
# Trading More Food in the Context of High-end Climate Change: Implications for Land Displacement through Agricultural Trade

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***Abstract:***

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*Acknowledegment:*

**JEL Codes:** C61, Q15

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## Abstract

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Key words: international trade, climate change, trade liberalization, land displacement

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# 1 Introduction

How could a growing world population be feed? This is a central question facing our century, in particular, when climate change is present. The observed rising global mean temperature (GMT) exerts negative impacts on crop yields (Lobell et al., 2011), challenging sufficient global agricultural supply. Global demand for crop products is expected to double from 2005 to 2050 (Tilman et al., 2011). In addition, deployment of bioenergy, increasing material demand, and feed stock add additional pressure on agricultural production.

It is widely perceived among agricultural economists that agricultural trade can function as a key adaptation option to climate change (Fischer et al., 1994; Reilly and Hohmann, 1993). As an economic adjustment, it could help to alleviate the challenge by benefiting from comparative productivity advantages between countries (Ruiter et al., 2016). It is expected to reduce market distortion, and therefore to increase total agricultural welfare and slow the increase of food prices (Stevanović et al., 2016), but also spare cropland area used for agricultural production on the global level(Schmitz et al., 2012). However, it remains unclear among existing research whether, and if so, to what extend trade liberalization will contribute to global agricultural supply when cropland distribution all over the world is to be considered. Trade liberalization often reinforces spatial displacement of cropland. With increasing globalization of agricultural production, land use becomes interconnected among regions through agricultural trade (Meyfroidt et al., 2013). As a consequence, global cropland area for export production grows rapidly (Kastner et al., 2014). In particular, regions, such as Latin America, endowed with rich tropic forests tends to experience increasing cropland expansion (Schmitz et al., 2012). Studies suggest that the redistribution of natural resources embodied in the agricultural goods should be considered when analyzing the trade effect (Kastner et al., 2014; Meyfroidt et al., 2013).

Current studies mainly focus on the historical pattern, whereas little attention is paid to projecting future patterns, in which climate change is a factor which cannot be ignored. The presented study intends to fill the research gap by taking into account climate impacts and analyze the redistribution of cropland embedded in key crop commodities when there is further trade liberalization. The challenge of analyzing the trade-offs and projecting land-use patterns is to account, within one modeling framework, for the socio-economic determinants of agricultural demands as well as for the spatial heterogeneity of land's suitability for agricultural production(Lotze-Campen et al., 2010). By linking to a global gridded dynamic vegetation model (Müller et al., 2017), we are able to quantify the redistribution of cropland through agricultural trade in the context of climate change which alters biophysical conditions for crop production. The remainder of the paper is organized as follows. Section 2 briefly introduces the model employed to project land use dynamics and cropland displacement, followed by a description of trade liberalization scenarios and climate scenarios in section 3. Results of land sue and trade patterns are presented and discussed in Section 4. Section 5 draws conclusions.

# 2 Simulation methods

MAgPIE (Model of Agricultural Production and its Impact on Environment) is a partial equilibrium, agro-economic model for the optimization of land use and production patterns under given agricultural demand and subject to spatially explicit biophysical constraints (Lotze-

Campen et al., 2008). The food demand for crop and livestock products enters the model as exogenous projections based on population and income growth as well as dietary preferences (Bodirsky et al., 2015). The model covers 10 world regions[1], the classification of which is based on geo-economic conditions. Increasing agricultural yields through technological investments and cropland expansion are primary means of providing sufficient supply of agricultural goods(Dietrich et al., 2014). The major associated costs are technological investments, land conversion costs, costs of production input factors, domestic transportation costs, and trade costs. Socio-economic constraints like trade liberalization in terms of faster trade barrier reduction are prescribed at the regional level, while biophysical constraints such as crop yield potentials and water availability, derived from the global crop, hydrology and vegetation model LPJmL (Lund-Potsdam-Jena with managed Land (Müller et al., 2017), as well as land availability  are prescribed at the 0.5 degree grid level (Krause et al., 2013).

## 2.1 Bilateral trade implementation

Differentiated from previous versions of MAgPIE in which international trade is implemented based on prescribed self-sufficiency rates, this study models agricultural trade as an extension of Koopmans-Hitchcock transport cost-minimization model (Takayama, 1967) with multiple homogenous commodities. Trade margins drive a wedge between the price received by the exporter and the price paid by the importer, and therefore can affect the quantity of trade (Burfisher, 2011). Let $i, ii \in I$ denote MAgPIE regions, $k \in K$ a traded commodity, then $x_{i,ii,k}^{trade}$ is non-negative trade volume of $k$ commodity between region $i$ and $ii$ , and $c_{i,ii,k}^{trade\ margin}$ is trade margin between a pair of regions with units of USD/ton DM (dry matter), and $d_{i,ii,k}^{sdt}$ is specific duty tariffs with units of USD/ton DM. Total trade cost $f(x)$, is a function of trade volume and is part of total costs in the objective function of MAgPIE, which is minimized when the model reaches an optima. Three constraints have to be fulfilled, the first two of which indicate the relationships of export and import.

$$f(x) = \sum_{i,ii,k} (c_{i,ii,k}^{trade\ margin} + d_{i,ii,k}^{sdt}) * x_{i,ii,k}^{volume}$$

$$x_{i,k}^{production} \geq \sum_{l} x_{i,ii,k}^{trade}$$

$$x_{i,k}^{demand} \leq \sum_{l} x_{l,i,k}^{trade}$$

$$x_{i,ii,k}^{trade} \geq 0$$

The first constraint determines that the domestic supply should be larger than the sum of domestic demand and the total export. Similarly, the second constraint indicates that for commodity $k$ in region $i$, the total amount of domestic production and the imported should be

[1] AFR is Sub-Saharan Africa; CPA includes China and other centrally planned countries in East and Southeast Asia; EUR is Europe; FSU contains regions in the former Soviet Union; LAM is Latin America; MEA is the Middle East and North Africa region; NAM refers to the United States and Canada; PAO is Pacific OECD, i.e., Japan, Australia, New Zealand; PAS is mainly island countries in Southeast Asia; SAS includes India, Pakistan and other countries in South Asia.

larger than the domestic demand. A similar version of the bilateral trade representation is used for analyzing virtual water trade (Biewald et al., 2014).

