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Comparative analysis of agriculture-related GHG emissions in China and Germany

by Lea Siebert

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1. Introduction

The agricultural sector is one of the largest contributors to climate change and at the same time one of the sectors most vulnerable to it. Greenhouse gases (GHG) from livestock production, agricultural land use, and the conversion of forests into agricultural land account for up to one quarter of total emissions caused by human activities (Tubiello et al. 2022). When considering the purpose of agriculture, namely the supply of food for humans, it becomes obvious that the intermediate stages between the farm gate and the consumer, together with agricultural production, form a complex **agri-food system**. Even though agricultural activities mostly contribute methane (CH_4) and nitrous oxide (N_2O), for a holistic assessment of GHG emissions, direct carbon dioxide (CO_2) emissions from combustion processes (Fig. 1) are also relevant – as well as fluorinated gas (F-gases) emissions, which have mainly been caused by refrigeration systems since the 1990s.

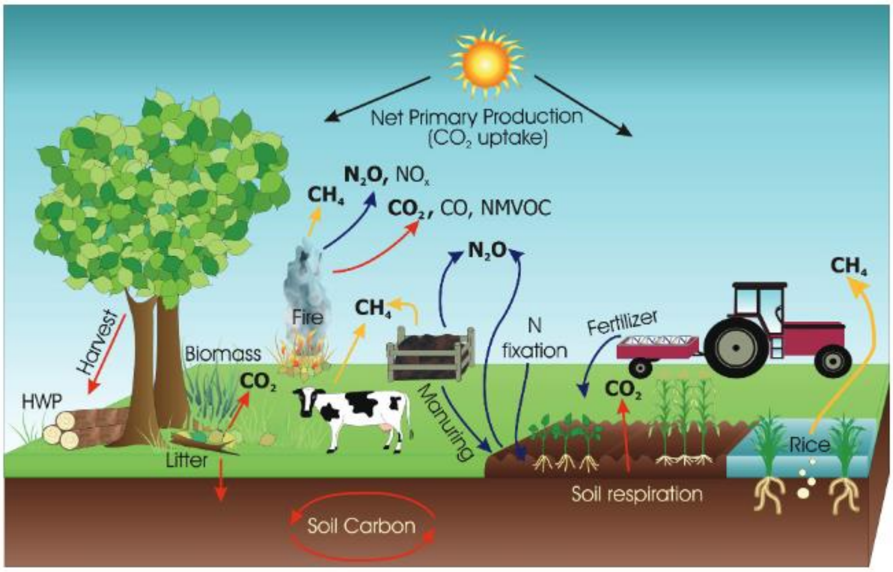

Figure 1: The main GHG emission processes in the managed ecosystem (IPCC, 2006); CO_2 = carbon dioxide, CH_4= methane, N_2O= nitrous oxide

Recent calculations based on a new set of GHG emission data at country-level attribute an ever higher share of global GHG emissions to agriculture. According to Crippa et al. (2021), the global agri-food system is responsible not just for a quarter (cf. Tubiello et al. 2022) but for a third of anthropogenic GHG emissions (18 Gt CO_2eq). **China** is the largest contributor globally, with annual food-related emission of 2.4 Gt CO_2eq (in 2015), which is 13.5% of the global total and twice as much as emissions from the European Union (EU) (1.2 Gt CO_2eq in 2015, 6.7%). Looking back at the last 25 years, since 1990, individual countries developed differently: unlike in most developing countries, China's agri-food emissions increased by +41% (1990-2015), whereas in **Germany** emissions decreased in the same period. In this regard, the trend in Germany is consistent with most developed countries.

National policies and regulations are a country's main instrument to fulfil the targets of keeping global warming well below 2°C through reducing domestic GHG emissions as it was stipulated in the Paris Agreement at COP 21 in Paris in 2015. Traditionally, agricultural production is included in the reporting on national GHG inventories to the United Nations Framework Convention on Climate Change (UNFCCC), accounting exclusively for non-CO_2 emissions, namely methane and nitrous oxide emissions from livestock, crops, and agricultural and forest soils. The emissions resulting from land conversion into farmland are separately recorded as emissions from "land use, land use change and forestry (LULUCF)" (FAO, 2020). However, the limitation of only including non-CO_2 emissions from on-farm activities, while the other food-related GHG emissions are scattered across other sectors such as energy, transport, and waste results in an underestimation of the impact of the agri-food system on the climate. Correspondingly, policy actions aiming at a reduction of food-related GHG emissions run the risk of focusing only on the agricultural production sector, neglecting the necessity and potential of reducing the related/corresponding emissions in the other sectors along the food value chain.

In this study, the development and status quo of agri-food system GHG emissions in China and Germany are presented alongside both countries' endeavors to tackle these emissions through policies. Finally, their efforts are analyzed in the context of per capita emission data and global trends.

2. Methodology

2.1 Data sources

A joint team of researchers from the European Commission, Joint Research Centre (JRC), and the statistics division of the Food and Agriculture Organization of the United Nations (FAO) have recently provided the first database on food system emissions, combining global data of GHG (CO_2, CH_4, N_2O, fluorinated gases) emissions, differentiated for six life-cycle stages of the agri-food system (Crippa et al. 2021a). As the data is currently freely available for 222 countries and for the years 1990-2018, the **EDGAR-FOOD database**[1] allows comprehensive analyses of trends in the agri-food system sectors in time and space. Wherever data was not available for the specific sub-sector or country, the authors had to make assumptions or extrapolate data from other sources. The detailed sources as well as limitations can be found in Crippa et al. (2021a). Even though follow-on research has further refined some of the component baseline data (e.g. Tubiello et al. 2022), EDGAR-FOOD is still the most up-to-date database in its field and therefore the best data basis for this study.

2.2 Framework

The basic framework for this analysis is the subdivision of the agri-food system into six life-cycle stages. Each stage comprises a set of activities that cause GHG emissions, including production as well as pre- and post-production processes of human nutrition. The chart below illustrates the activities and their corresponding GHG by stage as it is considered in this study (Fig. 2).

