input factors (such as fertilisers and seeds) must be taken into account when analysing the future of crop production. Plant breeding positively influences the phenotypic characteristics of the varieties and crops used. Therefore, this sector plays a crucial role in climate change adaptation and mitigation by improving primary crop production, food security and resource efficiency. Increasing yields under different conditions remains the main priority of plant breeders. With the right policies, yield increases can reduce the expansion of agricultural land and thus protect natural ecosystems. Nevertheless, it is a challenge to adapt to the rapidly changing climate and to anticipate not only climatic conditions, but also consumer preferences and international trade flows. Such a globalised challenge requires international cooperation in the exchange of genetic material and experience with different varieties or crops within different climatic zones and cropping systems. National or international funding of research and development within the sector should also be maintained – this way, the breeding benefits for climate change adaptation and mitigation can be optimised.

References:

Acevedo-Garcia, J., Spencer, D., Thieron, H., Reinstädler, A., Hammond-Kosack, K., Phillips, A.L., & Panstruga, R. (2016). *mlo*-based powdery mildew resistance in hexaploid bread wheat generated by a non-transgenic TILLING approach. *Plant Biotechnology Journal 15*(3), 367-378. DOI:10.1111/pbi.12631

Borrelli, P., Ballabio, C., Panagos, P., & Montanarella, L. (2014). Wind erosion susceptibility of European soils. *Geoderma*, 232–234, 471-478

Cuthbert, M.O., Gleeson, T., Moosdorf, N., Befus, K.M., Schneider, A., Hartmann, J., & Lehner, B. (2019). Global patterns and dynamics of climate–groundwater interactions. *Nature Climate Change, 9*, 137-141

Deike, S. (2018). Trockenheit: So können Sie reagieren. *DLG-Mitteilungen Sonderheft Landwirtschaft im Klimawandel*, 13-15. Retrieved from https://www.kuhn.de/internet/webde.nsf/mobile/8900E84EA5B-4F1A5C12583E0004C1E24/$File/DLG%20Mitteilung%20Klimawandel%20KUHN.pdf

EEA (European Environment Agency) (2015). *Projected changes in annual mean temperature (left) and annual precipitation (right)* [figure]. Retrieved from https://www.eea.europa.eu/data-and-maps/figures/projected-change-in-annual-mean

EEA (European Environment Agency) (2017a). *Climate change, impacts and vulnerability in Europe 2016: An indicator-based report.* Luxembourg City, Luxembourg: Publications Office of the European Union

EEA (European Environment Agency) (2017b). *Heavy precipitation in Europe.* Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment

EEA (European Environment Agency) (2018). *Global and European temperature.* Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-8/assessment

Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., & White, L.L. (Eds.). (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, NY, U.S.A.: Cambridge University Press

Freier, B., Krengel, S., Kula, C., Kühne, S., & Kehlenbeck, H. (2017). *Report on findings of scientific investigations on possible direct and indirect impacts of plant protection on biodiversity in agricultural landscapes.* Quedlinburg, Germany: Julius Kühn-Institut, Bundesforschungsinstitut für Kulturpflanzen

Fuhrer, J. (2003). Agroecosystem responses to combinations of elevated CO_2, ozone, and global climate change. *Agriculture, Ecosystems & Environment, 97*(1-3), 1-20

Iglesias, A & Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management, 155,* 113-124

Jeong, S.J., Ho, C.H., Gim, H.J., & Brown, M.E. (2011). Phenology shifts at start vs. end of growing season in temperate vegetation over the Northern Hemisphere for the period 1982-2008. *Global Change Biology, 17*(7), 2385-2399

Keenan, T.F., Hollinger, D.Y., Bohrer, G., Dragoni, D., Munger, J.W., Schmid, H.P., & Richardson, A.D. (2013). Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. *Nature, 499*, 324-327

Kornhuber, K., Petoukhov, V., Petri, S., Rahmstorf, S., & Coumou, D. (2017). Evidence for wave resonance as a key mechanism for generating high-amplitude quasi-stationary waves in boreal summer. *Climate Dynamics, 49*, 1961-1979

Kovats, R.S., Valentini, R., Bouwer, L.M., Georgopoulou, E., Jacob, D., Martin, E., Rounsevell, M., & Soussana, J.-F. (2014). Europe. In V.R, Barros, C.B, Field, D.J, Dokken, M.D, Mastrandrea, K.J, Mach, T.E, Bilir, M, Chatterjee, K.L, Ebi, Y.O, Estrada, R.C, Genova, B, Girma, E.S, Kissel, A.N, Levy, S, MacCracken, P.R, Mastrandrea, & L.L, White (Eds.). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1267-1326). Cambridge, UK and New York, NY, U.S.A.: Cambridge University Press

Kretschmer, M., Coumou, D., Agel, L., Barlow, M., Tziperman, E., & Cohen, J. (2018). More-Persistent Weak Stratospheric Polar Vortex States Linked to Cold Extremes. *Bulletin of the American Meteorological Society, 99*(1), 49-60

Kruijt, B., Witte, J.-P.M., Jacobs, C.M.J., & Kroon, T. (2008). Effects of rising atmospheric CO_2 on evapotranspiration and soil moisture: A practical approach for the Netherlands. *Journal of Hydrology, 349*(3-4), 257-267

Lüttringhaus, S., Noleppa, S., Gornott, C., & Hermann, L.-C. (2019). *Climate change impacts on European crop production: A literature review.* Berlin, Germany: HFFA Research GmbH

Matthews, E. (Ed.). (2019). *Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050. World Resources Report.* Washington, DC, U.S.A.: World Resources Institute

Mbow, C., Rosenzweig, C., Barioni, L.G., Benton, T., Herrero, M., Krishnapillai, M.V., Liwenga, E., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F., Xu, Y., & Amanullah, A. (2019). Chapter 5: Food Security. In P.R, Shukla, J, Skea, E, Calvo Buendia, V, Masson-Delmotte, H.-O, Pörtner, D.C, Roberts, P, Zhai, R, Slade, S, Connors, R, van Diemen, M, Ferrat, E, Haughey, S, Luz, S, Neogi, M, Pathak, J, Petzold, J, Portugal Pereira, P, Vyas, E, Huntley, K, Kissick, M, Belkacemi, & J, Malley (Eds.). *Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* In press. Retrieved from https://www.ipcc.ch/srccl/chapter/chapter-5/

McDonald, A., Riha, S., DiTommaso, A., & DeGaetano, A. (2009). Climate change and the geography of weed damage: Analysis of U.S. maize systems suggests the potential for significant range transformations. *Agriculture, Ecosystems & Environment, 130*(3-4), 131-140

NASA/GISS (NASA's Goddard Institute for Space Studies) (2019). *Global Temperature* [figure]. Retrieved from https://climate.nasa.gov/vital-signs/global-temperature

Olesen, J.E., Carter, T.R., Díaz-Ambrona, C.H., Fronzek, S., Heidmann, T., Hickler, T., Holt, T., Minguez, M.I., Morales, P., Palutikof, J.P., Quemada, M., Ruiz-Ramos, M., Rubæk, G.H., Sau, F., Smith, B., & Sykes, M.T. (2007). Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems based on scenarios from regional climate models. *Climatic Change, 81,* 123-143

Otto, F.E.L., Massey, N., van Oldenborgh, G.J., Jones, R.G., & Allen, M.R. (2012). Reconciling two approaches to attribution of the 2010 Russian heat wave. *Geophysical Research Letters, 39*(4). DOI:10.1029/2011GL050422

