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Analysis

# Food regimes and their trade links: A socio-ecological perspective

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ABSTRACT

The concept of food regimes has become a prominent theory in political economy. We here provide socio-ecological underpinning of the food regimes theory and thereby connect it closer to an ecological economics perspective. We quantify physical trade with main agricultural commodities between world regions from the mid-19th century to 2016 and ask how trade patterns relate to issues of resource use, in particular, to land use, soil fertility and the energetic basis of agriculture. Agricultural exports rose from a few million t/yr around 1870 to 1.4 billion t/yr in 2016. Growth in trade and production did not follow a continuous trend, periods of accelerated growth alternating with phases of relative stability can be distinguished. Rather than directed modernization we observe shifts in unequal relations of power, physical exchange and environmental pressure between changing centers and peripheries. The periods of growth in trade match with the periodization of food regimes. We find that regime shifts are closely related to changes in societies energy metabolism, in the resource base of agricultural production and also to agro-ecological crisis. Our analysis emphasizes that food regimes not only reflect changes in power relations in the world system, but also changes in societies natural relations.

## 1. Introduction

Global trade is not a new phenomenon. Shipments of gold and silver, sugar, spices and silk have shaped society, economy and environment since centuries (Pomeranz and Topik, 2013), but in the 19th century something changed. With new means of fossil fuel powered transportation and communication, trade flows diversified and the size of flows surged. Trade was no longer limited to high priced luxury goods but bulk materials such as ores, coal or grain were shipped in unprecedented quantities across and between continents to fuel industrialization and to feed an emerging urban working class in Europe's industrial centers (Krausmann et al., 2008b; O'Rourke and Williamson, 2001; Pomeranz, 2009). The size of trade flows continued to grow throughout the 20th century, accelerating after the World War II (WWII). By the beginning of the 21st century annual export flows had risen to 13 Gt/yr (1 Gt = 1 Pg = $10^{15}$ g) of materials, up from around 0.9 Gt/yr in 1950 (Dittrich and Bringezu, 2010; Schaffartzik et al., 2014). Trade has been recognized as a major driver for global environmental change (Wiedmann and Lenzen, 2018). The telecoupling between consumption in one place and environmental change elsewhere on the globe and the outsourcing of environmental pressure from high income economies to the Global South moved into the focus of research in interdisciplinary sustainability science, in particular in Ecological Economics (Dittrich et al., 2012; Ekins et al., 1994; Kander et al., 2017; Wiedmann et al., 2007). Trade with food commodities is a case of special interest (Dalin and Rodríguez-Iturbe, 2016; Falconi et al., 2017; MacDonald et al., 2015). Food is a not only the most essential resource for human existence, the production of food has also been a major factor of pervasive global change throughout human history. Since the Columbian Exchange global food trade played a major role in the transformation of society and environment in the Old and New World (Crosby, 1972; Mintz, 1986; Pomeranz and Topik, 2013), even though the actual share of the harvested biomass that is traded internationally is small compared to other materials. While over 50% of all extracted ores and fossil energy carriers were exported in 2010, only 12% of all harvested crops were shipped across national boundaries. But also food trade is on a fast rise. Since 1961 global exports of agricultural products have increased from 0.17 Gt/yr to 1.4 Gt/yr in 2016, that is, at a much faster pace than production. The share of exports in harvested crops has doubled.

Also social science research has gained interest in trade with agricultural commodities. The concept of food regimes, which goes back to Friedmann (1987) and was further specified by Friedmann and McMichael (1989) investigates the role of global food trade and

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transnational production chains in the evolution of the capitalist world economy and has become a prominent theory in political economy/ecology (Bernstein, 2016; Magnan, 2012). It presents a structured perspective to the understanding of the role of agriculture and food in capital accumulation across time and space and emphasizes agriculture's foundational role in political economy/ecology (McMichael, 2009). Food regimes theory draws on world systems theory (Wallerstein, 2004) and regulation theory (Boyer and Saillard, 2005) and emphasizes the role of agricultural trade and the corresponding regulatory and accumulation processes and power relations for development. Constitutive element of a food regime is a more or less stable world price for staple crops which first emerged in the mid-19th century (McMichael, 2013). Food regimes stabilize, come into crisis when the established regulatory mechanisms become contradictory and a new regime may emerge. In this sense, the food regime is a historical concept, which demarcates stable periodic arrangements in the production and trade of food on a world scale associated with particular configurations of geopolitical power (McMichael, 2009). Commonly three food regimes are distinguished in the literature: A British centered or extensive food regime, ranging from roughly 1870 to 1914/29, a US dominated or intensive regime from 1947 to 1973 and the emergence of a new regime in the late 1980s, which has been termed corporate or neoliberal regime and is centered around the World Trade Organization (WTO). Whether or not such a regime is currently in place is an issue of debate (McMichael, 2009).

So far the focus of food regime analysis has been on the role of the state system, the international division of labor and patterns of trade, forms of capital accumulation and relations between agriculture and industry. Although food regime theoreticians do acknowledge the role of technical and environmental issues in the emergence of food regimes and their crisis, comparatively little attention has been paid to these factors in the literature. Here we take a socio-ecological and agro-ecological perspective and focus on the role of natural resource issues for food regime emergence and crisis (Fischer-Kowalski and Haberl, 2007). Moreover, we take the concept of commodity frontier from a 'world-ecological' perspective as a source of inspiration: as site of capitalist expansion through appropriation of cheap labor and resources (Moore, 2015). We quantify the size of physical trade flows and ask how the observed trade patterns relate to issues of resource use, in particular, to land use, soil fertility and the energetic basis of agriculture. By analyzing the development of long term international trade for three major agricultural commodity groups (cereals, oil crops and meat) since the mid-19th century in the context of natural resource use and agro-ecological change, we aim at providing socio-ecological underpinning of the food regimes theory and thereby connect it to an ecological economics perspective. Specifically, we try to answer the following research questions:

a) How does physical net trade between world regions develop, who are the importing and exporting regions and how does trade development reflect the periodization of the established food regimes?
b) What was the resource base (with a focus on commodity frontiers of land, plant nutrients, energy) of the different food regimes and for export growth?
c) Which sustainability challenges and environmental problems were related to the three food regimes?