Forming the often-neglected pre-production stage, **land use and land use change (LULUC)** is the prerequisite for the type of agricultural practices that is most common in the world. In order to make land cultivation possible, former natural vegetation – often forests – is converted into fields. In fact, the expansion of arable land is the main driver globally of deforestation caused by humans.

[1] The EDGAR-FOOD database mainly combines the Emissions Database of Global Atmospheric Research (EDGAR) and the land use/land-use change emission data from the FAOSTAT database.

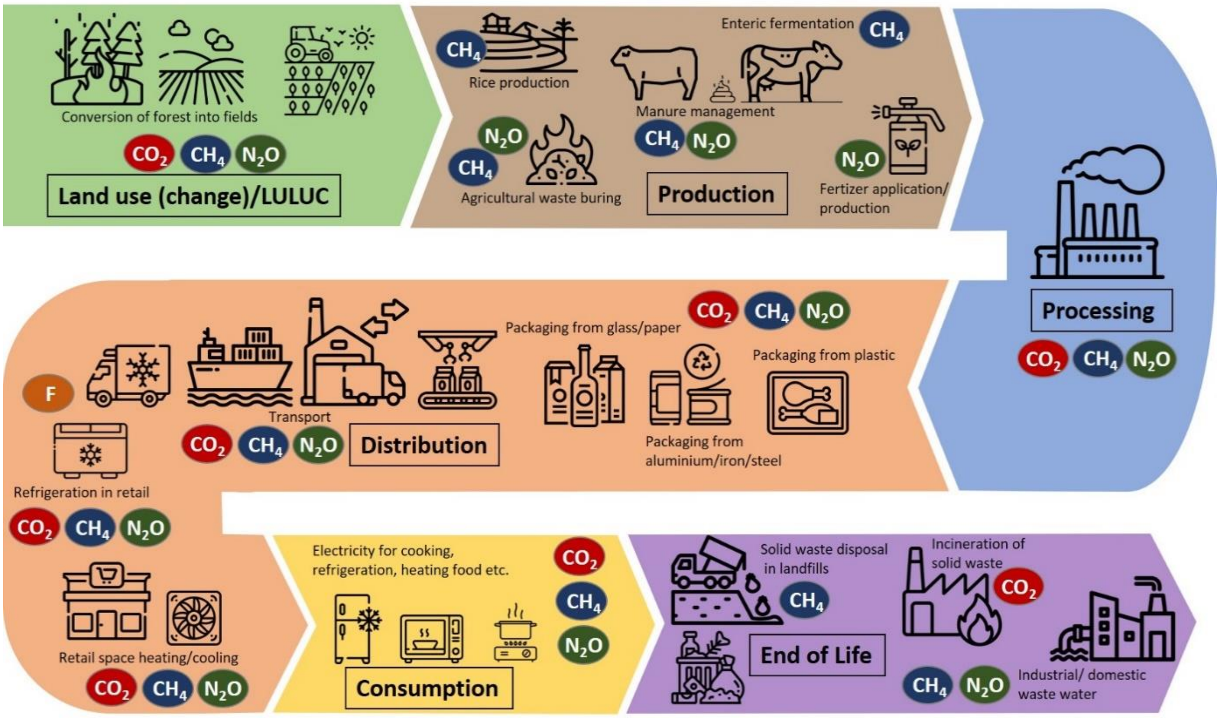

Figure 2: Six life-cycle stages in agri-food systems, defined by Crippa 2021 and the corresponding GHG emissions (Tubiello et al. 2021); CO_2 = carbon dioxide, CH_4= methane, N_2O= nitrous oxide, F= fluorinated gases

The fastest way of removing vegetation is burning it down, which – besides the resulting decomposition of organic matter in the soils – leads to CO_2, CH_4, and N_2O emissions. The negative impact on the climate is especially severe when tropical peatland is burnt.

The **production stage** comprises agricultural activities and husbandry, but also fertilizer application and management of crop residues and manure – in brief, all activities "within the farm gate". Animal manure management and the burning of agricultural waste leads to CH_4 and N_2O emissions. Due to their special digestive system, the enteric fermentation of cattle causes CH_4. Another special case is wet rice production. The growth process in open, constantly flooded fields also produces CH_4. Both the production and the application of synthetic fertilizers in the fields releases N_2O, especially as only a small part of the applied amounts is absorbed by the plants or the soil.

During the **processing stage**, the raw foodstuffs are processed by the food industry (including beverages), which mainly requires energy and which is accounted for as CO_2, CH_4, and N_2O emissions.

The **distribution stage** comprises emissions related to packaging, transport, and retail. Due to their different levels of emissions, the use of different materials for food packaging are separately assessed, namely iron and steel, glass, plastic, paper, and aluminum. For transport, a share of international and domestic transport is assigned to the food system, which can be differentiated by cargo vessels, road transport, and aviation. Due to the combustion caused by these processes as well as the energy required, here CO_2, CH_4, and N_2O emissions are accounted for. The retail sector also contributes emissions for its energy demand for space heating and cooling as well as refrigeration. For the refrigeration in retail, also F-gas emissions are included in the assessment.

During the **consumption stage**, electricity is required for cooking, refrigeration, and various household devices used according to the country-specific cooking habits. The different fuels (gas, oil, solid) that are used for cooking are also considered and converted correspondingly, leading to CO_2, CH_4, and N_2O emissions.

At the final stage, the so-called **end of life**, the choice of disposal of agri-food system related waste and waste water has a relevant impact on overall emissions. The incineration of solid waste mainly causes CO_2 emissions, whereas the deposition in landfills triggers fermentation processes leading to CH_4 emissions. Waste water, which includes domestic and industrial sources, e.g. from food-packaging-related pulp production and activities at the processing stage, causes CH_4 and N_2O emissions.

