The contribution of agricultural trade and transport to climate change

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Abstract

Climate change inducing greenhouse gas emissions have grown considerably over the last decades and will grow further. We will analyze the impact of possible future trade scenarios until 2045 on greenhouse gas emissions, by looking not only on emissions generated by agricultural production, but also on CO_2-emissions resulting from the global transport of agricultural goods. The analysis of the combined effect is performed using the global land use model MAgPIE_trade ("Model of Agricultural Production and its Impact on the Environment"). The optimization model maps not only spatially explicit land use patterns and related greenhouse gas emissions, but due to the implemented bilateral trade we can also determine the CO_2-emissions stemming from the transport of the agricultural goods. With this study we are therefore able to compare CO_2-emissions resulting from an increased international trade to landuse- and landuse change emissions resulting from producing agricultural goods in economically more appropriate regions.

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1 Introduction

Agriculture is responsible for a considerable part of global greenhouse gas emissions. 13.5 % of the global, anthropogenic emissions are produced by the production of agricultural goods, 80 % of these are emitted through the production of livestock [10].
An increase in trade-liberalization, moving towards free trade will have an impact on the amount and the geographical distribution of agricultural emissions. Not only regarding production emissions, but also concerning transport emissions through the increased use of transport fuels [10]. Considering the contribution of the transport sector to global emissions of 23 % [10], the impact of changes on the extent of international agricultural trade could be decisive.
Different studies have tried to determine the share of emissions of the transport of agricultural goods to the total volume of emissions produced by agricultural production. Studies have been mostly regional and crop-specific and have arrived at different results. The transport emissions for different sorts of wheat exported from the US to Japan account for 39-56 % of total (production and transport) emissions [14]. A study looking at agricultural emissions from food consumption in Sweden [6] found that transportation emissions were 16 % for carrots and 31 % for potatoes, while dry peas and tomatoes amounted to less than 10 %. For the relative emission-intensive production of livestock the transport only amounted to 5 %. Studies for Germany found that 3.8-8 % of food-related emissions are caused by transportation (kjer, taylor), where 70 % of these transport emissions are oversea emissions. For food production in the US the transport emissions where estimated 11 % [18].
The land and water use model MAgPIE_trade with bilateral trade flows allows us not only to look at agricultural emissions, created through different land uses, fertilizing or methane-related livestock- emissions, but also at the transport related emissions. Since agricultural production and transport depend on each other, with our consistent model-approach, we are able to see the impact of even small changes in agricultural transport volume.

2 Methods and data – Material and Methods

2.1 Model description MAgPIE

MAgPIE ("Model of Agricultural Production and its Impact on the Environment") is a global, spatially explicit, economic landuse model solving in a recursive-dynamic mode [12]. The model distinguishes ten world regions on the demand side (Figure 1) and solves grid-specific (up to 0.5 degree resolution) on the supply side.
With income and population projections [based on the ADAM project 17] as

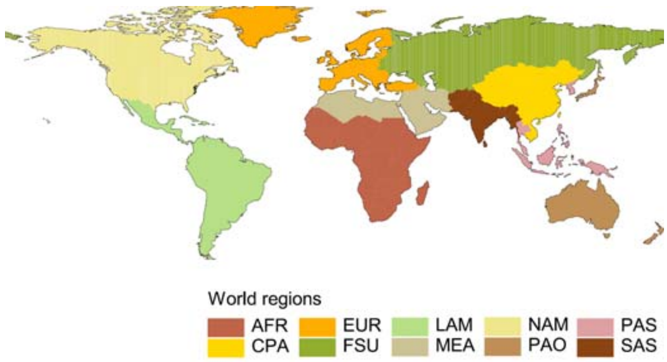

Figure 1: Economic regions in MAgPIE: AFR = Sub-Sahara Africa, CPA = Centrally Planned Asia (incl. China), EUR = Europe (incl. Turkey), FSU = Former Soviet Union, LAM = Latin America, MEA = Middle East and North Africa, NAM = North America, PAO = Pacific OECD (Australia, Japan and New Zealand), PAS = Pacific Asia, SAS = South Asia (incl. India)