For estimating cropland displacement due to agricultural trade, we calculate the quantity of traded agricultural products in terms of the land area necessary to produce them.

$$x_{i,k_{trade}}^{cropland} = \frac{x_{i,k\_trade}^{net\ trade}}{x_{i,k\_trade}^{yield}}$$

For regions that have net exports of agricultural products, they virtually exports their land to other regions, while regions that possess net imports have net imports of land required for production.

### 2.2 Calibration and validation of net trade volume

In order to arrive at a valid answer to the research question, calibration of net trade flows at the stating time step is necessary. Since the results of bilateral trade depend on the estimates of trade costs including freight costs and trade tariffs, the model needs to be calibrated regarding certain important variables such as trade volumes, either in terms of bilateral trade or net trade volumes. Techniques related to this specific calibration purpose including solving a bi-level programming problem (BLPP) (Jansson and Heckelei, 2009) and using maximum entropy estimates (Bouët et al., 2013). As MAgPIE does not explicitly model price as an endogenous variable, and demand is provided exogenously, BLPP is currently not compatible with the model framework. Therefore, we come to a different approach by calibrating net trade volumes in the year of 1995 through imposing an additional costs which penalize the deviation of previous trade position. The idea is consistent with the tariff-rate quota (TRQ), which is an additional tariff to the existing specific duty tariffs in the model. Technically, the penalty is a linear constraint as follows.

$$x_{i,t,k\_trade}^{penalty} \geq a_{k\_trade}^{penalty\ factor} * a_{i,k_{trade}}^{price} * \left(x_{i,t,k\_trade}^{net\ trade} - a_{i,t-1,k\_trade}^{net\ trade}\right)$$

$$x_{i,t,k\_trade}^{penalty} \geq 0$$

As MAgPIE optimizes the global production costs, i.e., cost minimization, regions have incentives to avoid changing the trade position. The value of the calibration factor, $a_{k\_trade}^{penalty\ factor} \in [0,1]$, which is decided when the model simulates a net trade patterns close to the historical pattern. The calibration factor is crop specific but uniform across regions.

## 3 Data and scenarios

For the representation of bilateral trade, data of trade margin costs and trade tariffs are derived from GTAP7 together with FAO world and regional prices of traded commodity. Trade tariffs are expressed as specific duty tariffs for a pair of regions for a traded commodity. The primary data for trade calibration including the net trade volume in the year of 1995 is based on FAO data of food balance sheet. The calibrated net trade pattern in 1995 is close to the historical pattern indicated by FAO (Figure S1). The Kendall correlation coefficient is 0.76, and Spearman confident is 0.80. Both coefficient are significant at 1% level. In addition, we also use projections from 11 economic 11 economic models[2] in AgMIP[3] projections to cross validate the projection of net trade pattern for the coarse grain, rice and oil crops in the year of 2005, 2030 and 2050. The validation results indicate that our model results of net trade patterns are in a reasonable range, compared to other model projections (Figure S3 – S5). In addition, we also compare the growth rate of production

[2] AIM, CAPRI, ENVISAGE, EPPA, FARM, GCAM, GLOBIOM, GTEM, IMPACT, MAGNET, MAGPIE

[3] AgMIP refers to The Agricultural Model Intercomparison and Improvement Project

Climate impacts on crop yields are computed by the global dynamic vegetation model LPJmL Climate scenario, RCP 8.5, is chosen to quantify high-end climate change impacts on land displacement. To take into account the uncertainty of climate impacts, five different GCMs[4] (general circulation models) used in ISI-MIP[5]are used. The climate projection in the RCP 8.5 shows uncertainty regarding the changes in temperature and precipitation by end of the twenty-first century (Warszawski et al., 2014).

The trade liberalization scenario is implemented as gradual reduction of the penalty cost imposed on the deviation of trade position, as mentioned in the method section. The penalty factor in the reference scenario is implemented according to the Uruguay Round Negotiation, and therefore the penalty factor decreases until 2005 for developing regions, and until 2000 for developed regions.

Table 1: Share of effective penalty factor in the trade liberalization scenario

| | AFR | CPA | EUR | FSU | LAM | MEA | NAM | PAO | PAS | SAS |
|---|---|---|---|---|---|---|---|---|---|---|
| y1995 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| y2000 | 0.95 | 0.95 | 0.87 | 0.95 | 0.95 | 0.95 | 0.87 | 0.87 | 0.95 | 0.95 |
| y2005 | 0.9 | 0.9 | 0.83 | 0.9 | 0.9 | 0.9 | 0.83 | 0.83 | 0.9 | 0.9 |
| y2010 | 0.85 | 0.85 | 0.79 | 0.85 | 0.85 | 0.85 | 0.79 | 0.79 | 0.85 | 0.85 |
| y2015 | 0.81 | 0.81 | 0.75 | 0.81 | 0.81 | 0.81 | 0.75 | 0.75 | 0.81 | 0.81 |
| y2020 | 0.77 | 0.77 | 0.71 | 0.77 | 0.77 | 0.77 | 0.71 | 0.71 | 0.77 | 0.77 |
| y2025 | 0.73 | 0.73 | 0.67 | 0.73 | 0.73 | 0.73 | 0.67 | 0.67 | 0.73 | 0.73 |
| y2030 | 0.69 | 0.69 | 0.64 | 0.69 | 0.69 | 0.69 | 0.64 | 0.64 | 0.69 | 0.69 |
| y2035 | 0.66 | 0.66 | 0.6 | 0.66 | 0.66 | 0.66 | 0.6 | 0.6 | 0.66 | 0.66 |
| y2040 | 0.62 | 0.62 | 0.57 | 0.62 | 0.62 | 0.62 | 0.57 | 0.57 | 0.62 | 0.62 |
| y2045 | 0.59 | 0.59 | 0.54 | 0.59 | 0.59 | 0.59 | 0.54 | 0.54 | 0.59 | 0.59 |
| y2050 | 0.56 | 0.56 | 0.52 | 0.56 | 0.56 | 0.56 | 0.52 | 0.52 | 0.56 | 0.56 |
| y2055 | 0.53 | 0.53 | 0.49 | 0.53 | 0.53 | 0.53 | 0.49 | 0.49 | 0.53 | 0.53 |
| y2060 | 0.5 | 0.5 | 0.46 | 0.5 | 0.5 | 0.5 | 0.46 | 0.46 | 0.5 | 0.5 |
| y2065 | 0.48 | 0.48 | 0.44 | 0.48 | 0.48 | 0.48 | 0.44 | 0.44 | 0.48 | 0.48 |
| y2070 | 0.45 | 0.45 | 0.42 | 0.45 | 0.45 | 0.45 | 0.42 | 0.42 | 0.45 | 0.45 |
| y2075 | 0.43 | 0.43 | 0.4 | 0.43 | 0.43 | 0.43 | 0.4 | 0.4 | 0.43 | 0.43 |
| y2080 | 0.41 | 0.41 | 0.38 | 0.41 | 0.41 | 0.41 | 0.38 | 0.38 | 0.41 | 0.41 |
| y2085 | 0.39 | 0.39 | 0.36 | 0.39 | 0.39 | 0.39 | 0.36 | 0.36 | 0.39 | 0.39 |
| y2090 | 0.37 | 0.37 | 0.34 | 0.37 | 0.37 | 0.37 | 0.34 | 0.34 | 0.37 | 0.37 |
| y2095 | 0.35 | 0.35 | 0.32 | 0.35 | 0.35 | 0.35 | 0.32 | 0.32 | 0.35 | 0.35 |
| y2100 | 0.33 | 0.33 | 0.3 | 0.33 | 0.33 | 0.33 | 0.3 | 0.3 | 0.33 | 0.33 |

