SUPPLEMENTARY INFORMATION

Land-use emission leakages from China's dietary shift and afforestation amplify food insecurity and economic losses under the 2 °C target

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Contents

Mathematically, various ways exist to represent applied general equilibrium (AGE) models, all of which describe the same model and lead to the same equilibrium solutions [1]. To identify the optimal solution towards greater sustainability and enable the efficient allocation of resources in the economy, we use the Negishi welfare format of the AGE models for our analysis. We chose this format because it is more effective in addressing tipping points and non-convexities, similar to the start of the era of large-scale integrated assessment models, i.e., dynamic integrated climate-economy (DICE) model [2]. This is crucial for addressing sustainability challenges, as many environmental issues involve non-convexities that deviate from conventional economic assumptions. The Supplementary Information (SI) is structured into three sections: Supplementary Methods, Supplementary Results, and Supplementary Discussion. In the Supplementary Methods, we specify the model for our study by explicitly considering producers, consumers, production goods, consumption goods, and intermediate goods. This is followed by a description of the model calibration and scenario definitions. The subsequent sections present the Supplementary Discussion. Finally, we provide 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 [3].

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

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:

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

where consumption goods s refers to cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, other 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, other 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:

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

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

$$(COF_{i,j})^{\eta_{14i,j}}(BRAN_{i,j})^{\eta_{15i,j}}(PULP_{i,j})^{\eta_{16i,j}}(CAKE_{i,j})^{\eta_{17i,j}} \quad (3)$$

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, other 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, an*d* $\sum_{f=1}^{18} \eta_f = 1$.

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), livestock (non-ruminant meat, dairy products, and ruminant meat) 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 and phosphorus, 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, specifying that crop yields per hectare remain constant. Since there is no substitution between feed input and factor input for livestock production (simply because livestock must eat), we kept the total output of livestock as a fixed ratio of feed inputs. A similar constraint was applied to the relationship between livestock (dairy products and ruminant meat) output and pastureland input, specifying that livestock 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:

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

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:

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

$$\delta_{i,frs} = \frac{LD3_{i,frs}}{LD3_{i,frs}+FRS_{i,frs}} \quad (6)$$

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. [4] are presented in **Supplementary Table 11**. $\delta_{i,frs}$ 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. [5] and Golub, et al. [4].

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 [5-8]. 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. A three-tier structure of land supply is provided in **Supplementary Fig. 1**. We classify forest land into accessible and inaccessible categories based on the country-specific shares of accessible forest area, using data provided by Sohngen, et al. [9]. Accessible forests include both managed (timber-producing) and unmanaged forests. Inaccessible forest land is excluded from our modelling, as we assume that deforestation occurs on the accessible forest land, which is less costly to access than the remaining inaccessible forest land.

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. [6], 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 absolute elasticity of transformation between agricultural land and forest land (-0.25) is lower than that between cropland and pastureland (-0.5). Both are lower than the absolute elasticities of transformation among crop types (-1.0) and between dairy products and ruminant meat (-1.0). Elasticities of transformation between different land types by region, which are derived from Golub, et al. [4], are presented in **Supplementary Table 12**.

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 other 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:

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

$$\delta_{i,agr} = \frac{LDLV_{i,agr}}{LDLV_{i,agr}+LDCRO_{i,agr}} \tag{10}$$

where $LDAGR_{i,frs}$ 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:

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

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

where $LDAGF_{i,agf}$ is the composite of agricultural land (i.e., cropland and pastureland) and accessible 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 accessible forest land in the composite of agricultural land (i.e., cropland and pastureland) and accessible forest 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 [10-12]. The constraint on the physical area of total land in region i is specified as follows:

$$CROLD_i + PASLD_i + FRSLD_i \leq \overline{TOTALD_i} \tag{13}$$

where $CROLD_i$, $PASLD_i$, and $FRSLD_i$ are the physical area of cropland, pastureland, and accessible 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:

$$\varepsilon_{gg,i,j} = \frac{EM^{+0}_{gg,i,j}}{Y^0_{i,j}} \tag{14}$$

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

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

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. [13].

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

$$\mathrm{CSTOCK}_{i,frs} \leq \mathrm{CSTOCK0}_{i,frs} + (NEWFRSLD_i - FRSLD_i) * FCS_i \tag{20}$$

$$NETMG_i^{+} = \sum_j EMG_{i,j}^{+} - \mathrm{CSTOCK}_{i,frs} \qquad (p_{eg,i}) \tag{21}$$

where $\mathrm{CSTOCK}_{i,frs}$ and $\mathrm{CSTOCK0}_{i,frs}$ are the forest carbon stock in scenarios S0-S4 and in the baseline scenario S0, respectively. $NEWFRSLD_i$ and $FRSLD_i$ are the physical area of accessible forest land in scenarios S0-S4 and in 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 [14] and BSI [15]. FCS_i derived from Nguyen, et al. [16] and China's National Forest Management Plan (2016-2050) [17] is presented in **Supplementary Table 13**. $NETMG_i^{+}$ is the net total GHGs emissions including forest carbon sequestration in scenarios S0-S4 in region i.

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 other 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 other 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 [18]. 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 other non-food crops in region i are as follows:

$$C_{i,cer} + CER_{i,oap} + CER_{i,rmk} + CER_{i,ctl} + CER_{i,cof} + CER_{i,bran} + CER_{i,pulp} + CER_{i,otf} + XNET_{i,cer} \leq Y_{i,cer} \qquad (p_{i,cer}) \tag{22}$$

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

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

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

(25)

$$C_{i,sgr} + SGR_{i,oap} + SGR_{i,rmk} + SGR_{i,ctl} + SGR_{i,cof} + SGR_{i,otf} + XNET_{i,sgr} \le Y_{i,sgr} \quad (p_{i,sgr})$$

(26)

$$C_{i,ocr} + OCR_{i,oap} + OCR_{i,rmk} + OCR_{i,ctl} + OCR_{i,cof} + OCR_{i,otf} + XNET_{i,vf} \le Y_{i,ocr} \quad (p_{i,ocr})$$

(27)

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 other 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 other 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:

$$BRAN_{i,oap} + XNET_{i,bran} \le Y_{i,bran} \qquad (p_{i,bran}) \tag{28}$$

$$PULP_{i,oap} + XNET_{i,pulp} \le Y_{i,pulp} \qquad (p_{i,pulp}) \tag{29}$$

$$CAKE_{i,oap} + XNET_{i,cake} \le Y_{i,cake} \qquad (p_{i,cake}) \tag{30}$$

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:

$$COF_{i,oap} + COF_{i,rmk} + COF_{i,ctl} + XNET_{i,cof} \le Y_{i,cof} \qquad (p_{i,cof}) \tag{31}$$

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:

$$C_{i,j} + XNET_{i,j} \le Y_{i,j} \qquad (p_{i,j}) \tag{32}$$

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:

$$C_{i,frs} + FRS_{i,frs} + FRS_{i,nf} + XNET_{i,frs} \le Y_{i,frs} \qquad (p_{i,frs}) \tag{33}$$

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:

$$NFE_{i,cer} + NFE_{i,osd} + NFE_{i,vf} + NFE_{i,rt} + NFE_{i,sgr} + NFE_{i,ocr} + XNET_{i,nfe} \leq Y_{i,nfe} \qquad (p_{i,nfe}) \tag{34}$$

$$PFE_{i,cer} + PFE_{i,osd} + PFE_{i,vf} + PFE_{i,rt} + PFE_{i,sgr} + PFE_{i,ocr} + XNET_{i,pfe} \leq Y_{i,pfe} \qquad (p_{i,pfe}) \tag{35}$$

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 other 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 other 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:

$$\textstyle\sum_i XNET_{i,j} = 0 \qquad (p_j) \tag{36}$$

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:

$$\textstyle\sum_j KL_{i,j} \leq \overline{TKL_i} \qquad (r_i) \tag{37}$$

$$\textstyle\sum_j LB_{i,j} \leq \overline{TLB_i} \qquad (w_i) \tag{38}$$

$$\textstyle\sum_j LD1_{i,j} \leq \overline{TLD1_i}$$

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

(39)

$$\textstyle\sum_j LD2_{i,j} \leq \overline{TLD2_i}$$

for sector j = dairy products and ruminant meat

(40)

$$\textstyle\sum_j LD3_{i,j} \leq \overline{TLD3_i}$$

for sector j = forestry

(41)

$$\textstyle\sum_j LD1_{i,j} + \sum_j LD2_{i,j} + \sum_j LD3_{i,j} \leq \overline{TLD1_i} + \overline{TLD2_i} + \overline{TLD3_i} \qquad (k_i) \tag{42}$$

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, and k_i are the shadow prices of capital, labour, and 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:

$$\textstyle\sum_j EMG^{+}_{i,j} + \mathrm{CSTOCK}_{i,frs} \leq \overline{NETMG^{+}_i} \qquad (p_{eg,i}) \tag{43}$$

$$\textstyle\sum_j EMA^{+}_{i,j} \leq \overline{TMA^{+}_i} \qquad (p_{ea,i}) \tag{44}$$

$$\sum_j EME_{i,j}^{+} \leq \overline{TME_i^{+}} \qquad (p_{ee,i}) \tag{45}$$

where $\overline{NETMG_i^{+}}$ is the permitted level of the net total GHGs emissions including forest carbon sequestration in region i. $\overline{TMA_i^{+}}$ and $\overline{TME_i^{+}}$ are the permitted level of the total emissions of 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.

