SUPPLEMENTARY INFORMATION

Unintended trade-offs between food security and environmental sustainability: Impacts of China's dietary shift and afforestation under a stringent climate mitigation policy

Weitong Long[1,2], Xueqin Zhu[1*], Oene Oenema[2,3], Yong Hou[2*], Luis M Peña-Lévano[4], Luis Garcia Covarrubias[4], Karl-Friedrich Boy[4]

[1]Environmental Economics and Natural Resources Group, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands
[2]State Key Laboratory of Nutrient Use and Management, College of Resources and Environmental Science, China Agricultural University, 100193 Beijing, China
[3]Wageningen Environmental Research, 6708 PB Wageningen, The Netherlands
[4]School of Veterinary Medicine, University of California, Davis, CA 95616 Davis, United States

* Corresponding author at: Wageningen University, 6706 KN Wageningen, The Netherlands; China Agricultural University, 100193, Beijing, China.
E-mail addresses: xueqin.zhu@wur.nl (X. Zhu); yonghou@cau.edu.cn (Y. Hou).

Contents

Mathematically, various ways exist to represent applied general equilibrium (AGE) models, according to Ginsburgh and Keyzer [1]. To identify the optimal solution towards greater sustainability and enable the efficient allocation of resources in the economy, we used the welfare format of the AGE models for our analysis. In the supplementary information, we specified the model for our study by explicitly considering producers, consumers, production goods, consumption goods, and intermediate goods. Subsequently, we presented the calibration of our model. Finally, we provided supplementary figures and tables, along with the sectoral aggregation scheme, social accounting matrices, and emissions data for all the regions in our study.

Supplementary Methods

Objective function

The objective function "social welfare (W)" is the weighted sum of the log utility (U_i) of all consumers, according to Zhu and Van Ierland [2].

$$\mathrm{W} = \max \sum_i \alpha_i \log U_i \tag{1}$$

where α_i is the Negishi weight of the representative consumer in each region i (i=China (CN), Brazil (BR), United States (US), and Canada (CA)).

Utility function

In our model, the consumer's utility depends on the consumption of rival goods. The utility function is a Cobb-Douglas (C-D) function describing the behaviour of a representative consumer (household to maximise its utility subject to budget constraints) consuming rival goods. The utility function of the consumer in region i is written as:

$$U_i = \prod_s C_{i,s}^{\beta_{i,s}} \tag{2}$$

where consumption goods s refers to cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, non-food crops, non-ruminant meat, dairy products, ruminant meat, forestry, processed food, and non-food. $C_{i,s}$ is the consumption of the rival good in region i. $\beta_{i,s}$ is the elasticity of utility concerning the consumption of rival good s in region i, i.e., the expenditure share of consumption good s in consumption of rival goods in region i, and $\sum_s \beta_{i,s} = 1$.

Production functionl

We present the production functions of eighteen producers, namely, cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, non-food crops, non-ruminant meat, dairy products, ruminant meat, forestry, compound feed, cereal brans, alcoholic pulps, oil cakes, processed food, nitrogen fertiliser, phosphorus fertiliser, and non-food.

The production function of producer j excluding forestry in region i is specified as:

$$Y_{i,j} = A_{i,j}\left(KL_{i,j}\right)^{\eta_{1i,j}}\left(LB_{i,j}\right)^{\eta_{2i,j}}\left(LD1_{i,j}\right)^{\eta_{3i,j}}\left(LD2_{i,j}\right)^{\eta_{4i,j}}\left(NFE_{i,j}\right)^{\eta_{6i,,j}}\left(PFE_{i,j}\right)^{\eta_{7i,j}}$$

$$\left(CER_{i,j}\right)^{\eta_{8i,j}}\left(OSD_{i,j}\right)^{\eta_{9i,j}}\left(VF_{i,j}\right)^{\eta_{10i,j}}\left(RT_{i,j}\right)^{\eta_{11i,j}}\left(SGR_{i,j}\right)^{\eta_{12i,j}}\left(OTC_{i,j}\right)^{\eta_{13i,j}}$$

$$\left(COF_{i,j}\right)^{\eta_{14i,j}}\left(BRAN_{i,j}\right)^{\eta_{15i,j}}\left(PULP_{i,j}\right)^{\eta_{16i,j}}\left(CAKE_{i,j}\right)^{\eta_{17i,j}}$$

(3)

where $Y_{i,j}$ is the production of sector j in region i. $A_{i,j}$ is the technological parameter of the production of sector j in region i. $KL_{i,j}$, $LB_{i,j}$, $LD1_{i,j}$, and $LD2_{i,j}$ are capital, labour, cropland, and pastureland inputs for production of sector j in region i, respectively. $NFE_{i,j}$, $PFE_{i,j}$, $CER_{i,j}$, $OSD_{i,j}$, $VF_{i,j}$, $RT_{i,j}$, $SGR_{i,j}$, $OTC_{i,j}$, $COF_{i,j}$, $BRAN_{i,j}$, $PULP_{i,j}$, and $CAKE_{i,j}$ are nitrogen fertiliser, phosphorus fertiliser, cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, non-food crops, compound feed, cereal bran, alcoholic pulp, and oil cake inputs for the production of sector j in region i, respectively. η_f (f=1, 2, 3, …, 17) is the cost share of each factor and intermediate input for production, and $\sum_{f=1}^{18} \eta_f = 1$.

We also add several additional constraints on the production of crops (i.e., cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, other non-food crops) and food processing by-products (i.e., cereal brans, alcoholic pulps, oil cakes) based on the information from the social accounting matrices (SAM) (see Appendix Tables 2-5) in the base year of 2014 for China and its trading partners.

Crops can't be produced in a "factory-like" setting because the chemical processes within plants require specific nutrients that can't be substituted for one another. Different combinations of nutrients, such as nitrogen (N) and phosphorus (P_2O_5), lead to varying crop yields. Thus, we kept the total output of crop as a fixed ratio of nitrogen and phosphorus fertiliser inputs. In other words, the ratio of nitrogen and phosphorus fertiliser inputs for per unit of crop output remained constant across all scenarios. A similar constraint was applied to the relationship between crop output and cropland input, ensuring that crop yields per hectare remain constant. Since food processing by-products are calculated based on the consumption of food products and specific technical conversion factors, we maintained a constant ratio of by-product output to the consumption of corresponding food products across all scenarios.

The production function of forestry in region i is specified as:

$$Y_{i,frs} = A_{i,frs}\left(KL_{i,frs}\right)^{\eta_{1i,frs}}\left(LB_{i,frs}\right)^{\eta_{2i,frs}}\left(CFRS_{i,frs}\right)^{\eta_{3i,frs}} \tag{4}$$

where $Y_{i,frs}$ is the production of forestry in region i. $A_{i,frs}$ is the technological parameter of the production of forestry in region i. $KL_{i,frs}$ and $LB_{i,frs}$ are capital and labour inputs for production j in region i, respectively. $CFRS_{i,frs}$ is the consumption of a forestry land-biomass composite of forest land and own use of forest biomass in region i. η_f (f=1, 2, 3) is the cost share of each factor and intermediate input for production, and $\sum_{f=1}^{3} \eta_f = 1$.

The composite of forest land and own use of forest biomass ($CFRS_{i,frs}$) in region i is defined in a constant elasticity of substitution (CES) function as:

$$CFRS_{i,frs} = [\delta_{i,frs}{}^{\frac{1}{\sigma_{i,frs}}} LD3_{i,frs}^{\frac{\sigma_{i,frs}-1}{\sigma_{i,frs}}} + \left(1-\delta_{i,frs}\right)^{\frac{1}{\sigma_{i,frs}}} FRS_{i,frs}^{\frac{\sigma_{i,frs}-1}{\sigma_{i,frs}}}]^{\frac{\sigma_{i,frs}}{\sigma_{i,frs}-1}} \tag{5}$$

$$\delta_{i,frs} = \frac{LD3_{i,frs}}{LD3_{i,frs}+FRS_{i,frs}} \tag{6}$$

where $LD3_{i,frs}$ and $FRS_{i,frs}$ are the composite of forest land and own use of forest biomass in region i, respectively. $\sigma_{i,frs}$ is the elasticity of substitution between forest land and own use of forest biomass in region i. $\sigma_{i,frs}$ derived from Golub, et al. [3] are presented in Supplementary Table 9. $\delta_{i,frs}$ is the cost share of forest land in the composite of forest land and own use of biomass in region i. In this way, forest carbon stocks can be increased by increasing the biomass on existing forest acreage (the intensive margin) or by expanding forest land (the extensive margin), according to Hertel, et al. [4] and Golub, et al. [3].

Competition for land use

There are numerous barriers to land conversion between agricultural land (i.e., cropland and pastureland) and forest land, as well as within agriculture, such as shifts between crop and livestock uses. In the model, the allocation of land is determined through a constant elasticity of transformation (CET) function, which is widely used in the previous literature [4-7]. The rent-maximising landowner initially determines the allocation of land among three land cover types, i.e., cropland, pastureland, and forest land, based on relative returns to land. Subsequently, the landowner allocates cropland among various crops and pastureland between dairy products and ruminant meat.

Only dairy products and ruminant meat directly use land, while non-ruminant meat does not, as its feed is produced using land elsewhere in the system. With intensification, non-ruminant meat production increasingly occurs in facilities resembling manufacturing rather than land-based sectors. Therefore, we exclude direct land competition for non-ruminant meat production. However, there is indirect competition, as higher non-ruminant meat production increases feed demand, driving up land use for feed. This competition is captured through intermediate demand equations for feed in non-ruminant production. Consequently, following Golub, et al. [5], we exclude land rents from the cost structure of non-ruminant meat production.

The calibration of CET land supply functions in the model relies on econometric evidence indicating that the elasticity of transformation between agricultural land and forest land is lower than that between cropland and pastureland. Both are also lower than the elasticity of transformation among crop types and between dairy products and ruminant meat. Elasticities of transformation between different land types by region, which are derived from Golub, et al. [3], are presented in Supplementary Table 10.

When the elasticities of transformation are -1, the CET land supply functions become C-D functions. Thus, the CET land supply functions for cropland and pastureland in region i are specified as follows:

$$LDCRO_{i,agr} = BCRO_{i,agr}\left(LD1_{i,cer}\right)^{\beta_{1i,cer}}\left(LD1_{i,osd}\right)^{\beta_{2i,osd}}\left(LD1_{i,vf}\right)^{\beta_{3i,vf}}$$

$$\left(LD1_{i,rt}\right)^{\beta_{4i,rt}}\left(LD1_{i,sgr}\right)^{\beta_{5i,sgr}}\left(LD1_{i,ocr}\right)^{\beta_{6iocr}} \tag{7}$$

$$LDLV_{i,agr} = BLV_{i,agr}\left(LD2_{i,rmk}\right)^{\beta_{1i,rmk}}\left(LD2_{i,ctl}\right)^{\beta_{2i,ctl}} \tag{8}$$

where $LDCRO_{i,agr}$ and $LDLV_{i,agr}$ are the composites of cropland and pastureland in region i, respectively. $BCRO_{i,agr}$ and $LDLV_{i,agr}$ are the scaling parameter of cropland and pastureland output in region i, respectively. $LD1_{i,cer}$, $LD1_{i,osd}$, $LD1_{i,vf}$, $LD1_{i,rt}$, $LD1_{i,sgr}$, and $LD1_{i,ocr}$ are cropland used by cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, and non-food crops in region i, respectively. $LD2_{i,rmk}$ and $LD2_{i,ctl}$ are pastureland used by dairy products and ruminant meat in region i, respectively. β_f (f=1, 2, 3, …, 6) is the cost share of cropland input, and $\sum_{f=1}^{6} \beta_f = 1$. β_f (f=1, 2, 3) is the cost share of pastureland input, and $\sum_{f=1}^{3} \beta_f = 1$.

The CET land supply function for agricultural land in region i is specified as follows:

$$LDAGR_{i,agr} = [\delta_{i,agr}^{\frac{1}{\sigma_{i,agr}}} LDLV_{i,agr}^{\frac{\sigma_{i,agr}-1}{\sigma_{i,agr}}} + (1-\delta_{i,agr})^{\frac{1}{\sigma_{i,agr}}} LDCRO_{i,agr}^{\frac{\sigma_{i,agr}-1}{\sigma_{i,agr}}}]^{\frac{\sigma_{i,agr}}{\sigma_{i,agr}-1}} \quad (9)$$

$$\delta_{i,agr} = \frac{LDLV_{i,agr}}{LDLV_{i,agr}+LDCRO_{i,agr}} \quad (10)$$

where $LD\mathrm{AGR}_{i,frs}$ is the composite of cropland and pastureland in region i. $\sigma_{i,agr}$ is the elasticity of substitution between pastureland and cropland in region i. $\delta_{i,agr}$ is the cost share of pastureland in the composite of cropland and pastureland in region i.

The CET land supply function for total land in region i is specified as follows:

$$LDAGF_{i,agf} = [\delta_{i,agf}^{\frac{1}{\sigma_{i,agf}}} LD3_{i,frs}^{\frac{\sigma_{i,agf}-1}{\sigma_{i,agf}}} + (1-\delta_{i,agf})^{\frac{1}{\sigma_{i,agf}}} LDAGR_{i,agr}^{\frac{\sigma_{i,agf}-1}{\sigma_{i,agf}}}]^{\frac{\sigma_{i,agf}}{\sigma_{i,agf}-1}} \quad (11)$$

$$\delta_{i,agf} = \frac{LD3_{i,frs}}{LD3_{i,frs}+LDAGR_{i,agr}} \quad (12)$$

where $LDAGF_{i,agf}$ is the composite of agricultural land and forest land in region i. $\sigma_{i,agf}$ is the elasticity of substitution between forest land and agricultural land in region i. $\delta_{i,agf}$ is the cost share of forest land in the composite of forest land and agricultural land in region i.