2.3 Units used in the analysis

In order to assess the realistic impact of GHG on the climate, the global warming potential (GWP) values of different gases are calculated, with the latest standard published in the *Fifth Assessment Report* of the IPCC. As carbon dioxide is taken as the standard with a GWP value of 1, the common unit is **carbon dioxide equivalents (CO2eq)**. The GWP value used for methane is 28 (i.e. 1 unit of methane has an impact equivalent to 28 units of CO_2), while a a GWP value of 265 was assumed for nitrous oxide. Four fluorinated gases commonly used for refrigeration – HFC-134a (GWP value of 1300), HFC-32 (GWP value of 677), HFC-143 (GWP value of 328), and HFC-125 (GWP value of 3170) – were included in the calculation.

2.4. Scope

As the following analysis compares two countries, it is important to point out that the data available per country reflects the GHG emissions that occur within a country's borders – regardless of the location of consumption of the final product. In other words, GHG emissions embedded in a country's food imports are not accounted for in national GHG emission levels, whereas emissions embedded in food exports are, even as the food is consumed outside of the producing country's borders. This means that the EDGAR-FOOD database used in this study does not necessarily reflect domestic final demand as it cannot disentangle the emissions embodied in cross-border trade. However, given the lack of international trade-adjusted emission data, the data set used in this study still offers a useful approximation to agricultural GHG emissions generated by the agriculture and food sectors in both Germany and China.

3. Status quo and development of GHG emissions from the agri-food system

Global GHG emissions from the food system were 17 Gt CO_2eq in 2018, which is a share of approx. 31%[2]. Comparisons between industrialized and so-called developing countries have shown that only about one quarter of emissions related to the agri-food system are emitted by industrialized countries, while almost 75% of emissions are caused by activities in developing countries (including China). Looking at trends in those two groups since 1990, it can be said that the fraction of food-related GHG emissions to total emissions decreased significantly in the developing countries and remained fairly stable and rather low in the industrialized countries (Crippa et al. 2021). However, as this trend is influenced by high increases of non-food emissions, it is obvious that absolute numbers allow a more transparent assessment of the development in food-related GHG: total global emissions from the agri-food system increased from 14.7 Gt CO_2eq in 1990 to 16.9 Gt CO_2eq in 2018. Crippa et al. (2021) showed that emissions in industrialized countries decreased by 6%, whereas developing countries emitted approx. 100% more food-related GHG in 2015 than in 1990.

Looking at the stages of the agri-food system, it can be seen that land-based emissions, i.e. emissions due to LULUC and agricultural production, globally still cause the majority of food-related GHG emissions – 79% in 1990 and 68% in 2018 (Fig. 3). Even though it seems as if these emissions have been on a downward trend, in absolute numbers, emissions from LULUC and agricultural production increased between 1990 and 2018 by 1.1 and 1.2 Gt CO_2eq, respectively. Due to rising awareness and corresponding policies, deforestation for land gain has been halted or restricted, reducing the growth rate of emissions from LULUC between 1990 and 2018. Even though the share of emissions from the post-production stages, i.e., from the farmgate to the consumer and to waste disposal, is much smaller than land-based emissions, it is noticeable that both their relative share as well as their absolute emissions in CO_2eq have increased. The retail

[2] Global anthropogenic GHG emissions for 2018 vary, depending on the source, between as much as 58 Gt CO2eq (Minx et al., 2021) and 49 Gt CO2eq (Tubiello et al. 2021). Here, an intermediate value of 54 Gt CO2eq GHG emissions for 2018 was used.

sector shows the most significant increase, emitting 0.2 Gt CO_2eq in 1990, whereas in 2018 already 0.8 Gt CO_2eq were caused by retail activities.

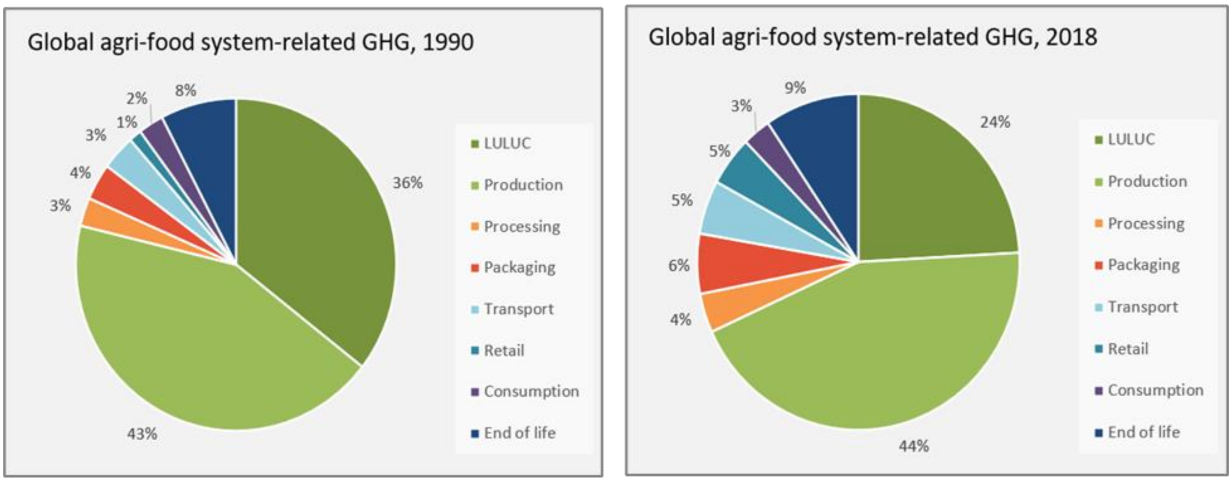

Figure 3: Global greenhouse gases (GHG) emitted during activities by stages of the agri-food life-cycle in 1990 (left) and 2018 (right). The "distribution" stage from the framework (Fig. 2) is here further subdivided into packaging, transport, and retail.