In the next section we briefly introduce the methods and data we have used to quantify global trade flows with cereals, oil crops and meat. In a joint Results and discussion section we than present the resulting physical trade balances and discuss trade patterns of each of the three regimes in the context of insights from food regime studies and socio-ecological research. The focus here is on land use, management of plant nutrients and soil fertility and energy and related technologies. In the final section we summarize how food regimes relate to socio-ecological transitions.

## 2. Data and methods

We quantify global import and export flows for three groups of agricultural products: cereals (wheat, maize, rice, barley, oats, rye and other cereals), oil crops (soy bean, linseed, groundnuts, palm kernels, copra and other oil crops) and meat (beef, pork, mutton and poultry). Cereals are the main staple of the majority of the world population and oil crops and meat main ingredients of the Western Diet (Grigg, 1995; Popkin, 1993). Together these products accounted for 50–60% of all global exports (in tons) of agricultural products between 1961 and 2016. We compiled data for cereals for the period 1850–2016, for meat for 1870–2016 and for oil crops for 1909/1924–2016. Data for cereal trade prior to 1909 were sourced from different international data compilations, mainly from a statistical compendium of the development of global cereal trade published by the Austrian agricultural ministry in several volumes (Getreide im Weltverkehr, (GIW, 1909, 1905, 1900)), and Mitchell's (2003) collection of international historical statistics. Additionally, we used country specific data from national material flow (MFA) studies (Gierlinger and Krausmann, 2012; Krausmann et al., 2016a, 2008b; Manthy and Potter, 1978; Schandl and Schulz, 2002). These data have been published in aggregate form; here we had access to detailed data on the three-digit level of MFA provided by the authors. Data for the period from 1909 to 1946 are from the International Yearbook of Agricultural Statistics of the International Institute for Agriculture (IIA, 1922), from 1947 to 1960 from the statistical yearbooks of the Food and Agricultural Organization and from 1961 onwards from FAO's (2018) online database FAOSTAT. For meat trade for the period 1870 to 1961 we used data on exports of the main exporting countries provided in Mitchell (2003), complemented by import and export data for the USA and the UK from the above mentioned national studies. We assumed that until the 1930s exports of meat mainly went to Europe (Langthaler, 2016; Oddy, 2016). Data on trade with oil crops is available only for 1909 and then from 1924 onwards from IIA and FAO. For the period from 1961 to 2016 we sourced data from FAOSTAT for both meat and oil crops.

We distinguish 7 world regions or country groupings: Europe, Russia/USSR/Former Soviet Union, North & Central America, South America, Asia, Africa and Oceania. From import and export data we calculate physical trade balances (PTB) for the 7 world regions. PTB measures the physical trade surplus or deficit of an economy/region and is defined as imports minus exports (OECD, 2008); The PTB indicator is commonly used in material flow analysis (MFA) and studies concerned with ecologically unequal exchange (Giljum and Eisenmenger, 2004; Perez-Rincon, 2006). By using PTB we suppress trade that may occur within a region (intracontinental trade) and instead focus on intercontinental trade. For cereals the share of intracontinental trade (e.g. the trade between European countries) rose from roughly 20% in the late 19th century towards 50% at the beginning of the 21st century. Global net-export refers to the sum of net-exports of all net-exporting regions. In Fig. 2 we also present data for total global exports which refers to the sum of gross-exports of all countries. In addition to data on trade flows we also use data on harvested area and production from the same sources to calculate yields per unit of area and shares of exports in production. All data shown in Figs. 1, 2 and 3 are available in a Supplementary data file, also available doi:10.17632/zhg59thjzp.1 from the web page of the Institute of Social Ecology https://www.wiso.boku.ac.at/sec/data-download/.

The quality of physical trade data for agricultural commodities can be considered good; aggregation is easier than for monetary trade flows, since there are no problems with exchange rates and inflation. Export and import flows reported in statistical sources are, however, not fully consistent due to differences in statistical reporting across countries and incomplete data; at the global scale, where export flows should equal import flows, exports generally exceed imports. On average, this difference is well below 5% for the period when FAO data are available; for the 19th century global exports exceed global imports