Shadow prices

In the Negishi welfare format of the AGE model, there are no direct price equations. Instead, the vector of Lagrange multipliers associated with the commodity constraints reflects the contribution of the associated commodities to the objective function of social welfare maximisation, referred as shadow prices. The vector of shadow prices is a vector of parameters that are used to verify whether the budget constraint of each consumer holds. Specifically, the shadow price of a good corresponds to the marginal value of the associated market clearance condition. For example, suppose that emission permits for all sectors in the entire economy are in fixed supply, and all producers demand emission permits. Then, the equilibrium permit price is given by the marginal value of the equation stating that the total demand for emission permits equals the supply of permits. Similarly, the shadow prices of goods and factors are equal to the marginal values for the corresponding market clearance conditions. In our simulations, the endogenous emission taxes in scenarios S3 and S4 are determined as the shadow prices of the emission constraints (equation 55). These emission taxes represent the marginal cost of emitting one additional unit under certain emission caps. According to the first-order Kuhn-Tucker conditions, these emission taxes increase marginal production costs, which, under competitive market assumptions, are passed to consumer prices. A fundamental property of AGE models is that doubling all prices and incomes does not change demand and supply. This reflects the theoretical requirement that only relative prices matter and that an infinite number of solutions to an AGE model exist. For example, multiplying a solution (i.e., all prices) by a factor x gives a new solution. To ensure uniqueness, a price numeraire must be selected. In our model, the price of labour in China serves as the price numeraire. Consequently, all other prices are scaled and thus relative to the price of labour in China.

We can directly derive a set of shadow prices from the general algebraic modelling system (GAMS) software package [19]. GAMS may take several steps to converge to the equilibrium (i.e., the budget constraint is fulfilled). Thus, we use an explicit iteration procedure (in the current base model, we assume 50 times) to update the values of shadow prices and solve the model iteratively. The GAMS solver can compare the value of the objective function with the one from the previous solve. If no further improvement in the objective function is possible under the current set of shadow prices, we can consider that the "optimal" solution has been found. This iterative process is implemented using a LOOP command in GAMS. After the SOLVE statement, but still inside the LOOP, the model recalculates the shadow prices using the marginal values of the equations and income.

Budget constraint

Since goods are tradable, the consumer has to either finance its trade deficit or invest its trade surplus. Thus, the budget constraint for consumer i holds such that total expenditure, adjusted for the trade balance, must equal be equal to the income:

$$Exp_i + \sum_j (p_j XNET_{i,j}) = h_i \tag{46}$$

where Exp_i is the total expenditure of consumer in region i. $\sum_j (p_j XNET_{i,j})$ is the trade balance in region i. A positive trade balance value indicates a trade surplus in region i, while a negative trade balance value signifies a trade deficit in region i. h_i is the income of consumer in region i.

The total expenditure of consumer in region i consists of spending income on consumption of goods:

$$Exp_i = \sum_s (p_{i,s} C_{i,s}) \tag{47}$$

where consumption goods s refers to cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, other non-food crops, non-ruminant meat, dairy products, ruminant meat, processed food, and non-food. 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. Thus, the consumer's income is:

$$h_i = r_i \overline{TKL_i} + w_i \overline{TLB_i} + k_i(\overline{TLD1_i} + \overline{TLD2_i} + \overline{TLD3_i}) + p_{eg,i}\overline{TMG_i^+} + p_{ea,i}\overline{TMA_i^+} + p_{ee,i}\overline{TME_i^+} \tag{48}$$

where $p_{eg,i}\overline{TMG_i^+}$, $p_{ea,i}\overline{TMA_i^+}$, 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 and equal zero:

$$PROF_{i,j} = p_j Y_{i,j} - r_i KL_{i,j} - w_i LB_{i,j} - k_i(LD1_{i,j} + LD2_{i,j} + LD3_{i,j}) - p_{cer} CER_{i,j} - p_{osd} OSD_{i,j} - p_{vf} VF_{i,j} - p_{rt} RT_{i,j} - p_{sgr} SGR_{i,j} - p_{ocr} OCR_{i,j} - p_{cof} COF_{i,j} - p_{bran} BRAN_{i,j} - p_{pulp} PULP_{i,j} - p_{cake} CAKE_{i,j} - p_{nfe} NFE_{i,j} - p_{pfe} PFE_{i,j} - p_{frs} FRS_{i,j} - p_{eg,i} EMG_{i,j}^+ - p_{ea,i} EMA_{i,j}^+ - p_{ee,i} EME_{i,j}^+ \tag{49}$$

Model calibration

As in the literature on AGE models, we followed the Harberger convention [20] 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 [21]. 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 economic and environmental conditions of all sectors (including agriculture, industries, and services) in the entire economies of China and MTP in 2014. It corresponds to the Representative Concentration Pathway (RCP) 8.5 [22], the worst-case climate change scenario in which emissions continue to increase with no mitigation.

For scenarios S1-S4, in order to enable land-use changes across different land types, we relax the land supply constraints as outlined below:

$$\sum_j LD1_{i,j} \leq 1.1 * \overline{TLD1_i}$$

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

(50)

$$\sum_j LD2_{i,j} \leq 1.1 * \overline{TLD2_i}$$

for sector j = dairy products and ruminant meat

(51)

$$\sum_j LD3_{i,j} \leq 1.2 * \overline{TLD3_i}$$

for sector j = forestry

(52)

S1 – Food scenario: A dietary shift in China

In scenario S1, we simulate an exogenous dietary shift in China toward the Chinese Dietary Guidelines (CDG) 2022 diet recommendations [23]. We first estimate the gap in food consumption between current levels in China and the recommended targets in the CDG diet. Subsequently, we adjust China's food consumption patterns to close 20% of this gap, accounting for the unaffordability of a complete dietary shift for households. Detailed information about the dietary shift in China is provided in **Supplementary Table 10**.

In addition to primary food products, our model, like all GTAP-based global AGE models, also includes food processing sectors that connect primary production to final consumption. Following Gatto, et al. [24], we update primary contents based on the percentage change in food consumption, ensuring that quantities adjust proportionally to final demand. While not perfect, this approach allows us to impose a diet in terms of primary content, rather than fixing both primary and processed food consumption. Our model can, therefore, flexibly reallocate demand across food types, provided the dietary constraint is met. This approach addresses the challenge of multiple food items entering food processing sectors by applying a weighted change to intermediate inputs. Under the CDG scenario, the consumption of all crops except oilseeds & pulses and vegetables & fruits require a reduction, all of which are partly consumed via processed food. To estimate changes in processed food demand, we apply a weighted average of the reductions in all crops (excluding oilseeds & pulses and vegetables & fruits) and the increase in oilseeds & pulses and vegetables & fruits, using their primary content in processed food as weights, to approximate the dietary target as closely as possible.

The equation below shows an exogenous dietary shift towards the CDG 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, ruminant meat, and processed food

(53)

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 20% of the gap in food consumption between current levels in China and the recommended targets in the CDG diet.

S2 – Land scenario: An afforestation policy in China

In scenario S2, we simulate an afforestation policy in China based on the National Forest Management Plan (2016-2050) [17]. This plan outlines an ambitious tree-planting program to expand forest land in China by 23 Mha (equivalent to 4% of China's agricultural land) by 2030.

This afforestation policy increases the physical area of accessible forest land in China by 20%, as specified in the following equation:

$$NEWFRSLD_{CN} = 1.2 * FRSLD_{CN} \tag{54}$$

S3 – Climate scenario: A global uniform carbon tax with carbon tax revenue recycling

In scenario S3, we implement a global uniform carbon tax to achieve a 25% reduction in net total GHG emissions in China and MTP by 2030. This aligns with the 2°C climate stabilisation target [25] outlined in the Paris Agreement [26], which corresponds to the RCP2.6 and requires global GHG emissions to peak by 2025 and decline by 25% by 2030.

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

$$\sum_i NETMG_i^+ \leq 0.75 * \sum_i \overline{NETMG_i^+} \qquad (p_{eg}) \tag{55}$$

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 regional uniform carbon taxes.