Crippa et al. (2021) also compared emission trends along the different stages of the agri-food system in industrialized and developing countries. They noticed that as most emissions related to LULUC occur in developing countries, the share of land-based emissions is much higher than in industrialized countries. However, looking at the development over time, the share of land-based emissions dropped by 13% in developing countries, while CO_2 emissions related to the energy sector increased by 78%. Furthermore, different trends can also be observed in the share of emissions due to waste disposal: in the developing countries those increased, while industrialized countries have seen emissions decrease since 1990.

3.1 China

Emissions caused by LULUC activities, perhaps surprisingly, account for less than 1% of the 2.5 Gt CO_2eq annual food-related emissions in China (Fig. 4). The largest share of emissions, 46% or 1.1 Gt CO_2eq, occur during agricultural production "within the farmgate". The processing stage caused 7% or 173 Mt CO_2eq in 2018, whereas the distribution stage – packaging, transport and retail combined – accounted for 27% (0.7 Gt) of GHG emissions. With 18% of annual emissions (0.5 Gt CO_2eq), the packaging sector is remarkably large – far larger than the average global share, especially for developing countries. At the consumption stage, Chinese consumers cause 7% (171 Mt CO_2eq) of food-related emissions. Finally, at the end-of-life stage of food products, waste disposal caused a comparatively large amount of 0.3 Gt CO_2eq (13% of total Chinese emissions) in 2018.

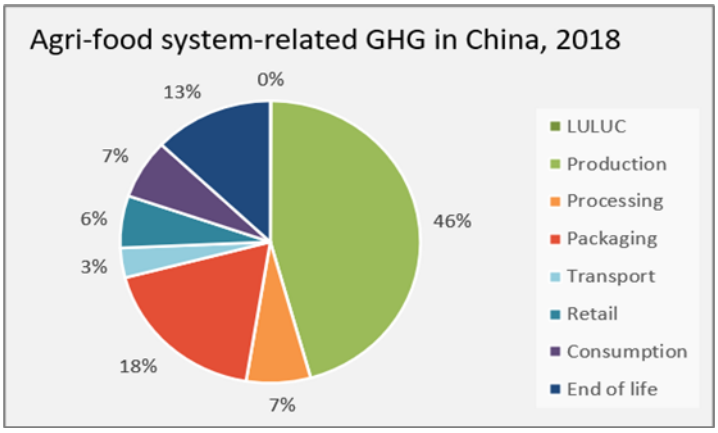

Figure 4: Shares of GHG emitted in China in 2018 during activities of the agri-food life-cycle. The "distribution" stage from the framework (Fig. 2) is here further subdivided into packaging, transport and retail.

In most developing countries, land-based emissions amount to much more than 50% of annual GHG emissions from the agri-food system, with at least a quarter of total emissions caused by LULUC (Crippa et al. 2021). In China, agricultural production causes by far the largest share of GHG emissions related to the food system. The comparatively small increase of 4.4% since 1990 indicates that this has not changed much over the last 28 years (Fig. 6). Emissions caused by LULUC, however, are almost irrelevant in China (Fig. 4). This might be due to the limited land resources in China and the high degree of industrialization, which led to the utilization of all arable land at an early stage as well as to the protection of the remaining forest areas. Pressure on resources is nevertheless high and hence, emissions from LULUC have increased by 5% since 1990 (Fig. 6). The increase of overall GHG emissions in the Chinese agri-food system between 1990 and 2018 from 1.7 to 2.5 Gt CO_2eq led to increases across all sectors. For land-based stages and consumption (+5.6%), these emissions rose only moderately. All industry-based stages, however, show huge increases in GHG emissions rates since 1990, namely at the processing stage (+84.7%), in the packaging sector (+220.8%), in transport (+512%), and retail (+851%). The disposal of food waste also causes 73.4% GHG emissions more than in 1990. With exception of the retail sector, the same gases dominate in the respective sector in 1990 and in 2018 – mainly CO_2 emissions. Only at the agricultural production stage and at the waste disposal stage, methane emissions have the largest share. In the retail sector, it is obvious that F-gases contribute the largest share of food-related GHG emissions since their large-scale introduction in 2000, which is also related to the high GWP of F-gases, resulting in even small emissions causing a steep rise in CO_2eq. In general, a strong increase of direct CO_2 emissions can be noticed across all sectors.

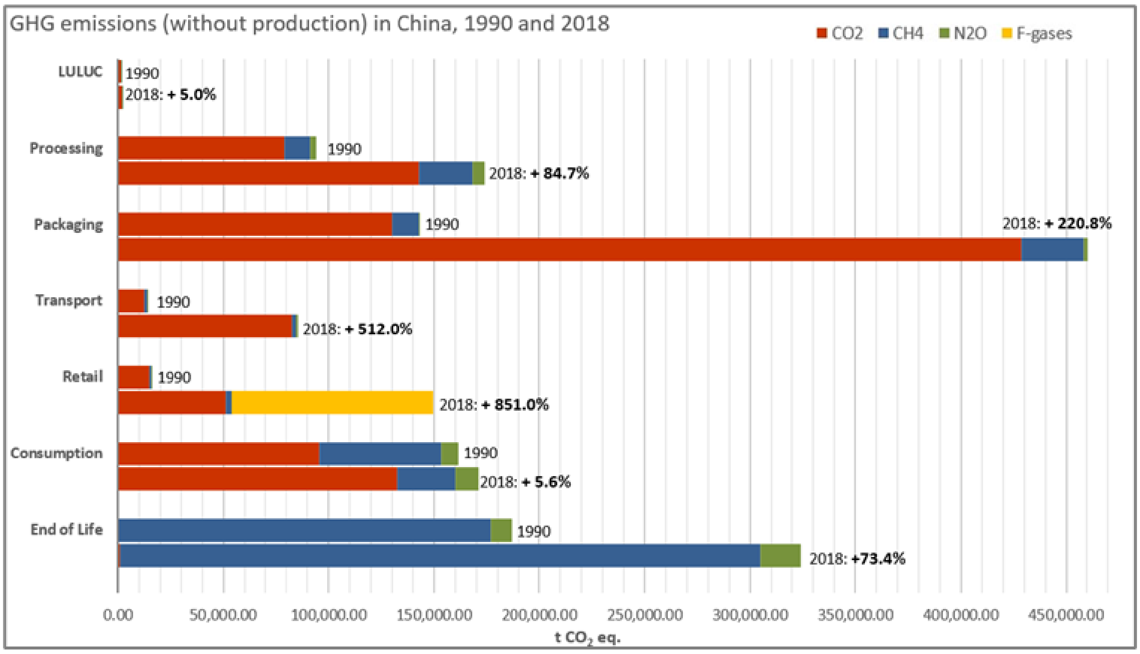

Figure 5: The proportion of GHG (CO_2, CH_4, N_2O) in absolute numbers (in t CO_2eq), caused by activities in the agri-food system (LULUC, processing, packaging, transport, retail, consumption, end of life)