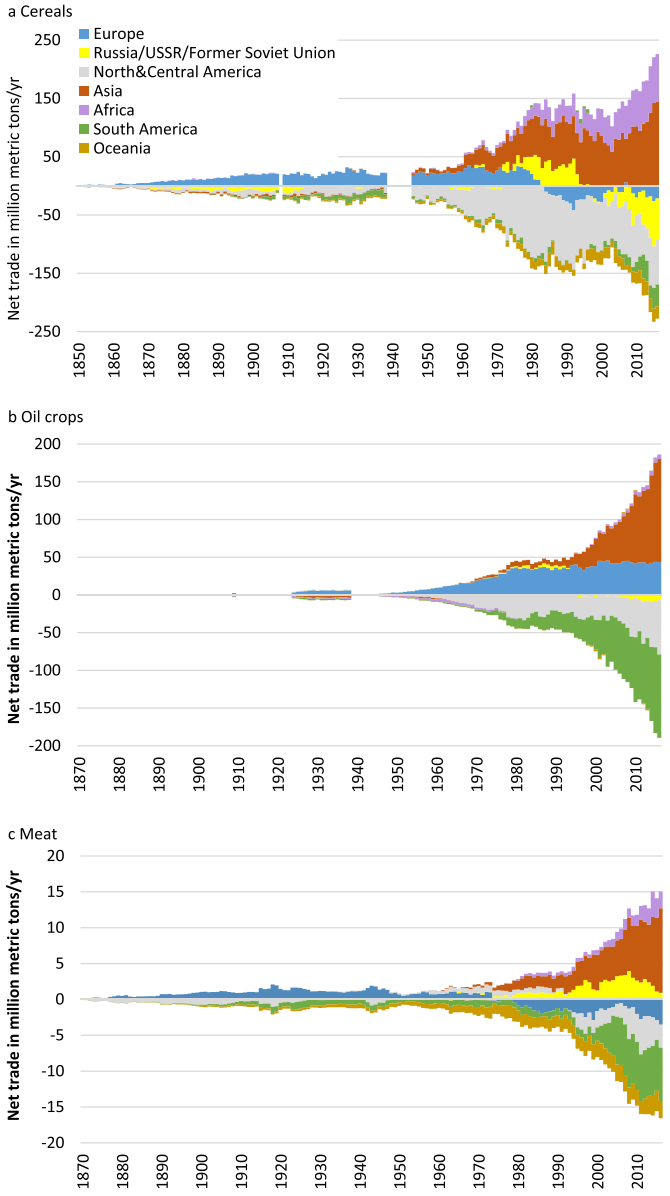


**Fig. 1.** Global net-trade flows for main agricultural commodities 1850/70 to 2016. Physical trade balances of world regions; negative values denote net-exports, positive values net-imports. Panel a: cereals; panel b: oil crops; panel c: meat. Note the different scale of 1a, 1b and 1c.

on average by 15% due to better coverage of exports in statistical sources. From 1961 onwards FAOSTAT provides full coverage of all countries of the world; for the years prior to WWII and in particular in the 19th century country coverage becomes less complete and trade data for the years of WWII (1939–1945) are missing for all three commodity groups. Statistical sources are mainly focused on Old and New World countries and coverage of Asian and African countries is poor. International trade in the 19th century, however, indeed concentrated on the industrializing countries in Europe and the Americas (O'Rourke and Williamson, 2001), the rest of the world was hardly involved in trade with staple foods; we hence assume that the underestimation of global trade flows in the 19th century is low and the overall pattern of intercontinental trade robust.

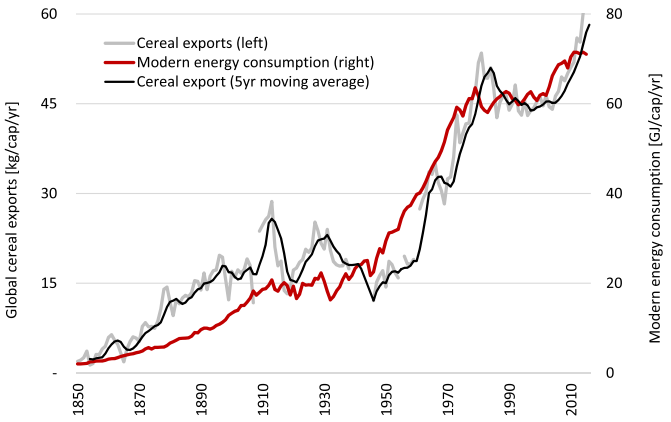


**Fig. 2.** Global consumption of modern primary energy and global cereal exports 1850–2015. Exports in kg/cap/yr and energy use in GJ/cap/yr; the grey line shows annual values of global cereal exports, the black line 5 yr moving averages. Note that cereal exports here refer to total global (gross-) export; modern primary energy comprises fossil energy carriers and other modern energy forms (mainly hydro-, nuclear- and wind power). Data on energy consumption based on Krausmann et al. (2016b).

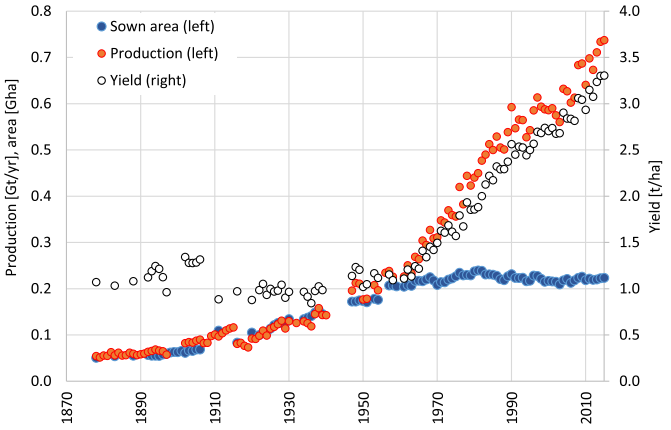


**Fig. 3.** Global wheat production 1878–2016: Sown area (1 Gha = $10^9$ ha = $10^7$ km$^2$), production (Gt/yr) and global average yield per unit of area (t/ha/yr).