The new consumer's income is specified as follows:

$$h_i = r_i\overline{TKL_i} + w_i\overline{TLB_i} + k_i(\overline{TLD1_i} + \overline{TLD2_i} + \overline{TLD3_i}) + p_{eg}\overline{TMG_i^+} + p_{ea,i}\overline{TMA_i^+} + p_{ee,i}\overline{TME_i^+} \tag{56}$$

The new producers' profits are specified as follows:

$$PROF_{i,j} = p_jY_{i,j} - r_iKL_{i,j} - w_iLB_{i,j} - k_i(LD1_{i,j} + LD2_{i,j} + LD3_{i,j}) - p_{cer}CER_{i,j} - p_{osd}OSD_{i,j} - p_{vf}VF_{i,j} - p_{rt}RT_{i,j} - p_{sgr}SGR_{i,j} - p_{ocr}OCR_{i,j} - p_{cof}COF_{i,j} - p_{bran}BRAN_{i,j} - p_{pulp}PULP_{i,j} - p_{cake}CAKE_{i,j} - p_{nfe}NFE_{i,j} - p_{pfe}PFE_{i,j} - p_{frs}FRS_{i,j} - p_{eg}EMG_{i,j}^+ - p_{ea,i}EMA_{i,j}^+ - p_{ee,i}EME_{i,j}^+ \tag{57}$$

We link our AGE model with the Global Timber Model (GTM) [27,28], a partial equilibrium, dynamic optimisation model representing the global forestry sector, by calibrating the forest carbon sequestration component of the AGE model. The calibration procedure aims to ensure that the two models produce consistent forest carbon sequestration responses under the same carbon tax rate. The calibration is performed by adjusting the incremental annual forestry carbon sequestration intensities to mimic the GTM's assumptions. In line with GTM, we assume that one hectare of new forest sequesters the same amount of carbon, regardless of whether it is converted from cropland or pastureland.

S4 – Combined scenarios: S1+S2+S3

In the combined scenario S4, all measures are combined to examine their potential synergies or trade-offs in the food-land-climate nexus. This scenario integrates China's dietary shift (S1) and afforestation policy (S2) with the implementation of a global uniform carbon tax with carbon tax revenue recycling (S3).

All additional equations introduced in scenarios S1-S3 are included in scenario S4, along with new constraints on forest land supply, as detailed below:

$$LD3_{CN,frs} \leq ((1 + PFRS1_{CN}) + (1 + PFRS2_{CN}) + (1 + PFRS3_{CN})) * \overline{TLD3_{CN}} \quad (58)$$

$$LD3_{BR,frs} \leq ((1 + PFRS1_{BR}) + (1 + PFRS2_{BR}) + (1 + PFRS3_{BR})) * \overline{TLD3_{BR}} \quad (59)$$

$$LD3_{US,frs} \leq ((1 + PFRS1_{US}) + (1 + PFRS2_{US}) + (1 + PFRS3_{US})) * \overline{TLD3_{US}} \quad (60)$$

$$LD3_{CA,frs} \leq ((1 + PFRS1_{CA}) + (1 + PFRS2_{CA}) + (1 + PFRS3_{CA})) * \overline{TLD3_{CA}} \quad (61)$$

where $PFRS1_i$, $PFRS2_i$, and $PFRS3_i$ are the computed percentage changes in the physical area of accessible forest land in scenarios S1, S2, and S3, respectively, compared to the baseline scenario (S0) in region i, respectively.

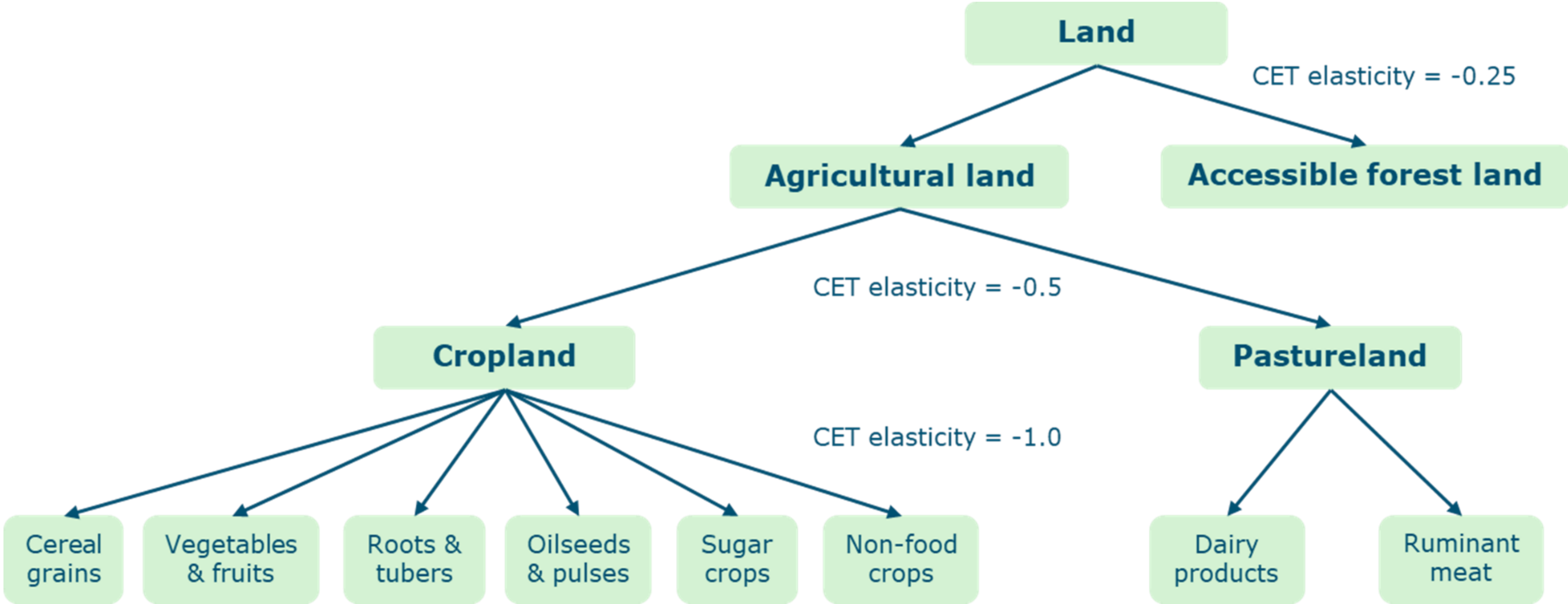
Supplementary Discussion

Limitations and future outlook

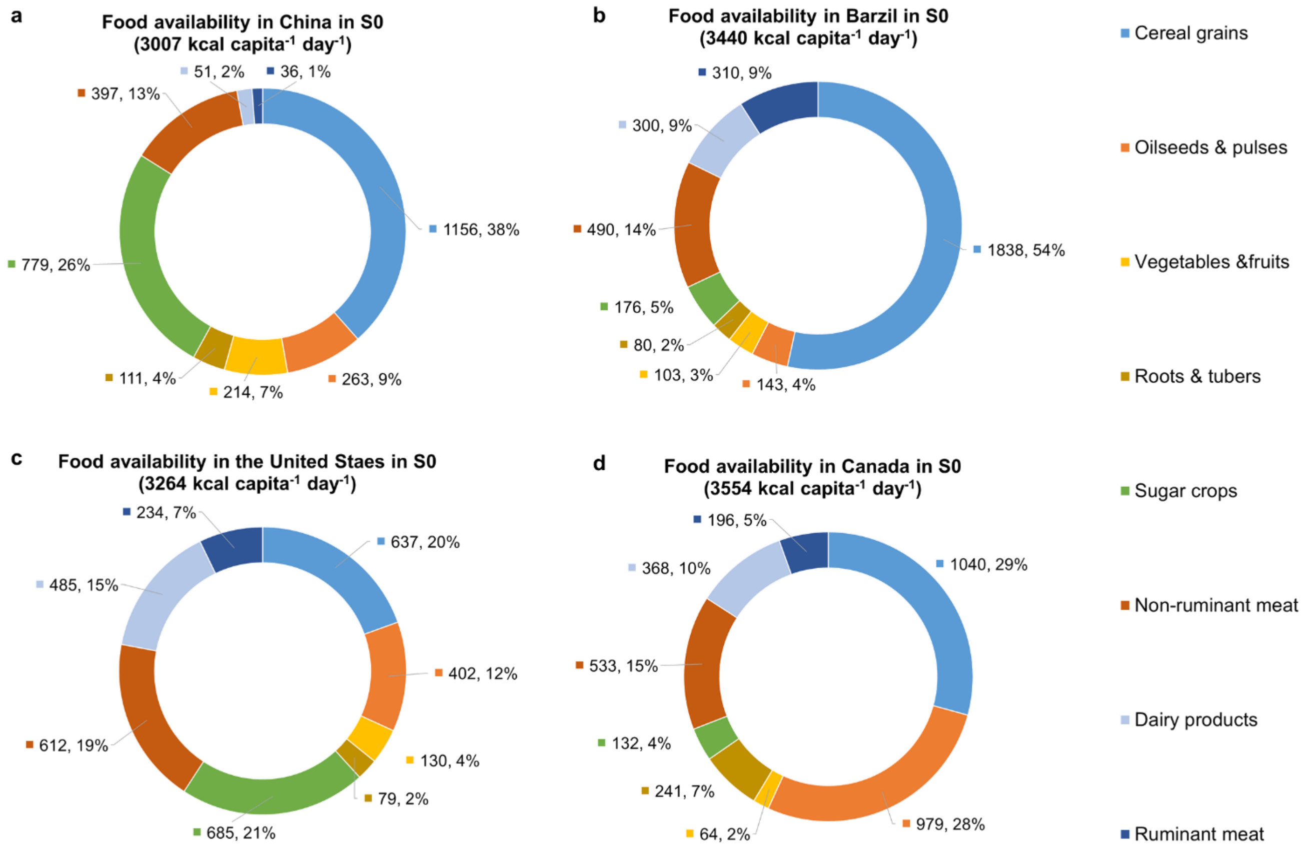
First, some specifications in our model are appropriate for illustrating potential synergies or trade-offs within the food-land-climate nexus, but some simplifications may exaggerate trends. Our model assumes fixed budget shares for consumers, fixed cost shares for producers, full mobility of factor endowments (capital, labour, and land) across sectors, the absence of trade barriers, and the treatment of domestic and imported goods as perfect substitutes. For instance, future research necessitates introducing separate labour and capital markets for agricultural and non-agricultural sectors or allowing for land shifts within agroecological zones with similar soil, landform, and climatic features, as included in the MAGNET [29] and GTAP-AEZ [30] models to account for barriers to factor mobility. Additionally, refining the trade assumption by adopting the Armington assumption [31], which allows for imperfect substitutability between domestic and imported goods, could provide a more nuanced representation of trade. However, this approach also adds complexity, weakens the role of comparative advantage, and may overstate trade frictions. Therefore, the careful selection of the Armington elasticity, which determines the ease of substitution between domestic and imported goods, is essential. Second, our model includes only China and MTP (i.e., Brazil, the United States, and Canada), which may underestimate land-use emission leakages from China's dietary shift and afforestation, thereby further amplifying food insecurity and economic losses under the 2 °C target. Although MTP accounts for over 75% of China's total food and feed trade value, expanding the model to include the rest of the world, especially China's main importers of dairy products and ruminant meat, such as Australia and New Zealand, could provide a more comprehensive assessment. Nonetheless, the omission is expected to result in limited underestimation, given Oceania's small contribution (0.3%) to the global accessible forest land area [32]. Third, our analysis does not account for the adverse effects of climate change on crop yields, which may lead to an underestimation of food insecurity and economic losses under the 2 °C target, though this would not alter our main conclusions. While this falls beyond the scope of our study, future research could include it in the food-land-climate nexus, as explored in previous research [7,33]. Fourth, this study employs a static modelling framework to isolate the impacts of China's dietary shift and afforestation under the 2 °C target, based on current economic conditions. This approach does not account for long-term dynamics (e.g., population growth, economic development, evolving trade policies) or external shocks (e.g., African swine fever, the US-China trade war, COVID-19). Since these factors could reshape crop and livestock production portfolios in China and its trading partners, with broader implications for global food security and environmental sustainability, future research could incorporate dynamic modelling and additional scenario analyses to better capture these uncertainties.