Otto, F.E.L., Philip, S., Kew, S., Li, S., King, A., & Cullen, H. (2018). Attributing high-impact extreme events across timescales – a case study of four different types of events. *Climatic Change, 149*(3-4), 399-412

Panagos, P., Ballabio, C., Meusburger, K., Spinoni, J., Alewell, C., & Borrelli, P. (2017). Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets. *Journal of Hydrology, 548*, 251-262

Peters, K., Breitsameter, L., & Gerowitt, B. (2014). Impact of climate change on weeds in agriculture: A review. *Agronomy for Sustainable Development, 34*(4), 707-721

Pfleiderer, P., Schleussner, C.-F., Kornhuber, K., & Coumou, D. (2019). Summer weather becomes more persistent in a 2 °C world. *Nature Climate Change, 9*, 666-671. DOI:10.1038/s41558-019-0555-0
Powell, J.P & Reinhard, S. (2016). Measuring the effects of extreme weather events on yields. *Weather and Climate Extremes, 12*, 69-79. DOI: 10.1016/j.wace.2016.02.003

Rahmstorf, S & Coumou, D. (2011). Increase of extreme events in a warming world. *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 108*(44), 17905-17909

Ramesh, K., Matloob, A., Aslam, F., Florentine, S.K., & Chauhan, B.S. (2017). Weeds in a Changing Climate: Vulnerabilities, Consequences, and Implications for Future Weed Management. *Frontiers in Plant Science, 8*, 95

Ribeiro, D.M., Araújo, W.L., Fernie, A.R., Schippers, J.H.M., & Mueller-Roeber, B. (2012). Action of Gibberellins on Growth and Metabolism of Arabidopsis Plants Associated with High Concentration of Carbon Dioxide. *Plant Physiology, 160*(4), 1781-1794

Rosenzweig, C., Iglesias, A., Yang, X.B., Epstein, P.R., & Chivian, E. (2001). Climate Change and Extreme Weather Events: Implications for Food Production, Plant Diseases, and Pests. *Global Change and Human Health, 2*(2), 90-104

Rötter, R & van de Geijn, S. (1999). Climate Change Effects on Plant Growth, Crop Yield and Livestock. *Climate Change, 43*(4), 651-681

Searchinger, T., Hanson, C., & Lacape, J.-M. (2014). *Crop Breeding: Renewing the Global Commitment.* Washington, DC, U.S.A.: World Resources Institute

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., & Miller, H.L. (Eds.). (2007). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, NY, U.S.A.: Cambridge University Press

Statista (2018). *Hektarertrag von Getreide in Deutschland nach Art bis 2018* [figure]. Retrieved from https://de.statista.com/statistik/daten/studie/28888/umfrage/hektarertrag-von-getreide-in-deutschland-seit-1960

Tans, P & Keeling, R. (2020). T*rends in Atmospheric Carbon Dioxide. Mauna Loa CO2 annual mean data.* [figure]. Retrieved from https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html

Trnka, M., Olesen, J.E., Kersebaum, K.C., Skjelvåg, A.O., Eitzinger, J., Seguin, B., Peltonen-Sainio, P., Rotter, R., Iglesias, A., Orlandini, S., Dubrovsky, M., Hlavinka, P., Balek, J., Eckersten, H., Cloppet, E., Calanca, P., Gobin, A., Vucetic, V., Nejedlik, P., Kumar, S., Lalic, B., Mestre, A., Rossi, F., Kozyra, J., Alexandrov, V., Semeradova, D., & Zalud, Z. (2011). Agroclimatic conditions in Europe under climate change. *Global Change Biology, 17*(7), 2298-2318

Tubiello, F.N., Soussana, J.F., & Howden, S.M. (2007). Crop and pasture response to climate change. *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 104*(50), 19686-19690

Van Meijl, H., Havlik, P., Lotze-Campen, H., Stehfest, E., Witzke, P., Pérez Domínguez, I., Bodirsky, B., van Dijk, M., Doelman, J., Fellmann, T., Humpenoeder, F., Levin-Koopman, J., Mueller, C., Popp, A., Tabeau, A., & Valin, H. (2017). *Challenges of Global Agriculture in a Climate Change Context by 2050 (AgCLIM50).* Luxembourg City, Luxembourg: Publications Office of the European Union

Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs (2011). *Tagungsband der 61. Jahrestagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, 23.-25. November 2010, Raumberg-Gumpenstein. Ertrag vs. Qualität bei Getreide, Öl- und Eiweisspflanzen. Wheat stress.* Raumberg-Gumpenstein, Österreich: Höhere Bundeslehr- und Forschungsanstalt für Landwirtschaft Raumberg-Gumpenstein

Voss-Fels, K.P., Stahl, A., Wittkop, B., Lichthardt, C., Nagler, S., Rose, T., Chen, T.-W., Zetzsche, H., Seddig, S., Baig, M.M., Ballvora, A., Frisch, M., Ross, E., Hayes, B.J., Hayden, M.J., Ordon, F., Leon, J., Kage, H., Friedt, W., Stützel, H., & Snowdon, R.J. (2019). Breeding improves wheat productivity under contrasting agrochemical input levels. *Nature Plants, 5*(2), 706-714. DOI:10.1038/s41477-019-0445-5

Wang, Y., Cheng, X., Shan, Q., Zhang, Y., Liu, J., Gao, C., & Qiu, J.-L. (2014). Simultaneous editing of three homoeoalleles in hexaploid bread wheat confers heritable resistance to powdery mildew. *Nature Biotechnology, 32*(9), 947-951. DOI:10.1038/nbt.2969

Zaidi, S.S.-E.-A., Vanderschuren, H., Qaim, M., Mahfouz, M.M., Kohli, A., Mansoor, S., & Tester, M. (2019). New plant breeding technologies for food security. *Science*, 363(6434), 1390-1391. DOI:10.1126/science.aav6316

Zhao, Y., Li, Z., Liu, G., Jiang, Y., Maurer, H.P., Würschum, T., Moch, H.P., Matros, A., Ebmeyer, E., Schachschneider, R., Kazman, E., Schacht, J., Gowda, M., Longin, C.F., & Reif, J.C. (2015). Genome-based establishment of a high-yielding heterotic pattern for hybrid wheat breeding. *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 112*(51), 15624-15629. DOI:10.1073/pnas.1514547112

Chapter 4:
Current Global Developments and their Impact on Greenhouse Gas Emissions in Agriculture

With a contribution from:

Daniel Müller
Leibniz Institute of Agricultural Development in Transition Economies (IAMO)

Geography Department, Humboldt-Universität zu Berlin

Integrative Research Institute on Transformations of Human-Environment Systems (IRI THESys), Humboldt-Universität zu Berlin

Abstract

Global pork production has increased five-fold between 1961 and 2017. The rise in pork production has come with substantial environmental costs, including nutrient overload, air pollution, as well as greenhouse gas emissions from manure and the production of protein-rich feed crops. Most emissions are generated at the site of production, but increasing quantities of pig feed, mainly soybeans imported from a few major producing countries, are also responsible for substantial emissions. Here, I compare greenhouse gas emissions from pork production and feed imports in China and the EU since 1990. I highlight the implications of the recent trade disruptions between China and the United States and the effect of African swine fever on trade flows of pig feed, pork meat, and related emissions, which are embodied in the changes in trade. In Brazil, the major global soybean exporter, emissions associated with soybean production have likely increased due to the additional demand for soybeans as a result of the trade disruptions. The expected growth in future demand for pork meat and the limited scope for further improvement of emission intensity in production justify greater attention to the emissions embodied in trade. The shift from production-based to consumption-based emissions accounting can create incentives to replace emission-intensive imports with domestically produced goods or with imports that have lower emissions.