## 3. Results and discussion

### 3.1. The British centered food regime 1870–1914/29

The British centered or extensive food regime with wheat as the principal commodity begins in the mid-19th century. Authors have proposed to date the beginning with the abolishment of the protective British Corn Laws in 1846 or with the establishment of the first multilateral free trade agreement in 1860 (Winders, 2009). McMichael (2013) argues, that the free trade system enacted by Britain and supported with sterling as an international currency established a world wheat price with relative convergence among countries between 1870 and the beginning of World War I (WWI). The British centered food regime enhanced Britain's dominating role in the world economy and its imperial power. In terms of trade flows, it combined colonial tropical imports with imports of cereals (in particular wheat) and later also meat from the commodity frontiers of settler colonies in the New World, providing a growing urban-industrial labor force initially mainly in the UK but increasingly also in other European industrializing countries with inexpensive food (McMichael, 2013).

In Fig. 1 we show the development of intercontinental trade with cereals, beginning in 1850, shortly after the British Corn Laws had

fallen (see Fig. S1 in the Supporting data file for a zoom into the period 1850–1940). We observe a steady growth of global cereal net-exports from the 1860s from around 2 mio. tons to 20 mio. tons at the turn of the century, a level at which they remained roughly stable until WWI. Wheat accounted for 40–50% of global cereal exports. Initially the main supplying region was Russia (Goodwin and Grennes, 1998); only from the 1870s on North America increased exports and eventually became the dominating force. Together the two regions accounted for over 85% of global net exports in the beginning, their share slowly dropping to around 60% at the outbreak of WWI, as exports from South American and other regions gained significance. Russia completely vanished as a cereal exporter after the Revolution and WWI. Fig. 1a exhibits a clear direction of global cereal flows: From 1850 to WWII all global net-exports went to Europe, initially almost exclusively to the UK, only since the 1880s increasingly also to other European industrializing economies. In this period, trade gained relative significance: Global wheat export increased from 10% to around 20–25% of global production and the share of import in European supply rose from one fifth to roughly one third. Cereals were by far the dominating mass flow in agricultural exports, but also exports of meat and oil crops gained significance in the British centered regime, albeit at a much lower level. Meat exports from the USA and later also South America and Australia & New Zealand to Europe rose from around 0.07 mio. t/yr (1 mio. $t = 10^6$ $t = 10^{12}$ g) in 1870 to 1.5 mio. t/yr before WWI; data for exports of oil crops are only available after 1909, when 2.5 mio. tons were exported from Asia, Africa and South America to Europe; oil crop exports from these regions to Europe rose to over 6 mio. t/yr in 1938.

In the first food regime rapid population growth, urbanization and industrialization drove the demand for crop products in Europe. Increasing quantities of staple cereals primarily for human consumption were shipped to Europe. In the UK cereal imports increased from 0.7 mio.t/yr to 5 mio. t/yr between 1850 and 1910 and self-sufficiency with food was given way towards a high dependency on imports from overseas. Food imports surpassed domestic production in the UK from around 1885 onwards. Krausmann et al. (2008b) have shown that in parallel with the externalization of agricultural production the overseas “Land Footprint” of UK's food consumption rose to 7.5 mio hectares by 1900, mainly in North America; this is, it rose to an area larger than the UK's domestic cropland. While the offshoring of cereal production damaged the advanced domestic agriculture and put pressure on British land owners, it supported the political and economic interests of industrialists. Imports helped to secure cheap food for British industrial workers and enabled specialization in Britain as workshop of the world (Koning, 1994). In the last decades of the 19th century also Germany, Belgium, France, Italy and other European countries followed to import significant amounts of cereals. The biophysical basis for the surge in cereal exports in the 19th century was an unprecedented expansion of global cropland. Exports mainly came from European settler colonies where commodity frontiers expanded through land occupation. Settlers ploughed up fertile grasslands in the Eastern Steppes of Russia (Moon, 2013, 2012) and from the mid-1860s onward also on the vast North American Great Plains (Cunfer, 2005). In particular, the US homestead act of 1863 and the Canadian dominion lands act of 1872 encouraged white settlers from the East and new immigrants from Europe to occupy and cultivate previously unsettled grassland ecosystems in the Midwest. A precondition was the establishment of a railroad network, the first transcontinental line opening in 1869, that facilitated long distance overland transport of bulk commodities. As a consequence, between 1870 and 1930 around 40 mio ha of prairie land were converted into cropland and planted with corn in the more humid Eastern and wheat in the dryer Western part of the continent (Cunfer, 2005). In the course of this process the native population was displaced violently and nearly extinguished and the grassland environment fundamentally transformed. From an agro-ecological perspective cultivating the previously unploughed grassland soils meant tapping into large, historically accumulated reservoirs of plant nutrients. Ploughing the soil helped to mobilize these nutrients and to make them available for crops in plant utilizable form. While this supported initially high crop yields, these were not sustainable in the long run. The larger fraction of the mobilized nitrogen was lost to the atmosphere (Aguilar et al., 1988; Haas et al., 1957), the same applied to soil organic carbon, which was released in large quantities contributing to rising $CO_2$ concentrations in the atmosphere (Hartman et al., 2011; Parton et al., 2015). The combined effect of dry climate and the depletion of soil nutrients resulted in a downward trend of crop yields in the long run. In Kansas, in the center of the Great Plains, average cereal yields were as high as 3 t/ha/yr in the 1880s, that is, much higher as in the UK (1.9 t/ha/yr) or Austria (1 t/ha/yr); weather induced yield fluctuations were large but in the long run average cereal yields in Kansas declined to around 1.3 t/ha/yr in the 1930s (Cunfer and Krausmann, 2009).