Other limitations include the lack of policy simulations to support dietary shifts, limited representation of socioeconomic and environmental heterogeneity, and the absence of health impact assessments, all of which present avenues for future research. For example, our analysis models the dietary shift by using a preference shift, without explicitly simulating the policy instruments required to induce such a shift, consistent with previous studies on dietary transition [24]. How to design and implement policies to promote this shift remains a critical area for future research. Additionally, incorporating within-country income distributions and variations in purchasing power into our modelling framework could further enhance the analysis of distributional impacts. Furthermore, the scope of the environmental impacts could be enhanced by including additional indicators, such as water use and biodiversity loss, which merit further study. Moreover, future research could enhance the model's spatial resolution to capture sub-national heterogeneity and identify deforestation hotspots, enabling more targeted policy design and offering a more comprehensive sustainability perspective. Last but not least, health impacts resulting from changes in food consumption, such as diet- and weight-related risks [34], could also be considered.

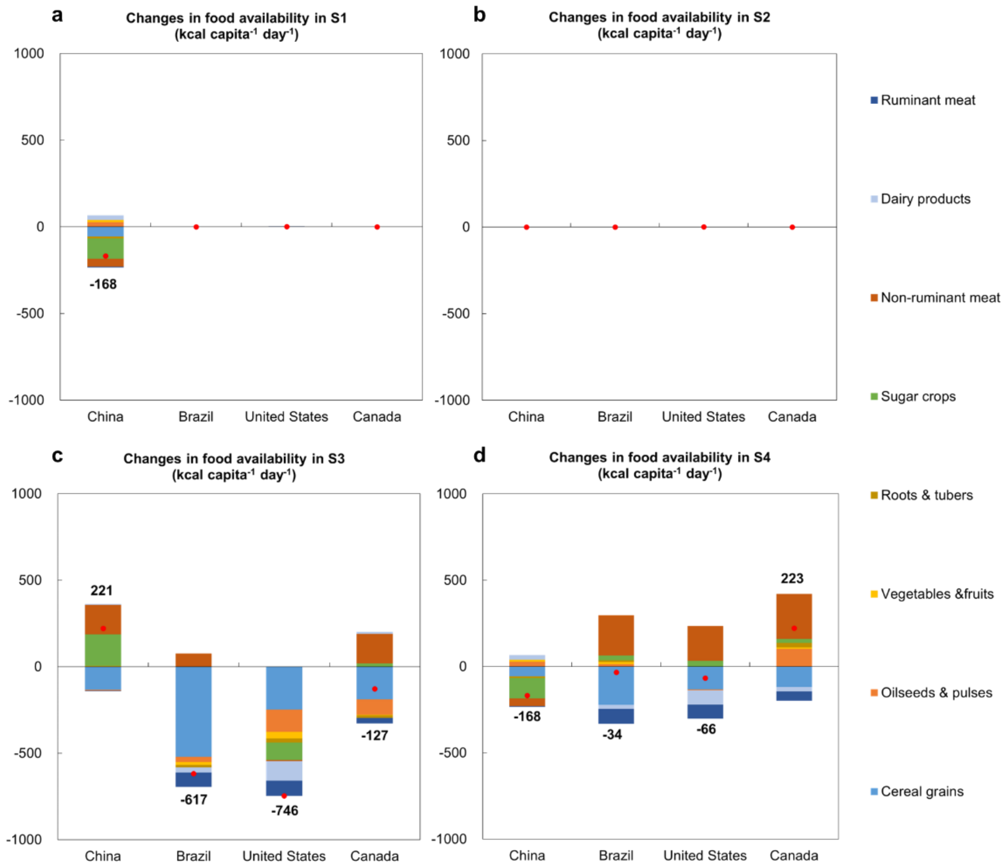
Supplementary Figures



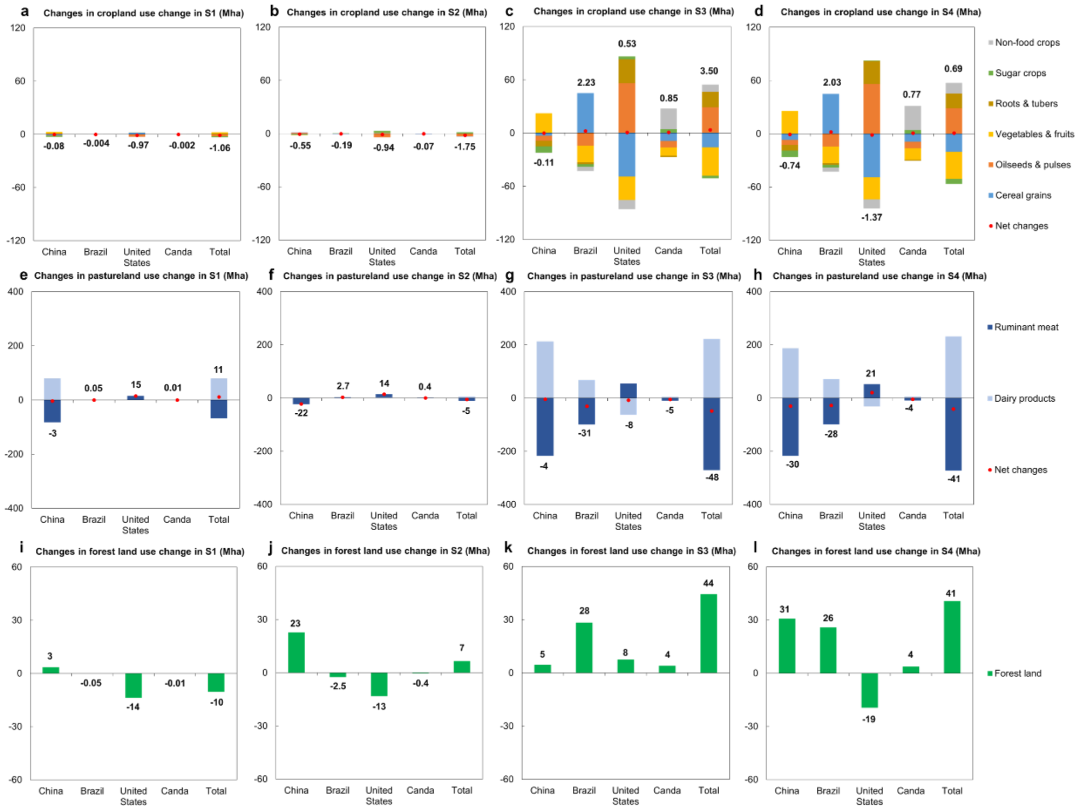
Supplementary Fig. 1 | Three-tier structure of land supply. CET = constant elasticity of transformation.