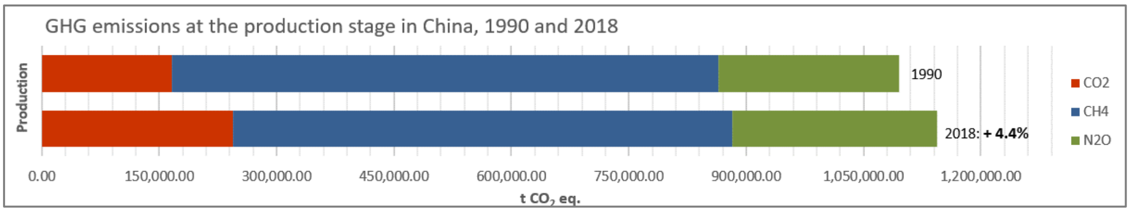

Figure 6: The proportion of GHG (CO_2, CH_4, N_2O) in absolute numbers (in t CO_2eq), caused by agricultural production in China, in 1990 and 2018.

3.2 Germany

In 2018, the German agri-food system caused 165 Mt CO_2eq of GHG emissions. 51% of these emissions were emitted due to land-based activities, split between 8% (13.28 Mt CO_2eq) due to LULUC and 43% (70.49 Mt CO_2eq) due to agricultural production (Fig. 7). The processing stage caused 14.32 Mt CO_2eq (9%). At the distribution stage, annual emissions almost equally occur in packaging (12%; 19.14 Mt CO_2eq), transport (10%; 17.20 Mt CO_2eq), and in retail (9%; 14.72 Mt CO_2eq). The smallest share of emissions occurs at the consumption stage: in 2018, only 3% (5.38%)

of food-related emissions were caused in the household of the German consumer. Food waste disposal causes 6% or 10 Mt CO_2eq GHG emissions annually.

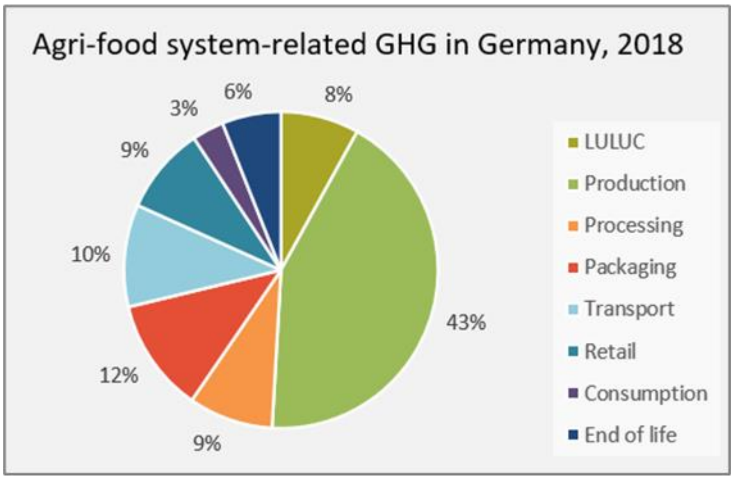

Figure 7: Shares of GHG emitted in Germany in 2018 during activities of the agri-food life-cycle. The "distribution" stage from the framework (Fig.2) is here further subdivided into packaging, transport and retail.

In accordance with the assessment of Crippa et al. (2021), Germany as an industrialized country generates around half of its food-related emissions in the land-based sector (Fig. 7). Within that sector, emissions from LULUC amount to only 8% of Germany's agricultural GHGs – a share significantly below the global average. This might be due to relatively low rates of deforestation – the main proxy for the LULUC value. In contrast to Crippa et al. (2021), the German LULUC Inventory even assesses the German land sector as a whole to act as a net emissions sink (Henders et al. 2017). Industrial processes at post-production stages of the agri-food system account for most of the second half of emissions. Overall, between 1990 and 2018 emissions from the agri-food system in Germany declined in most sectors (Fig. 8, 9). This can also be seen at the agricultural production stage: in 1990 agricultural practices still caused 104.21 Mt CO_2eq, which has been reduced by 32.4% since then (Fig. 9). Industrial processes all showed a significant reduction of GHG emissions, namely at the processing stage (-28.9%), in packaging (-12.4%), and in the transport sector (-4.0%). The retail sector is the only sector that increased over the period 1990-2018, which is partly due to the introduction of F-gases in 1993. However, the whole increase by +88.2% cannot be explained by F-gases. Emissions at the household level also reduced by -32.3% since 1990. It is clear that with exception for F-gases in the retail sector, the GHG composition over time has not changed (Fig. 8).