Also in the Old World agricultural production increased in the 19th century but rather through labor intensive organic intensification than through cropland expansion. The bottleneck for yield increases under the traditional organic land use system was the scarcity of plant nutrients, above all of nitrogen; the application of imported mineral and biotic/fossil fertilizers such as Guano or Chile Saltpeter (Cushman, 2013) was limited to certain cash crops and compared to traditional fertilization practices the amount of plant nutrients mobilized through these flows remained small. Instead, the nutrient bottleneck was encountered by a reduction in fallow area and an increase in the area planted with new forage crops, in particular leguminous crops which increase nitrogen availability by tapping into the large atmospheric reservoir. More feed also meant more livestock and combined with better manure management this also contributed to more fertilizer with nutrients readily available for plant uptake (Güldner and Krausmann, 2017; Mazoyer and Roudart, 2006; Shiel, 2006). This advancement of the traditional organic agriculture remained within the solar based energy system and even improved the positive energy return of agricultural production, i.e. it raised the output of food energy per unit of energy investment (Krausmann, 2004). In the UK these agricultural advancements have helped to double cereal yields already in the 18th century; on the European continent the transition to advanced organic agriculture gained momentum only in the 19th century. In spite of these efficiency gains in Old World agriculture, it could not compete with the inexpensive imports from overseas which were based on low labor inputs and costs, the exploitation of accumulated soil nutrients and low transport costs based on cheap coal (O'Rourke, 1997). In the second half of the 19th and early 20th century both labor and land productivity were considerably lower than in the New World (Cunfer and Krausmann, 2009) and the imports of large amounts of cereals put agriculture in the UK and – despite tariff barriers – also on the European continent increasingly under pressure.

The rise of first food regime was based on the expansion of agricultural land into grassland ecosystems in North America and Russia. From a socio-ecological perspective, the export production from the newly settled grasslands was based on the self-exploitation of settler families and unsustainable soil mining. The first food regime was also intrinsically linked to the emergence of the fossil fuel based energy system which not only facilitated the growth of urban industrial centers with high demand for food, but also made the transport of bulk commodities in large quantities at low cost possible. This is illustrated in Fig. 2 which shows, how during the first food regime both global cereal exports and fossil energy consumption grew (both per capita of population) from the mid-19th century until WWI.

With WWI and the Great Depression the British centered food regime came into crisis. Food prices surged at the end of WWI (Jacks, 2018). The war had drastically revealed the vulnerability of the import dependent European food systems (Offer, 1991) and European countries, including the UK as former leader of the free-trade movement, implemented tariffs to protect their markets. Together with the abandonment of the gold standard, this ended the free trade scheme of the British centered food regime (McMichael, 2013). But the first food

regime and its frontier model of soil mining also experienced a severe ecological crisis. Fertile grasslands suitable for further cropland expansion became scarce and crop yields declined. The negative agro-ecological consequences of the rapid expansion of cropland into increasingly arid lands and a labor scarce frontier agriculture based on soil mining became drastically visible in the dust bowl years of the 1930s. A combination of severe draught and wind erosion damaged the ecology and agriculture of the American and Canadian prairies during the 1930s (Cunfer, 2005; Worster, 1982). The stabilization of the US agricultural sector via government intervention led to the emergence of the state-managed food regime during the World Economic Crisis and World War II.

### 3.2. The US centered or intensive food regime 1947–1973

Under the US centered food regime, the nation state gained significance as a regulatory institution (Friedmann and McMichael, 1989). Food exports and aid were used as an economic and political weapon to fight communism and hunger in the context of global population growth and the cold war. Ideological core was a productivist vision of agriculture that strived to meet the growing demand for food by boosting agricultural productivity through agro-technological progress. In terms of regulation the new regime was based on the General Agreement on Tariffs and Trade (GATT) which came into effect in 1947 and largely exempted the agricultural sector from trade liberalization. It granted the member states protectionist measures to protect their agricultural sectors and privileged in particular the US farm programs then in existence (González-Esteban, 2018). The US, which had emerged as the new center of the world economy, continued to dominate the global agricultural market and exported subsidized surplus production to Europe or shipped it as food aid under the Food for Peace Program (Public Law 480) to hunger prone and strategically important countries in the Global South, securing loyalty against communism and to US dominated markets (McMichael, 2013, 2009).

After the US agricultural crisis in the 1930s the New Deal and the war economy drove the fossil fuel based industrialization of US agriculture. Price subsidies and the abolishment of production caps triggered a strong growth of US crop production during the war years (Winders, 2009). The vast capacities of the war related nitrogen industry became available for fertilizer production. Agricultural exports surged. Global cereal net-exports, dominated by the US, multiplied from 20 mio. t/yr in the pre-war years (4% of global production) to 140 mio. t/yr in the mid-1980s (12% of global production). The significance of trade for the global transfer of food reached an unprecedented level: Total exports of cereals per capita of global population doubled from below 20 kg in in the pre-war years to 40 kg/cap/yr in 1973 and rose further to around 50 kg/cap/yr in the late 1970s (Fig. 2). A brake in the growth of global trade flows occurred only in the early 1980s when global net-exports stabilized at a high level (Fig. 1a). This signals a certain time delay of the manifestation of the instability diagnosed in the food regime literature for the early 1970s in physical trade flows. Next to wheat also maize became a major export cereal and oil crops (above all soy beans) emerged as important trade commodity. These new export crops were mainly used as feed in the fast expanding meat production industry in the industrial countries. In the US soy production was massively promoted and subsidized and after WWII exports rose within only one decade from near zero to over 5 mio t/yr in the late 1950s and further to over 30 mio t/yr in 1980 (Langthaler, 2018); South American countries only slowly gained significance as soy exporters towards the end of this regime (Fig. 1b).