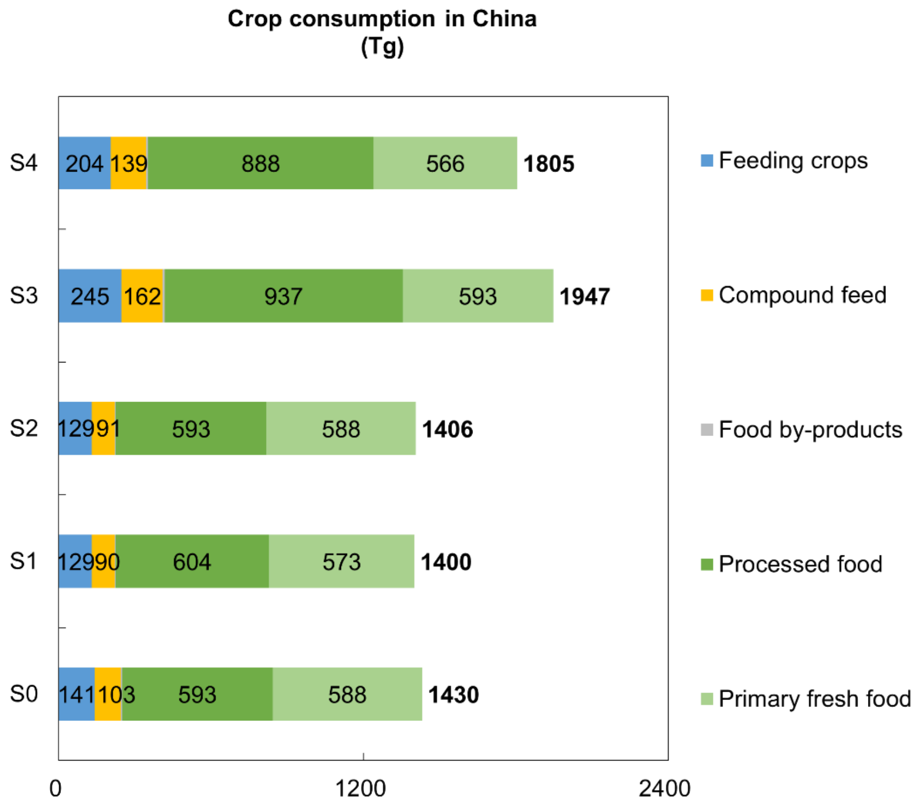
Supplementary Fig. 2 | Composition of food availability (%; kcal capita^{-1} day^{-1}) in (a) China, (b) Brazil, (c) the United Staes, and (d) Canada in the baseline (S0).



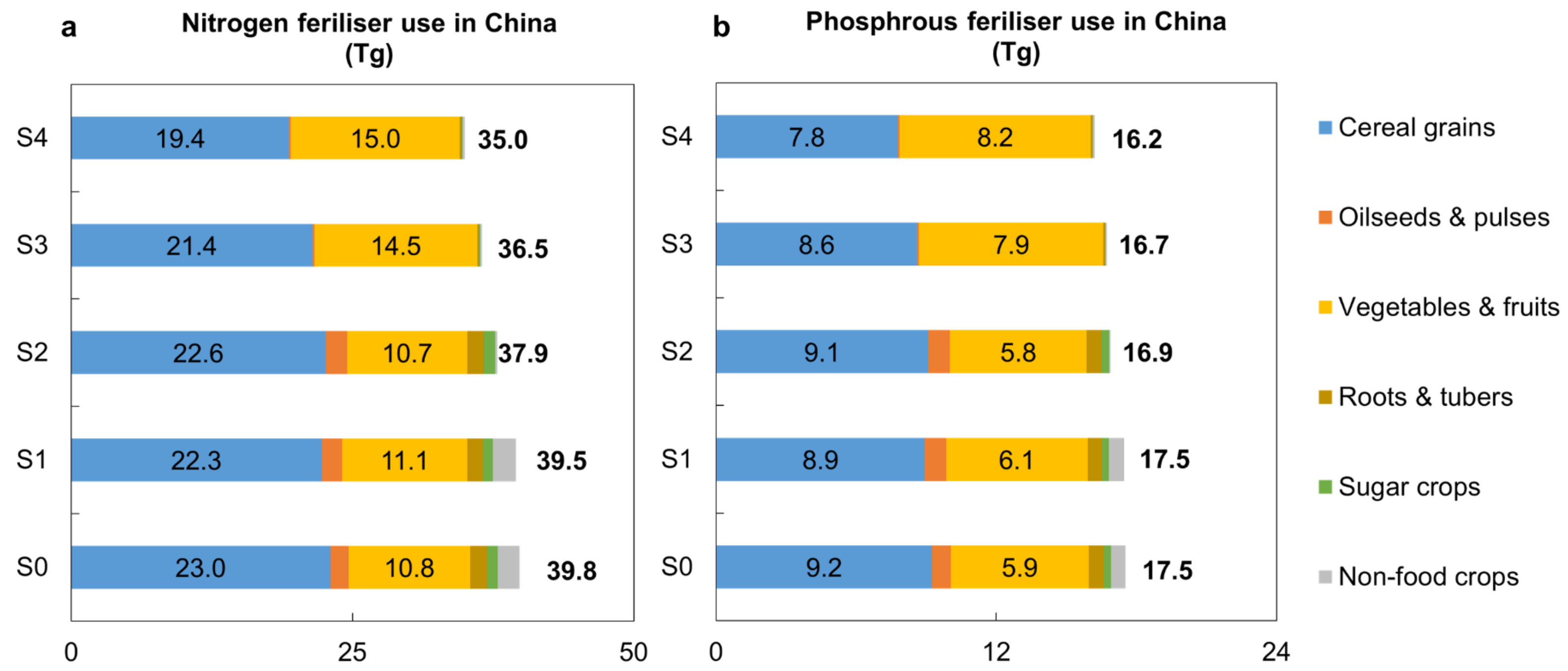
Supplementary Fig. 3 | Changes in food availability (kcal capita^{-1} day^{-1}) in China and MTP in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0).



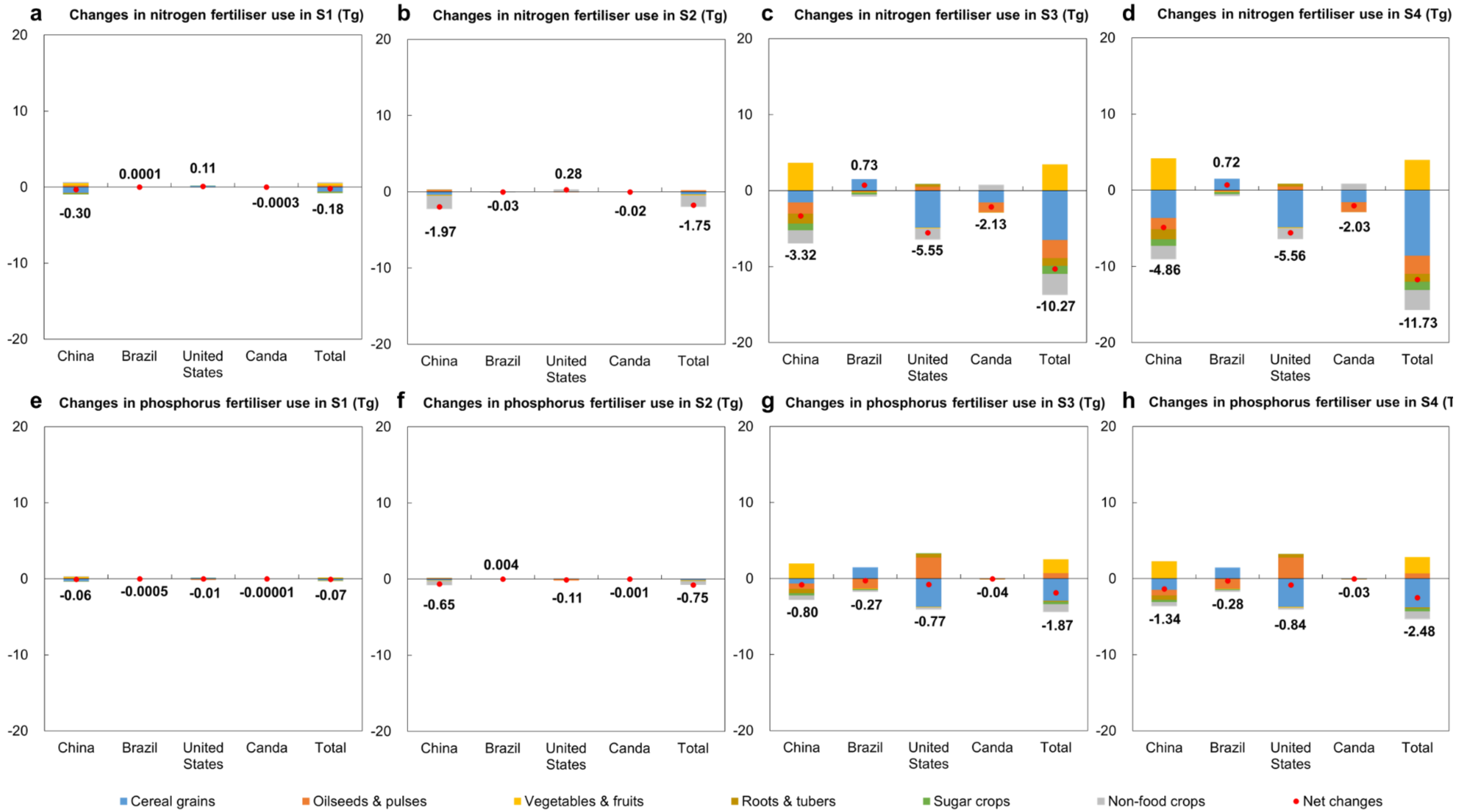
Supplementary Fig. 4 | Changes in cropland use (Mha) in China and MTP in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0). Changes in pastureland use (Mha) in China and MTP in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 with respect to the baseline (S0). Changes in forest land use (Mha) in China and MTP in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 with respect to the baseline (S0).