[4] The GCMs used for computing grid-level crop yields from the crop model include GFDL_ESM2M, HadGEM2_ES, IPSL_CM5A_LR, MIROC_ESM_CHEM, and NorESM1_M.

[5] The abbreviation refers to the Inter-Sectoral Impact Model Intercomparison Project.

# 4 Results

## 4.1 Virtual trade of cropland through international trade of key food commodities

Since there is a reduction of trade barriers implemented in the reference scenario, according to the agreement in the Uruguay round for the developing regions from 1995 to 2005 and for the developed regions from 1995 to 2000, a further trade liberalization can reduce the global cropland area in 2095 by around 64.0 million hectares without increasing cropland area in LAM (left panel in Figure 1). When climate impacts are taken into consideration, trade liberalization can reduce 111.4 million hectares of cropland, compared to the situation when there is no trade liberalization. However, as noticed, regions such as Latin America and China will experience increasing cropland expansion, although Sub-Saharan Africa could reduce cropland area (right panel in Figure 1).

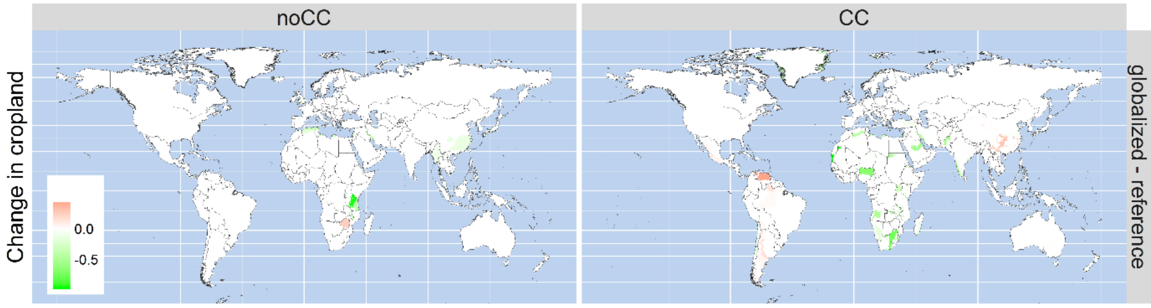
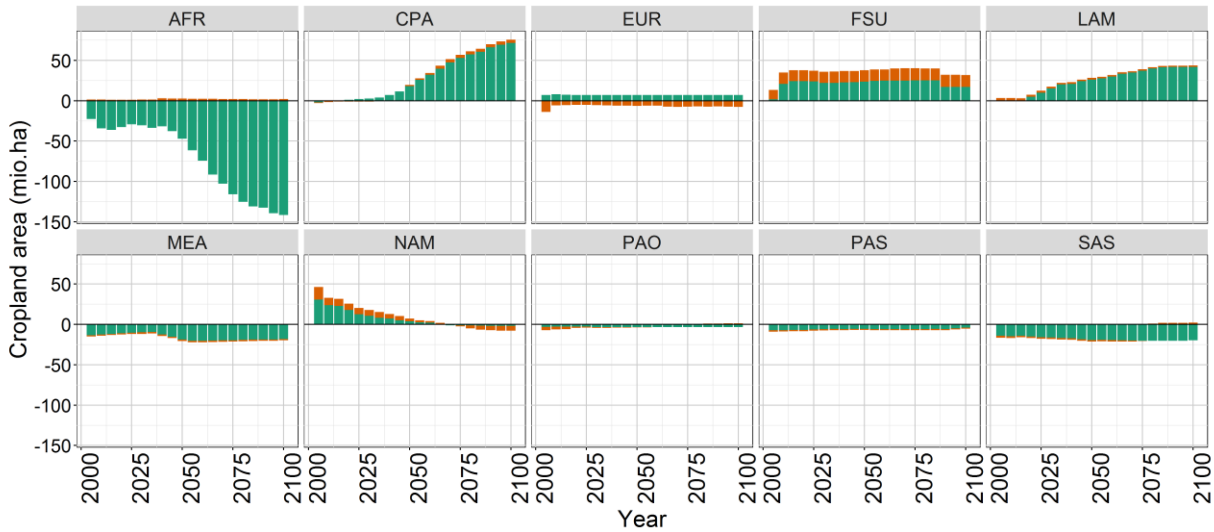



Figure 1: Change in cropland in cells (0.5°) between globalized and reference with climate impacts (right) and without climate impacts (left) in 2095. The GCM used for simulating crop yield is HadGEM2_ES.

It becomes obvious that climate change have large impacts on the spatial pattern of cropland area (Figure S6). Therefore, in the following analysis, we focus on the results related to the impacts of trade liberalization and climate change on cropland use dynamics, by comparing two scenarios, i.e., reference scenario without climate change (reference_noCC) and the scenario of trade liberalization and climate change (globalized_CC).