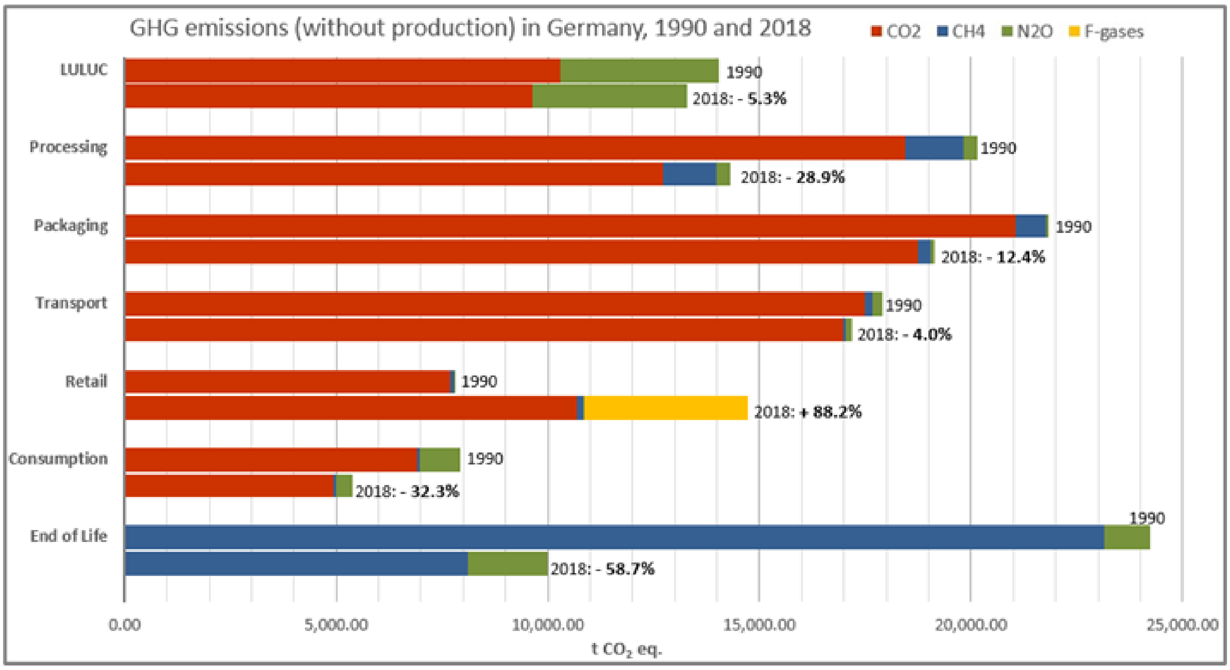

Figure 8: The proportion of GHG (CO_2, CH_4, N_2O) in absolute numbers (in t CO_2eq), caused by activities in the agri-food system (LULUC, processing, packaging, transport, retail, consumption, end of life) in Germany, in 1990 and 2018.

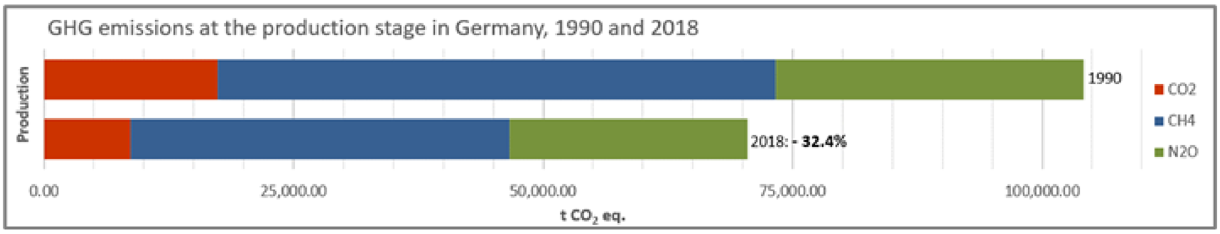

Figure 9: The proportion of GHG (CO_2, CH_4, N_2O) in absolute numbers (in t CO_2eq), caused by agricultural production in Germany, in 1990 and 2018.

3.3 Chinese and German agri-food system emissions in the global context

When comparing GHG emissions from the agri-food system in different countries, varying scales can make a comparison of absolute numbers difficult. Even though many factors influence GHG emissions that must not directly be correlated to land size or economy, the population size is one of the crucial impact factors for food-related emissions. Hence, in the following, GHG emissions caused on various stages of the agri-food system in Germany and China are presented in relation to each country's population size and alongside the global average value (Fig. 10). On global average, there is a share of 2.2 t CO_2eq emissions from the food system per person. This share is lower in both countries, Germany and China: annual food-related emissions amount to 1.81 t CO_2eq per capita in Germany and 1.98 t CO_2eq per capita in China.[3]