exogenous inputs, required demand is projected in the future and produced by 15 food crops, 5 livestock products, fiber, and fodder as intermediate input (Table 1). Feed requirements for the livestock production activities consist of a mixture of pasture, fodder, and food crops. The livestock-specific requirements depend on biological needs for maintenance and growth but also temperature effects and the use of extra energy for grazing [20]. The implementation in MAgPIE is described in [19]. On the biophysical side the model is linked to the grid-based dynamic vegetation model LPJmL [5], which simulates crop yields depending on climatic conditions on a 0.5 degree resolution. In addition to crop yields, LPJmL transfers water inputs, like water availability and requirements per cell and crop, to MAgPIE. The model simulates time steps of 10 years and uses in each period the optimal land-use pattern from the previous period as initial condition.
The objective function of MAgPIE minimizes global costs, which involves production costs for the agricultural commodities, technological change costs, land expansion costs and trade and transport costs. Production costs are derived from the GTAP database [13] and include factor costs for labour, capital, and intermediate inputs. Investments in technological change allow MAgPIE to increase crop yields in a particular region. The endogenous implementation of technological change (TC) is based on a surrogate measure for agricultural land use intensity and is described extensively in [1]. Expansion of cropland is the other alternative to increase the production level. The expansion involves land-conversion costs for every unit of cropland, which account for the preparation of new land and basic infrastructure investments [11]. Land conversion costs are based on country-level marginal access costs generated by the Global Timber Model (GTM) [16].

Table 1: Production activities in MAgPIE

Categories	**Production Activities**
cereals	temperate cereals; maize; tropical cereals; rice
oilcrops	soybean; rapeseed; groundnut; sunflower
oilpalm	oilpalm
roots/pulses	pulses; potato; cassava
sugar	sugarbeet; sugarcane
veg/fruits	vegetables, fruits, nuts (one category)
other	fodder; fiber
livestock	ruminant meat; pork; chicken; eggs; milk

Finally, the special feature of MAgPIE_trade is the inclusion of bilateral trade between each of the world regions instead of using self-sufficiency rates as in the general MAgPIE version [3]. For this, international trade and transport costs for each traded unit is added to the objective function. The costs for bilateral transport for each commodity are derived by calculating the difference between bilateral export values at FOB prices (Free On Board) and bilateral import values at CIF prices (Cost Insurance and Freight) and dividing it by the traded quantity. Since the data are based on the GTAP database [13] and GTAP reports all quantities in US$ values, we had to divide the trade volume by prices taken from FAO to get the traded quantity [7]. In a similar manner, the trade barriers are calculated. Import duties are derived as the difference between bilateral import values at market prices and at world prices, whereas export duties are derived as the difference between bilateral export values at world prices and at market prices. As with transport costs, we divide the results by the traded quantities to obtain trade margins per ton.

2.2 Estimating the intra-regional transport emissions

In our approach, CO_2 emissions from the transport of agricultural commodities (Table 1) in bilateral trade are made up of two components. First, the emissions caused by the transport of agricultural export commodities in the producing region (intra-regional component), and, second, the emissions that are created when these commodities are freighted from the producing region to the region of consumption (inter-regional component). In order to calculate emissions from the intra-regional transport of agricultural export commodities, we assume that these goods are transported directly from the location of production to a port or airport, from where they are freighted to other regions. In addition, we presume that intra-regional transport is solely confined to roads. Following formula is used to calculate transport emissions (E_{intra}) f or each crop/livestock product (Table 1) inside each MAgPIE region (Figure 1):