Effects of the Sino-American Trade War and African Swine Fever for Greenhouse Gas Emissions in Pork Production

Daniel Müller
Leibniz Institute of Agricultural Development in Transition Economies (IAMO)

Geography Department, Humboldt-Universität zu Berlin

Integrative Research Institute on Transformations of Human-Environment Systems (IRI THESys), Humboldt-Universität zu Berlin

Daniel Müller

Effects of the Sino-American Trade War and African Swine Fever for Greenhouse Gas Emissions in Pork Production

2. *Changes in pork production and consumption*

Globally, there were about 1 billion domesticated pigs in 2017 with a total value of gross production of almost 300 billion US$. China has been home to 45% of these pigs, and another 15% are in the EU. The two regions also have some of the highest per capita consumption of pork, with 31 kilograms (kg) per capita and year in China and 35 kg in the EU (OECD, 2019). While per capita pork consumption in the EU has remained stable since 1990, it has doubled in China over this period. Overall, Chinese consumption amounted to 46% and EU consumption to 17% of total world pork production in 2018 (USDA, 2019).

Pork production in the EU has increased from 20 to 24 million tonnes between 1990 and 2017 (Figure 1). Large, industrial production complexes dominate pig production structures in the EU; there have been no major productivity increases or changes in production structures. In China, on the other hand, productivity and efficiency of pork production rapidly increased, mainly due to fundamental changes in production structures. Traditional pig production on small farms, which was characterised by integrated crop-livestock systems before the household responsibility system was introduced in 1978, has changed rapidly since then due to the increasing demand for pork (Bai et al., 2018; Wang et al., 2017).

Increasing demand and supply-side incentives from the Chinese government led to a rapid transition from small-scale production systems to industrial pig production, which relies on purchased grain and oil crops to feed livestock. In 1980, only 2.5% of China's livestock was produced in large-scale, industrial farms; by 2010, this proportion had risen to 56% (Bai et al., 2018). Government policies over the past two decades have contributed to a shift from land-intensive ruminant production, which feed on grass and grazing, to the production of monogastric animals, mainly pigs and chickens (Bai et al., 2018; FAO, 2019).

At present, the pig production systems in the EU and in China are largely comparable. Both regions produce most of their pork in large units, which rely heavily on domestically produced maize and protein feed supplied from abroad. The production systems are very efficient in terms of animal protein production, yield high profits and, at least before the outbreak of ASF, ensured a steady supply of cheap and uniform pork meat to consumers. In contrast to China, the EU, with its smaller domestic market, is also a major exporter of pig meat and pig by-products, including to China.

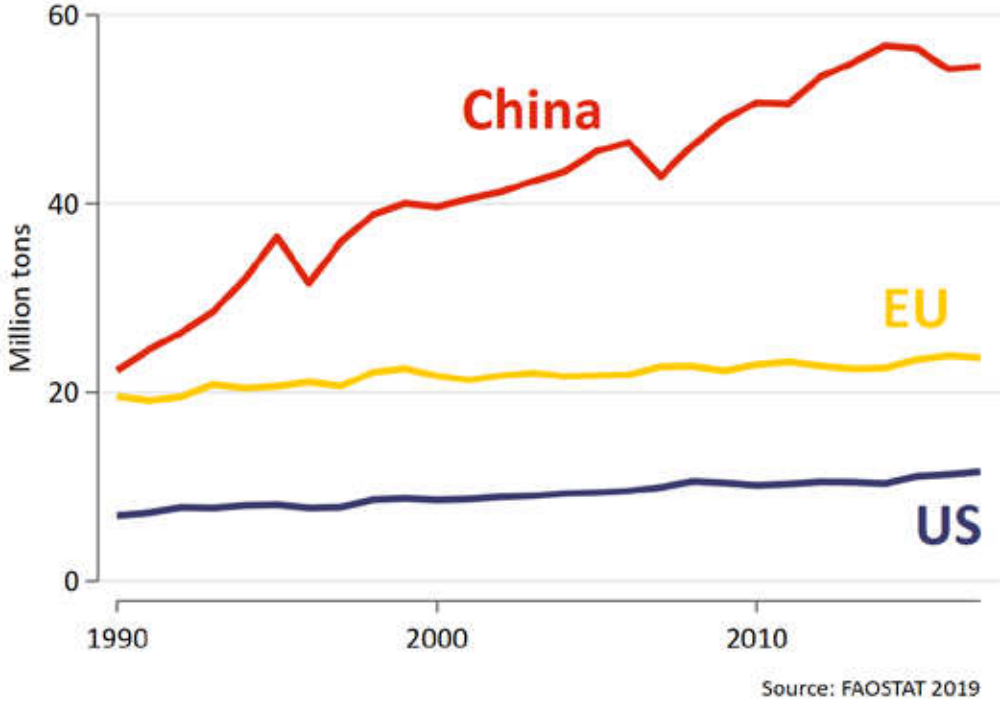


Figure 1. **Strong increase of pork production in China**

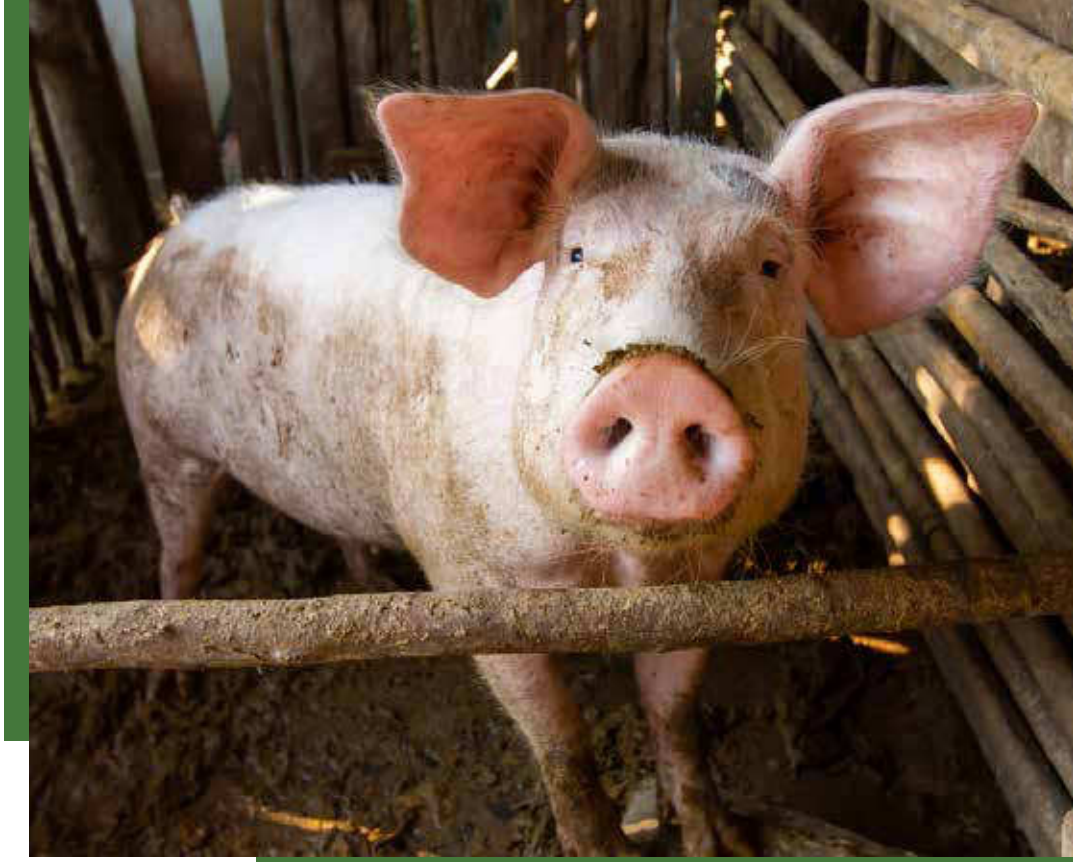
Adapted from *Statistics / Food and Agriculture Organization of the United Nations,* by FAO, 2019, retrieved from http://faostat.fao.org