CET functions may fail to maintain the balance of the physical area of land due to heterogeneity in land rents. To address this, we employ an ex-post scaling approach to restore balance by introducing ad hoc adjustments in land allocation, following the methodology adopted in alternative versions of the GTAP-BIO model [8-10]. The constraint on the physical area of total land in region i is specified as follows:

$$CROLD_i + PASLD_i + FRSLD_i \leq \overline{TOTALD_i} \quad (13)$$

where $CROLD_i$, $PASLD_i$, and $FRSLD_i$ are the physical area of cropland, pastureland, and forest land in region i, respectively. $\overline{TOTALD_i}$ is the physical area of total land in region i.

Emissions

When emissions are outputs of the production process, the emissions intensities of greenhouse gases (GHGs) ($\varepsilon_{gg,i,j}$, kg CO_2 equivalent USD^{-1}), acidification pollutants ($\varepsilon_{ga,i,j}$, kg NH_3 equivalent USD^{-1}), and eutrophication pollutants (EP, $\varepsilon_{ge,i,j}$, kg N equivalent USD^{-1}) from producer j in region i are calculated as:

$$\varepsilon_{gg,i,j} = \frac{EM_{gg,i,j}^{+0}}{Y_{i,j}^{0}} \quad (14)$$

$$\varepsilon_{ga,i,j} = \frac{EM^{+0}_{ga,i,j}}{Y^0_{i,j}} \tag{15}$$

$$\varepsilon_{ge,i,j} = \frac{EM^{+0}_{ge,i,j}}{Y^0_{i,j}} \tag{16}$$

where $EM^{+0}_{gg,i,j}$ is the emissions of GHGs gg (gg=CO_2, CH_4, and N_2O emissions) from producer j in region i in the base run. $EM^{+0}_{ga,i,j}$ is the emissions of acidification pollutants ga (ga=NH_3, NO_x, and SO_2 emissions) from producer j in region i in the base run. $EM^{+0}_{ge,i,j}$ is the emissions of eutrophication pollutants ge (ge= N and P losses) from producer j in region i in the base run. $Y^0_{i,j}$ is the production of producer j in region i in the base run.

Next, the emissions in different scenarios are calculated by multiplying the current production level by corresponding emission intensities. The total emissions of GHGs, acidification and eutrophication pollutants from all producers in region i are calculated as follows:

$$EMG^{+}_{i,j} = \sum_{gg} \varepsilon_{gg,i,j} * Y_{i,j} * Eqv_{gg}$$

for emissions of GHGs gg = CO_2, CH_4, and N_2O emissions

(17)

$$EMA^{+}_{i,j} = \sum_{ga} \varepsilon_{ga,i,j} * Y_{i,j} * Eqv_{ga}$$

for emissions of acidification pollutants ga = NH_3, NO_x, and SO_2 emissions

(18)

$$EME^{+}_{i,j} = \sum_{ge} \varepsilon_{ge,i,j} * Y_{i,j} * Eqv_{ge}$$

for emissions of eutrophication pollutants ge = N and P losses

(19)

where $EMG^{+}_{i,j}$, $EMA^{+}_{i,j}$, and $EME^{+}_{i,j}$ are the total emissions of GHGs, acidification and eutrophication pollutants from producer j in region i, respectively. Eqv_{gg}, Eqv_{ga}, and Eqv_{ge} are the GWP, AP, and EP equivalent factors based on Goedkoop, et al. [11].

Balance equations

In our applied model, we consider factor inputs (i.e., capital, labour, and land) to be mobile between different sectors but immobile between China and its trading partners. Cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and non-food crops are used for direct consumption and intermediate use for non-ruminant meat, dairy products, ruminant meat, compound feed, food processing by-products (i.e., cereal bran, alcoholic pulp, and oil cake), and processed food production. Food processing by-products (i.e., cereal bran, alcoholic pulp, and oil cake) and compound feed are produced for intermediate use for non-ruminant meat, dairy products, and ruminant meat. Non-ruminant meat, dairy products, ruminant meat, processed food, and non-food are used for direct consumption. Nitrogen fertiliser and phosphorus fertiliser are used for cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and non-food crops production but not for consumption. We note C for consumption, XNET for net export (exports minus imports), and Y for production. Variables with a bar stand for exogenous ones.

International trade is modelled using the assumption of perfect substitutes between domestic and imported goods, adhering to the Heckscher-Ohlin assumption [12]. With this assumption, production will take place in countries with comparative advantages, meaning goods will be produced in the countries that can produce them most efficiently. To prevent a strong specialisation effect under free international trade, which could reduce some goods' production to zero in a certain region, we set a lower bound of 10% of the original production for each sector in our model.

The balance equations for cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and non-food crops in region i are as follows:

$$C_{i,cer} + CER_{i,oap} + CER_{i,rmk} + CER_{i,ctl} + CER_{i,cof} + CER_{i,bran} + CER_{i,pulp} + CER_{i,otf} + XNET_{i,cer} \leq Y_{i,cer} \qquad (p_{i,cer}) \tag{20}$$

$$C_{i,osd} + OSD_{i,oap} + OSD_{i,rmk} + OSD_{i,ctl} + OSD_{i,cof} + OSD_{i,cake} + OSD_{i,otf} + XNET_{i,osd} \leq Y_{i,osd} \qquad (p_{i,osd}) \tag{21}$$

$$C_{i,vf} + VF_{i,oap} + VF_{i,rmk} + VF_{i,ctl} + VF_{i,cof} + VF_{i,otf} + XNET_{i,vf} \leq Y_{i,vf} \qquad (p_{i,vf}) \tag{22}$$

$$C_{i,rt} + RT_{i,oap} + RT_{i,rmk} + RT_{i,ctl} + RT_{i,cof} + RT_{i,otf} + XNET_{i,rt} \leq Y_{i,rt} \qquad (p_{i,rt}) \tag{23}$$

$$C_{i,sgr} + SGR_{i,oap} + SGR_{i,rmk} + SGR_{i,ctl} + SGR_{i,cof} + SGR_{i,otf} + XNET_{i,sgr} \leq Y_{i,sgr} \qquad (p_{i,sgr}) \tag{24}$$

$$C_{i,ocr} + OCR_{i,oap} + OCR_{i,rmk} + OCR_{i,ctl} + OCR_{i,cof} + OCR_{i,otf} + XNET_{i,vf} \leq Y_{i,ocr} \qquad (p_{i,ocr}) \tag{25}$$

where $CER_{i,oap}$, $CER_{i,rmk}$, $CER_{i,ctl}$, $CER_{i,cof}$, $CER_{i,bran}$, $CER_{i,pulp}$, and $CER_{i,otf}$ are cereals used for non-ruminant meat, dairy products, ruminant meat, compound feed, cereal bran, alcoholic pulp, and processed food production in region i, respectively. $OSD_{i,oap}$, $OSD_{i,rmk}$, $OSD_{i,ctl}$, $OSD_{i,cof}$, $OSD_{i,bran}$, and $OSD_{i,otf}$ are cereals used for non-ruminant meat, dairy products, ruminant meat, compound feed, oil cake, and processed food production in region i, respectively. $VF_{i,oap}$, $VF_{i,rmk}$, $VF_{i,ctl}$, $VF_{i,cof}$, and $VF_{i,otf}$ are vegetables & fruits used for non-ruminant meat, dairy products, ruminant meat, compound feed, and processed food production in region i, respectively. $RT_{i,oap}$, $RT_{i,rmk}$, $RT_{i,ctl}$, $RT_{i,cof}$, and $RT_{i,otf}$ are roots & tubers used for non-ruminant meat, dairy products, ruminant meat, compound feed, and processed food production in region i, respectively. $SGR_{i,oap}$, $SGR_{i,rmk}$, $SGR_{i,ctl}$, $SGR_{i,cof}$, and $SGR_{i,otf}$ are sugar crops used for non-ruminant meat, dairy products, ruminant meat, compound feed, and processed food production in region i, respectively. $OCR_{i,oap}$, $OCR_{i,rmk}$, $OCR_{i,ctl}$, $OTC_{i,cof}$, and $OTC_{i,otf}$ are non-food crops used for non-ruminant meat, dairy products, ruminant meat, compound feed, and processed food production in region i, respectively. $p_{i,cer}$, $p_{i,osd}$, $p_{i,vf}$, $p_{i,rt}$, $p_{i,sgr}$, and $p_{i,ocr}$ are the shadow prices of cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and non-food crops in region i, respectively.

The balance equations for food processing by-products (i.e., cereal bran, alcoholic pulp, and oil cake) in region i are as follows:

$$BRAN_{i,oap} + XNET_{i,bran} \leq Y_{i,bran} \qquad (p_{i,bran}) \tag{26}$$

$$PULP_{i,oap} + XNET_{i,pulp} \leq Y_{i,pulp} \qquad (p_{i,pulp}) \tag{27}$$

$$CAKE_{i,oap} + XNET_{i,cake} \leq Y_{i,cake} \qquad (p_{i,cake}) \tag{28}$$

where $BRAN_{i,oap}$, $PULP_{i,oap}$, and $CAKE_{i,oap}$ are cereal bran, alcoholic pulp, and oil cake used for monogastric livestock production in region i, respectively. $p_{i,bran}$, $p_{i,pulp}$, and $p_{i,cake}$ are the shadow prices of cereal bran, alcoholic pulp, and oil cake in region i.

The balance equation for compound feed in region i is as follows:

$$COF_{i,oap} + COF_{i,rmk} + COF_{i,ctl} + XNET_{i,cof} \leq Y_{i,cof} \qquad (p_{i,cof}) \qquad (29)$$

where $COF_{i,oap}$, $COF_{i,rmk}$, and $COF_{i,ctl}$ are compound feed used in non-ruminant meat, dairy products, and ruminant meat production in region i, respectively. $p_{i,cof}$ is the shadow price of compound feed in region i.

The balance equation for non-ruminant meat, dairy products, ruminant meat, processed food, and non-food in region i is as follows:

$$C_{i,j} + XNET_{i,j} \leq Y_{i,j} \qquad (p_{i,j}) \qquad (30)$$

where $p_{i,j}$ is the shadow price of good j in region i.

The balance equation for forestry in region i is as follows:

$$C_{i,frs} + FRS_{i,frs} + FRS_{i,nf} + XNET_{i,frs} \leq Y_{i,frs} \qquad (p_{i,frs}) \qquad (31)$$

where $FRS_{i,frs}$, and $FRS_{i,nf}$ are own use of forest biomass and forest biomass used for non-food production in region i, respectively. $p_{i,frs}$ are the shadow price of forestry in region i.

The balance equations for nitrogen and phosphorus fertiliser in region i are as follows:

$$NFE_{i,cer} + NFE_{i,osd} + NFE_{i,vf} + NFE_{i,rt} + NFE_{i,sgr} + NFE_{i,ocr} + XNET_{i,nfe} \leq Y_{i,nfe} \qquad (p_{i,nfe}) \qquad (32)$$

$$PFE_{i,cer} + PFE_{i,osd} + PFE_{i,vf} + PFE_{i,rt} + PFE_{i,sgr} + PFE_{i,ocr} + XNET_{i,pfe} \leq Y_{i,pfe} \qquad (p_{i,pfe}) \qquad (33)$$

where $NFE_{i,cer}$, $NFE_{i,osd}$, $NFE_{i,vf}$, $NFE_{i,rt}$, $NFE_{i,sgr}$ and $NFE_{i,ocr}$ are the nitrogen fertiliser used for cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and non-food crops production in region i, respectively. $PFE_{i,cer}$, $PFE_{i,osd}$, $PFE_{i,vf}$, $PFE_{i,rt}$, $PFE_{i,sgr}$ and $PFE_{i,ocr}$ are the phosphorus fertiliser used for cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and non-food crops production in region i, respectively. $p_{i,nfe}$ and $p_{i,pfe}$ are the shadow prices of nitrogen fertiliser and phosphorus fertiliser in region i, respectively.

For trade balance of all goods:

$$\sum_i XNET_{i,j} = 0 \qquad (p_j) \qquad (34)$$

In the applied model, we assume that factor endowments (i.e., capital, labour, cropland, pastureland, and forest land) are mobile between different sectors but immobile among the regions. For the balance equations of production factor inputs:

$$\sum_j KL_{i,j} \leq \overline{TKL_i} \qquad (r_i) \qquad (35)$$

$$\sum_j LB_{i,j} \leq \overline{TLB_i} \qquad (w_i) \qquad (36)$$

$$\sum_j LD1_{i,j} \leq \overline{TLD1_i} \qquad (k1_i)$$

for sector j = cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and non-food crops

(37)

$$\sum_j LD2_{i,j} \leq \overline{TLD2_i} \qquad (k2_i)$$

for sector j = dairy products and ruminant meat

(38)

$$\sum_j LD3_{i,j} \le \overline{TLD3_i} \qquad (k3_i)$$
$$\text{for sector } j = \text{forestry} \tag{39}$$

where $\overline{TKL_i}$, $\overline{TLB_i}$, $\overline{TLD1_i}$, $\overline{TLD2_i}$ and $\overline{TLD3_i}$ are the factor endowments (i.e., capital, labour, cropland, pastureland, and forest land) supply in region i, respectively. r_i, w_i, $k1_i$, $k2_i$, and $k3_i$ are the shadow prices of capital, labour, cropland, and pastureland, and forest land in region i, respectively.