In both scenarios, regions including CPA, LAM, and FSU are the main exporter of cropland related to food production, while AFR imports the largest amount of cropland (Figure 2). NAM gradually decreases exports of cropland and becomes an importer, due to increasing of oil crop products. In general, grain crops determines the pattern of virtual trade of cropland. Climate impacts on crop yields alters comparative advantages among regions, although the general trend remain the same for most of regions. For instance, SAS starts to export land related to oil crops after the middle of the century, while FSU deceases land export (panel b in Figure 2). Climate impacts and trade liberalization policy have different impacts, regarding the two aspects of cropland expansion, i.e., the regional total cropland area and the spatial displacement of cropland between regions. Climate impacts have strong impacts on the former, while trade liberalization mainly have effects on the latter one.

a)




b)

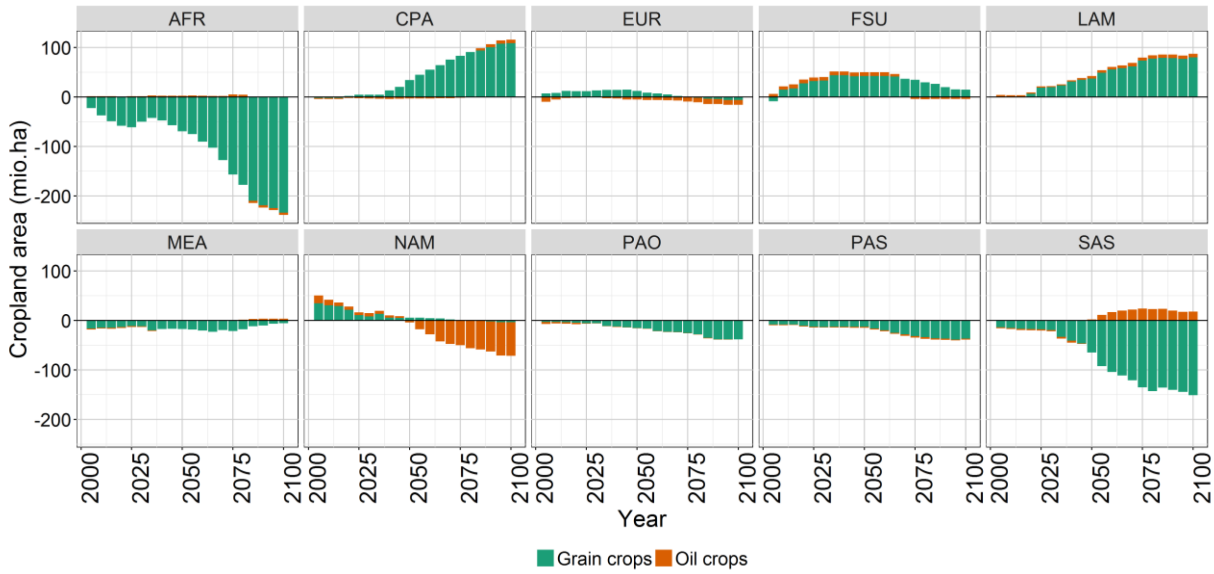



Figure 2: Virtual trade of cropland area due to international trade of grain and oil crops in scenarios of refernce_noCC(panel a) and globalized_CC (panel b).

Cropland area for export production grows rapidly in regions including CPA, LAM and FSU. Where there is climate impact considered, cropland area with export oriented in CPA and LAM increases further. On the other side, regions such as AFR, PAO and NAM will increase cropland import, which account for 100% to 150 % of their own land for producing the corresponding crops. It is evident that with increasing trade liberalization in the context of climate change, regions exporting cropland previous could further increase the export of natural resources. More than half of the cropland area for the key food crops in CPA and LAM is dedicated to export production in 2100 (Figure 3). Imbalances between imports and exports in terms of land area required for agricultural production therefore will also increase. The absolute value of total cropland imbalance will increase from 42.6 million hectares (reference_noCC) to 314.8 million hectares (globalized_CC) in 2095 when there is trade liberalization and climate change.

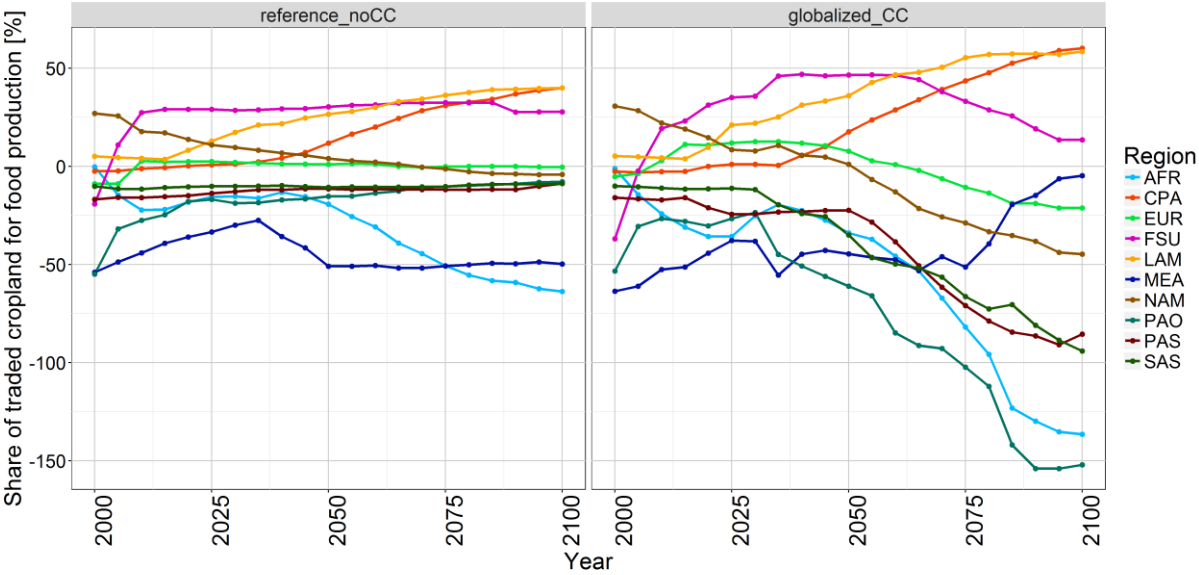



Figure 3: share of cropland area for trade to the total cropland area in a region in the reference scenario without climate impacts and globalized scenario with climate impacts

## 4.2 Uncertainties of cropland displacement in the high-end climate change

As there are uncertainties regarding the future climate projections, it is helpful to take this into account when considering the climate impacts on crop production. In this analysis, we include five different crop yield projection from LPJmL using five different GCM projection. This results in a large range of cropland area in AFR and LAM, while cropland area projections in other regions are stable (Figure 5). In AFR and LAM, climate impacts lead to larger cropland area, compared to no climate change scenario.