3. Environmental effects of pork production

The production of pork involves substantial environmental costs, including ammonia (NH_3) pollution, nitrate leaching into waterways, greenhouse gas emissions from manure releasing nitrous oxide (N_2O) into the atmosphere, and from the production of pig feed. In Germany, for example, 95% of all NH_3 emissions come from the agricultural sector, predominantly from pig production (German Environment Agency (UBA), 2019). In China, the increase in pig production is responsible for the rise in NH3 emissions from 3.9 teragram (Tg) in 1980 to 7.6 Tg in 2010 (Bai et al., 2018). Moreover, nutrient leaching from pig farms contributes to an excess of nitrogen (N) in the soil, which reacts to nitrate (NO3) through oxidation and endangers water quality. While the environmental challenges in industrial pig production loom large, I will focus here on the greenhouse gas (GHG) emissions associated with the production of pork and pig feed.

In 2005, pork production emitted approximately 668 million tonnes of carbon dioxide equivalents (CO2-eq) worldwide. Pork emissions are likely to increase substantially, as the demand for pork is projected to grow by one-third between 2005 and 2030 (MacLeod et al., 2014). In the Netherlands, France and Germany, the emission intensity (the emissions in CO2-eq per kilogram of meat) is between 3 and 5 CO2-eq per kg of pork. The direct GHG emissions associated with imported feed, i.e. the emissions in the production process without taking land-use change into account, account for between 25 and 40% of this (e.g., van Grinsven et al., 2019). In China, the emission intensity is in the range of 2.9 kg CO2-eq/kg pork in 2009 (Lin et al., 2015), without taking into account the emissions embodied by trade. The emission intensity in China is much higher in small-scale pig production systems, which were predominant in the past with 10.8 CO2-eq/kg pork in 1979, but improved rapidly with the systemic change in Chinese agriculture that began after 1978 (Lin et al., 2015). In other words, the shift from traditional to industrial pig production systems has greatly increased the emission efficiency and thus reduced greenhouse gas emissions per unit of produce.

These emission estimates are based on life cycle assessments, which take into account emissions from domestically produced feed, but fail to account for the emissions from land-use changes, including deforestation, which are included in feed imports. Yet, the large quantities of soybean-based products in the diet of industrially produced monogastric animals were partly responsible for the rise in global soybean prices in the 1990s and 2000s, which in turn stimulated investment into soy production and the expansion of soybean cultivation in the central producing regions.



4. Soybean production

The soybean is a legume with high protein and oil content. Almost 90% of the world's soybean production is processed into soybean oil and soybean meal (or soybean cake). The flour or cake has a protein content of about 50% and is used almost exclusively as animal feed. In 2017, 535 million tonnes of soybeans were produced worldwide (FAO, 2019). The largest producer in 2017 was the United States with a production of 120 million tonnes (34% of global production), followed by Brazil (115 million tonnes, 32%), and Argentina (55 million tonnes, 16%). Less important but still significant players in the global soy business are Paraguay, Bolivia and Uruguay, which together produced another 15 million tonnes of soy in 2017. Chinese soy production amounted to 13 million tonnes in 2017, or 4% of total global production (FAO, 2019). Overall, global soybean production has more than tripled from 108 million tonnes in 1990 to 353 million tonnes in 2017. In the same period, chicken production also tripled, while pork production increased by a factor of 1.7 (FAO, 2019).

Nearly 60% of the increase in soybean production since 1990 is due to increased production in Brazil and Argentina, which grew by 576% and 514% respectively (Figure 2). China, on the other hand, has increased its domestic soy production by only 16% over the same period, despite the strong growth in soybean demand. Since 2002, the year following China's accession to the WTO, its domestic soybean production has actually fallen by 26% or 3.4 million tonnes (FAO, 2019). The reduction in soybean acreage in China over this period has also had negative consequences for the N balance in soils due to the shift from N-fixing crops such as soybeans to N-extracting crops such as maize and rice (Sun et al., 2018).

Several enabling factors have led to an increase in soybean production in South America. The global success of the soybean came with the introduction of the transgenic variety Roundup Ready soy (RR soy), which is resistant to a glyphosate-based herbicide (one of these herbicides is called Roundup). RR soy was originally developed and patented by the U. S. agrochemical company Monsanto. The transgenic soybean was first approved in Argentina in 1995, then quickly smuggled and illegally grown in neighbouring countries, including Brazil, where transgenic soybeans were not officially approved until 2003 (Oliveira & Hecht, 2016).

At present, soy cultivation is a highly commercialised, large-scale and capital-intensive farming model that relies almost entirely on transgenic plant material. This soybean production system mainly relied on reduced or no-tillage methods and allowed two harvests per year, mostly in rotation with maize, and was well suited for tropical and subtropical areas. Brazil, Argentina and the United States, which almost exclusively plant transgenic soy, also have the highest soybean yields, at over 3 tonnes per hectare, while China's yields averaged 1.8 tonnes per hectare between 2015 and 2017. The enormous productivity increases in the main producing countries combined with the lower production cost led to the dramatic area expansion of soy cultivation.

The economic success of soybean cultivation has replaced traditional land-use systems across large parts of South America, including smallholder farms and forest-dependent indigenous groups (Oliveira & Hecht, 2016). It has also resulted in the emergence of a highly efficient value chain in which traders, processing facilities and transportation means focus on soy trade. At present, soybean-based exports are a crucial source of export income for many South American countries, particularly Brazil and Argentina.

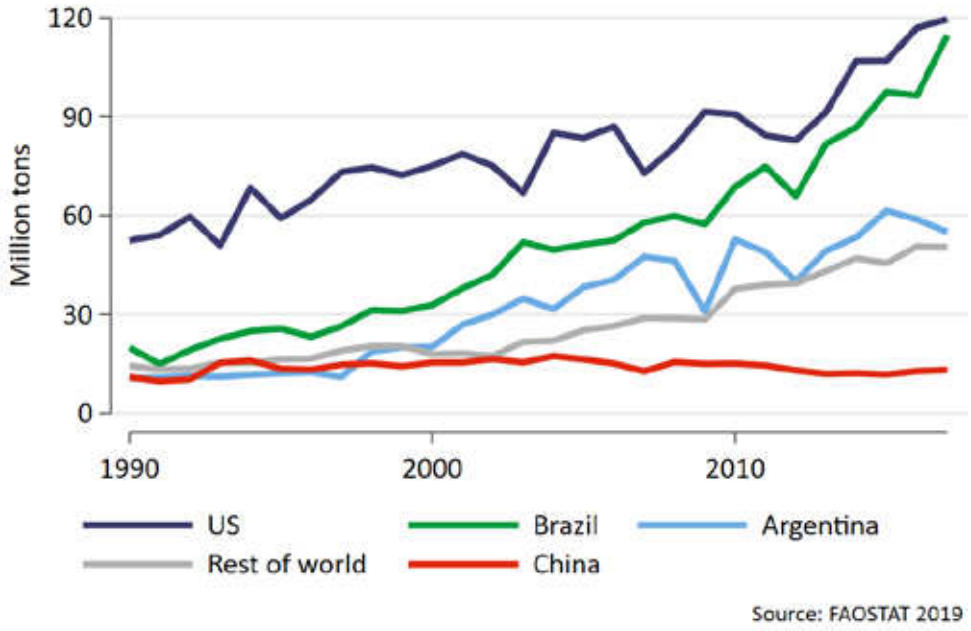


Figure 2. **Rise in global soybean production.**

Adapted from *Statistics / Food and Agriculture Organization of the United Nations,* by FAO, 2019, retrieved from http://faostat.fao.org

In 2017, the area harvested with soy cultivation amounted to 57 million hectares in South America, 46% of the total global area (FAO, 2019). In recent decades, soy production in both Brazil and Argentina has expanded from south to north, replacing cattle pastures or native forest areas in the Amazon region or the dry forests of the Cerrado and Chaco biomes (Graesser et al., 2018).