North America remained the main export region both for cereals and also for oil seeds (Fig. 1a and b). Meat exports, in contrast, were dominated by South America and Oceania and mainly went to Europe and the USSR (Fig. 1c). In the immediate post war period and supported by Marshall aid, the overwhelming part of cereal exports was still destined for Europe, but exports to Asia steadily gained significance and eventually Asia overtook Europe as import region in the 1960s (Fig. 1a). With rapid yield and production increases in Europe in the 1950s and 1960s, European cereal imports went down and Europe even turned into a net-exporter of cereals in the mid-1980s. Instead, European imports of oil crops from North America rapidly increased. Only towards the end of the regime, also South America appeared as an oilseed exporter (Fig. 1b). Under this regime, the direction of US exports of cereals and in particular wheat, increasingly shifted towards poor and insecure countries in Africa and Asia, where wheat replaced local staples (González-Esteban, 2018).

In the US centered food regime, we observe a fundamental shift in the mechanisms behind production increases and a convergence in Old and New World agricultural intensification which also spread to other world regions: The fossil fuel based industrialization of agriculture, i.e., the Green Revolution, triggered a shift from land expansion as the main strategy to increase output towards input intensification and yield improvement, thereby moving from extensive to intensive frontier expansion. Starting from the USA the industrialization of agriculture captured Europe after WWII and in the 1960s also certain parts of the agricultural sector in the countries of the Global South. After WWII a radical break in the relation of production and sown area can be observed, as indicated in Fig. 3 for the example of wheat: Until the 1940s increases in global wheat production were based on the expansion of area planted with wheat. Global average wheat yields showed no upward trend but fluctuated between 1 and 1.5 t/ha/yr between 1870 and 1939. After WWII area expansion came to an abrupt halt and fast increases in production were achieved by rising yields per unit of area. In the three decades from the late 1950s to the early 1990s yields increased at a rate of 1.7% per year; after that growth continued, but at a somewhat lower rate of 1.1%/yr. The industrialization of agriculture implied a decoupling of production from the expansion of agricultural land. Less productive land was even taken out of production and partly reforested, contributing to the so called forest transition (Meyfroidt and Lambin, 2011). Production growth also exceeded population growth, above all in the industrialized countries. From 1880 to 1950 cereal production fluctuated around 4 to 5 GJ of nutritional energy per capita of global population and year; with the Green Revolution it doubled to 9 GJ/cap/yr in the early 1980s, where it since remained. This surge in per capita cereal output was basis for the “meatification” of Western diets i.e., a massive increase in the per capita consumption of meat and other animal products in industrialized countries after WWII (Weis, 2013). An increasing fraction of crop production could be diverted from direct human consumption towards feeding livestock to produce animal protein. This was also the driver for the surge in production of and trade with oil crops, net-export reaching almost 50 mio. t/yr around 1980. While oil cakes were used as animal food, vegetable oils, especially from soybeans, were channeled into human consumption, fueling the “oilification” of Western diets (Langthaler, 2018). Meat net-exports, in contrast, remained comparatively low and only began to rise sharply in the next regime (Fig. 1c).

From a socio-ecological perspective, the US centered food regime was based on the complete integration of agricultural production into the fossil fuel based energy system (Krausmann et al., 2008a) and it corresponds with the oil based surge in per capita energy consumption from WWII to the 1970s (Fig. 2). The simultaneous increase in land and labor productivity was based on large energy subsidies of agricultural production. The core innovations of industrialized agriculture were based on the combination of new high yielding crop varieties with energy intensive technologies: These included mechanization and the substitution of human and animal work through machinery using internal combustion or electrical engines, water pumps, energy intensive agrochemical processes (i.e., the Haber-Bosch process for Ammonia synthesis) and the use of electricity to heat stables or dry crops. The direct and indirect energy inputs rose at a faster pace than the output of agricultural produce and diminished the energy efficiency of agricultural production (Gingrich et al., 2018; Pimentel et al., 1973). The

deterioration of the energy balance of agriculture was aggravated by the growing significance of industrial meat production. The conversion of fast growing quantities of feed grains and oil crops into animal protein implied a loss of large amounts of nutritional energy. Together these processes changed the role of agriculture in the energy system of society. It has been shown that at an economy-wide level often more energy was invested into industrial agricultural production systems than was contained in the output of food for final consumption; agriculture turning from an energy source to an energy sink (Krausmann, 2016). During the US centered food regime agriculture increasingly shifted from the management of renewable resources towards a reliance on – ultimately - limited fossil and mineral resources, a transition which had large impacts on human interference with global biogeochemical cycles: Next to becoming a major emitter of greenhouse gases, agriculture channeled ever growing amounts of atmospheric nitrogen and rock phosphate into soils and ecosystem nutrient cycles and began to use about 90% of global freshwater consumption altering hydrological cycles (Bouwman et al., 2013; Oki and Kanae, 2006; Vitousek et al., 1997). While the productivist agriculture that had emerged under the US centered food regime had allowed meeting accelerated population growth with a growing output of food and providing more people with meat and other luxury food products, these achievements came at the expense of high ecological costs and drove global environmental change. In the second food regime agriculture became a major factor in humanity transgressing planetary boundaries (Steffen et al., 2015).