$$E_{intra} = \sum e_m * M_{c,r} * D_{c,r} \tag{1}$$

In the formula, e_m represents an emission factor [kg CO_2 ton^{-1} km^{-1}] per ton of goods transported over one kilometer with a specific mode m of transport, $M_{c,r}$ is the mass [tons] of the good c (i.e. a crop or livestock product in MAgPIE) that is exported from region r, and $D_{c,r}$ is the average distance [km] from the production locations of good c to the closest port/airport in region r. The emission factor e_m for a lorry was determined by using the average of three different lorry sizes (0.18 kg CO_2 ton^{-1} km^{-1}) in the basic freight calculator from the Network for Transport and Environment [2]. Export quantities of crop and livestock products in each region were obtained from a MAgPIE_trade data set, which provides trade flows between regions. Average distances from the production locations of each agricultural good were estimated using the geographical coordinates of important ports/airports (data about ports/airports was obtained from several national and international statistical databases) , and MAgPIE production grids, giving the locations and quantities of production in each regions. Utilizing the distance tool in the geographical information system ArcGIS, we first calculate the closest distance from each grid cell to the closest port/airport in each region (Figure 2). Subsequently, these distances were multiplied with the amount of production of each agricultural good in the corresponding cell, and divided the regional sum of this product by the total regional amount of production. By means of this procedure, average, production-weighted distances can be achieved for each good in each region.

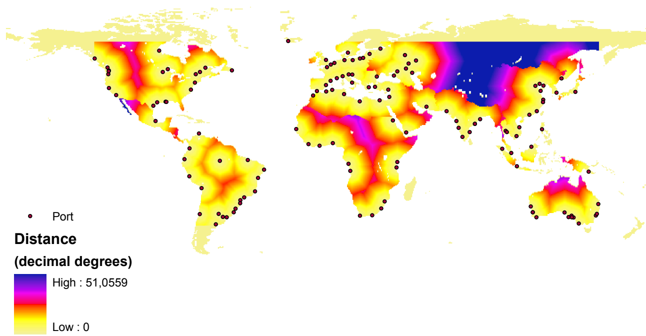

Figure 2: Shortest distances from each cell to the closest port in each region.

2.3 Estimating the inter-regional transport emissions

For the calculation of emissions caused by the inter-regional transport of agricultural commodities, we allowed only for transport on ships and cargo airplanes, and assigned one major exporting port/airport to each region. Exchange of commodities between regions is, therefore, only taking place through these 10 ports/airports. Consequently, transport distances between regions are assumed to be the same for each crop or livestock product. The formula used for the calculation of inter-regional transport emissions (E_{inter}) is thus as follows:

$$E_{inter} = \sum e_m * M_{c,r} * D_{r_1,r_2} \qquad (2)$$

where e_m and $M_{c,r}$ are the same as in (1), and D_{r_1,r_2} is the distance [km] between the exporting region r_1 and the region of consumption r_2. Emission factors (e_m) for cargo ships and airplanes were determined with the basic freight calculator from the Network for Transport and Environment [2]. For ships, the average of three different sized container ships was taken (0.012 kg CO_2 ton^{-1} km^{-1}). The emission factor for airplanes was computed by taking the average of continental and intercontinental cargo planes (0.818 kg CO_2 ton^{-1} km^{-1}). The distances D_{r_1,r_2} between these 10 ports in the respective regions were obtained from the Network for Transport and Environment, while flying distances between airports were determined with the air distance calculator from the Directory of Indian Suppliers. In our model, only fruits, vegetables, and livestock products are transported by airplane. We assume that 2 % of these products are transported by plane, while the remaining quantity is shipped.

2.4 Estimating the agricultural emissions

MAgPIE calculates greenhouse gas emissions of CO_2, CH_4 and N_2O resulting from land-use changes and agricultural activities.

CO_2 emissions are calculated as the difference in carbon content between natural vegetation and managed crop production. CO_2 emissions from land-use change occur whenever natural vegetation is converted into cropland. The carbon stocks of natural vegetation are estimated by the LPJml model. We assume that all vegetation and litter carbon is released, and that a climate specific share of soil organic carbon [9] is released. The carbon fixed in the crops growing on the converted area is also estimated by LPJml and offsets a part of the released emissions.