If an emission permit system is implemented to control the total emissions of GHGs, acidification and eutrophication pollutants from all producers, then the following relationship holds:

$$\sum_j EMG^+_{i,j} \le \overline{TMG^+_i} \qquad (p_{eg,i}) \tag{40}$$

$$\sum_j EMA^+_{i,j} \le \overline{TMA^+_i} \qquad (p_{ea,i}) \tag{41}$$

$$\sum_j EME^+_{i,j} \le \overline{TME^+_i} \qquad (p_{ee,i}) \tag{42}$$

where TMG^+_i, TMA^+_i, and TME^+_i are the total emissions of GHGs, acidification and eutrophication pollutants from all producers in region i, respectively. $\overline{TMG^+_i}$, $\overline{TMA^+_i}$, and $\overline{TME^+_i}$ are the permitted level of the total emissions of GHGs, acidification and eutrophication pollutants in region i, respectively. Emissions should not be above a certain level for the regeneration of the environment. For benchmarking, the permitted emission level is the total emission level in the base year. For an environmental policy study (scenarios S3-4), the permitted emission level can be an exogenous emission permit determined by the ecological limit. $p_{eg,i}$, $p_{ea,i}$, and $p_{ee,i}$ are the shadow prices of the emissions of GHGs, acidification and eutrophication pollutants in region i, respectively.

Budget constraint

The budget constraint for a consumer i holds such that the expenditure must be equal to the income:

$$\sum_s \left(p_{i,s} C_{i,s}\right) = h_i \tag{43}$$

where consumption goods s refers to cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, other non-food crops, monogastric livestock, ruminant livestock, processed food, and non-food. $\sum_s \left(p_{i,s} C_{i,s}\right)$ is the total expenditure on the consumption goods in region i. The Negishi weight (α_i) in the welfare function (equation 1) will be chosen such that the budget constraints hold for each representative consumer in region i.

Consumer's income is the sum of the remuneration of initial endowments employed in production and payments to the environmental sector. Given that food waste is either consumed by livestock as feed or consumed by consumers as a cost of collecting food waste from the municipality, we should also include income from food waste treatment. Since goods are tradable, the consumer's income should exclude the export part. Thus, the consumer's income is:

$$h_i = r_i\overline{TKL_i} + w_i\overline{TLB_i} + k1_i\overline{TLD1_i} + k2_i\overline{TLD2_i} + k3_i\overline{TLD3_i} - \sum_j (p_j XNET_{i,j}) + p_{eg,i}\overline{TMG^+_i} +$$

$p_{ea,i}\overline{TMA_i^+} + p_{ee,i}\overline{TME_i^+}$

(44)

where $\sum_j(p_j XNET_{i,j})$ is the income from exports. $p_{eg,i}\overline{TMG_i^+}$, $p_{ea,i}\overline{TMA_i^+}$, and $p_{ee,i}\overline{TME_i^+}$ are the income from selling emission permits of GHGs, acidification and eutrophication pollutants.

The producers' profits are specified as follows:

$$PROF_{i,j} = p_j Y_{i,j} - r_i KL_{i,j} - w_i LB_{i,j} - k1_i LD1_{i,j} - k2_i LD2_{i,j} - k3_i LD3_{i,j} - p_{cer} CER_{i,j} - p_{osd} OSD_{i,j} - p_{vf} VF_{i,j} - p_{rt} RT_{i,j} - p_{sgr} SGR_{i,j} - p_{ocr} OCR_{i,j} - p_{cof} COF_{i,j} - p_{bran} BRAN_{i,j} - p_{pulp} PULP_{i,j} - p_{cake} CAKE_{i,j} - p_{nfe} NFE_{i,j} - p_{pfe} PFE_{i,j} - p_{frs} FRS_{i,j} - p_{eg,i} EMG_{i,j}^+ - p_{ea,i} EMA_{i,j}^+ - p_{ee,i} EME_{i,j}^+$$

(45)

Model calibration

As in the literature on AGE models, we followed the Harberger convention [13] to calibrate the model using the base year SAMs. It means that the prices of all goods and factors are set to one, and the quantities of consumption and production goods equal the monetary value of the base year SAMs [14]. We calibrate the parameters in production and utility functions based on the cost shares of inputs in total production output and expenditure shares of consumption goods in total expenditure.

Definition of scenarios

S0 - Baseline

The baseline (S0) represents the economies of China and its trading partners in 2014, assuming no efforts in the dietary shift, afforestation, and climate mitigation. It corresponds to the Representative Concentration Pathway (RCP) 8.5 [15], the worst-case climate change scenario in which emissions continue to increase throughout the 21st century.

In order to enable land-use changes across different land types, we relax the land supply constraints as outlined below. These following equations are applicable to scenarios S1–S4:

$$\sum_j LD1_{i,j} \leq 1.2 * \overline{TLD1_i} \qquad (k2_i)$$

for sector j = cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and non-food crops

(46)

$$\sum_j LD2_{i,j} \leq 1.2 * \overline{TLD2_i} \qquad (k2_i)$$

for sector j = dairy products and ruminant meat

(47)

$$\sum_j LD3_{i,j} \leq 1.3 * \overline{TLD3_i} \qquad (k3_i)$$

for sector j = forestry

(48)

The forest carbon stock in region i is calculated as follows:

$$\mathrm{CSTOCK}_{i,frs} \leq (NEWFRSLD_i - FRSLD_i) * FCS_i \qquad (49)$$

$$NETMG_i^+ = \sum_j EMG_{i,j}^+ + \mathrm{CSTOCK}_{i,frs} \qquad (p_{eg,i}) \qquad (50)$$

where $\mathrm{CSTOCK}_{i,frs}$ is the forest carbon stock in region i. $NEWFRSLD_i$ and $FRSLD_i$ are the physical area of forest land in scenarios S1-S4 and the baseline scenario S0 in region i, respectively. FCS_i is the annual forestry carbon sequestration intensity in region i, which is distributed evenly over a depreciation period of 20 years, as suggested by IPCC [16] and BSI [17]. FCS_i derived from Nguyen, et al. [18] is presented in Supplementary Table 11. $NETMG_i^+$ is the net total GHGs emissions including forest carbon sequestration in region i.

S1 – Food scenario: A dietary shift in China

In scenario S1, we simulated an exogenous dietary shift in China toward the EAT-Lancet diet recommendations [19]. We first estimated the gap in food consumption between current levels in China and the recommended targets in the EAT-Lancet diet. Subsequently, we adjusted China's food consumption patterns to close one-third of this gap, accounting for the unaffordability of a complete dietary shift for households. Detailed conditions for the dietary shift in China were provided in Supplementary Table 8.

The equation below shows an exogenous dietary shift towards the EAT-Lancet diet recommendations in China:

$$NEWC_{CN,f} = C_{CN,f} * (1 + DRE_{CN,f})$$

for food f = cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, non-ruminant meat, dairy products, and ruminant meat

(51)

where $NEWC_{i,f}$ and $C_{i,f}$ are the food f consumption levels in the scenarios S1 and S0 in China, respectively. $DRE_{CN,f}$ is the percentage change to close one-third of the gap in food consumption between current levels in China and the recommended targets in the EAT-Lancet diet.

S2 – Land scenario: A unilateral afforestation policy in China

In scenario S2, we simulated a unilateral afforestation policy in China based on the National Forest Management Plan (2016–2050) [20]. This plan, proposed by China's National Forestry and Grassland Administration, outlines an ambitious tree-planting program to expand forest land in China by 20% (41.6 Mha) by 2050.

The 20% increase in the physical area of forest land in China is specified as follows:

$$NEWFRSLD_{CN} = 1.2 * FRSLD_{CN} \tag{52}$$

S3 – Climate scenario: A global uniform carbon tax

In scenario S3, we implemented a global uniform carbon tax to achieve a 25% reduction in net total GHG emissions in China and its trading partners by 2030. This aligns with the 2°C climate stabilisation target [21] outlined in the Paris Agreement [22,23], which aims to limit global warming well below 2°C above pre-industrial levels, requiring global GHG emissions to peak by 2025 and drop by 25% by 2030. This tax is applied uniformly across all economic sectors, including agriculture, land use, and non-agricultural sectors, following the most widely adopted approach in the literature [24,25]. We selected the 2°C target instead of the 1.5°C target because Matthews and Wynes [26] demonstrated that while current global efforts are insufficient to limit warming to 1.5°C, they provide a greater than 95% chance of staying below 2°C.

The equation below shows that net total GHG emissions in China and its trading partners are reduced by 25% than the baseline (S0) emission levels:

$$\sum_i NETMG_i^+ \leq \ 0.75 * \sum_i \overline{TMG_i^+} \qquad (p_{eg}) \tag{53}$$

where p_{eg} is the shadow price of the emissions of GHGs. p_{eg} replaces all places of $p_{eg,i}$ in previous equations to reflect the implementation of a global uniform carbon tax instead of region-specific heterogeneous carbon taxes.

For the specified emission reduction target, our AGE model endogenously calculates the corresponding carbon tax rate (\$/t CO_2-eq) as follows:

$$REGDP_i = \left(\sum_j NEWC_{i,j} + \sum_i NEWXNET_{ij}\right) - \left(\sum_j C_{i,j} + \sum_i XNET_{ij}\right) \tag{54}$$

$$RECO2_i = \ NETMG_i^+ - \overline{TMG_i^+} \tag{55}$$

$$CTAX \ = \ \sum_i REGDP_i \,/\, \sum_i RECO2_i \tag{56}$$

where $REGDP_i$ and $RECO2_i$ are the reductions in Gross Domestic Product (GDP) and net total GHG emissions, in scenario S3 compared to S0, in region i, respectively. $CTAX$ is the global uniform carbon tax (\$/t CO_2-eq).

The average annual greenhouse gas mitigation in the forestry sector under different carbon tax rates (see Supplementary Table 12) is derived from the Global Timber Model (GTM) [27,28], a partial equilibrium, dynamic optimisation model representing the global forestry sector. Following the assumptions in the GTM, one hectare of new forest converted from cropland has the same carbon gain as one hectare of new forest converted from pastureland. As outlined by Golub, et al. [5], the GTM and the AGE model are linked through the calibration of the forest carbon sequestration component in the AGE model. This calibration ensures that both models produce identical forest carbon sequestration responses under the same carbon tax rate.

The calibration procedure adjusts the average annual greenhouse gas mitigation in the forestry sector by modifying the constraints on forest land supply as follows:

$$LD3_{CN,frs} \leq 1.025 * \overline{TLD3_{CN}} \qquad (k3_{CN}) \tag{57}$$

$$LD3_{BR,frs} \leq 1.045 * \overline{TLD3_{BR}} \qquad (k3_{BR}) \tag{58}$$

$$LD3_{US,frs} \leq 1.016 * \overline{TLD3_{US}} \qquad (k3_{US}) \tag{59}$$

$$LD3_{CA,frs} \leq 1.016 * \overline{TLD3_{CA}} \qquad (k3_{CA}) \tag{60}$$

S4 – Combined scenarios: S1+S2+S3

In the combined scenario S4, all measures were combined to examine their potential synergies or trade-offs in the food-land-climate nexus. This scenario incorporates a dietary shift (S1) and a unilateral afforestation policy (S2) in China, along with a global uniform carbon tax (S3).

All additional equations introduced in scenarios S1–S3 are included in scenario S4, except for the replacement of new constraints on forest land supply, as detailed below:

$$LD3_{CN,frs} \leq (1.017 + (1 + PFRS1_{CN}) + (1 + PFRS2_{CN})) * \overline{TLD3_{CN}} \qquad (k3_{CN}) \tag{61}$$

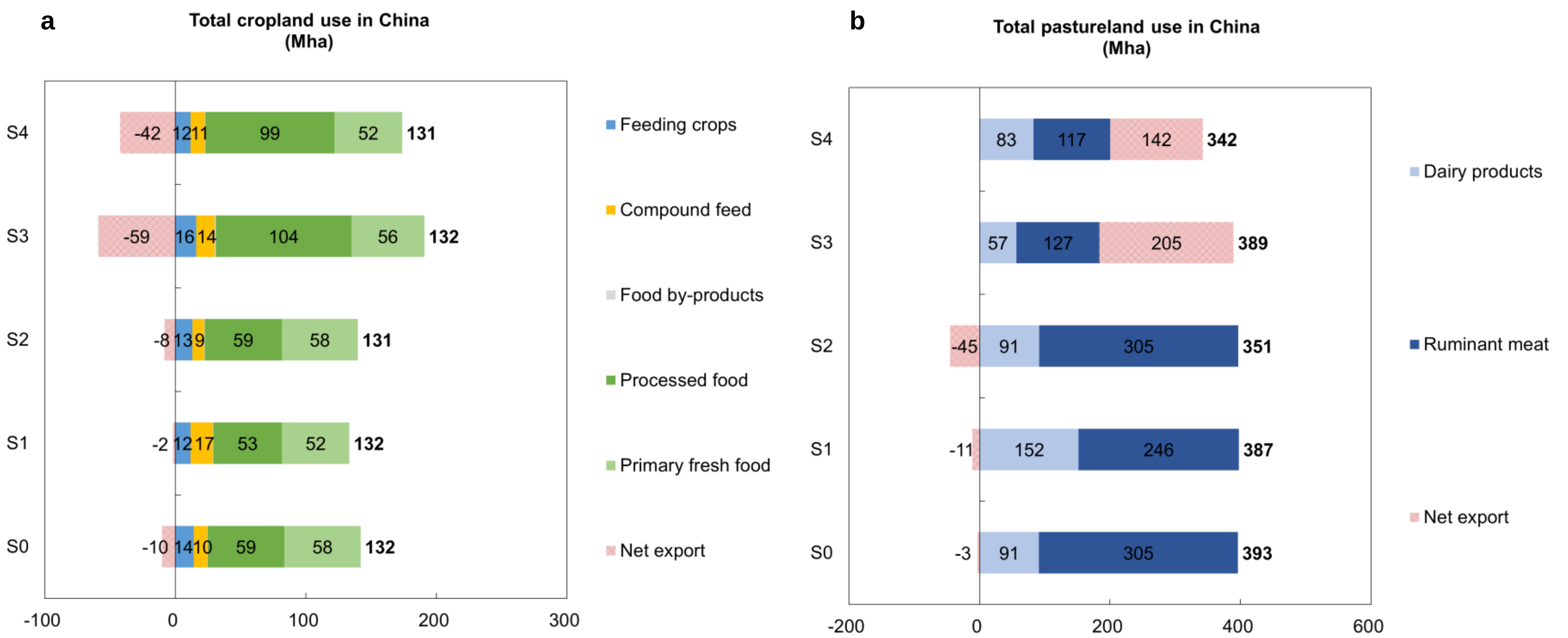
$$LD3_{BR,frs} \leq (1.047 + (1 + PFRS1_{BR}) + (1 + PFRS2_{BR})) * \overline{TLD3_{BR}} \qquad (k3_{BR}) \tag{62}$$

$$LD3_{US,frs} \leq (1.016 + (1 + PFRS1_{US}) + (1 + PFRS2_{US})) * \overline{TLD3_{US}} \qquad (k3_{US}) \tag{63}$$