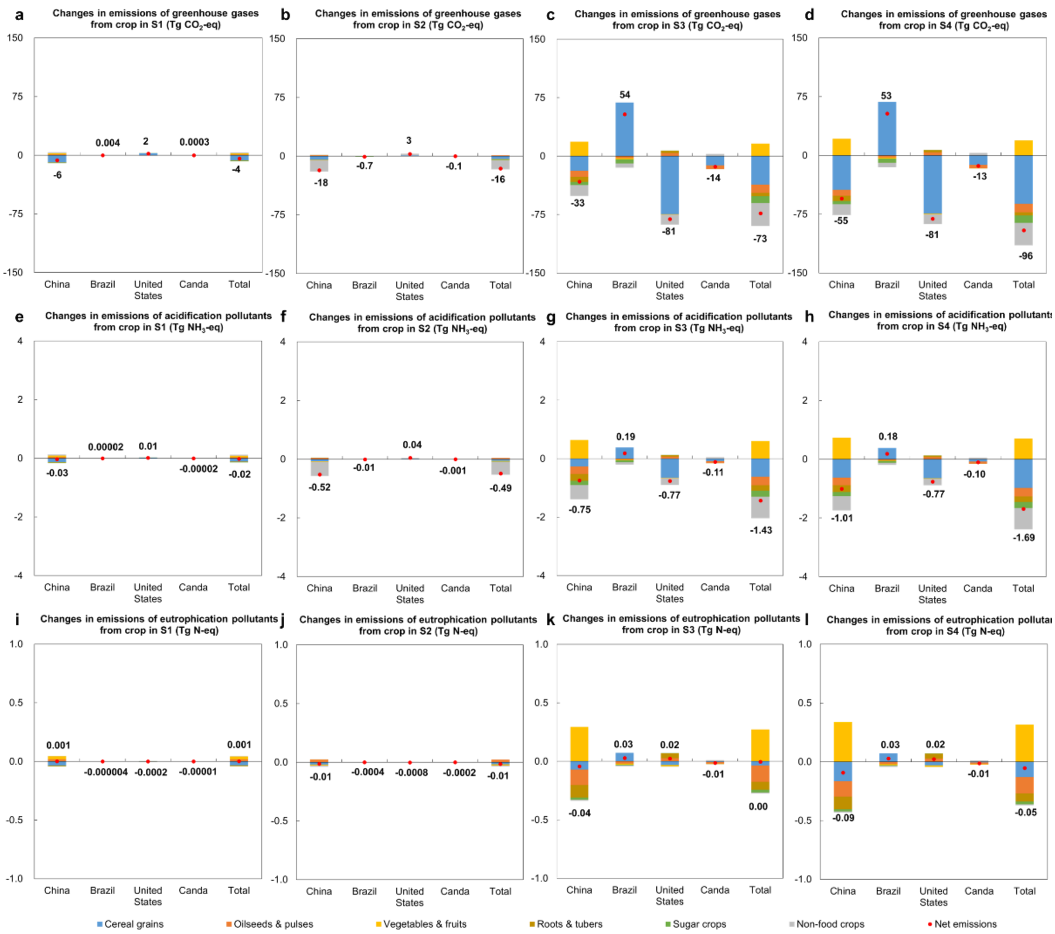
Supplementary Fig. 5 | Total crop consumption (Tg) in China in scenarios.



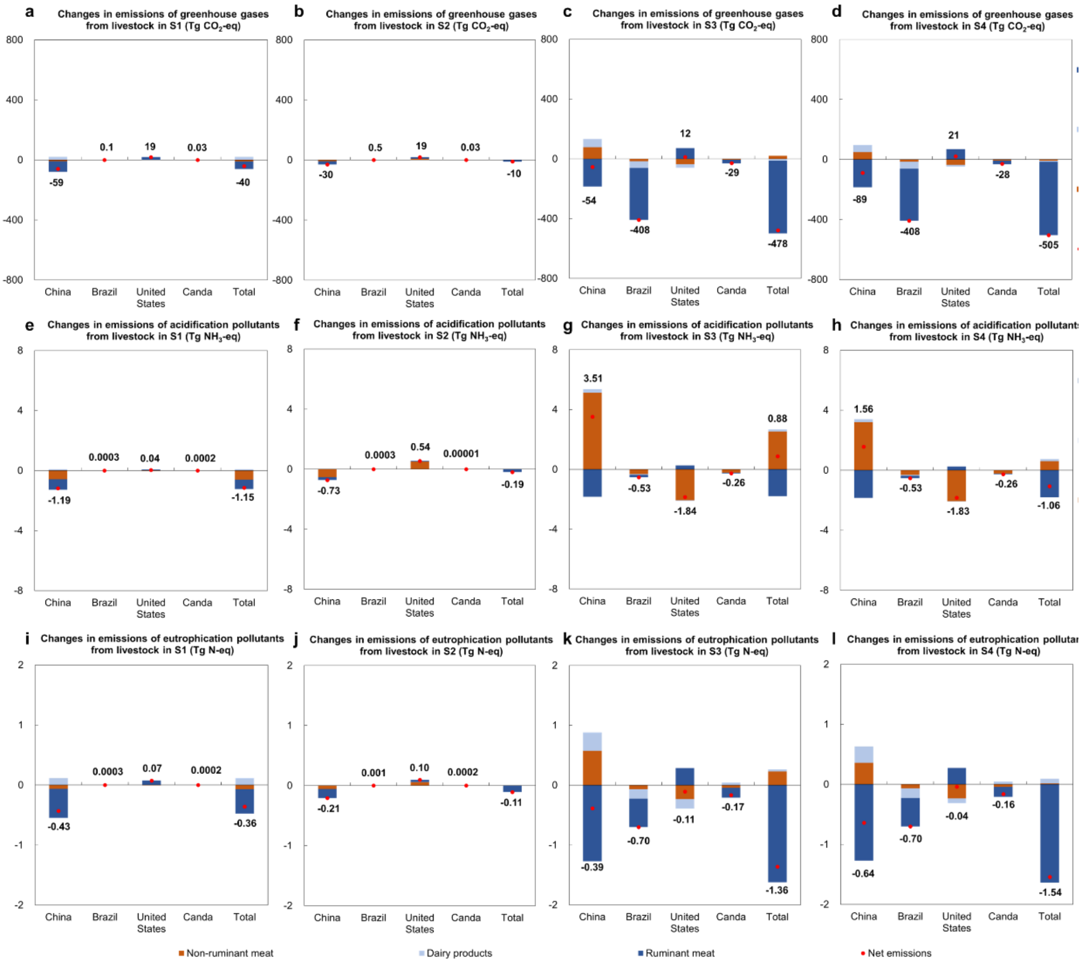
Supplementary Fig. 6 | Total (a) nitrogen fertiliser use (Tg) and (b) phosphorous fertiliser use (Tg) in China in scenarios.