5.
Trade in soybean products

Soybeans are an export crop. Of the 120 million hectares of soybean cultivation area worldwide, about 50 million ha are destined for export; this is the largest area and the highest proportion of all major crops destined for international trade (Levers & Müller, 2019). Most of the soybeans traded internationally go to China. In 2017, China imported a total of almost 96 million tonnes of soybeans, representing 28% of global production and 64% of the volume of soybeans traded worldwide (FAO, 2019). 94% of these imports (91.5 million tonnes) were imported from only three countries: the United States, Brazil and Argentina (Figure 3). China predominantly imports raw soybeans, which are processed in China into soybean oil, mainly for human consumption, but by far the largest share is converted into soybean cakes, which are used as animal feed.

China's soybean imports have increased steadily since the trade liberalisation linked to China's accession to the WTO in 2001. The United States and Brazil were the main supplier during the 2000s. Since 2013, the largest share of China's soybean imports has come from Brazil, and in 2017, imports from Brazil amounted to 53% (52 million tonnes) (Figure 3).

The EU imported 10% of all internationally traded soybeans in 2017, but unlike China imported an additional 40% of internationally traded soybean cake, also for use as animal feed (FAO, 2019). In 2017, the EU imported 31 million tonnes of soybean equivalents[1] (38% from Brazil, 28% from Argentina and 16% from the United States; Figure 4). Import volumes peaked in 2009 at 40 million tonnes and then started to decline. During this period, the EU increased its own soybean crop area from 0.35 to 0.89 million hectares and almost tripled domestic production to 2.7 million tonnes (FAO, 2019); domestic production in the EU, however, covers less than 10% of domestic consumption.

1 Processed products that are traded, such as soybean cake, must be made comparable to the primary crop. This has been done by converting the traded products into primary equivalents based on their calorie content. For example, one kg of soybean cake contains 78% of the calories of the raw soybean (Kastner et al., 2011).

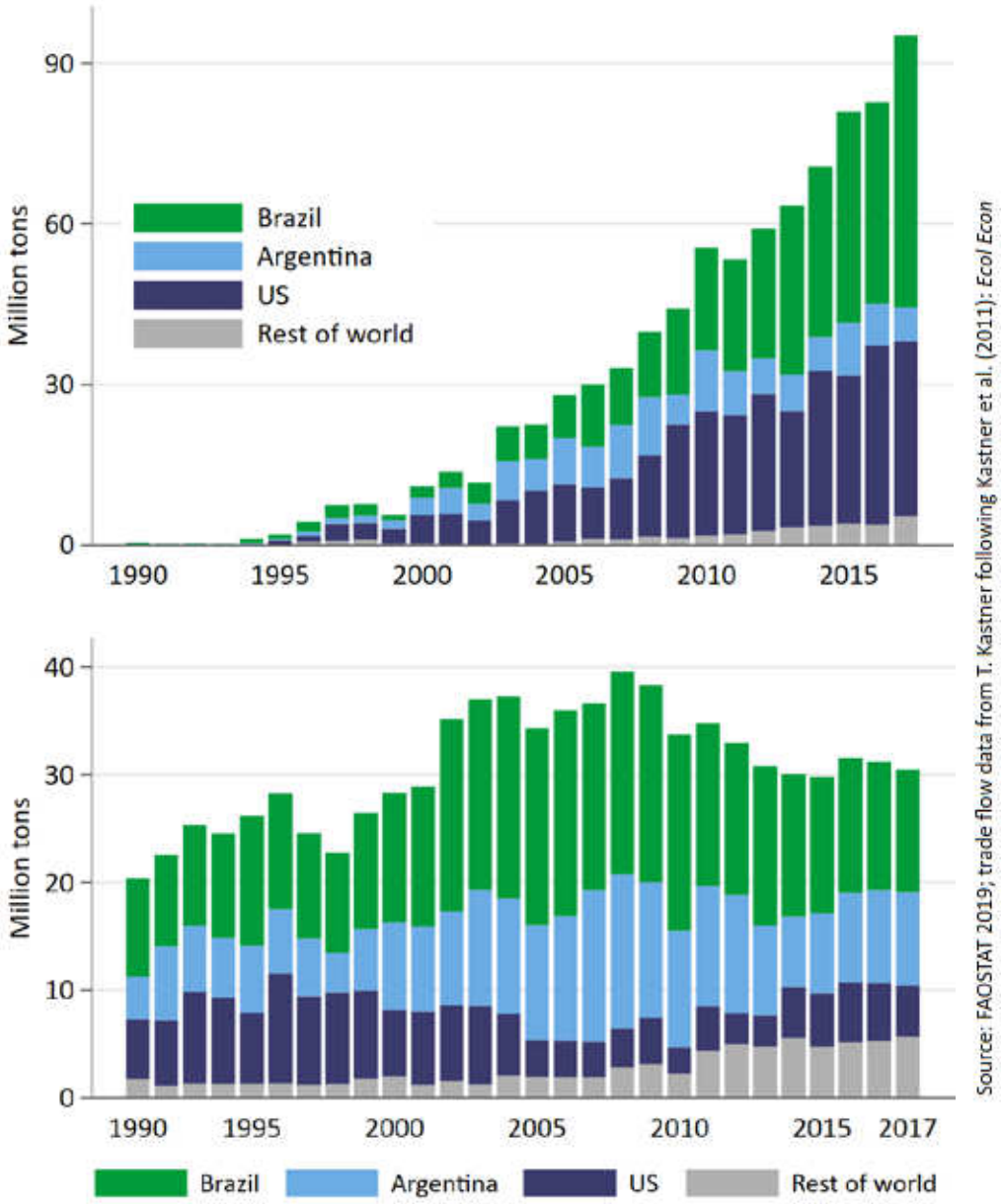


Figure 3. **Imports of soybean equivalents of China. (above)**
Figure 4. **Imports of soybean equivalents of the EU. (below)**

Adapted from *Statistics / Food and Agriculture Organization of the United Nations,* by FAO, 2019, retrieved from http://faostat.fao.org

5.1
Emissions from soybean imports

The expansion of soybean cultivation in South America has contributed to the high deforestation rates in the region, particularly during the 2000s (Macedo et al., 2012). More recently, soy expansion has mainly taken place on often degraded cattle pastures, but there is strong evidence that soy expansion has also displaced cattle pastures further north, where pasture expansion contributes to deforestation (Barona et al., 2010; Gollnow & Lakes, 2014). Therefore, soybean expansion is held responsible for direct and indirect deforestation and thus for high CO2 emissions caused by deforestation.