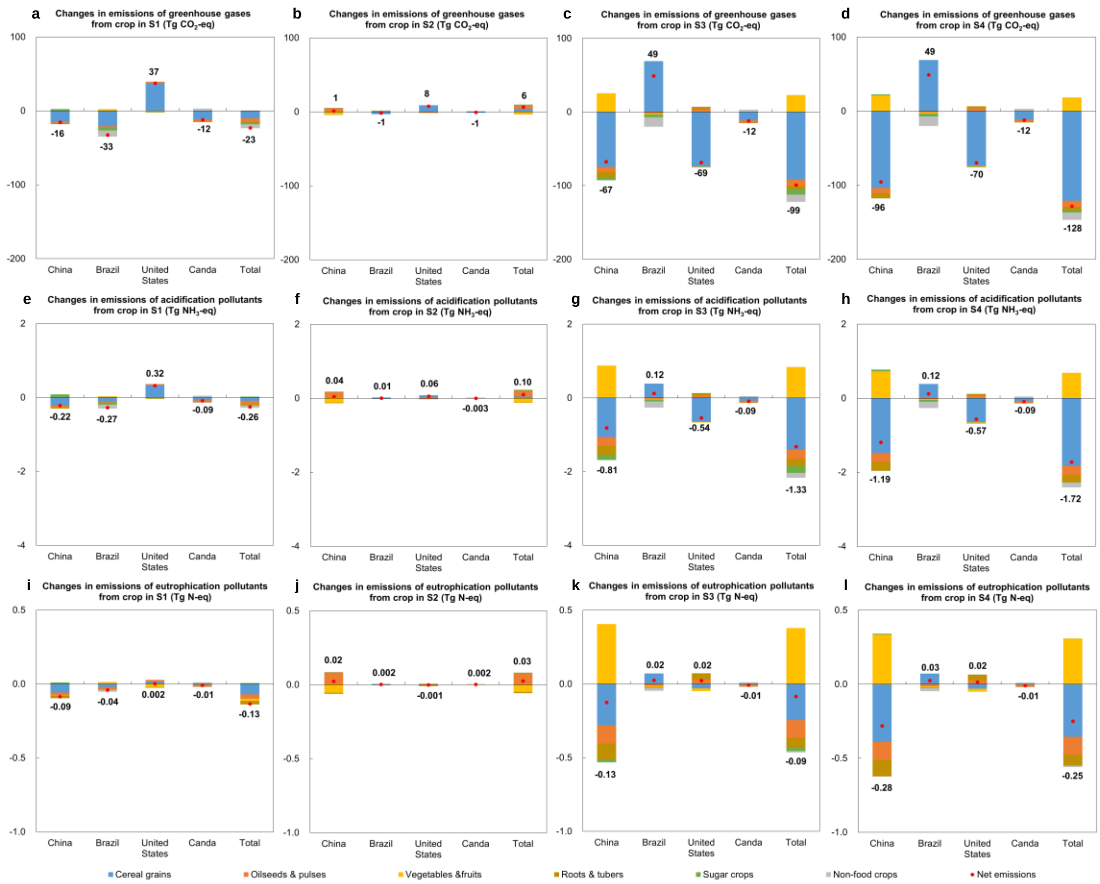
$$LD3_{CA,frs} \leq (1.011 + (1 + PFRS1_{CA}) + (1 + PFRS2_{CA})) * \overline{TLD3_{CA}} \qquad (k3_{CA}) \tag{64}$$

where $PFRS1_i$ and $PFRS2_i$ are the percentage changes in the physical area of forest land in scenarios S1 and S2, respectively, compared to the baseline scenario (S0) region i, respectively.

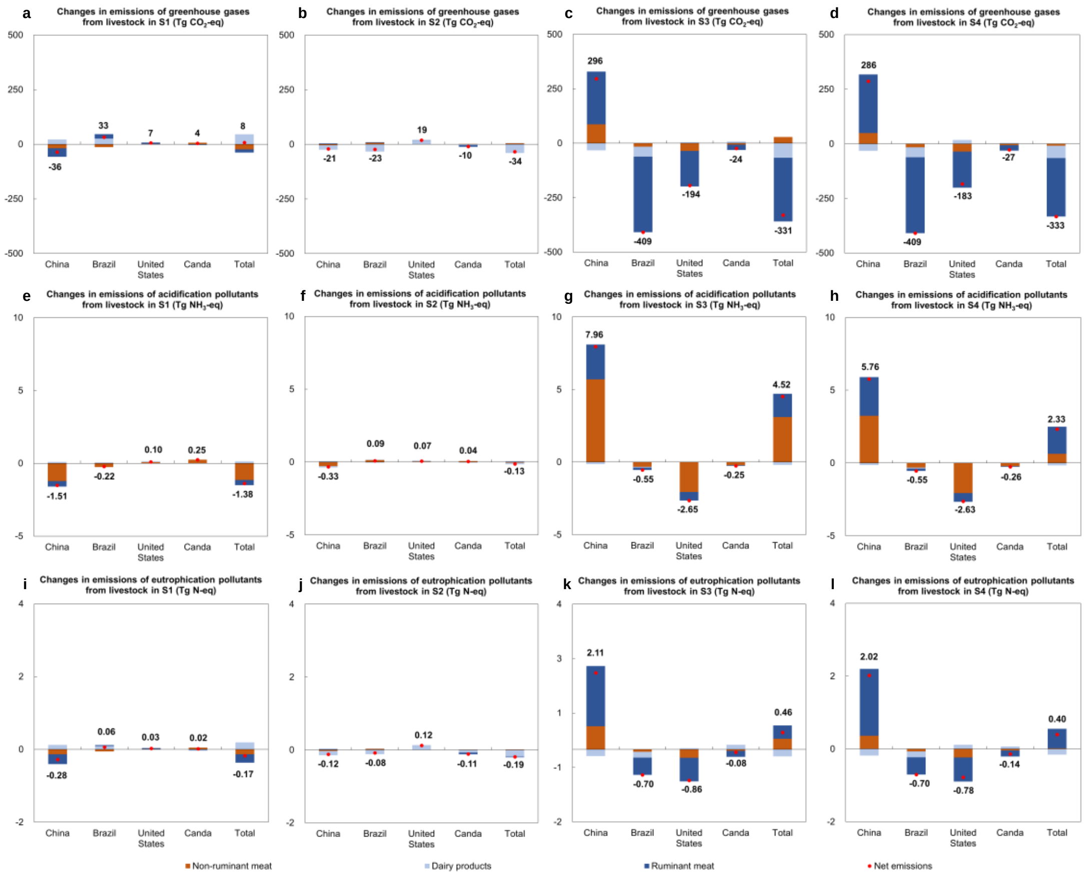
Supplementary Figures



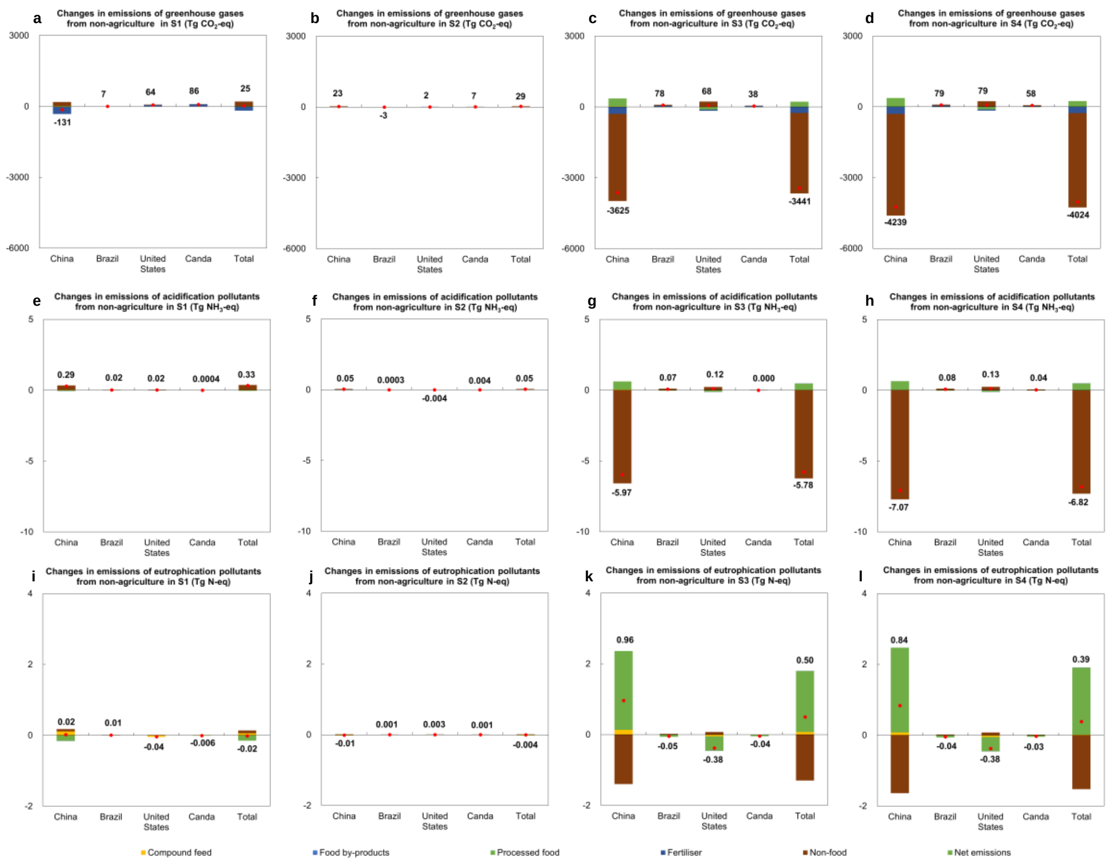
Supplementary Fig. 1 | Total (a) cropland use (Mha) and (b) pastureland use (Mha) in China scenarios. Cropland use includes cropland used for intermediate use (i.e, feeding crops, compound feed, food by-products, processed food), direct consumption (i.e., primary fresh food), and net export. Pastureland use includes pastureland used for direct consumption (i.e., dairy products and ruminant meat) and net export.



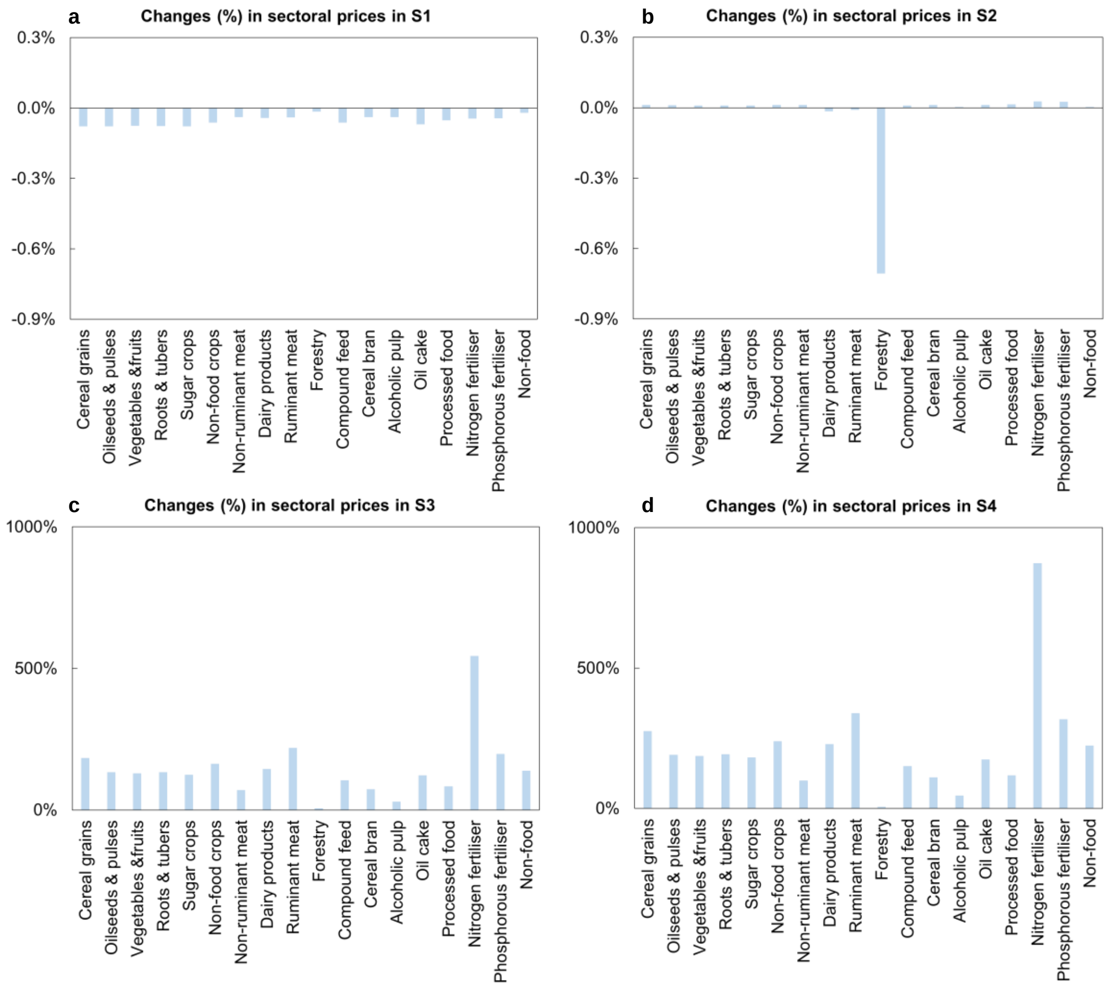
Supplementary Fig. 2 | Changes in emissions of greenhouse gases (Tg CO_2-eq) from crop production in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0). Changes in emissions of acidification pollutants (Tg NH_3-eq) from crop production in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0). Changes in emissions of eutrophication pollutants (Tg N-eq) from crop production in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0).