CH_4 emissions in MAgPIE have three possible sources. First, animal waste management systems (AWMS) are responsible for CH_4 emissions by the anaerobic decomposition of manure. In MAgPIE, this effect is influenced by temperature, the kind of livestock, and the development level of the region. Second, ruminant livestock, like cattle, sheep, or goats, produce methane

by fermenting feed in stomach and intestine. Third, rice cultivation is responsible for CH_4 emissions from flooded fields. Besides the amount of rice cultivation, this emission type depends on water management practices and a specific regional factor. CH_4 emissions are estimated using the emission factors of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories [8]. Further information on the detailed calculation of CH_4 emissions within MAgPIE is provided in [15].
N_2O emissions in MAgPIE have two possible sources. Like in the case of CH_4, one source is the AWMS which produces N_2O by denitrification and nitrification of animal excrements. The second source is N_2O emissions from cultivated soils affected by the kind of nitrogen fertilizer used (synthetic fertilizer, manure, crop residues and N-fixing crops). In addition, indirect effects occur through atmospheric deposition of NO_x and NH3 and through leaching of reactive nitrogen. All N_2O emissions are based on nutrient flows estimated with a simplified version of the nitrogen flow model described in Bodirsky et al. (2012) [4], using emission factors of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [9]. All emissions are expressed in CO_2-equivalents using a "global warming potential" (GWP) of 25 for methane and 298 for N_2O ([10]).

3 Results

For the comparison of the transport, land-use change, and land use component of emissions caused by the international trade of agricultural commodities, we allocated the generated transport emissions to the importing region. In general, transport emissions from international trade constitute a small proportion of the total agricultural emissions in a region (Figure 3), with an average share of 8.1 % (σ: 7.9 %). Highest shares are found in CPA (11.6 %), EUR (14.7 %), and MEA (26.9 %), while it is lowest in AFR (1.1 %).
When looking at global emission flows caused by transport (Figure 4), it is notable that CPA, LAM, and NAM import, but also export high transport emissions. EUR, FSU, SAS, and MEA import high transport emissions through trade, while the emission flows for AFR, PAO, and PAS seem rather balanced. Comparing these emission flows with the flows of trade quantities (Figure 5), one recognizes that quantities and transport emissions of traded goods are not linearly correlated. For example, emission and trade flows between NAM and LAM have similar arrow-thicknesses, while emission flows from China are created by a smaller quantity of agricultural export commodities.

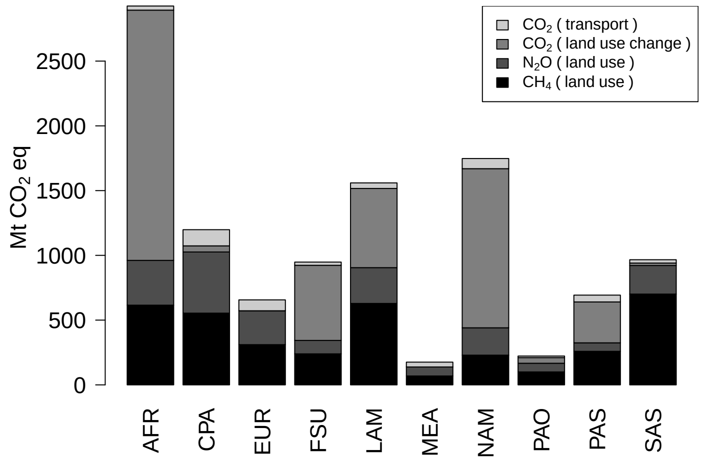

Figure 3: Emissions from agricultural production, and transport of agricultural commodities..