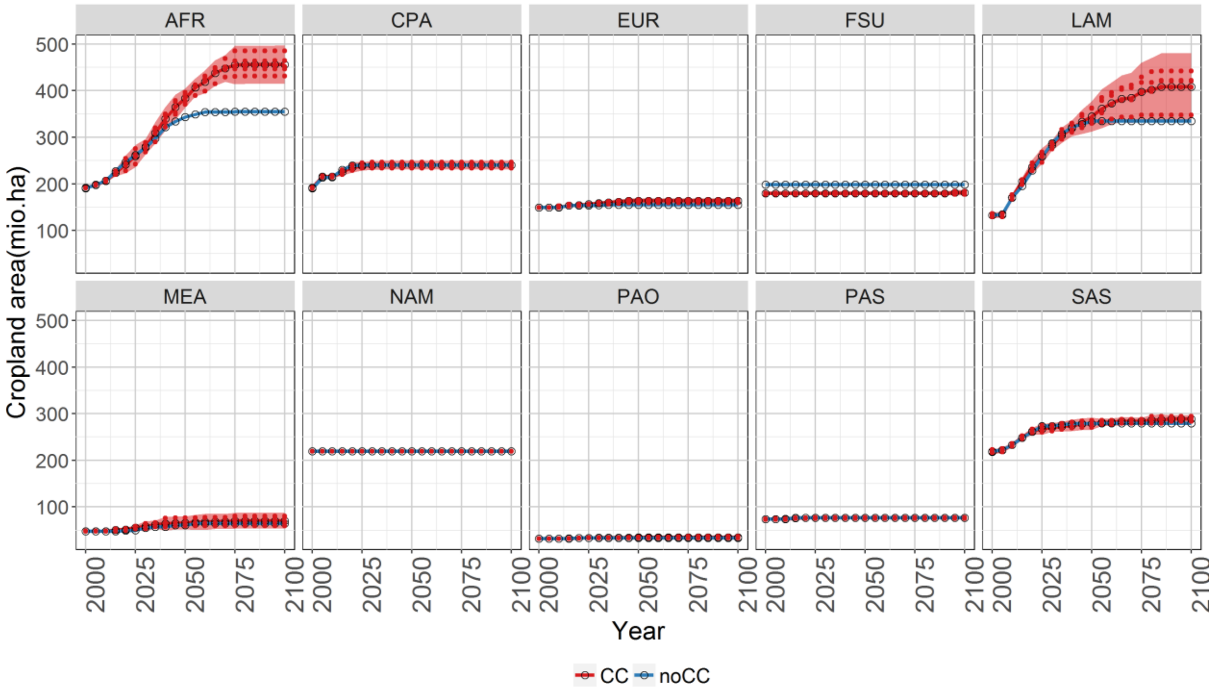



Figure 4: Cropland area in reference scenario between 2000 and 2100. For each climate scenario (5GCMs) used in the analysis, actual simulated cropland area are indicated by dots, while solid lines for each panel in the color of red. Shaded area depict double stand deviation from the mean.

This uncertainty therefore also transfers to the projection of virtual trade of cropland. The boxplot bellows show the uncertainty of traded cropland due to climate impacts in the future. The general pattern remains, although AFR and SAS have relative large uncertainty for the amount of imported cropland for grain crops.

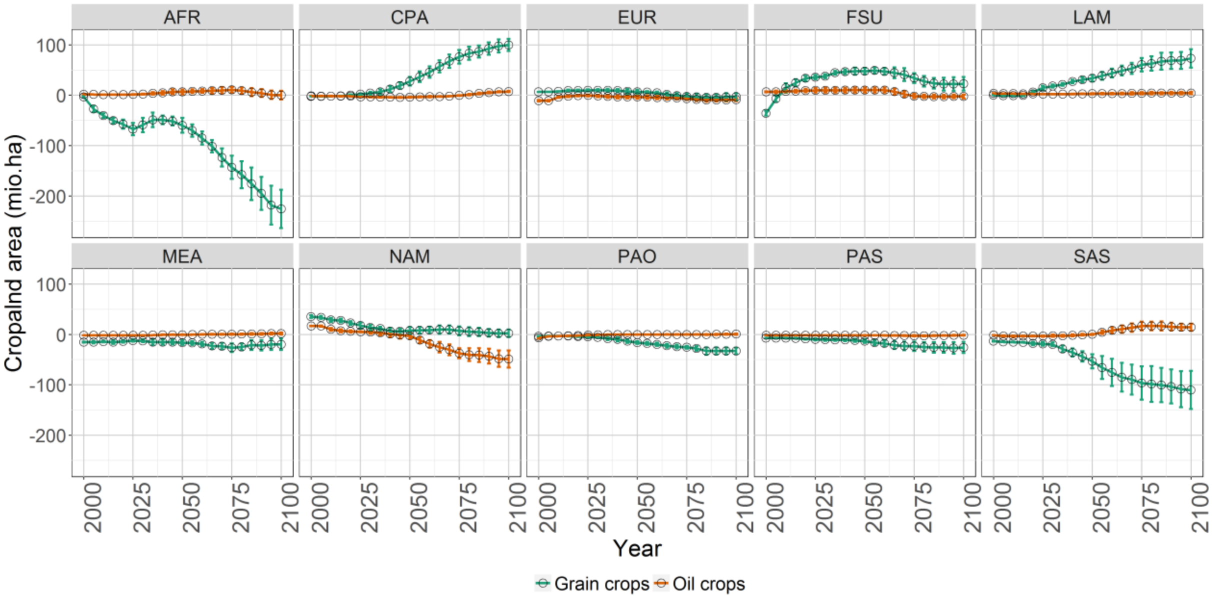



Figure 5: Virtual trade of cropland area due to international trade of grain and oil crops in scenarios of globalized_CC. For each climate scenario (5GCMs) used in the analysis, simulated cropland area from HadGEM2_ES are indicated by dots, which are connected with solid lines. Error bars depict double stand deviation from the mean.