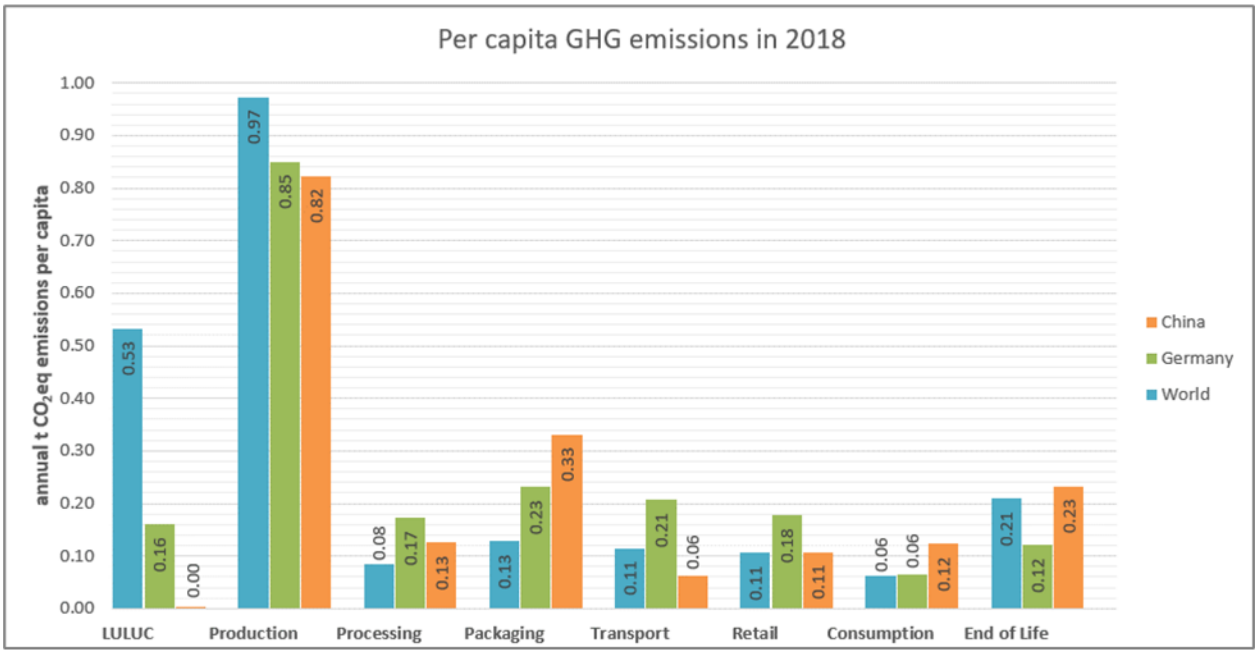

Figure 10: GHG emissions related to stages of the agri-food system in China, Germany and on world average, respectively. The emission values in each sector for 2018 have been divided by the respective population size (China = 1.39 billion; Germany = 82,905,000; world = 7.662 billion)

When putting emissions into proportion to country population, land-based GHG emissions in Germany and China are significantly lower than world average – mainly due to the low emissions from LULUC (Fig. 10). In most of the industry-related processes with emissions mainly occurring from energy usage, both countries' emissions are higher than world average. Especially, the share of emissions from the packaging stage is quite large in China – in comparison with other sectors of the Chinese agri-food system as well as in the context of the global and the German per capita average.

[3] As emissions embodied in food imports and export cannot be accounted for by currently available data sets, readers should keep in mind that the numbers presented here do not represent emissions generated by final consumer demand but merely the per-capita share of food-related GHG emissions generated within a country's borders.

At the processing, transport, and retail stages, German emissions – calculated per capita – exceed the world average, whereas China's emissions here are close or below the global average. Emissions caused by consumption in China are twice as high as they are at the world average and in Germany. Waste disposal causes significantly less emissions per person in Germany than on world average or in China.

4. Policy actions and targets to decarbonize the agri-food system

4.1 China

By ratifying the Paris Agreement (PA) in September 2016, China committed to the long-term goal of limiting the average global temperature rise to less than 2°C above pre-industrial levels. In 2020, Chinese president Xi Jinping announced China's "dual carbon" strategy, specifying that CO_2 emissions would peak before 2030 and that the goal of carbon neutrality would be achieved before 2060. In line with the PA, China published its Nationally Determined Contributions (NDC) in 2020, which set targets to "increase the share of non-fossil fuels in primary energy consumption to around 25 percent by 2030" and "its total installed capacity of wind and solar power to over 1.2 billion kW by 2030" (NDC, 2020). These low-carbon development goals are being implemented on province level by linking CO_2 emissions to economic growth. By 2025, a reduction of 18% of CO_2 emissions per unit of GDP should be achieved (with 2020 as the baseline year) and corresponding targets should be formulated in the five-year plans of the provinces.

With regard to **agricultural production**, the focus is on reducing methane emissions from rice and animal farming and to cut the use of chemical fertilizer. Under the "dual carbon" strategy, in July 2022, the Ministry of Agriculture and Rural Affairs (MARA) and the National Development and Reform Commission (NDRC) jointly released an implementation plan for emission reduction and carbon sequestration in the agricultural and rural sector. By 2030, the plan aims to decrease GHG emissions from crop and animal farming, while simultaneously improving agriculture's carbon sequestration capacity (Rouzi 2022). Key actions in the plan focus on reducing methane emissions from paddy fields through improved cultivation methods and water-saving techniques as well as from animal farms through applying low-protein feed formula and manure recycling.

Cutting the use of chemical fertilizer and improving fertilizer efficiency is also in the focus and received further impetus in December 2022, when MARA released its *2025 Fertilizer Reduction Action Plan*, committing to reduce the use of chemical fertilizers to reasonable levels by 2025 under consideration of regular scientific soil testing. This plan, however, does not specifically address N_2O emissions, but rather soil health issues, as it also promotes an increase of organic fertilizer application, which might cause additional N_2O emissions. Furthermore, manure from livestock is managed under the premise of reducing emissions, aiming for an 80% utilization rate of livestock and poultry manure by 2025 (Chen et al. 2022a). In 2021, the Chinese government provided 266 million RMB to phase out 30,000 inefficient agricultural machines and to promote energy-saving machinery instead (NDC, 2020).

Besides land-based activities, GHG emissions from **other food-related activities** are partly addressed in other sectors: Although in 2021 56% of China's total energy consumption was supplied by coal, capacities for renewable energy are being rapidly expanded and reached 2.480 TWh in 2021, accounting for 29.7% of annual power generation. It is expected that the NDC target to install over 1,200 GW of solar and wind power capacity by 2030 will be exceeded (Yu et al. 2022). High emissions from the packaging industry are being addressed in the *14th Five-Year Plan on Circular Economy Development*, which promotes green packaging and recyclable express packing as well as a reduction of overpacking in e-commerce (Chen et al. 2022b). To what degree this can be applied for packaging of food productions has to be seen. Improving energy efficiency in the food processing industry and the reduction of F-gases in refrigeration are also on the agenda – however, without providing clear targets or thresholds. In 2021, the reduction of food waste was stipulated in the *Anti-Food Waste Law*, mainly tackling excessive leftovers in the catering and restaurant industry (NPC, 2021).

4.2 Germany

The reduction of GHG emissions for various sectors is part of current German legislation. With regard to international commitments, Germany as a member state of the European Union (EU) ratified the PA in 2016. Formalizing the European Green Deal, the *European Climate Law* sets the target of reducing GHG emissions by at least 55% by 2030 compared to 1990 levels and defines that carbon neutrality should be achieved by 2050 (EU Regulation 2021/1119). These goals were incorporated in the *German Climate Change Act*, which further lowered the target of achieving climate neutrality in Germany to 2045, setting binding GHG emission limits for all relevant sectors.