Supplementary Fig. 3 | Changes in emissions of greenhouse gases (Tg CO_2-eq) from livestock production in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0). Changes in emissions of acidification pollutants (Tg NH_3-eq) from livestock production in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0). Changes in emissions of eutrophication pollutants (Tg N-eq) from livestock production in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0).



Supplementary Fig. 4 | Changes in emissions of greenhouse gases (Tg CO_2-eq) from non-agriculture production in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0). Changes in emissions of acidification pollutants (Tg NH_3-eq) from non-agriculture production in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0). Changes in emissions of eutrophication pollutants (Tg N-eq) from non-agriculture production in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 in China and its main food and feed trading partners in scenarios with respect to the baseline (S0).



Supplementary Fig. 5 | Changes (%) in sectoral prices in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0).

Supplementary Tables

Supplementary Table 1 | Summary of key assumptions used in scenario narratives and their correspondence with sustainable development goals (SDGs).

Scenarios	SDG 2 (Zero hunger) [a]	SDG 15 (Life on land) [b]	SDG 13 (climate action) [c]
Baseline (S0)	No dietary shift in China	No afforestation policy in China	No global uniform carbon tax
Food scenario (S1): A dietary shift in China	A dietary shift towards less animal-based diet closing one-third of the gap between current food consumption and EAT-Lancet diet recommendation [19] for China	No afforestation policy in China	No global uniform carbon tax
Land scenario (S2): A unilateral afforestation policy in China	No dietary shift in China	A unilateral afforestation policy in China based on the National Forest Management Plan (2016–2050) [20] to expand forest land in China by 20% (42 Mha) by 2050	No global uniform carbon tax
Climate scenario (S3): A global uniform carbon tax	No dietary shift in China	No afforestation policy in China	A global uniform carbon tax to achieve a 25% reduction in net total greenhouse gases emissions in China and its trading partners by 2030, aligned with the 2°C climate stabilisation target [21] outlined in the Paris Agreement [22,23]
Combined scenario (S4): S1 + S2 + S3	A dietary shift in China	A unilateral afforestation policy in China	A global uniform carbon tax to achieve a 25% reduction in net total greenhouse gases emissions in China and its trading partners by 2030, aligned with the 2°C climate stabilisation target [21] outlined in the Paris Agreement [22,23]

[a] It corresponds with SDG 2.1 (safe, nutritious and sufficient food), SDG target 2.2 (end all forms of malnutrition), and SDG 2.c.1 (food price anomalies).

[a] It corresponds with SDG 15.1.1 (forest area as a proportion of total land area) and SDG 15.2 (increase afforestation and reforestation).

[a] It corresponds with SDG 13.2.2 (total greenhouse gas emissions).

Supplementary Table 2 | Physical quantities (Tg) in fresh form for each product in China and its main food and feed trading partners in S0.

	China	Brazil	United States	Canada
Cereal grains [a]	521.33	101.40	442.85	51.68
Oilseeds & pulses [a]	74.04	99.48	126.37	29.80
Vegetables & fruits [a]	397.23	49.35	63.93	3.11
Roots & tubers [a]	119.82	27.72	21.40	5.64
Sugar crops [a]	133.61	736.11	55.98	0.58
Non-food crops [a]	36.48	9.82	13.38	0.04
Non-ruminant meat [a]	103.15	18.65	36.74	3.71
Dairy products [a]	41.88	36.42	93.49	7.81
Ruminant meat [a]	10.65	9.86	11.80	1.11
Compound feed [b]	102.60	13.83	78.83	10.35
Cereal bran [c]	11.37	3.93	7.24	0.83
Alcoholic pulp [c]	3.41	6.41	66.91	2.77
Oil cake [c]	58.06	34.00	44.37	6.00
Processed food [d]	593.20	99.16	437.17	44.47
Nitrogen fertiliser [a]	39.60	0.81	9.13	3.71
Phosphorous fertiliser [a]	17.43	2.10	6.56	0.30

[a] Physical quantities of cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, other non-food crops, monogastric livestock, ruminant livestock, nitrogen fertiliser, and phosphorous fertiliser were obtained from FAO [29]. Here, physical quantities of cereal grains waste, oilseeds & pulses waste, vegetables & fruits waste, and roots & tubers waste were excluded.
[b] Compound feed production data was calculated according to the weighted averages of crops included in the compound feed at the national level.
[c] Physical quantities of cereal bran, alcoholic pulp, and oil cake were estimated from the consumption of corresponding food products and specific technical conversion factors [30]. Here, physical quantities of discard biomass of cereal bran, alcoholic pulp, and oil cake were excluded.
[d] Processed food was calculated according to the weighted averages of crops included in the processed food at the national level.

Supplementary Table 3 | Physical area (Mha) of cropland, pastureland, and forest land in China and its main food and feed trading partners in S0. [a]

	Cropland (Mha)	Pastureland (Mha)	Forest land (Mha)	Total land (Mha)
China	132	393	208	732
Brazil	63	172	505	740
United States	159	258	310	726
Canada	38	20	347	405
Total	391	842	1370	2604

[a] Physical area of cropland, pastureland, and forest land are obtained from FAO [29]. Following the GTAP land use and land cover database [31-33], we align the land cover data in our AGE model with FAO land cover data. Specifically, cropland, pastureland, and forest land in our AGE model correspond to arable and permanent cropland, permanent meadows and pastures, and forest land, respectively.

Supplementary Table 4 | Cropland (Mha) used by different crop types in China and its main food and feed trading partners in S0. [a]

	Cereal grains (Mha)	Oilseeds & pulses (Mha)	Vegetables & fruits (Mha)	Roots & tubers (Mha)	Sugar crops (Mha)	Non-food crops (Mha)	Total cropland use (Mha)
China	43.71	5.95	66.85	7.02	8.06	0.03	132
Brazil	15.15	11.58	20.72	1.35	2.70	11.22	63
United States	54.56	36.22	55.34	6.87	4.67	1.14	159
Canada	9.82	6.53	11.01	0.68	0.47	9.70	38
Total	123	60	154	16	16	22	391

[a] The FAO [29] crop categories are aggregated based on the crop sector aggregation scheme (see Appendix Table 1) in the GTAP database to determine cropland use by region.

Supplementary Table 5 | Pastureland (Mha) used by dairy products and ruminant meat in China and its main food and feed trading partners in S0. [a]

	Dairy products (Mha)	Ruminant meat (Mha)	Total pastureland use (Mha)
China	90.48	302.35	393
Brazil	58.59	113.41	172
United States	125.73	131.95	258
Canada	12.47	7.23	20
Total	287	555	842

[a] The FAO [29] livestock categories are aggregated based on the livestock sector aggregation scheme (see Appendix Table 1) in the GTAP database to determine pastureland use by region. Note: Only dairy products and ruminant meat directly use land, while non-ruminant meat does not (see details under the subtitle: "Competition for land use").

Supplementary Table 6 | Nitrogen fertiliser (Tg) used by different crop types in China and its main food and feed trading partners in S0. [a]

	Cereal grains (Tg)	Oilseeds & pulses (Tg)	Vegetables &fruits (Tg)	Roots & tubers (Tg)	Sugar crops (Tg)	Non-food crops (Tg)	Total nitrogen fertiliser use (Tg)
China	23.03	1.53	10.91	1.49	0.97	0.22	38.15
Brazil	0.50	0.12	0.09	0.00	0.23	0.68	1.63
United States	5.41	0.32	0.21	0.09	0.07	0.17	6.27
Canada	1.70	1.15	0.02	0.01	0.0017	0.31	3.19
Total	30.64	3.11	11.22	1.59	1.28	1.38	49.23

[a] Data on nitrogen fertiliser use by crop type and country are derived from Ludemann, et al. [34].

Supplementary Table 7 | Phosphorous fertiliser (Tg) used by different crop types in China and its main food and feed trading partners in S0. [a]

	Cereal grains (Tg)	Oilseeds & pulses (Tg)	Vegetables & fruits (Tg)	Roots & tubers (Tg)	Sugar crops (Tg)	Non-food crops (Tg)	Total phosphorous fertiliser use (Tg)
China	9.24	0.76	5.95	0.66	0.32	0.07	17.00
Brazil	0.49	1.05	0.07	0.02	0.10	0.56	2.29
United States	4.14	1.78	0.17	0.13	0.10	0.03	6.34
Canada	0.05	0.04	0.001	0.001	0.0001	0.02	0.12
Total	13.92	3.64	6.19	0.80	0.52	0.69	25.75

[a] Data on phosphorous fertiliser use by crop type and country are derived from Ludemann, et al. [34].

Supplementary Table 8 | Food consumption (kcal capita^{-1} day^{-1}) in scenarios S0-S1in China, the recommended targets in the EAT-Lancet diet, and changes (%) to close one-third of the gap in food consumption in China in S0 and the recommended targets in the EAT-Lancet diet.

	EAT-Lancet diet (kcal capita^{-1} day^{-1}) [b]	Food consumption in China in S0 (kcal capita^{-1} day^{-1}) [a]	Food consumption in China in S1 (kcal capita^{-1} day^{-1}) [a]	Changes to close one-third of the gap (%)
Cereal grains	811	1236	1095	-11.47
Oilseeds & pulses	1025	267	519	94.85
Vegetables &fruits	204	297	266	-10.46
Roots & tubers	39	122	94	-22.68
Sugar crops	120	779	559	-28.20
Non-ruminant meat	297	397	297	-25.27
Dairy products	85	51	85	66.49
Ruminant meat	29	36	29	-19.40
Total	2463	3185	2944	-7.55

[a] Food consumption in scenarios S0-S1in China are calculated by our AGE model. [b] EAT-Lancet diet recommendations are based on Willett, et al. [19].

Supplementary Table 9 | Elasticities of substitution between forest land and own use of forest biomass in China and its main food and feed trading partners. [a]

	Value
China	1.80
Brazil	1.26
United States	1.26
Canada	1.26

[a] Data source: Golub, et al. [3].

Supplementary Table 10 | Elasticities of substitution between different land types in China and its main food and feed trading partners.[a]

	Value
Between agricultural land and forest land	-0.25
Between cropland and pastureland	-0.5
Between cropland used by different crop types	-1.0
Between pastureland used by dairy products and ruminant meat	-1.0

[a] Data source: Golub, et al. [3]. These values are the same for China, Brazil, the United States, and Canada.

Supplementary Table 11 | Annual forestry carbon sequestration intensities (in t C ha^{-1}, t CO_2 ha^{-1}, and t CO_2 USD^{-1}) in China and its main food and feed trading partners. [a]

	Annual forestry carbon sequestration intensities		
	(t C ha^{-1})	(t CO_2 ha^{-1})	(t CO_2 USD^{-1})
China	-91.75	-16.82	-0.56
Brazil	-163.70	-30.01	-14.28
United States	-193.60	-35.49	-2.68
Canada	-148.80	-27.28	-4.12

[a] Data source: Nguyen, et al. [18]. Annual forestry carbon sequestration intensities are distributed evenly over a depreciation period of 20 years, as suggested by IPCC [16] and BSI [17]. Note: Following the assumptions in the Global Timber Model (GTM) [27,28], one hectare of new forest converted from cropland has the same carbon gain as one hectare of new forest converted from pastureland.

Supplementary Table 12 | Average annual greenhouse gas mitigation in the forestry sector (Tg CO_2-eq yr^{-1}) in 2035 in China and its main food and feed trading partners under different carbon tax rates and 1% growth rate in the Global Timber Model (GTM). [a]

	China	Brazil	US	Canada	Total [b]
\$5/t CO_2-eq	14	53	37	18	122 (20%)
\$20/t CO_2-eq	28	309	104	57	497 (23%)
\$35/t CO_2-eq	43	652	164	95	954 (30%)
\$50/t CO_2-eq	94	855	208	129	1286 (34%)
\$75/t CO_2-eq	114	1146	269	174	1703 (37%)
\$100/t CO_2-eq	144	1368	331	222	2064 (40%)

[a] Data source: Austin, et al. [28]. [b] The numbers in brackets indicate the total shares of annual forestry sector greenhouse gas mitigation by China and its trading partners under different carbon prices relative to the entire world.