## 5 Conclusion

The study employs an agro-economic dynamic optimization model in which international trade is implemented as bilateral trade representation to the impacts of agricultural trade liberalization on cropland use dynamics, focusing not only on the total amount of cropland area, but also on the spatial allocation among regions. The study contributes to the methodological development by extending and calibrating a spatial equilibrium model to generate valid trade patterns of major food crop commodities. On the content aspect, with an agro-economic dynamic optimization model, the study is able to analyze the leakage effects resulted from trade liberalization as well as climate impacts on crop yields, by using crop yields simulation output from a vegetation model based on different climate models. In the scenario of high-end climate impacts on crop yields, although trade liberalization mitigates the negative impacts of climate impacts on agricultural supply and spares the land resource on the global scale, it further deteriorates the virtual trade of cropland among regions. The absolute amount of total cropland imbalance will increase by 272.2 million hectares at the end of the twenty-fist century. Latin America and China are the main exporters of cropland relate to food production, while Sub-Saharan Africa and South Asia are the regions of exporting cropland. By considering climate projection uncertainty, the study finds that the general trend of cropland displacement remains, although there exists a wide range for the amount of traded cropland in Sub-Saharan Africa, South Asia and Latin America.

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# Supporting information (SI)

## Validation of net exports in 1995

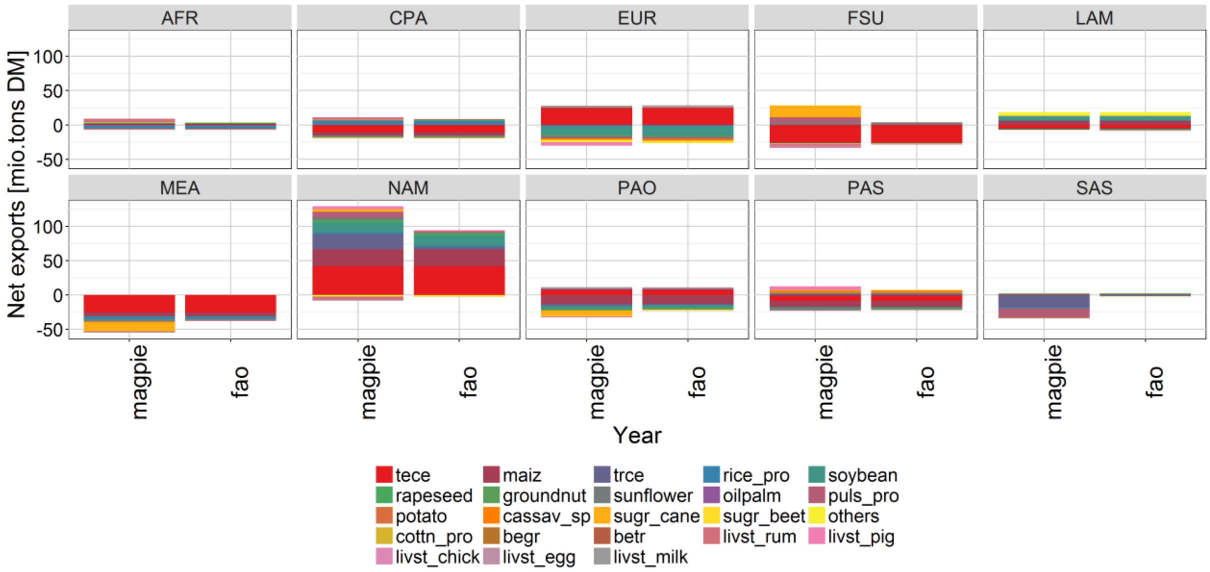


Figure S1: Validation of net export of traded agricultural commodities in 1995 w.r.t. FAO

## Cross validation of net exports of key food commodities

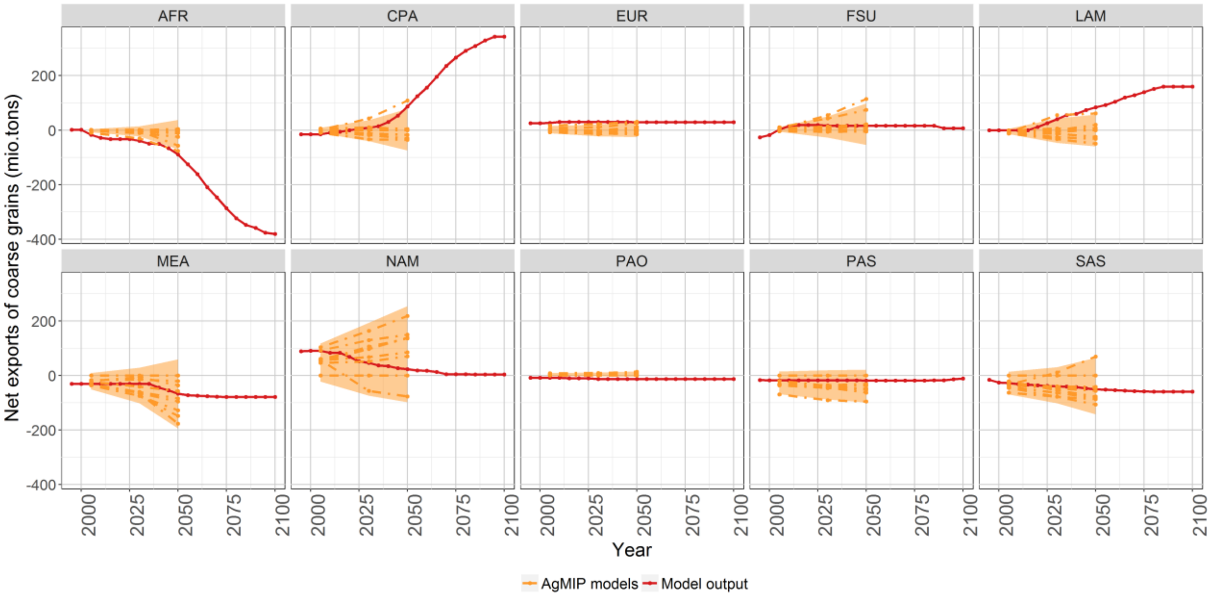


Figure S1: Validation of net exports of coarse grains w.r.t. AgMIP model projections in reference scenario