To quantify the emissions footprint of imports of soybean equivalents, we need to relate the volume of imports to the demand for land at the point of origin. Multiplying China's soybean imports by the average soybean yields in the respective exporting countries reveals that China's soybean imports in 2017 required about 15 million hectares of soybean cultivation in Brazil, 2 million ha in Argentina and 10 million ha in the United States. EU imports in 2017 were equivalent to 3.4 million ha in Brazil, 2.7 million ha in Argentina and 1.4 million ha in the United States. However, from the point of view of emissions, it matters where in the exporting countries the soy imports come from and whether these imports have led to deforestation associated with soy production.

It has recently become possible to trace imports back to their place of origin with data that link imports to jurisdictional regions of origin (e.g., districts) by tracking the supply chains of commodities (Godar et al., 2016). Such data are available from https://trase.earth; however, at the time of writing, these data only included soybean value chains for Brazil with data on jurisdictional deforestation rates and associated CO2 emissions. Moreover, only data on deforestation since 2006 are available (the years 2001 to 2005, when deforestation rates in Brazil were much higher, are unfortunately not available). Fortunately, the Trase data include the Amazon and the Cerrado biomes, which are the two biomes that account for the largest part of deforestation in Brazil.

Supply chain data show that emissions from deforestation associated with Brazil's soybean exports have fallen to below 20 million tonnes CO2-eq per year since 2013 (Figure 5). Emissions associated with soybean exports to China have stabilised in recent years, despite the substantial export increase. This suggests that less soybean production is associated with direct deforestation. The sharp decline in deforestation caused by soy cultivation after 2008 suggests that the *Amazon Soy Moratorium*, a voluntary commitment not to purchase soy on land deforested after 2006, has effectively reduced deforestation in the Amazon.

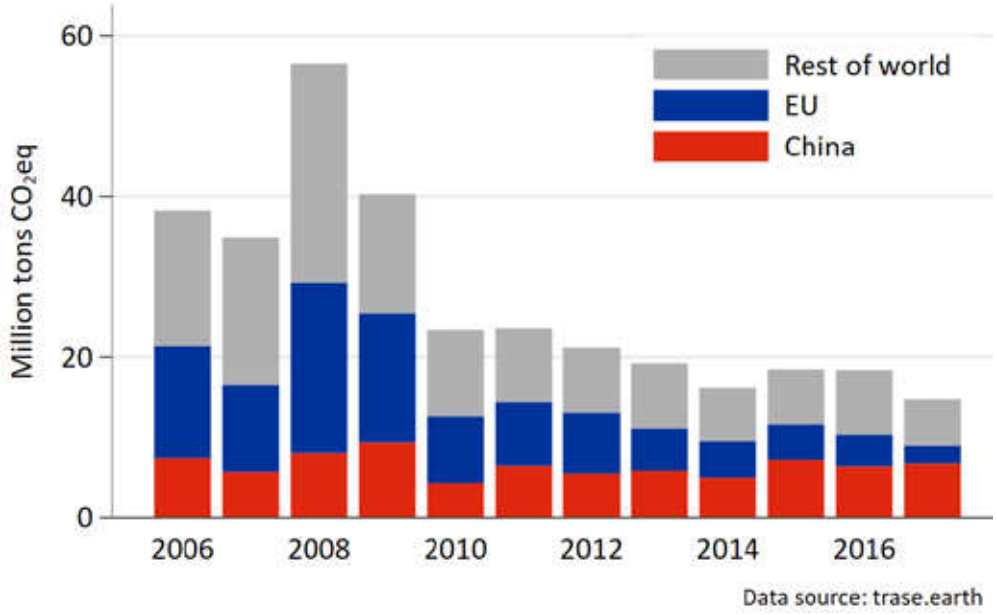


Figure 5. **Emissions from deforestation associated with soy exports of Brazil.**

Adapted from *Trase,* by Trase, 2019, retrieved from https://trase.earth

This commitment has been signed by all major soybean traders (Gibbs et al., 2015). Deforestation rates due to exported soy decreased to one-third of 2008 levels in the Amazon, while in the Cerrado (not shown here), they decreased much less. Nevertheless, deforestation rates and emissions in the Trase data are a very conservative estimate, as they only take into account deforestation directly caused by soybean expansion in the last five years. However, most forests are initially converted to pasture (about 80% between 2000 and 2014, see Zalles et al., 2018). The conversion of pastures into soybean cultivation may take longer than the five years chosen by Trase, even for land that is suitable for soy and well connected to the road network (Tiago Reis; personal communication). Furthermore, indirect land-use changes and land speculation are not included in the Trase data.

6.
Trade and production shocks

6.1
The trade war between China and the United States

In mid-2018, the U.S. administration introduced tariffs on Chinese goods worth US$ 250 billion. The Chinese government responded with 25% tariffs on many U.S. goods, including soybeans. In return, U.S. soybean exports to China fell by 50% in 2018, from 33 million tonnes in 2017 to 16.6 million tonnes in 2018 (Fuchs et al., 2019; He et al., 2019). In the following, I will outline the consequences of the trade war and African swine fever for China using data from news reports, as the official statistical sources only contain data up to 2017.

As a result of the trade war, China is directing more attention on South American soybean producers at the expense of soy imports from the United States. Combined with the outbreak of African swine fever in mid-2018 (ASF; see below), China's soy imports decreased from 97 million tonnes in 2017 to 85 million tonnes in 2019; a growing amount of this soybean will be used to produce additional poultry, a main alternative to pork (Anand, 2019). To compensate for the import reductions from the U.S., China increased its imports from Brazil from 52 million tonnes in 2017 to 66 million tonnes in 2018, corresponding to 75% of all Chinese soybean imports in 2018 (Su, 2019). The increase of 14 million tonnes represents an additional demand for land of 4.5 million hectares, assuming average Brazilian soybean yields of 3.1 tonnes per hectare between 2015 and 2017. Among other things, an agreement was signed with Argentina, the world's largest exporter of soybean meal. Under this agreement, Argentina can produce soybean meal in its crushing industry for export to China (Bronstein & Heath, 2019).

The increase in soybean imports may cause further soy expansion in Brazil, including the direct replacement of forests with soybean cultivation and indirect deforestation by replacing pasture land. To approximate the emissions footprint of China's additional demand for Brazilian soybeans, I calculated the average emissions per tonne of soy imported from China in 2017 for the Cerrado (0.31 tonnes of CO2-eq per tonne of imported soy), assuming the *Amazon Soy Moratorium* effectively prevents deforestation in the Amazon. Then, I multiply the emission factor by the 4.5 million hectares of additional land demand (see above). This results in an increase in area-related emissions from 6.7 to 8.1 million tonnes CO2-eq, a rise of 18%. This is a conservative estimate, as it excludes indirect land-use changes and the recent increase in deforestation, arguably partly due to soy expansion.

It should again be noted that these emissions stem from direct deforestation caused by soybeans up to five years after deforestation, and not for indirect land-use changes and speculation.

It remains to be seen whether the forthcoming U.S. elections in 2020 will pose further risks for trade relations. The Trump administration may be inclined to further trade intervention, coupled with massive farm subsidies to offset the losses of U.S. farmers, to please conservative voters as well as farmers in America's agricultural heartland.