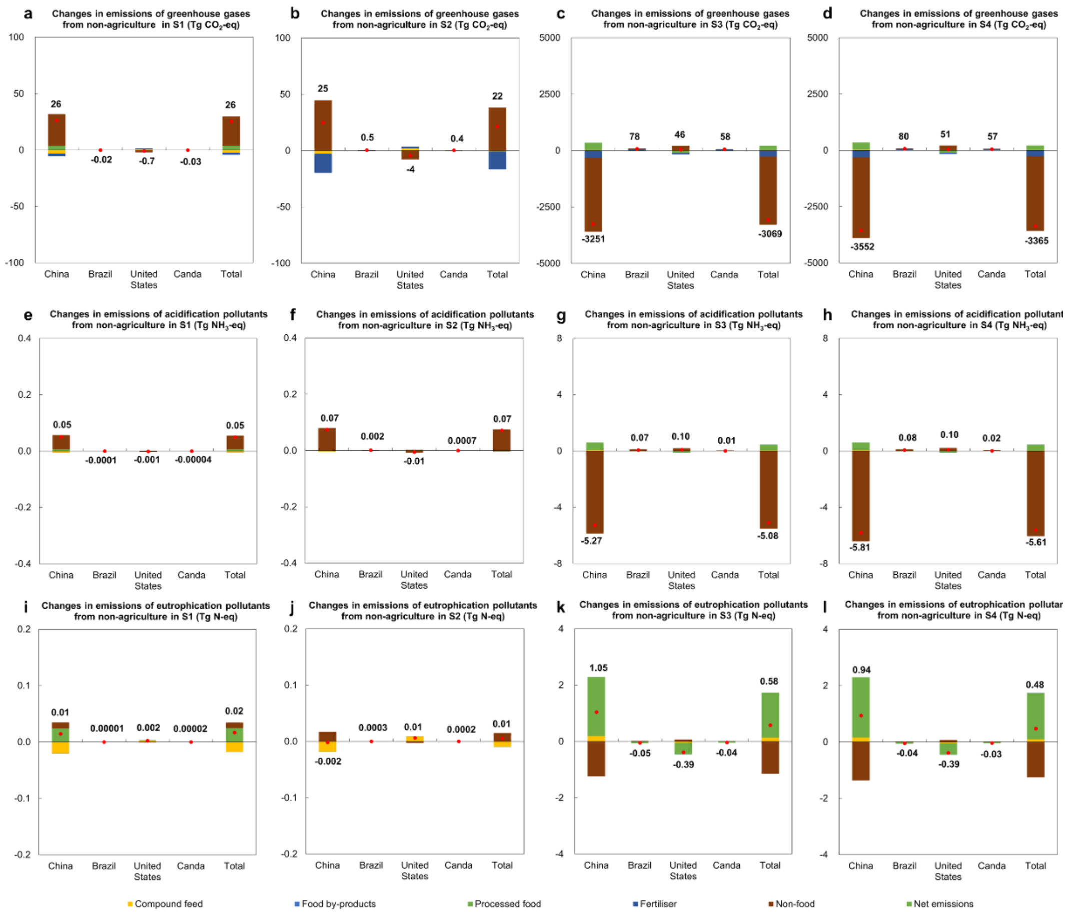
Supplementary Fig. 7 | Changes in nitrogen fertiliser use (Tg) in China and MTP in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0). Changes in phosphorous fertiliser use (Tg) in China and MTP in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 with respect to the baseline (S0).



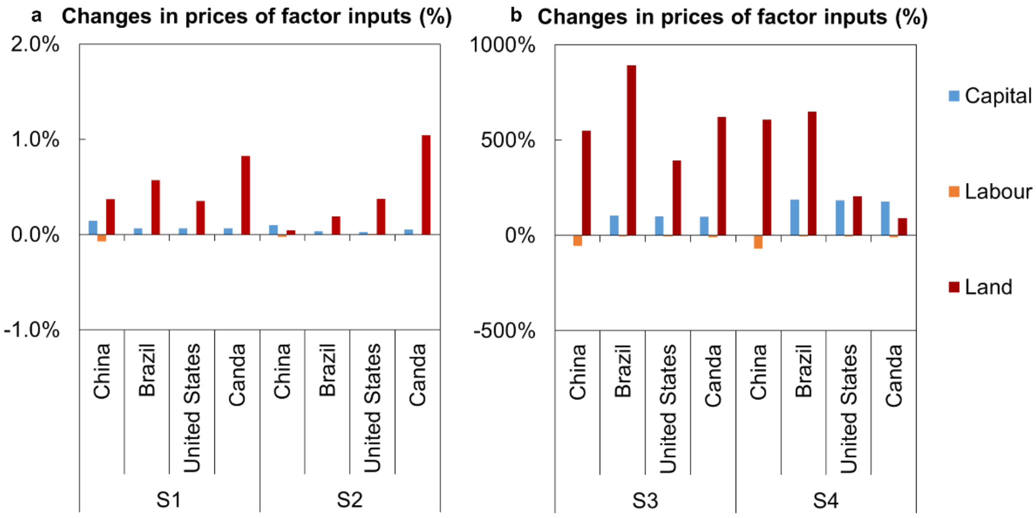
Supplementary Fig. 8 | Changes in emissions of greenhouse gases (Tg CO_2-eq) from crop setors in China and MTP in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0). Changes in emissions of acidification pollutants (Tg NH_3-eq) from crop setors in China and MTP in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 with respect to the baseline (S0). Changes in emissions of eutrophication pollutants (Tg N-eq) from crop setors in China and MTP in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 with respect to the baseline (S0).



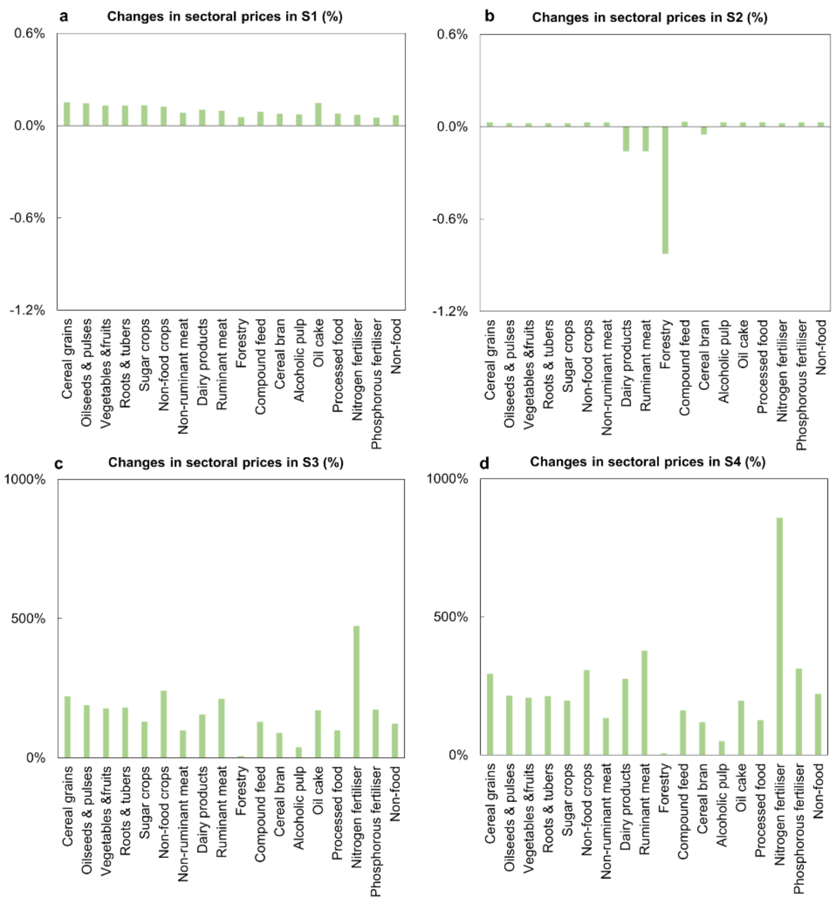
Supplementary Fig. 9 | Changes in emissions of greenhouse gases (Tg CO_2-eq) from livestock setors in China and MTP in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0). Changes in emissions of acidification pollutants (Tg NH_3-eq) from livestock setors in China and MTP in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 with respect to the baseline (S0). Changes in emissions of eutrophication pollutants (Tg N-eq) from livestock setors in China and MTP in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 with respect to the baseline (S0).