Supplementary Table 13 | Changes (%) in cereals price, average wages across the whole economy, and cereals affordability in China and its main food and feed trading partners in scenarios with respect to the baseline (S0). [a]

		Cereals price (%)	Wage (%)	Cereals affordability (%)
S1	China	-0.08	0.02	0.10
	Brazil	-0.08	0.06	0.13
	United States	-0.08	0.05	0.13
	Canada	-0.08	0.02	0.10
S2	China	0.01	0.00	-0.01
	Brazil	0.01	-0.05	-0.07
	United States	0.01	0.00	-0.01
	Canada	0.01	-0.01	-0.02
S3	China	183.74	-56.73	-240.46
	Brazil	183.74	-4.65	-188.39
	United States	183.74	-4.48	-188.21
	Canada	183.74	-8.30	-192.04
S4	China	275.47	-67.52	-342.99
	Brazil	275.47	-4.59	-280.05
	United States	275.47	-4.48	-279.94
	Canada	275.47	-8.28	-283.75

[a] Calculated by our AGE model.

Supplementary Table 14 | Changes (%) in gross domestic product (GDP), household welfare, and household expenditure in China and its main food and feed trading partners in scenarios with respect to the baseline (S0). [a]

		GDP (%)	Household welfare (%)	Household expenditure (%)
S1	China	0.00	-14.99	-14.78
	Brazil	0.00	3.68	3.67
	United States	0.00	3.70	3.7
	Canada	0.00	3.67	3.67%
S2	China	0.00	0.00	0.00
	Brazil	0.00	0.00	0.00
	United States	0.00	0.00	0.00
	Canada	0.00	0.00	0.00
S3	China	-4.95	0.88	-0.36
	Brazil	-0.41	-1.68	0.47
	United States	-0.11	-2.73	-0.36
	Canada	-0.57	4.21	6.58
S4	China	-7.85	-19.48	-20.54
	Brazil	-0.61	2.18	5.02
	United States	-0.19	1.51	5.17
	Canada	-1.09	3.36	6.64

[a] Calculated by our AGE model.

Supplementary References

1 Ginsburgh, V. & Keyzer, M. A. *The Structure of Applied General Equilibrium Models*. (The MIT Press, 2002).

2 Zhu, X. & Van Ierland, E. The enlargement of the European Union: Effects on trade and emissions of greenhouse gases. *Ecological Economics* **57**, 1-14 (2006). https://doi.org/https://dx.doi.org/10.1016/j.ecolecon.2005.03.030

3 Golub, A., Hertel, T., Lee, H.-L., Rose, S. & Sohngen, B. The opportunity cost of land use and the global potential for greenhouse gas mitigation in agriculture and forestry. *Resource and Energy Economics* **31**, 299-319 (2009). https://doi.org/https://doi.org/10.1016/j.reseneeco.2009.04.007

4 Hertel, T. W., Lee, H.-L. & Rose, S. in *Economic analysis of land use in global climate change policy* 143-173 (Routledge, 2009).

5 Golub, A. A. *et al.* Global climate policy impacts on livestock, land use, livelihoods, and food security. *Proceedings of the National Academy of Sciences* **110**, 20894-20899 (2013). https://doi.org/10.1073/pnas.1108772109

6 Peña-Lévano, L. M., Taheripour, F. & Tyner, W. E. Climate Change Interactions with Agriculture, Forestry Sequestration, and Food Security. *Environmental and Resource Economics* **74**, 653-675 (2019). https://doi.org/10.1007/s10640-019-00339-6

7 Taheripour, F., Zhao, X., Horridge, M., Farrokhi, F. & Tyner, W. Land use in computable general equilibrium models. *Journal of Global Economic Analysis* **5**, 63-109 (2020).

8 Golub, A. & Hertel, T. Modeling land-use change impacts of biofuels in the GTAP-BIO framework. *Climate Change Economics* **03**, 1250015 (2012). https://doi.org/10.1142/s2010007812500157

9 Hertel, T. W. *et al.* Effects of US Maize Ethanol on Global Land Use and Greenhouse Gas Emissions: Estimating Market-mediated Responses. *BioScience* **60**, 223-231 (2010). https://doi.org/10.1525/bio.2010.60.3.8

10 Taheripour, F., Zhao, X. & Tyner, W. E. The impact of considering land intensification and updated data on biofuels land use change and emissions estimates. *Biotechnology for Biofuels* **10**, 191 (2017). https://doi.org/10.1186/s13068-017-0877-y

11 Goedkoop, M. *et al.* ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. 1-126 (2009).

12 Deardorff, A. V. The general validity of the Heckscher-Ohlin theorem. *The American Economic Review* **72**, 683-694 (1982).

13 McLure Jr, C. E. General equilibrium incidence analysis: The Harberger model after ten years. *Journal of Public Economics* **4**, 125-161 (1975).

14 Shoven, J. B. & Whalley, J. *Applying general equilibrium*. (Cambridge university press, 1992).

15 Riahi, K. *et al.* The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change* **42**, 153-168 (2017). https://doi.org/https://doi.org/10.1016/j.gloenvcha.2016.05.009

16 IPCC. in *Agriculture, Forestry and Other Land Use* Vol. 4 (Intergovernmental Panel on Climate Change, 2006).

17 BSI. PAS 2050:2008 – Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. *British Standards, UK* **978**, 580 (2008).

18 Nguyen, T. L. T., Hermansen, J. E. & Mogensen, L. Environmental consequences of different beef production systems in the EU. *Journal of Cleaner Production* **18**, 756-766 (2010). https://doi.org/https://doi.org/10.1016/j.jclepro.2009.12.023

19 Willett, W. *et al.* Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet* **393**, 447-492 (2019). https://doi.org/10.1016/s0140-6736(18)31788-4

20 Forest Park of National Forestry and Grassland Administration (FPNFGA). *National Forest Management Plan (2016–2050)*, <http://www.forestry.gov.cn/main/58/20160728/892769.html> (2016).

21 Lee, H. *et al.* Synthesis report of the IPCC Sixth Assessment Report (AR6), Longer report. IPCC. (2023).

22 IPCC-WGIII. Summary for policymakers (AR5). (2014).

23 UNFCC. Paris agreement. (2015).

24 Hasegawa, T. *et al.* Risk of increased food insecurity under stringent global climate change mitigation policy. *Nature Climate Change* **8**, 699-703 (2018). https://doi.org/10.1038/s41558-018-0230-x

25 Fujimori, S. *et al.* Land-based climate change mitigation measures can affect agricultural markets and food security. *Nature Food* **3**, 110-121 (2022). https://doi.org/10.1038/s43016-022-00464-4

26 Matthews, H. D. & Wynes, S. Current global efforts are insufficient to limit warming to 1.5°C. *Science* **376**, 1404-1409 (2022). https://doi.org/10.1126/science.abo3378

27 Sohngen, B. & Mendelsohn, R. in *Human-Induced Climate Change: An Interdisciplinary Assessment* (eds Michael E. Schlesinger *et al.*) 227-237 (Cambridge University Press, 2007).

28 Austin, K. G. *et al.* The economic costs of planting, preserving, and managing the world's forests to mitigate climate change. *Nature Communications* **11**, 5946 (2020). https://doi.org/10.1038/s41467-020-19578-z

29 FAO. <http://www.fao.org/faostat/en/#data> (2022).

30 FAO. Technical Conversion Factors for Agricultural Commodities. (1997).

31 Baldos, U. L. Development of GTAP 9 land use and land cover data base for years 2004, 2007 and 2011. (Global Trade Analysis Project (GTAP), Department of Agricultural Economics, Purdue University, West Lafayette, IN, 2017).

32 Baldos, U. L. & Corong, E. Development of GTAP 10 Land Use and Land Cover Data Base for years 2004, 2007, 2011 and 2014. Report No. 36, (Global Trade Analysis Project (GTAP), Department of Agricultural Economics, Purdue University, West Lafayette, IN, 2020).

33 Pena Levano, L. M., Taheripour, F. & Tyner, W. Development of the GTAP land use data base for 2011. (Center for Global Trade Analysis, Department of Agricultural Economics …, 2015).

34 Ludemann, C. I., Gruere, A., Heffer, P. & Dobermann, A. Global data on fertilizer use by crop and by country. *Scientific Data* **9**, 501 (2022). https://doi.org/10.1038/s41597-022-01592-z

35 Sturm, V. Taking into account the emissions from the production and use of mineral fertilizers by imposing a 'carbon tax'. *14th Annual Conference on Global Economic Analysis* (2011).

36 Bartelings, H., Kavallari, A., van Meijl, H. & Von Lampe, M. Estimating the impact of fertilizer support policies: A CGE approach. *19th Annual Conference on Global Economic Analysis* (2016).

37 GTAP. *GTAP version 10 Database*, <http://www.gtap.agecon.purdue.edu/> (2014).

38 Climate Analysis Indicators Tool (CAIT). <https://www.climatewatchdata.org/?source=cait> (2014).

39 Mackenzie, S. G., Leinonen, I., Ferguson, N. & Kyriazakis, I. Towards a methodology to formulate sustainable diets for livestock: accounting for environmental impact in diet formulation. *British Journal of Nutrition* **115**, 1860-1874 (2016). https://doi.org/10.1017/S0007114516000763

40 Liu, L. *et al.* Exploring global changes in agricultural ammonia emissions and their contribution to nitrogen deposition since 1980. *Proceedings of the National Academy of Sciences* **119**, e2121998119 (2022). https://doi.org/doi:10.1073/pnas.2121998119

41 Huang, T. *et al.* Spatial and Temporal Trends in Global Emissions of Nitrogen Oxides from 1960 to 2014. *Environmental Science & Technology* **51**, 7992-8000 (2017). https://doi.org/10.1021/acs.est.7b02235

42 Dahiya, S. *et al.* Ranking the World's Sulfur Dioxide (SO2) Hotspots: 2019–2020. *Delhi Center for Research on Energy and Clean Air-Greenpeace India: Chennai, India* **48** (2020).

43 Hamilton, H. A. *et al.* Trade and the role of non-food commodities for global eutrophication. *Nature Sustainability* **1**, 314-321 (2018).

Appendix Tables

Appendix Table 1 | Sectoral aggregation scheme.

Aggregated sectors	GTAP original sectors
Cereal grains	“Paddy rice (pdr)”, “Processed rice (pcr)”, “Wheat (wht)”, and “Cereals grains nec (gro)” sectors
Oilseeds & pulses	“Oil seeds (osd)” sector, and pulses split from the original “Vegetables& fruits (v_f)” sector
Vegetables & fruits	“Vegetables, fruits, nuts (v_f)” sector after splitting out pulses, and roots & tubers
Roots &tubers	Split from the original “Vegetables& fruits (v_f)” sector
Sugar crops	“Sugar cane & Sugar beet (c_b)” and Sugar (sgr)” sectors
Non-food crops	“Plant-based fibers (pfb)”, and “Crops nec (ocr)” sectors
Non-ruminant meat	“Animal products nec (oap)” and “Meat products nec (omt)” sectors
Dairy products	“Raw milk (rmk)” and “Dairy products (mil)” sectors
Ruminant meat	“Cattle, sheep, goats, horses (ctl)”, “Meat: cattle, sheep, goats, horses (cmt)”, and “Wool, silk-worm cocoons (wol)” sectors
Forestry	“Forestry (frs)” sector
Compound feed [a]	Split from the original “Food products nec (ofd)” sector
Cereal bran [a]	Split from the original “Food products nec (ofd)” sector
Alcoholic pulp [a]	Distiller’s grains from maize ethanol production split from the original “Food products nec (ofd)” sector; Distiller’s grains from liquor production and brewer’s grains from barley beer production split from the original “Beverages and Tobacco products (b_t)” sector
Oil cake [a]	Split from the original “Vegetable oils and fats (vol)” sector
Processed food [a]	“Food products nec (ofd)” sector after splitting out splitting out compound feed, cereal bran, and distiller's grains from maize ethanol production; “Beverages and Tobacco products (b_t)” sector after splitting out distiller’s grains from liquor production and brewer’s grains from barley beer production; Vegetable oils and fats (vol)” sector after splitting out oil cake
Nitrogen fertiliser [b]	Split from the original “Manufacture of chemicals and chemical products (chm)” sector
Phosphorous fertiliser [b]	Split from the original “Manufacture of chemicals and chemical products (chm)” sector

Aggregated sectors	GTAP original sectors
Non-food	"Manufacture of chemicals and chemical products (chm)" sector after splitting out nitrogen fertiliser and phosphorous fertiliser; "Waste and water (wtr)" sector; "Fishing (fsh)", "Coal (coa)", "Oil (oil)", "Gas (gas)", "Minerals nec (oxt)", "Petroleum, coal products (p_c)", "Electricity (ely)", "Gas manufacture, distribution (gdt)", "Textiles （tex)", "Wearing apparel (wap)", "Leather products (lea)", "Wood products (lum)", "Paper products, publishing (ppp)", "Manufacture of pharmaceuticals, medicinal chemical and botanical products (bph)", "Manufacture of rubber and plastics products (rpp)", "Mineral products nec (nmm)", "Ferrous metal (i_s)", "Metal nec (nfm)", "Metal products (fmp)", Electronic equipment (ele)", "Manufacture of electrical equipment (eeq)", "Manufacture of machinery and equipment n.e.c. (ome)", "Motor vehicles and parts (mvh)", "Transport equipment nec (otn)", "Manufactures nec (omf)", "Construction (cns)", "Wholesale and retail trade; repair of motor vehicles and motorcycles (trd)", "Accommodation, Food and service activities (afs)", "Land transport and transport via pipelines (otp)", "Warehousing and support activities (whs)", "Sea transport (wtp)", "Air transport （atp)", "Communication (cmn)", "Financial services nec (ofi)", "Insurance (ins)", "Real estate activities (rsa)", "Other Business Services nec (obs)", "Recreation & other services (ros)", "Other Services (Government) (osg)", "Education (edu)", "Human health and social work (hht)", "Dwellings: ownership of dwellings (imputed rents of houses occupied by owners) (dwe)" sectors

[a] Compound feed was split from the "Food products nec (ofd)" sector in the original GTAP database. The substance flow from "Food products nec (ofd)" to monogastric livestock and ruminant livestock was compound feed. Cereal bran and distiller's grains from maize ethanol production were taken from the newly-splitted sector of compound feed according to the shares of economic values of cereal bran and distiller's grains from maize ethanol production in the total economic value of compound feed. Economic values of cereal bran and distiller's grains from maize ethanol production were calculated by multiplying the physical quantity (in tons) and the corresponding price (dollar per ton). Distiller's grains from liquor production and brewer's grains from barley beer production were split from the "Beverages and Tobacco products (b_t)" sector in the original GTAP database. The substance flow from "Beverages and Tobacco products (b_t)" to monogastric livestock were distillers' grains from liquor production and brewers' grains from barley beer production. Oil cake was split from the "Vegetable oils and fats (vol)" sector in the original GTAP database. The substance flow from the "Vegetable oils and fats (vol)" sector to monogastric livestock was oil cake.