6.2
African swine fever

ASF is a virus causing haemorrhagic fever in pigs, with a high mortality rate. China reported the outbreak of ASF in August 2018 and, one year after the outbreak, pig stocks have shrunk by at least 39% or about 170 million pigs in autumn 2019 (the numbers vary, and the actual decline may well be much greater), but the bottom seems to have been reached (Siu, 2019). As a result of the epidemic, pork prices in China reached record highs (up to CNY 50 (around €6.41) per kg carcass weight in October 2019, which is roughly three times the price for pork meat in Germany and the United States. Domestic demand for pork declined due to rising prices, and consumers partly replaced pork with alternative animal proteins, e.g. from poultry, beef and fish.

The ASF has two key effects on global trade flows: the lower number of pigs in China reduces the domestic demand for soy-based feed and thus China's soybean imports. Secondly, ASF causes increased imports of pork and pig offal from other countries, especially from the EU. Rising meat imports can be linked to higher emissions in producer countries as producers expand their stocks. Thirdly, fewer pigs mean less demand for soybeans and therefore fewer soybean imports from Latin America, with additional emissions in soy-producing countries.

In response to ASF, China has already increased its beef imports from Brazil by 50% in 2019 (Azevedo, 2019). More importantly, the rising demand for pork from China appears to offer new opportunities for the Brazilian agribusiness. For example, China has already approved 25 plants for pork production for export to Brazil (Fortune, 2019). Increased pork production in Brazil could facilitate a new wave of deforestation; soybean-maize rotations become more profitable, because both crops can be converted into cash: the soybean serves as a source of protein for the pigs, the maize provides the energy. The higher profitability of the soy-maize system makes deforestation more likely and will probably stimulate land speculation in the Amazon and Cerrado. In short, the emissions associated with pork consumption may increase substantially through direct and indirect land-use changes.

7. Discussion

Industrial pork production is concentrated in a few countries, with China and the EU being the main producers. Both players rely on substantial imports of protein feed from a few key producers, in particular the U.S., Brazil and Argentina. The global integration of value chains, however, renders the pig industry vulnerable to disruptions in trade relations. Besides, the large industrial production complexes make the pig industry vulnerable to outbreaks of infectious diseases, as the African swine fever epidemic shows. In recent years, China has experienced both a trade shock and a disease shock, and both shocks have fundamentally altered trade flows, production relations and the associated greenhouse gas emissions.

The trade war with the United States shifted China's soy imports away from the United States, especially to Brazil. Higher demand for Brazilian soy contributes to rising emissions from direct and indirect land-use changes in Brazil. Expectations of continued high demand from China improved the profit expectations of the Brazilian agribusiness, which were further strengthened by the Bolsonaro government's pro-agribusiness policy. It has already been suggested that the improving economic environment for commercial farming is at least partly responsible for the peak forest fires in Brazil in 2018 and the increase in deforestation in much of the Amazon and Cerrado (Fearnside, 2018).

While it is difficult to quantify the causal links between rising commodity imports and land-use changes in exporting countries, rising soy exports are likely to contribute to a further expansion of land use to previously forested areas in Brazil. If this is the case, the trade dispute has led to globally relevant additional greenhouse gas emissions.

Monitoring the emissions associated with imported feed is important, as the expected future increase in demand for pork, particularly in China, will also increase the demand for feed. It is currently unclear where this additional feed will come from and the danger is that much of this will be linked to additional deforestation in Brazil, and increasingly also in other Latin American soy producing countries, such as Argentina, Paraguay and Bolivia.

The ASF outbreak in summer 2018 was another shock to pork production, consumption and trade in China. In response to ASF, China began importing forgone domestic pork production from other producers. Since the United States had partly fallen off the shelves due to the trade war, imports of pork and pig parts were increasingly sourced from the EU. As the emission intensity, i.e. emissions per unit of product, is similar in China and the EU, replacing domestic production with imported pig meat has little effect on emissions as long as consumption remains stable (and apart from emissions from transporting the meat from Europe to China, which may be particularly relevant for chilled products). Further, rising pork imports from Brazil could substantially increase the pressure on Brazilian forests due to their impact on the rising profits of the soybean-maize rotation.

In summary, changes in trade flows of food commodities can fundamentally affect global greenhouse gas emissions and the distribution of emissions across countries. Much of the emissions are generated at the production site. However, the emissions embedded in the traded products remain unaccounted for at the places of consumption. As I have shown using Brazil as an example, the emissions embedded in trade flows can be substantial. Only recently has it become possible to approximate the full emissions embodied in meat on the basis of value chain data that trace imports back to their production site. These data open up opportunities to better manage consumption, such as by labelling products with their carbon footprint or by imposing emission taxes to internalise external environmental costs. A transition from production-based to consumption-based accounting, for example in pork production, could help to better steer consumption by internalising the cost of the emissions footprint into the end product.

Acknowledgements

I am grateful to Florian Schierhorn for many useful comments that have helped to improve this draft. I am also indebted to Thomas Kastner for providing the data on bilateral trade flow that redistribute exports to the places of origin of production. Sophie Wohlgemuth and Peggy Günther provided valuable editorial comments. All remaining errors are mine.

References

Anand, A. (2019, August 13). Global soybean demand in 2019-20 seen up 1% on year: USDA. *S&P Global Platts.* Retrieved from https://www.spglobal.com/platts/en/market-insights/latest-news/agriculture/081319-global-soybean-demand-in-2019-20-seen-up-1-on-year-usda

Azevedo, D. (2019, Jun 3). Brazil grabs pork export momentum due to ASF. *Pig Progress.* Retrieved from https://www.pigprogress.net/World-of-Pigs1/Articles/2019/6/Brazil-grabs-pork-export-momentum-due-to-ASF-434574E/

Bai, Z., Ma, W., Ma, L., Velthof, G.L., Wei, Z., Havlík, P., Oenema, O., Lee, M.R.F., & Zhang, F. (2018). China's livestock transition: Driving forces, impacts, and consequences. *Science Advances, 4*(7), eaar8534

Barona, E., Ramankutty, N., Hyman, G., & Coomes, O.T. (2010). The role of pasture and soybean in deforestation of the Brazilian Amazon. *Environmental Research Letters, 5*(2), 024002

Bronstein, H & Heath, M. (2019, September 10). China opens soymeal market to No. 1 exporter Argentina in 'historic' deal. Investing.com. Retrieved from https://www.investing.com/news/commodities-news/china-opens-soymeal-market-to-argentina-worlds-no-1-exporter-1974963

FAO (Food and Agriculture Organization of the United Nations) (2019, October 19). Statistics | Food and Agriculture Organization of the United Nations (FAOSTAT). Retrieved from http://faostat.fao.org

Fearnside, P.M. (2018, November 8). Why Brazil's New President Poses an Unprecedented Threat to the Amazon. *Yale Environment 360.* Retrieved from https://e360.yale.edu/features/why-brazils-new-president-poses-an-unprecedented-threat-to-the-amazon

Fortune, A. (2019, Sept 9). China approves 25 Brazilian meat plants for export. *GlobalMeatNews.* Retrieved from https://www.globalmeatnews.com/Article/2019/09/09/China-approves-25-Brazilian-meat-plants-for-export

Fuchs, R., Alexander, P., Brown, C., Cossar, F., Henry, R.C., & Rounsevell, M. (2019). Why the US–China trade war spells disaster for the Amazon. *Nature, 567,* 451-454

Gibbs, H.K., Rausch, L., Munger, J., Schelly, I., Morton, D.C., Noojipady, P., Soares-Filho, B., Micol, L., & Walker, N.F. (2015). Brazil's Soy Moratorium. *Science, 347*(6220), 377-378