Food regime literature diagnoses a crisis of the US centered food regime beginning in the early 1970s. Overproduction became increasingly expensive to subsidize and strained national budgets. Further, national protectionist agricultural policies more and more contradicted the interests of the transnational corporations which gained significance. In 1971 the US terminated the Bretton Woods system of monetary management. In 1972 the global food crisis, sparked by large scale drought caused crop failures and the USA directing a large part of its cereal surplus to the USSR, resulted in severe spikes in food prices (Jacks, 2018; Timmer, 2010); this was further aggravated by the oil price shocks of 1973 and 1979, which revealed the high energy dependence of the industrial food system (Pimentel et al., 1973). And last but not least also the negative effects of industrial agriculture and its high inputs of agrochemicals on the environment and human health became an issue of increasing concern and called for political action (see Rachel Carsons “Silent Spring” of 1962). Thus, also in the context of the crisis of the US centered food regime, resource and environmental factors played a considerable role. In terms of our indicators of agricultural production and trade we do find that the growth processes of the 1960s and 1970s distinctly slowed down or came to a halt in the late 1970s. The following decade was a period of remarkably little dynamic in global agriculture, with production and trade remaining rather stable. This changed only in the early 1990s.

### 3.3. The corporate food regime 1986/95–present

The food regime literature debates the emergence of a new food regime in the 1980s or 1990s related to the Uruguay round of the GATT reform, which began in 1986 and the resulted in the Agreement on Agriculture coming into effect in 1995. This third food regime has been termed corporate or neoliberal food regime (McMichael, 2009). It has no clear geographical center like the previous regimes, but with the World Trade Organization (WTO) and its agenda of deregulation of agricultural markets a central regulating body. Under this regime, food security was no longer considered plainly as the right to food, as it has been framed on the World Food Conference in 1974, but was realigned towards the ability to buy food. The negotiations of the GATT reform were dominated by the interests of transnational corporations, agribusinesses and export-orientated “new agricultural countries” (Friedmann, 1991). Although the nation state lost its dominant role in the regulation of the market towards serving the market, the industrialized countries continued to protect their agricultural production systems by shifting from direct price subsidies to indirect measures (McMichael, 2013). In the McSharry reform of the EU's common agricultural policy in 1992, production based price subsidies were exchanged for size-based subsidies and programs for rural development including the establishment of more environmentally friendly agricultural production systems. Also Japan, the USA and other industrialized countries engaged in this type of “greenwashing” their market-distorting subsidy schemes (Buckland, 2004). Consequently, food regime theory criticizes that rather than contributing to a fairer global trade system through liberalization, the corporate food regime has strengthened the disadvantages of the countries of the Global South and their smallholder agriculture and benefitted large agribusinesses and the interests of industrialized countries (McMichael, 2013).

The emergence of a new food regime is also visible in global trade flows. After a period of little dynamic in global agriculture and stagnating global net-exports we observe a clear turning point in trade with oil crops and meat in the early 1990s (Fig. 1b and c): from 1993 onwards, net-trade of these commodities began to rise at very high rates of 5–6% per year which continued throughout the observed period. Interestingly, for cereals the upswing set in a decade later. Only after 2002 cereal net-exports began to grow after 25 years of decline (Fig. 1a). In this period also growth in crop production accelerated and a massive increase in the rate of cropland expansion occurred. Between 2002 and 2016 on average 15 mio. ha of cropland were harvested additionally each year, after an average of only 2 mio. per year between 1990 and 2002 (FAO, 2018).

In addition to ongoing population growth, the new surge in agricultural production and trade in the third food regime was driven by dietary changes, in particular, rising meat consumption in the emerging economies and by increasing quantities of crops used for non-food purposes. Meat consumption in China, for example, rose from 24 kg/cap/yr in 1990 to 62 kg/cap/yr in 2013 (FAO, 2018) and global biofuel production increased from 15 mio. t/yr in 2002 to 101 mio. t/yr in 2016 (IEA, 2016), the latter corresponding to a cropland area of 50–60 mio. ha. In the corporate regime the USA lost its dominant role as agricultural exporter: As agriculture in Russia and other countries of the former Soviet Union (FSU) revived, this region emerged as a major cereal exporter, catching up with North America, and South America became the dominating export region of meat and oil crops. The size of oil crop exports reached a size similar to that of cereals. Net-exports are mainly destined for Asia, above all to China but increasingly also to Africa (cereals). FSU became a major meat importer. Overall, the regime is characterized by fast growth of exports and a diversification of participants the world market for agricultural products, encompassing parts of the former periphery.

The corporate food regime also bears contradictions, which have been described in the food regime literature as a quality and a quantity segment on the global food market or as “food from nowhere” vs. “food from somewhere” (Campbell, 2009; McMichael, 2009). Food from nowhere refers to cheap food from a world agriculture with conventional and highly industrialized production systems, a high degree of processing and long transnational supply chains, while food from somewhere denotes a new market segment comprising high priced, organic food commodities from place-based agriculture for wealthy and concerned consumers. While the large quantity segment mainly caters the countries of the Global South, in the industrialized countries both segments coexist. The quality segment has grown from a small niche with alternative production and distribution systems to a considerable market, that is gradually engrossed by the dominating food retailers which simultaneously serve both segments to consumers (Padel and Midmore, 2005). This progressive integration of the organic food segment into industrial production and supply chains has also criticized in the “conventionalization” debate (Darnhofer et al., 2010).