[b] The nitrogen and phosphorus fertilisers were taken from the original 'Manufacture of chemicals and chemical products' sector following the method of Sturm [35] and Bartelings, et al. [36].

Appendix Table 2 | The social accounting matrix in the base year of 2014 for China (million USD).[a]

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	frs	cof	bran	pulp	cake	otf	nfe	pfe	nf	CONS	XNET	TOT
cer	0	0	0	0	0	0	29229	2086	6969	0	11363	1372	67	0	81831	0	0	0	61825	-2016	192727
osd	0	0	0	0	0	0	1002	53	177	0	8312	0	0	182	42993	0	0	0	5092	-34661	23150
vf	0	0	0	0	0	0	5685	345	1151	0	18959	0	0	0	98059	0	0	0	145756	-139	269815
rt	0	0	0	0	0	0	595	36	121	0	1986	0	0	0	10270	0	0	0	15265	-15	28259
sgr	0	0	0	0	0	0	192	119	396	0	1280	0	0	0	6619	0	0	0	24553	-903	32256
ocr	0	0	0	0	0	0	664	60	202	0	197	0	0	0	1021	0	0	0	1282	-1465	1963
oap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	181650	-3292	178359
rmk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14642	-112	14530
ctl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48904	-372	48532
frs	0	0	0	0	0	0	0	0	0	6396	0	0	0	0	0	0	0	60096	1000	-1817	65675
cof	0	0	0	0	0	0	50572	1718	5740	0	0	0	0	0	0	0	0	0	0	854	58884
bran	0	0	0	0	0	0	3371	0	0	0	0	0	0	0	0	0	0	0	0	27	3398
pulp	0	0	0	0	0	0	800	0	0	0	0	0	0	0	0	0	0	0	0	-398	402
cake	0	0	0	0	0	0	215	0	0	0	0	0	0	0	0	0	0	0	0	-10	205
otf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	432109	714	432823
nfe	7396	521	3479	471	313	621	0	0	0	0	0	0	0	0	0	0	0	0	0	-78	12721
pfe	2412	211	1542	169	83	163	0	0	0	0	0	0	0	0	0	0	0	0	0	-28	4551
nf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2562284	356487	2918771
LAD1	53323	7694	80962	8445	9849	396	0	0	0	0	0	0	0	0	0	0	0	0	-160670	0	0
LAD2	0	0	0	0	0	0	0	2359	7881	0	0	0	0	0	0	0	0	0	-10240	0	0
LAD3	0	0	0	0	0	0	0	0	0	6227	0	0	0	0	0	0	0	0	-6227	0	0
LAB	94995	11819	148120	15450	17556	631	62255	5666	18926	44792	7946	959	155	8	89845	4413	1579	1534347	-2059463	0	0
CAP	34602	2905	35711	3725	4455	151	23777	2087	6971	8261	8841	1067	180	15	102185	8308	2972	1324328	-1570541	0	0
TRA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	312779	-312779	0

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	frs	cof	bran	pulp	cake	otf	nfe	pfe	nf	CONS	XNET	TOT
TOT	192727	23150	269815	28259	32256	1963	178359	14530	48532	65675	58884	3398	402	205	432823	12721	4551	2918771	0	0	4287021

[a] Data source: GTAP [37]. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=non-food crops. oap=non-ruminant meat. rmk=dairy products. ctl=ruminant meat. frs=forestry. cof=compound feed. bran=cereal bran. pulp=alcoholic pulp. cake=oil cake. otf=processed food. nfe=nitrogen fertiliser. pfe=phosphorous fertiliser. nf=non-food. CONS=consumption. XNET=net export. TOT=total. LAD1=cropland. LAD2=pastureland. LAD3=forest land. LAB=labour. CAP=capital. TRA=trade.

Appendix Table 3 | The social accounting matrix in the base year of 2014 for Brazil (million USD).[a]

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	frs	cof	bran	pulp	cake	otf	nfe	pfe	nf	CONS	XNET	TOT
cer	0	0	0	0	0	0	961	930	1799	0	1195	928	35	0	12745	0	0	0	11640	2	30237
osd	0	0	0	0	0	0	25	38	73	0	1102	0	0	3	6475	0	0	0	315	16623	24655
vf	0	0	0	0	0	0	199	233	450	0	3198	0	0	0	18783	0	0	0	8628	-91	31400
rt	0	0	0	0	0	0	21	24	47	0	335	0	0	0	1967	0	0	0	904	-9	3289
sgr	0	0	0	0	0	0	9	13	25	0	15	0	0	0	88	0	0	0	7820	839	8809
ocr	0	0	0	0	0	0	42	48	93	0	344	0	0	0	2019	0	0	0	5224	291	8062
oap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14946	638	15584
rmk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18542	-16	18526
ctl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35874	-53	35821
frs	0	0	0	0	0	0	0	0	0	1985	0	0	0	0	0	0	0	6322	865	11	9183
cof	0	0	0	0	0	0	35	2851	5512	0	0	0	0	0	0	0	0	0	0	27	8425
bran	0	0	0	0	0	0	2662	0	0	0	0	0	0	0	0	0	0	0	0	2	2664
pulp	0	0	0	0	0	0	103	0	0	0	0	0	0	0	0	0	0	0	0	1	104
cake	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5
otf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87276	500	87776
nfe	414	131	71	5	240	257	0	0	0	0	0	0	0	0	0	0	0	0	0	-453	665
pfe	247	723	35	14	65	129	0	0	0	0	0	0	0	0	0	0	0	0	0	-161	1051
nf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1167685	-14999	1152686
LAD1	3674	3841	5060	529	830	1247	0	0	0	0	0	0	0	0	0	0	0	0	-15181	0	0
LAD2	0	0	0	0	0	0	0	1410	2727	0	0	0	0	0	0	0	0	0	-4137	0	0
LAD3	0	0	0	0	0	0	0	0	0	1063	0	0	0	0	0	0	0	0	-1063	0	0
LAB	8814	5010	6417	671	2733	1587	4657	4903	9481	4683	1172	910	36	1	23213	236	374	597428	-672325	0	0
CAP	17088	14949	19817	2071	4940	4842	6868	8076	15614	1453	1064	826	33	1	22484	429	678	548937	-670168	0	0
TRA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3156	-3156	0

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	frs	cof	bran	pulp	cake	otf	nfe	pfe	nf	CONS	XNET	TOT
TOT	30237	24655	31400	3289	8809	8062	15584	18526	35821	9183	8425	2664	104	5	87776	665	1051	1152686	0	0	1438941

[a] Data source: GTAP [37]. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=non-food crops. oap=non-ruminant meat. rmk=dairy products. ctl=ruminant meat. frs=forestry. cof=compound feed. bran=cereal bran. pulp=alcoholic pulp. cake=oil cake. otf=processed food. nfe=nitrogen fertiliser. pfe=phosphorous fertiliser. nf=non-food. CONS=consumption. XNET=net export. TOT=total. LAD1=cropland. LAD2=pastureland. LAD3=forest land. LAB=labour. CAP=capital. TRA=trade.

Appendix Table 4 | The social accounting matrix in the base year of 2014 for the United States (million USD).[a]

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	frs	cof	bran	pulp	cake	otf	nfe	pfe	nf	CONS	XNET	TOT
cer	0	0	0	0	0	0	2765	14488	15203	0	2821	110	372	0	17774	0	0	0	2807	1734	58074
osd	0	0	0	0	0	0	33	58	61	0	1821	0	0	1914	8828	0	0	0	1309	15210	29234
vf	0	0	0	0	0	0	137	164	172	0	4813	0	0	0	23337	0	0	0	35913	57	64593
rt	0	0	0	0	0	0	14	17	18	0	504	0	0	0	2444	0	0	0	3761	6	6765
sgr	0	0	0	0	0	0	47	452	474	0	1461	0	0	0	7085	0	0	0	5666	67	15252
ocr	0	0	0	0	0	0	29	39	41	0	538	0	0	0	2607	0	0	0	6912	1196	11363
oap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77869	1999	79868
rmk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70079	110	70189
ctl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73283	367	73650
frs	0	0	0	0	0	0	0	0	0	1674	0	0	0	0	0	0	0	21831	5249	1233	29986
cof	0	0	0	0	0	0	27976	10231	10735	0	0	0	0	0	0	0	0	0	0	-919	48023
bran	0	0	0	0	0	0	1545	0	0	0	0	0	0	0	0	0	0	0	0	-28	1517
pulp	0	0	0	0	0	0	4760	0	0	0	0	0	0	0	0	0	0	0	0	438	5198
cake	0	0	0	0	0	0	2269	0	0	0	0	0	0	0	0	0	0	0	0	2	2271
otf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	388161	-1190	386971
nfe	1201	55	46	16	14	364	0	0	0	0	0	0	0	0	0	0	0	0	0	334	2030
pfe	1285	423	51	33	27	100	0	0	0	0	0	0	0	0	0	0	0	0	0	119	2037
nf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11016432	-299964	10716468
LAD1	18172	9241	18433	1919	1380	3810	0	0	0	0	0	0	0	0	0	0	0	0	-52955	0	0
LAD2	0	0	0	0	0	0	0	5001	5248	0	0	0	0	0	0	0	0	0	-10249	0	0
LAD3	0	0	0	0	0	0	0	0	0	4107	0	0	0	0	0	0	0	0	-4107	0	0
LAB	20082	10460	24684	2570	9778	3790	28976	25007	26241	8398	20576	803	2738	222	165696	1043	1046	7536888	-7888997	0	0
CAP	17334	9055	21379	2226	4054	3299	11316	14731	15458	15808	15490	604	2088	136	159199	987	991	3157749	-3451904	0	0
TRA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-279230	279230	0

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	frs	cof	bran	pulp	cake	otf	nfe	pfe	nf	CONS	XNET	TOT
TOT	58074	29234	64593	6765	15252	11363	79868	70189	73650	29986	48023	1517	5198	2271	386971	2030	2037	10716468	0	0	11603490

[a] Data source: GTAP [37]. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=non-food crops. oap=non-ruminant meat. rmk=dairy products. ctl=ruminant meat. frs=forestry. cof=compound feed. bran=cereal bran. pulp=alcoholic pulp. cake=oil cake. otf=processed food. nfe=nitrogen fertiliser. pfe=phosphorous fertiliser. nf=non-food. CONS=consumption. XNET=net export. TOT=total. LAD1=cropland. LAD2=pastureland. LAD3=forest land. LAB=labour. CAP=capital. TRA=trade.

Appendix Table 5 | The social accounting matrix in the base year of 2014 for Canada (million USD).[a]

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	frs	cof	bran	pulp	cake	otf	nfe	pfe	nf	CONS	XNET	TOT
cer	0	0	0	0	0	0	170	1182	687	0	492	13	18	0	2408	0	0	0	2150	279	7399
osd	0	0	0	0	0	0	13	45	26	0	427	0	0	146	1756	0	0	0	314	2828	5554
vf	0	0	0	0	0	0	27	58	34	0	449	0	0	0	1846	0	0	0	6214	172	8801
rt	0	0	0	0	0	0	3	6	4	0	47	0	0	0	193	0	0	0	651	18	922
sgr	0	0	0	0	0	0	3	46	27	0	142	0	0	0	585	0	0	0	2553	-2	3354
ocr	0	0	0	0	0	0	62	120	70	0	74	0	0	0	302	0	0	0	988	-22	1594
oap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7679	655	8334
rmk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10569	18	10586
ctl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6091	59	6149
frs	0	0	0	0	0	0	0	0	0	7459	0	0	0	0	0	0	0	10253	748	572	19032
cof	0	0	0	0	0	0	2867	2149	1248	0	0	0	0	0	0	0	0	0	0	38	6303
bran	0	0	0	0	0	0	136	0	0	0	0	0	0	0	0	0	0	0	0	0	136
pulp	0	0	0	0	0	0	238	0	0	0	0	0	0	0	0	0	0	0	0	-41	197
cake	0	0	0	0	0	0	177	0	0	0	0	0	0	0	0	0	0	0	0	4	181
otf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39384	-24	39360
nfe	919	756	14	17	1	65	0	0	0	0	0	0	0	0	0	0	0	0	0	197	1968
pfe	18	20	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	70	112
nf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	859347	-41524	817823
LAD1	1087	882	1549	160	51	421	0	0	0	0	0	0	0	0	0	0	0	0	-4150	0	0
LAD2	0	0	0	0	0	0	0	472	274	0	0	0	0	0	0	0	0	0	-746	0	0
LAD3	0	0	0	0	0	0	0	0	0	2300	0	0	0	0	0	0	0	0	-2300	0	0
LAB	2284	1829	3384	348	1684	585	2691	3434	1995	6755	2434	64	91	15	15010	762	43	465567	-508975	0	0
CAP	3091	2069	3853	397	1618	520	1946	3074	1786	2518	2236	59	88	21	17258	1207	69	342002	-383811	0	0
TRA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-36705	36705	0

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	frs	cof	bran	pulp	cake	otf	nfe	pfe	nf	CONS	XNET	TOT
TOT	7399	5554	8801	922	3354	1594	8334	10586	6149	19032	6303	136	197	181	39360	1968	112	817823	0	0	937805

[a] Data source: GTAP [37]. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=non-food crops. oap=non-ruminant meat. rmk=dairy products. ctl=ruminant meat. frs=forestry. cof=compound feed. bran=cereal bran. pulp=alcoholic pulp. cake=oil cake. otf=processed food. nfe=nitrogen fertiliser. pfe=phosphorous fertiliser. nf=non-food. CONS=consumption. XNET=net export. TOT=total. LAD1=cropland. LAD2=pastureland. LAD3=forest land. LAB=labour. CAP=capital. TRA=trade.