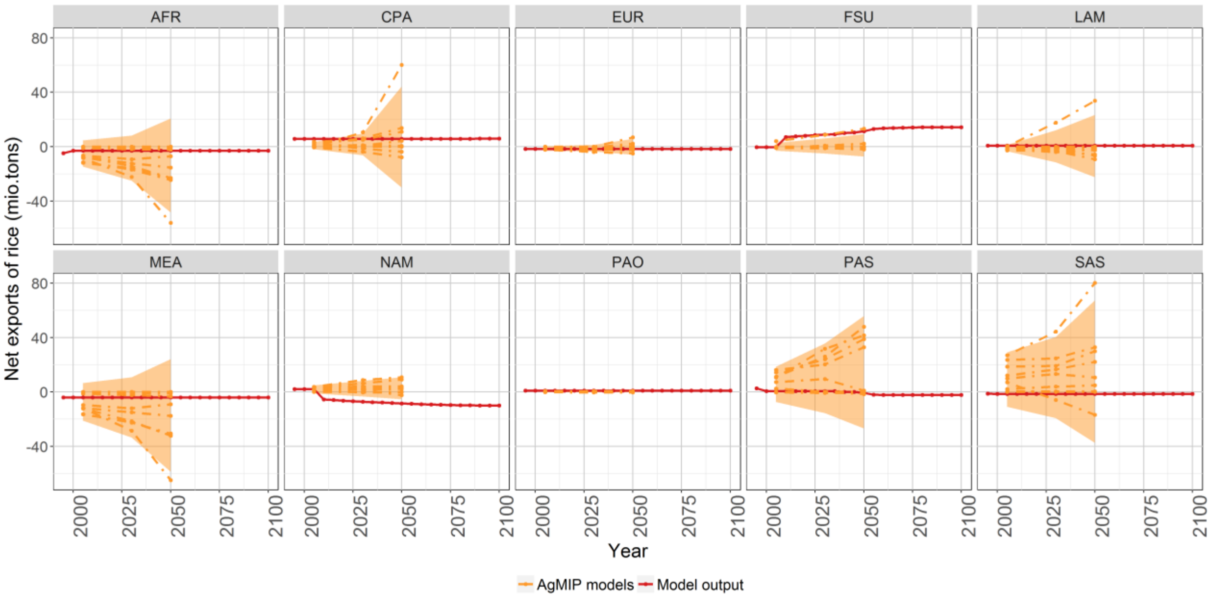


Figure S2: Validation of net exports of rice w.r.t. AgMIP model projections in reference scenario

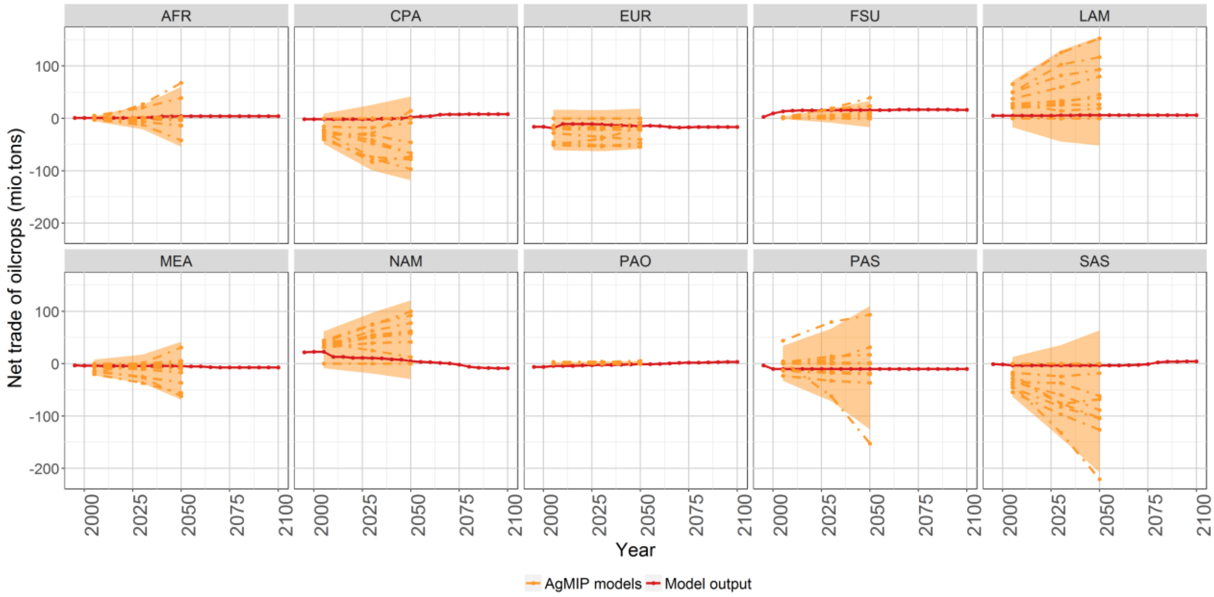


Figure S3: Validation of net exports of oil crops w.r.t. AgMIP model projections in reference scenario