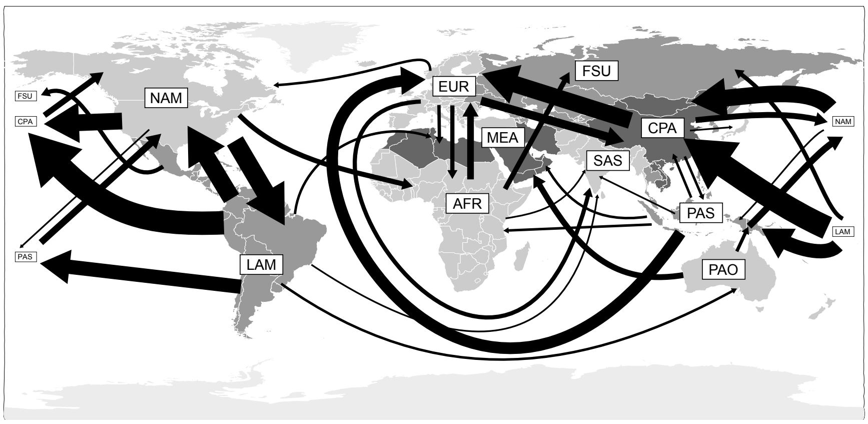

Figure 4: Emission flows caused by the transport of agricultural commodities in international trade. Arrow thickness is in relative proportion to the emissions in Mt CO_2-eq.

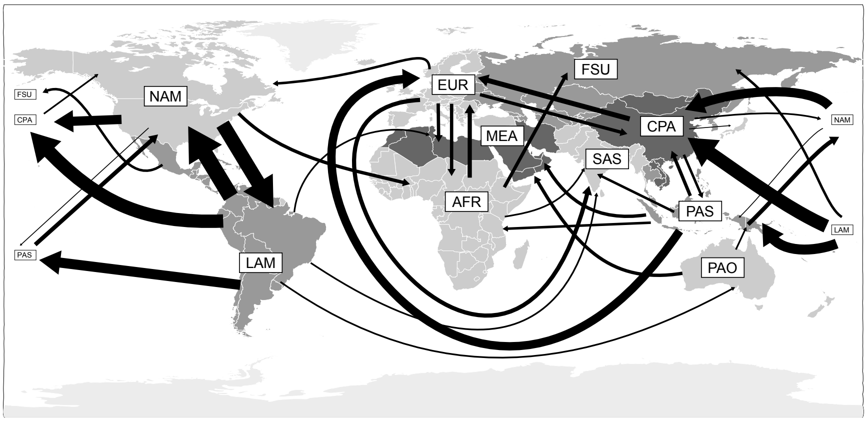

Figure 5: Trade flows of agricultural commodities between MAgPIE regions. Arrow thickness is in relative proportion to the traded quantity in Mt.

4 Discussion

The share of imported transport emissions in the total of agricultural GHG-emissions of a region needs a more detailed explanation, since various reasons can be thought of determining this share. This is already apparent, when the shares of imported transport emissions are compared with their absolute values. For example, MEA imports a comparatively small absolute amount of transport emissions, while CPA, NAM, and EUR import high absolute amounts. The total share of imported emissions in these regions is affected by the agricultural activity in the region itself, the degree of utilization of agricultural land (i.e. the share of CO_2 emissions from land-use change), and by the type of agricultural commodity that is primarily imported. CO_2 emissions from land-use change are small (or not present at all) in CPA, EUR, and MEA, which suggests a rather intensive use of the available agricultural land, without a substantial expansion of the area under crops. In addition, production emissions (i.e. CH_4 and N_2O) from agriculture are small in MEA. The import of luxury goods, like livestock products, in EUR and CPA, could also boost the share of imported CO_2 emissions in the two regions, because these products are also transported by airplanes, which are CO_2 intensive. This is also supported by the fact that emission flows to EUR and CPA are high compared to the actual quantity imported. In contrast to these regions, NAM has a high share of CO_2 emissions from land-use change, suggesting a more extensive utilization of land for the production of agricultural commodities. As a result, imported transport emissions in NAM carry almost no weight in comparison to the other emissions.

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