Appendix Table 6 | Emissions sources of greenhouse gases, acidification pollutants, and eutrophication pollutants across various sectors of the model. [a]

Sectors	Emissions of greenhouse gases ($Tg\ CO_2$ equivalents)	Emissions of acidification pollutants ($Tg\ NH_3$ equivalents)	Eutrophication pollutants (Tg N equivalents)
Crop	• Rice methane (CH_4) • Synthetic fertiliser and manure application (N_2O)	• Synthetic fertiliser and manure application (NH_3)	• Synthetic fertiliser and manure application (N and P losses)
Livestock	• Enteric fermentation (CH_4) • Manure management (CH_4 and N_2O) • Manure grassland (N_2O)	• Manure management (NH_3) • Manure grassland (NH_3)	• Manure management (N and P losses) • Manure grassland (N and P losses)
Forestry	• Deforestation (CO_2)	• -	• -
Non-agriculture	• Energy use (CO_2, CH_4, and N_2O)	• Energy use (NH_3, NO_x and SO_2)	• Energy use (N and P losses)

[a] Emissions from the production of N and P fertilisers are attributed to the respective fertiliser sector, while emissions from the application of these fertilisers are assigned to the crop sectors to prevent double counting. Data on N and P fertiliser use by crop types and countries are derived from Ludemann, et al. [34]. Manure data by animals are derived from FAO [29]. Allocation of manure for each crop is assumed to be consistent with the allocation of N fertiliser for each crop.

[b] Emission sources in non-agricultural sectors arise from energy use in sectors including compound feed, food processing by-products, processed food, fertilisers, and non-food sectors.

Appendix Table 7 | Total emissions of greenhouse gases (Tg CO_2 equivalents) in China and its main food and feed trading partners.[a]

	China		Brazil		United States		Canada	
	Total	Total (%)	Total	Total (%)	Total	Total (%)	Total	Total (%)
Cereal grains	276.70	2.36	23.11	2.04	82.72	1.35	12.95	1.85
Oilseeds & pulses	7.87	0.07	2.16	0.19	2.53	0.04	4.01	0.57
Vegetables &fruits	55.30	0.47	1.54	0.14	1.69	0.03	0.07	0.01
Roots &tubers	7.57	0.06	0.07	0.01	0.71	0.01	0.05	0.01
Sugar crops	4.57	0.04	4.57	0.40	0.58	0.01	0.01	0.00
Non-food crops	1.79	0.02	13.34	1.18	1.50	0.02	1.17	0.17
Non-ruminant meat	79.14	0.68	17.82	1.57	39.43	0.64	7.09	1.01
Dairy products	38.66	0.33	52.46	4.63	43.51	0.71	4.90	0.70
Ruminant meat	206.36	1.76	385.38	33.98	186.38	3.03	27.55	3.94
Forestry [b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compound feed	25.33	0.22	1.07	0.09	13.19	0.21	1.83	0.26
Cereal bran	0.0076	0.00006	0.0009	0.00008	0.0018	0.00003	0.0003	0.00004
Alcoholic pulp	0.000124	0.0000011	0.000008	0.0000007	0.000021	0.0000003	0.000001	0.0000002
Oil cake	0.0016	0.00001	0.0053	0.00047	0.0067	0.00011	0.0047	0.00067
Processed food	204.56	1.75	12.05	1.06	107.28	1.75	11.49	1.64
Nitrogen fertiliser	306.75	2.62	4.69	0.41	52.10	0.85	22.26	3.18
Phosphorus fertiliser	24.05	0.21	2.07	0.18	6.39	0.10	0.40	0.06
Non-food	10479.57	89.43	613.95	54.13	5605.45	91.24	605.47	86.59
Total	11718	100.00	1134	100.00	6143	100.00	699	100.00

[a] Data source: Climate Analysis Indicators Tool (CAIT) [38]. All greenhouse gases emissions calculations in our model follow the IPCC Tier 2 approach [16]. Emissions of food processing by-products (i.e., cereal bran, alcoholic pulp, oil cake) were derived from Mackenzie, et al. [39]. [b] Note: Forest carbon stock applies only to scenarios S1–S4 and is calculated using annual forestry carbon sequestration intensities provided in Supplementary Table 11.

Appendix Table 8 | Total emissions of acidification pollutants (Tg NH_3 equivalents) in China and its main food and feed trading partners.[a]

	China		Brazil		United States		Canada	
	Total	Total (%)	Total	Total (%)	Total	Total (%)	Total	Total (%)
Cereal grains	3.94	11.89	0.13	4.70	0.72	7.51	0.09	6.38
Oilseeds & pulses	0.27	0.82	0.03	1.04	0.05	0.47	0.06	4.37
Vegetables &fruits	1.91	5.76	0.02	0.74	0.03	0.32	0.0011	0.08
Roots &tubers	0.26	0.79	0.00	0.03	0.01	0.13	0.0008	0.06
Sugar crops	0.16	0.48	0.06	2.20	0.01	0.11	0.0001	0.01
Non-food crops	0.06	0.19	0.18	6.42	0.03	0.28	0.02	1.27
Non-ruminant meat	5.20	15.71	0.35	12.87	2.29	23.82	0.24	17.48
Dairy products	0.17	0.50	0.07	2.65	0.07	0.71	0.01	0.45
Ruminant meat	2.04	6.17	0.18	6.60	0.68	7.01	0.05	3.41
Forestry [b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compound feed	0.04	0.13	0.00	0.11	0.01	0.14	0.00	0.19
Cereal bran	0.00033	0.0010	0.00004	0.0015	0.00008	0.0008	0.00001	0.0008
Alcoholic pulp	0.00000072	0.000002	0.00000004	0.000002	0.00000012	0.000001	0.00000001	0.000001
Oil cake	0.0001	0.0002	0.0003	0.0100	0.0003	0.0035	0.0002	0.0168
Processed food	0.35	1.07	0.03	1.18	0.11	1.10	0.02	1.19
Nitrogen fertiliser	0.0009	0.003	0.0003	0.010	0.0028	0.029	0.0003	0.023
Phosphorus fertiliser	0.0007	0.002	0.0007	0.025	0.0020	0.020	0.0003	0.019
Non-food	18.72	56.49	1.68	61.40	5.62	58.35	0.91	65.07
Total	33.13	100.00	2.74	100.00	9.63	100.00	1.40	100.00

[a] Data source: Liu, et al. [40], Huang, et al. [41], and Dahiya, et al. [42]. Emissions of food processing by-products (i.e., cereal bran, alcoholic pulp, oil cake) were derived from Mackenzie, et al. [39]. [b] Note: Forestry sector has no emissions of acidification pollutants.

Appendix Table 9 | Total emissions of eutrophication pollutants (Tg N equivalents) in China and its main food and feed trading partners.[a]

	China		Brazil		United States		Canada	
	Total	Total (%)	Total	Total (%)	Total	Total (%)	Total	Total (%)
Cereal grains	1.04	10.48	0.02	1.95	0.03	0.92	0.01	0.95
Oilseeds & pulses	0.14	1.40	0.02	1.34	0.02	0.47	0.01	1.93
Vegetables &fruits	0.88	8.91	0.01	0.70	0.03	0.74	0.0018	0.27
Roots &tubers	0.12	1.22	0.0004	0.03	0.01	0.29	0.0011	0.17
Sugar crops	0.02	0.20	0.0048	0.39	0.0007	0.02	0.0001	0.01
Non-food crops	0.0012	0.01	0.02	1.73	0.0002	0.01	0.0040	0.60
Non-ruminant meat	0.58	5.87	0.08	6.23	0.26	6.98	0.05	7.09
Dairy products	0.22	2.23	0.18	15.00	0.29	7.81	0.09	13.06
Ruminant meat	1.41	14.24	0.53	42.72	0.75	20.07	0.18	27.41
Forestry [b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compound feed	0.17	1.69	0.01	0.47	0.06	1.49	0.01	1.04
Cereal bran	0.0000149	0.0002	0.0000018	0.0001	0.0000034	0.0001	0.0000005	0.0001
Alcoholic pulp	0.000000317	0.000003	0.000000019	0.000002	0.000000054	0.000001	0.000000004	0.000001
Oil cake	0.000004	0.00004	0.000013	0.00104	0.000016	0.00043	0.000011	0.00157
Processed food	1.35	13.67	0.07	5.32	0.45	12.08	0.04	6.51
Nitrogen fertiliser	0.0002	0.002	0.0001	0.004	0.0005	0.014	0.0001	0.009
Phosphorus fertiliser	0.0002	0.002	0.0002	0.016	0.0006	0.015	0.0001	0.013
Non-food	3.97	40.07	0.30	24.09	1.83	49.11	0.28	40.95
Total	9.91	100.00	1.23	100.00	3.72	100.00	0.67	100.00

[a] Data source: Hamilton, et al. [43]. Emissions of food processing by-products (i.e., cereal bran, alcoholic pulp, oil cake) were derived from Mackenzie, et al. [39]. [b] Note: Forestry sector has no emissions of eutrophication pollutants.

Appendix Table 10 | Emission intensities of greenhouse gases (t CO_2 equivalents million USD^{-1}) in China and its main food and feed trading partners.[a]

	China	Brazil	United States	Canada
Cereal grains	1435	766	1423	1783
Oilseeds & pulses	360	120	66	897
Vegetables &fruits	203	50	26	10
Roots &tubers	264	34	88	118
Sugar crops	142	659	34	2
Non-food crops	7923	760	1244	293
Non-ruminant meat	445	1107	494	851
Dairy products	2662	2836	620	461
Ruminant meat	4252	10762	2531	4470
Forestry [b]	0	0	0	0
Compound feed	431	133	273	289
Cereal bran	2.21	0.35	1.15	1.47
Alcoholic pulp	0.29	0.09	0.004	0.006
Oil cake	77	1150	3.16	8.88
Processed food	473	137	277	292
Nitrogen fertiliser	25477	7190	26461	11076
Phosphorus fertiliser	5389	2017	3254	2734
Non-food	3589	532	523	739

[a] Data source: Calculated by our study. [b] Note: Forest carbon stock applies only to scenarios S1–S4 and is calculated using annual forestry carbon sequestration intensities provided in Supplementary Table 11.

Appendix Table 11 | Emission intensities of acidification pollutants (t NH_3 equivalents million USD^{-1}) in China and its main food and feed trading partners.[a]

	China	Brazil	United States	Canada
Cereal grains	20.43	4.28	12.44	12.29
Oilseeds & pulses	12.42	1.59	1.20	13.67
Vegetables &fruits	7.02	0.65	0.47	0.16
Roots &tubers	9.10	0.44	1.59	1.81
Sugar crops	4.90	8.71	0.61	0.03
Non-food crops	273.39	10.05	22.44	4.46
Non-ruminant meat	29.26	21.95	28.72	29.37
Dairy products	11.45	3.94	0.97	0.59
Ruminant meat	42.14	5.06	9.17	7.75
Forestry [b]	0.00	0.00	0.00	0.00
Compound feed	0.75	0.36	0.27	0.42
Cereal bran	0.10	0.02	0.05	0.06
Alcoholic pulp	0.002	0.0005	0.00002	0.00004
Oil cake	3.93	59.03	0.16	0.45
Processed food	0.82	0.37	0.27	0.42
Nitrogen fertiliser	0.07	0.41	1.41	0.16
Phosphorus fertiliser	0.15	0.66	1.00	1.81
Non-food	6.41	1.46	0.52	1.11

[a] Data source: Calculated by our study. [b] Note: Forestry sector has no emissions of acidification pollutants.

Appendix Table 12 | Emission intensities of eutrophication pollutants (t N equivalents million USD^{-1}) in China and its main food and feed trading partners.[a]

	China	Brazil	United States	Canada
Cereal grains	5.39	0.80	0.59	0.88
Oilseeds & pulses	6.33	0.92	0.46	2.90
Vegetables &fruits	3.25	0.28	0.43	0.27
Roots &tubers	4.21	0.18	1.33	2.61
Sugar crops	0.62	0.69	0.04	0.02
Non-food crops	5.31	1.21	0.20	1.01
Non-ruminant meat	3.27	4.77	3.25	5.72
Dairy products	15.19	9.98	4.14	8.25
Ruminant meat	29.08	14.69	10.13	29.88
Forestry [b]	0.00	0.00	0.00	0.00
Compound feed	2.86	0.72	1.14	1.10
Cereal bran	0.004	0.001	0.002	0.003
Alcoholic pulp	0.001	0.0002	0.00001	0.00002
Oil cake	0.18	2.78	0.01	0.02
Processed food	3.13	0.75	1.16	1.11
Nitrogen fertiliser	0.02	0.08	0.27	0.03
Phosphorus fertiliser	0.05	0.19	0.29	0.59
Non-food	1.36	0.26	0.17	0.34

[a] Data source: Calculated by our study. [b] Note: Forestry sector has no emissions of eutrophication pollutants.