## Validation of trade expansion of crop commodities

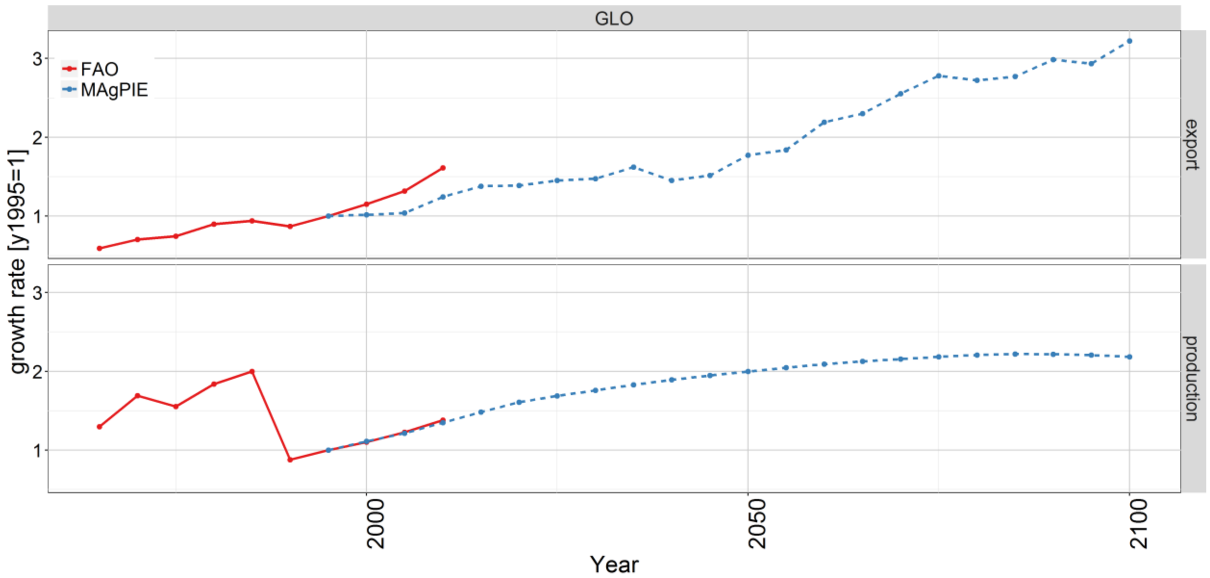


Figure S4: Expansion of exports and production of crop commodities in reference scenario.

## Additional results

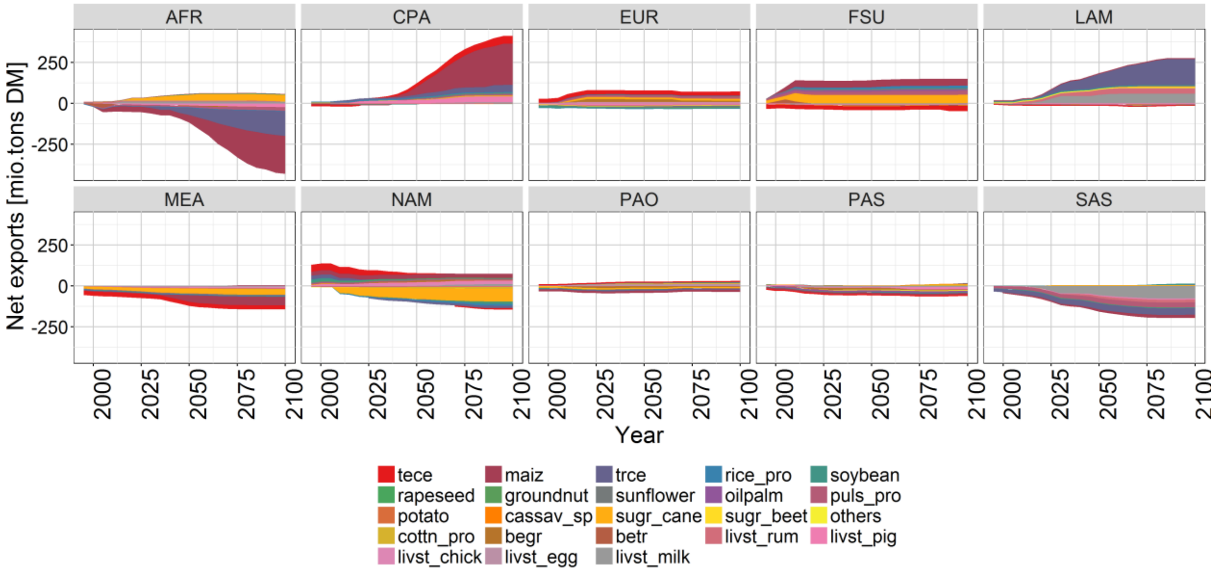


Figure S5: Net exports of traded agricultural products over time in the reference scenario

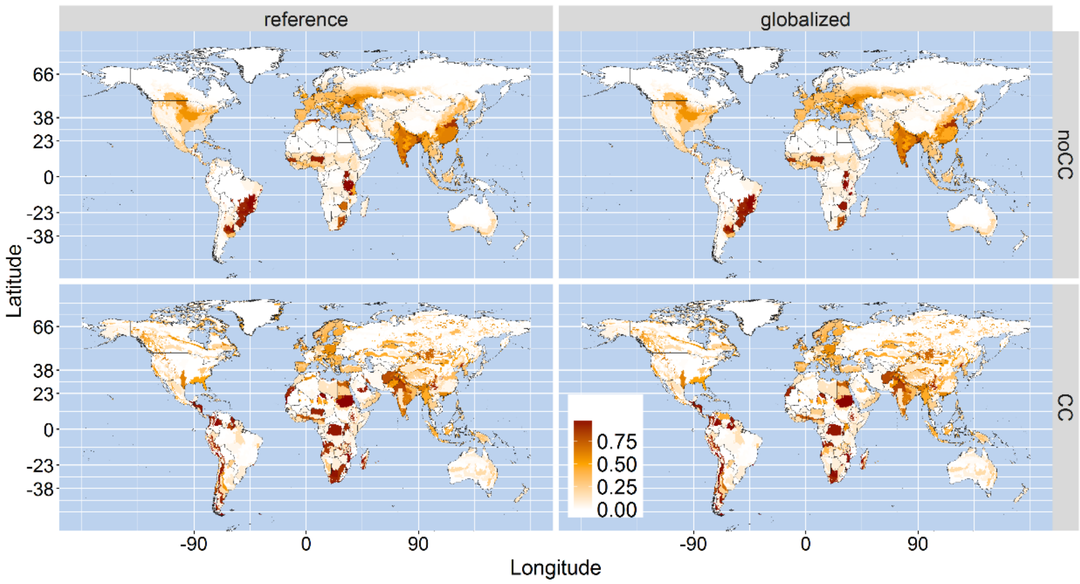


Figure S6: Cropland area on the grid level in different trade liberalization and climate scenarios in 2095.