For the **agricultural production** sector, in 2030, annual emissions must not exceed 58 Mt CO_2eq. This should be achieved by reducing the use of nitrogen fertilizers, increasing the share of organic farming, and providing additional funding to the German federal states for the implementation of low-carbon agricultural practices (including humus conservation, protection of moor soils, and increasing energy efficiency in farming).

The upper limit of emissions for the **energy sector** in 2030 is 175 Mt CO_2eq, which is a reduction of 63% compared to 1990. The *Coal Phase-Out Act* stipulates that the last coal-fired power station in Germany will be closed by 2038. At the same time, renewable energy is promoted: in 2030, 65% of gross electricity consumption should be generated by renewable energies. The emission limit set for the industrial sector to be reached by 2023 amounts to annual emissions below 140 Mt CO_2eq. The use of F-gases, which contribute a large part of emissions in the retail sector, are regulated by the F-gas regulation of the EU, limiting the total amount of F-gases that can be sold in the EU with the aim of bringing sales down to one-fifth of 2014 levels in 2023. Where less harmful alternatives exist, the use of F-gases should be banned (EU Regulation 517/2014).

4.3 Assessment of Chinese and German approaches

China annually emits 2.5 Gt CO_2eq through activities related to its agri-food system, which makes it the largest contributor of food-related GHG emissions. The largest share of emissions is caused at the **agricultural production stage**. Chen et al. (2022c) calculated the mitigation potential for non-CO_2 emissions during the agricultural production stage in China. As the most effective measures with the highest mitigation potential in the crop farming sector, they identified improved water management for rice cultivation (reduction of CH_4 emissions by 45 MtCO_2eq in 2060), efficient irrigation practices for upland crops (reduction of N_2O emissions by 34 Mt CO_2eq in 2060) and modified fertilizers for a slower release of urea and NH_4 (potential reduction of N_2O and CH_4 in rice cultivation by 33 Mt CO_2eq in 2060). Rice cultivation and fertilizer use are also the two aspects that are highlighted in China's NDC reporting for the PA. Furthermore, for the livestock sector, Chen et al. (2022c) found that reducing CH_4 emissions from ruminants through an optimization of their feedstuffs has the highest potential (50-74 and 100-134 Mt CO_2eq in 2060, respectively).

Addressing GHG emissions from **energy production** with relevance to the agri-food system turns out to be complex. It is a fact that currently more than half of China's energy production is supplied by coal with corresponding GHG emissions. However, clear targets promote renewable energy and aim for a phase out of coal. Specifically with regard to agricultural machinery, replacement of inefficient machinery is promoted. The large share of emissions from the packaging industry and at the consumption stage are addressed by regulations and laws to make the industry more sustainable and avoid food waste. However, meeting food security goals and the still-growing demand for livestock products while reducing emissions might be a challenge. Although policies promoting a low-carbon, greener future have increased in recent years, many of them do not provide clear thresholds and targets.

In **Germany**, on the other hand, the *German Climate Change Act* sets specific reduction targets for all sectors with relevant GHG emissions, including agriculture. However, whether these will be reached has to be seen. With regard to *agricultural production*, it seems as if the target of 56 Mt CO_2eq by 2030 could be achieved – in 2020, GHG emissions amounted to 62.4 Mt CO_2eq in this sector (UBA, 2022). With regard to the long-term goal of carbon neutrality, a study by the Öko-Institut concludes that these goals cannot be achieved without a reduction of national livestock numbers and corresponding changes in diets, i.e. a reduction of the consumption of animal products (Scheffler & Wiegmann, 2021). However, so far, no strategy to reduce the number of livestock in Germany for the purpose of GHG emission reduction has been set by the government and the amount of livestock is mainly influenced by market dynamics. When looking at emissions caused by the German agri-food system in 1990 and 2018, it is obvious that in most sectors significant reductions were already achieved. However, in direct comparison with data for the global average and the Chinese agri-food system, it is obvious that for all industrial and distribution processes – processing, packaging, transport and retail – German emissions in 2018 are still higher than the global average. How these emissions can be tackled in the next years will depend on the success of a transition in the energy and industry sectors towards renewable energy and cleaner production. Especially the target of limiting emissions from the energy sector to 175 Mt CO_2eq by 2030 looks ambitious in light of 311 Mt emissions in this sector in 2018. The industry sector must limit its emissions to 140 Mt CO_2eq in 2030, whereas in 2018 still an estimated amount of 196 Mt CO_2eq was emitted (BFM, 2019).

Looking at developments in the agri-food systems in Germany and China, it can be seen that food-related emissions that occur outside of activities directly related to agricultural land are increasing. This has also been found by Tubiello et al. (2022), who identified a trend towards GHG emissions from pre- and post-production processes. This is very relevant with regard to policy strategies aiming at reducing food-related GHG emissions. These should not be limited to agricultural activities within the farmgate, but also consider the impact of supply chains, consumer behavior, and waste disposal.

5. Summary

This study gave an overview of the recent GHG emissions from the agri-food system in Germany and China and also looked into how policies in both countries are currently trying to reduce GHG emissions in the relevant sectors. When looking at emission values in proportion to the individual countries' population size, agricultural emissions in Germany and China are below world average. However, a comparison between 1990 and 2018 shows an upward trend for Chinese GHG emissions over the past 28 years, whereas the trend in Germany is opposite: German emissions at most stages of the agri-food system have been decreasing since 1990.

When considering emissions from agri-food systems, it is important to consider all activities that cause greenhouse gases on the way to the consumer. The EDGAR-FOOD database used in this study is a valuable resource for such an analysis, even though it only allows an assessment of activities within country borders and does not take into account emissions embodied in food imports and exports. Readers should keep this limitation in mind when comparing the agriculture-related per-capita emissions between China and Germany. Accounting for GHG emissions embodied in the transport of food and intermediate products along the global food supply chain is a challenge that still remains to be solved.

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