Godar, J., Suavet, C., Gardner, T.A., Dawkins, E., & Meyfroidt, P. (2016). Balancing detail and scale in assessing transparency to improve the governance of agricultural commodity supply chains. *Environmental Research Letters, 11*(3), 035015

Gollnow, F & Lakes, T. (2014). Policy change, land use, and agriculture: The case of soy production and cattle ranching in Brazil, 2001–2012. A*pplied Geography, 55,* 203-211

Graesser, J., Ramankutty, N., & Coomes, O.T. (2018). Increasing expansion of large-scale crop production onto deforested land in sub-Andean South America. *Environmental Research Letters, 13*(8), 084021

He, R., Zhu, D., Chen, X., Cao, Y., Chen, Y., & Wang, X. (2019). How the trade barrier changes environmental costs of agricultural production: An implication derived from China's demand for soybean caused by the US-China trade war. *Journal of Cleaner Production, 227,* 578-588

Lin, J., Hu, Y., Cui, S., Kang, J., & Xu, L. (2015). Carbon footprints of food production in China (1979–2009). *Journal of Cleaner Production, 90,* 97-103

Kastner, T., Kastner, M., & Nonhebel, S. (2011). Tracing distant environmental impacts of agricultural products from a consumer perspective. *Ecological Economics, 70*(6), 1032-1040

Levers, C & Müller, D. (2019). Mapping Export-Oriented Crop Production. In C, Friis & J.Ø, Nielsen (Eds.). *Telecoupling: Exploring Land-Use Change in a Globalised World* (pp. 89-113). Basingstoke, UK: Palgrave Macmillan

Macedo, M.N., DeFries, R.S., Morton, D.C., Stickler, C.M., Galford, G.L., & Shimabukuro, Y.E. (2012). Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 109*(4), 1341-1346

MacLeod, M., Gerber, P., Mottet, A., Tempio, G., Falcucci, A., Opio, C., Vellinga, T., Henderson, B., & Steinfeld, H. (2013). *Greenhouse gas emissions from pig and chicken supply chains – A global life cycle assessment.* Rome, Italy: Food and Agriculture Organization of the United Nations (FAO)

OECD Data (2019). *Meat consumption* [figure]. Retrieved from https://data.oecd.org/agroutput/meat-consumption.htm

Oliveira, G & Hecht, S. (2016). Sacred groves, sacrifice zones and soy production: Globalization, intensification and neo-nature in South America. *The Journal of Peasant Studies, 43*(2), 251-285

Siu, T. (2019, September 25). China sees pig production capacity recovering. *Reuters*. Retrieved from https://www.reuters.com/article/china-agriculture-idUSL3N26G3DC

Su, J. (2019, June 26). US soybeans may lose China's market. *China Daily.* Retrieved from https://www.chinadaily.com.cn/a/201906/26/WS5d12a5baa3103dbf1432a34e.html

Sun, J., Mooney, H., Wu, W., Tang, H., Tong, Y., Xu, Z., Huang, B., Cheng, Y., Yang, X., Wei, D., Zhang, F., & Liu, J. (2018). Importing food damages domestic environment: Evidence from global soybean trade. *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 115*(21), 5415-5419

Trase (2019). *Transparent supply chains for sustainable economies.* Retrieved from https://trase.earth

UBA (German Environment Agency) (2019). *Ammoniak-Emissionen.* Retrieved from https://www.umweltbundesamt.de/daten/luft/luftschadstoff-emissionen-in-deutschland/ammoniak-emissionen#textpart-1

USDA (United States Department of Agriculture) (2019). *Foreign Agricultural Service: Markets and Trade Data.* Retrieved from https://apps.fas.usda.gov/psdonline/app/index.html#/app/home

Van Grinsven, H.J.M., van Eerdt, M.M., Westhoek, H., & Kruitwagen, S. (2019). Benchmarking Eco-Efficiency and Footprints of Dutch Agriculture in European Context and Implications for Policies for Climate and Environment. *Frontiers in Sustainable Food Systems, 3*(13)

Wang, L.-Z., Xue, B., & Yan, T. (2017). Greenhouse gas emissions from pig and poultry production sectors in China from 1960 to 2010. *Journal of Integrative Agriculture, 16*(1), 221-228

Zalles, V., Hansen, M.C., Potapov, P.V., Stehman, S.V., Tyukavina, A., Pickens, A., Song, X.-P., Adusei, B., Okpa, C., Aguilar, R., John, N., & Chavez, S. (2019). Near doubling of Brazil's intensive row crop area since 2000. *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 116*(2), 428-435

With support from

Federal Ministry
of Food
and Agriculture

by decision of the
German Bundestag

GFA CONSULTING GROUP

Partnering Institutions in China

Imprint

Published by

Sino-German Agricultural Centre
55 Nongzhan Beilu, Chaoyang District
100125 Beijing, China

Project lead

IAK Agrar Consulting GmbH
Bornaer Strasse 16
04288 Leipzig

Junior Partner

Leibniz Institute of Agricultural Development in Transition Economies
Theodor-Lieser-Str. 2
06120 Halle (Saale)

Lectorate and Editorial office
Sophie Wohlgemuth

Design, Composition, Layout, Typesetting, Image editing, infographics improvement and print production
Advertising Agency okkool berlin
Meike Bunten
Kantstrasse 149
10623 Berlin

Photo Credits

Peggy Günther:

Pictures on Pages: 28/29, 54/55 (middle), 55 (bottom), 58/59, 62/63, 68, 79 (bottom), 83, 91 (bottom), 102/103, 104, 111

www.freepik.com:

Vector images on Pages: 3 (real_ket4up), 10/11 (macrovector_official), 14 (misteremil), 36 (turkas.olya), 52/53 (truncus), 68 (nicelook), 80 (delstudio), 88/89 (tartila), 92 (real_ket4up), 112/113 (truncus), 116 (yliv)

Pictures on Pages: 12 top (chiradech), 12/13 middle (theevening), 13 bottom (blanscape), 20 (freepik), 31 (tzido), 34 top (bugphai), 34/35 middle (patcharin123), 35 bottom (n_u_t), 47 (fabrikasimf), 54 top (Dragana_Gordic), 67 (lifeforstock), 78 top (tsekhmister), 78/79 middle (polubiatka), 84/85 (fabio.lamanna), 90 top (naypong), 90/91 middle (vaksmanv), 99 (bonnontawat), 114 top (tsekhmister), 114/115 middle (user6924197), 115 bottom (mailsonpignata), 121 (user6835987), 130/131 (user6924197), 132/133 (polyanskaya)

Wikimedia Commons:

Pictures on Pages: 48/49 (Stadtwerke Energie Jena Poessneck), licensed under the Creative Commons Attribution 3.0 Unported, URL: https://creativecommons.org/licenses/by/3.0/deed.en

65 (werktuigendagen), licensed under the Creative Commons Attribution-Share Alike 2.0 Generic URL: https://creativecommons.org/licenses/by-sa/2.0/deed.en

Cover back (from left to right):

Peggy Günther **(PG)**

www.freepik.com **(FP)**

Wikimedia Commons **(WM)**

First row: FP (user6835987), FP (blanscape)

Second row: PG, FP (jcomp), FP (rafodessa), FP (torwaiphoto)

Third Row: FP (pompixs), PG, PG

Fourth row: PG, FP (n_u_t), PG

Fifth row: WM (werktuigendagen), FP (tsekhmister)

Sixth row: FP (bugphai), PG, FP (polubiatka)

Seventh row: FP (mailsonpignata), FP (rafapress), FP (user6924197), FP (chiradech), WM (Stadtwerke Energie Jena Poessneck)