Also from a socio-ecological perspective we can identify these contradictory trends between the core and the periphery and within

industrialized countries. The additional demand for agricultural produce was mainly met by agricultural expansion in the Global South and by the revival of the collapsed agriculture in the FSU countries. South America, Africa and FSU emerged as the new export regions due to extension of agricultural frontiers into near-natural habitats. Production was boosted by a combination of land expansion and intensification, including the large scale adoption of genetically modified crops (biotech crops) and the associated high input agriculture. In 2011 the acreage planted with biotech crops in the Global South (mainly in South America and Asia) surpassed that in the industrialized countries at around 90 mio. ha and is rising further (ISAAA, 2016). New agricultural land, mainly for export production, was reclaimed from savannahs, natural grasslands and tropical forests and drove global deforestation (Keenan et al., 2015). The area of sown cropland in South America and Africa grew by roughly 160 mio. between 1990 and 2015 (FAO, 2018). With the global food crisis of 2008 and biofuel and bioeconomy strategies in industrial countries promising new markets for agricultural products, new interest in investments in agriculture was generated. This caused a rise in large scale land acquisitions, often denoted as “land grab” (McMichael, 2012, 2010). This refers to private investors or countries buying or leasing very large amounts of land and is a highly contested process in terms of governance and impacts on livelihoods and human rights (McMichael, 2012). The land matrix database identified 900 land deals between 2000 and 2016, concerning 24 mio. ha of agricultural land mainly in the Global South (Nolte et al., 2016).

While in the Global South agriculture was expanding, we observe the contrary in Western industrialized countries, in particular in Europe, where agriculture contracted and forest cover further increased. In Europe and North America, sown area declined by 64 mio. ha between 1990 and 2015 (FAO, 2018). Fertilizer input in many countries peaked in the late 1990s and has declined considerably since (Jepsen et al., 2015; Lassaletta et al., 2014). Also energy is used more efficiently and the energy return on investment of agriculture has improved (Bonny, 1993; Gingrich and Krausmann, 2018; Pellegrini and Fernández, 2018; Uhlin, 1998). With the rise of the food from somewhere segment the demand for organic produce surged and organic farm land expanded from 11 mio. ha in 1999 to 58 mio. ha in 2016, corresponding to roughly 4% of global arable land. Most of the organic farm land is located in Europe and Australia, but also in Latin America and Asia organic farming is on the rise, however, mainly serving export production destined to Europe and North America (Willer and Lernoud, 2018). In spite of the observed efficiency gains, agriculture in the industrialized countries remains intensive. While extensifcation in some segments and regions indeed has positive environmental effects and the growing forest area benefits carbon sequestration, it has also been shown to be related to trade induced displacement effects (D'Odorico et al., 2014; Meyfroidt et al., 2010). Rather than a fundamental shift in the agro-ecological foundations of agriculture, we diagnose a maturation of modern industrial agriculture and its technologies, which have spread rapidly in the US centered food regime. This maturation is driven by rising prices of agricultural inputs, a shift from subsidy schemes fostering output increases towards programs and regulations that aim at curbing intensification and environmental damage and also increasing public concern about the negative environmental effects of intensive production (Jepsen et al., 2015; Van Grinsven et al., 2012). This maturation has led to a more efficient use of agricultural inputs and the mitigation of some negative environmental impacts, but not to a shift towards the adoption of more holistic agricultural production systems (ECA, 2017).

Overall, the socio-ecological perspective indicates a new dynamic of growth in agricultural production and trade since the 1990s and an acceleration after 2002, supporting the notion of a new food regime emerging due to both extensive and intensive expansions of commodity frontiers. This corresponds with the most recent acceleration in global resource use and a new rise in per capita energy consumption, driven by the industrialization processes in the emerging economies (Fig. 2). Our analysis confirms the central contradiction between intensification and food from nowhere in a world agriculture and extensification in a place-based agriculture and food from somewhere, but it does not provide substantive indications that a fundamental socio-ecological transition of agriculture is underway.

## 4. Resumen

In this study we have taken a socio-ecological perspective on the food regimes theory, quantifying trade flows of major agricultural export commodities and relating them to changes in the resource base of agricultural production and society since the mid-19th century. Our results show the tremendous growth in the volume of agricultural trade during the last one and a half centuries, exports of agricultural commodities rising from a few million t/yr in the mid-19th to 1.4 billion t/yr at the beginning of the 21st century. Growth in trade and also in agricultural production did not follow a continuous trend, but we can clearly identify periods of growth alternating with phases of stagnation. Rather than directed modernization we observe shifts in unequal relations of power and global commodity frontiers, physical exchange and environmental pressure between changing centers and peripheries. The periodization of food regimes in the literature matches well with the periods of surging trade flows, while during the transition from one regime to another trade flows stagnate and also production growth slows down. The food regimes also roughly correspond to major changes in societies metabolism, i.e. the rise of coal and per capita fossil energy consumption until WWI, the “great acceleration” of resource use based on oil and other modern energy carriers from WWII to the 1970s and the stark rise of global resource use driven by growth in the emerging economies since the 1990s (Krausmann et al., 2009). Overall, we find that the shift from one regime to another is related to changes in the resource base of agricultural production and includes components of ecological crisis. The first and the second food regime are very distinct in their socio-ecological characteristics and related sustainability challenges. Export production in the first food regime was based on agricultural expansion into new frontiers and the exploitation of plant nutrients accumulated over long periods in the newly ploughed grassland soils. The regime came into crisis when limits of land expansion and unsustainable soil mining were approached. The second food regime was characterized by intensification through fossil fuel based agricultural inputs; this process multiplied yields per unit of area but came at high energy and ecological costs. This new type of industrial agriculture emerged as a major driver of global environmental change, which became an issue of increasing concern towards the end of the second regime. We cannot identify such clear-cut socio-ecological characteristics for the third regime, in which land expansion and intensification in some regions and production system drives growth in global production, while in others extensification and ecologisation of agriculture occurs. A fundamental shift towards a more sustainable agriculture, however, cannot be observed. Overall, the socio-ecological perspective clearly shows that the three food regimes not only reflect changes in power relations in the world system, but also changes in societies natural relations.

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