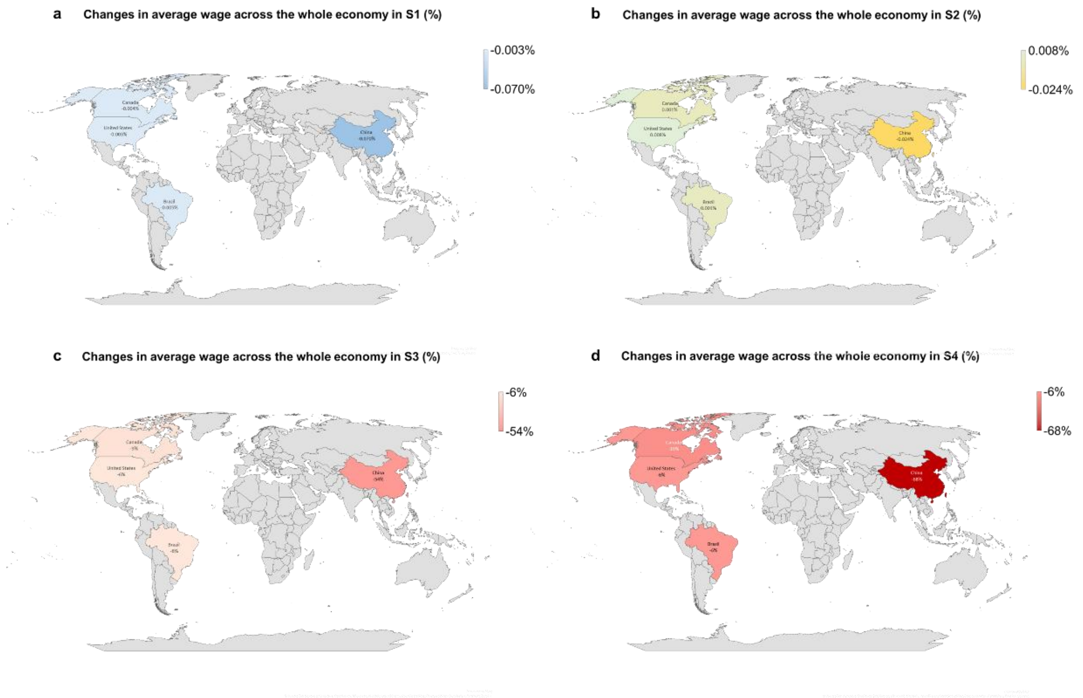
Supplementary Fig. 10 | Changes in emissions of greenhouse gases (Tg CO_2-eq) from non-agricultural setors in China and MTP in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0). Changes in emissions of acidification pollutants (Tg NH_3-eq) from non-agricultural setors in China and MTP in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 with respect to the baseline (S0). Changes in emissions of eutrophication pollutants (Tg N-eq) from non-agricultural setors in China and MTP in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 with respect to the baseline (S0).



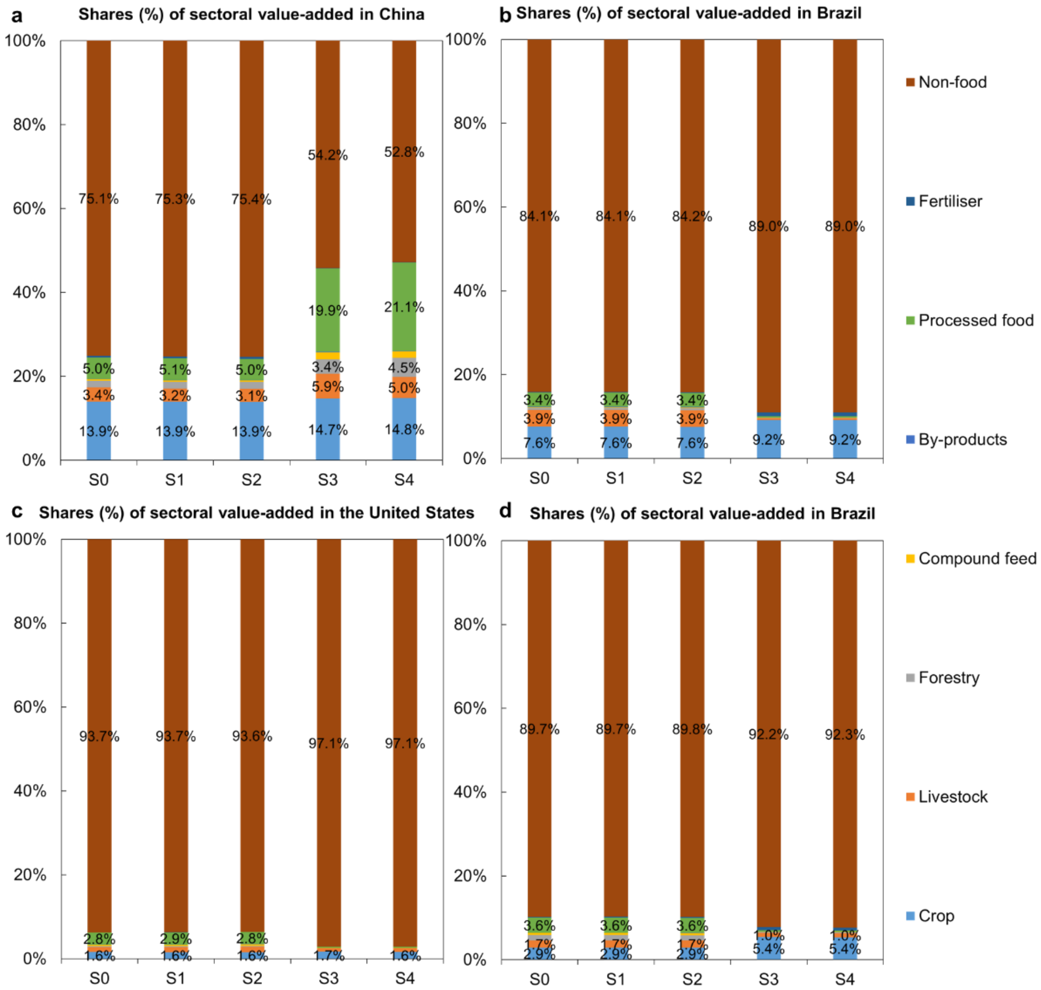
Supplementary Fig. 11 | Changes (%) in prices of factor inputs in scenarios (a) S1-S2 and (b) S3-S4 with respect to the baseline (S0).



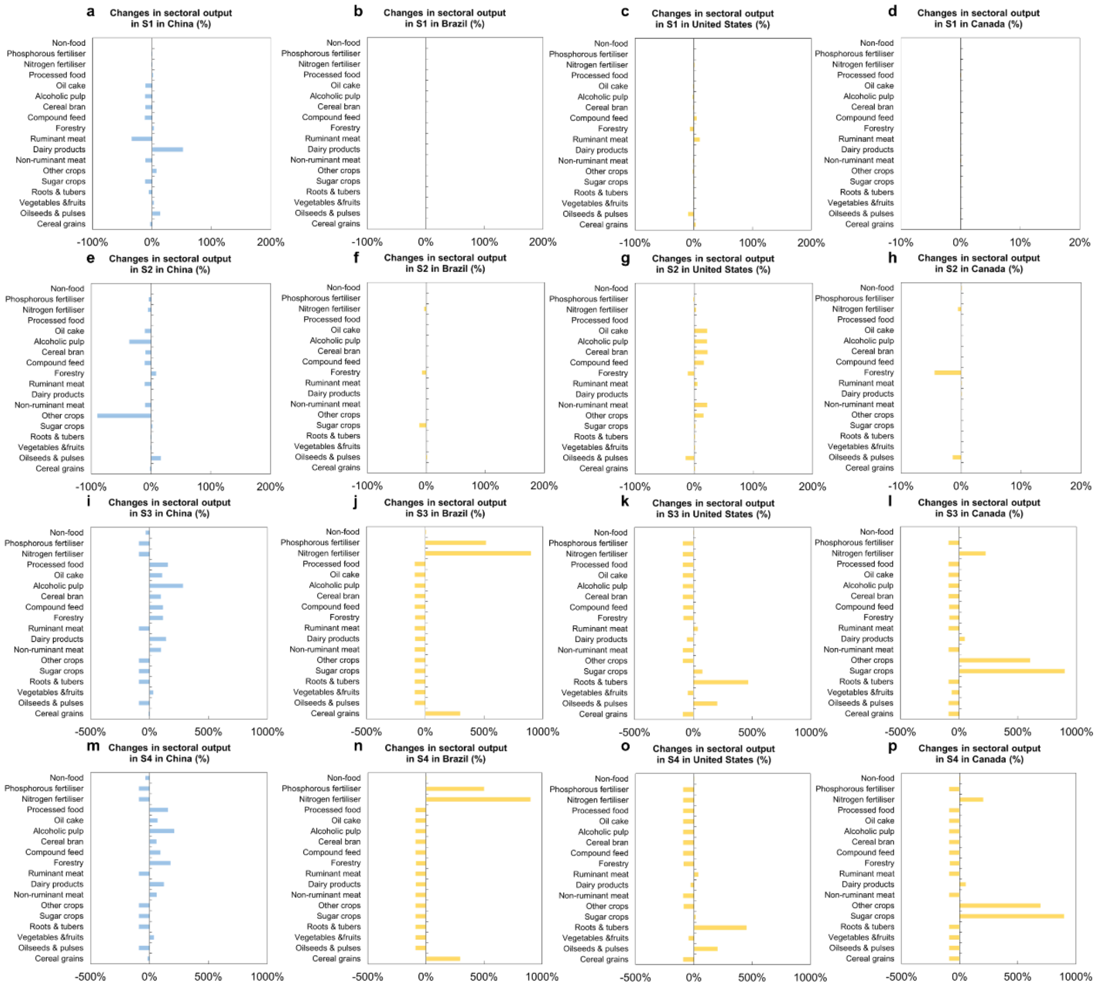
Supplementary Fig. 12 | Changes (%) in sectoral prices in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0).



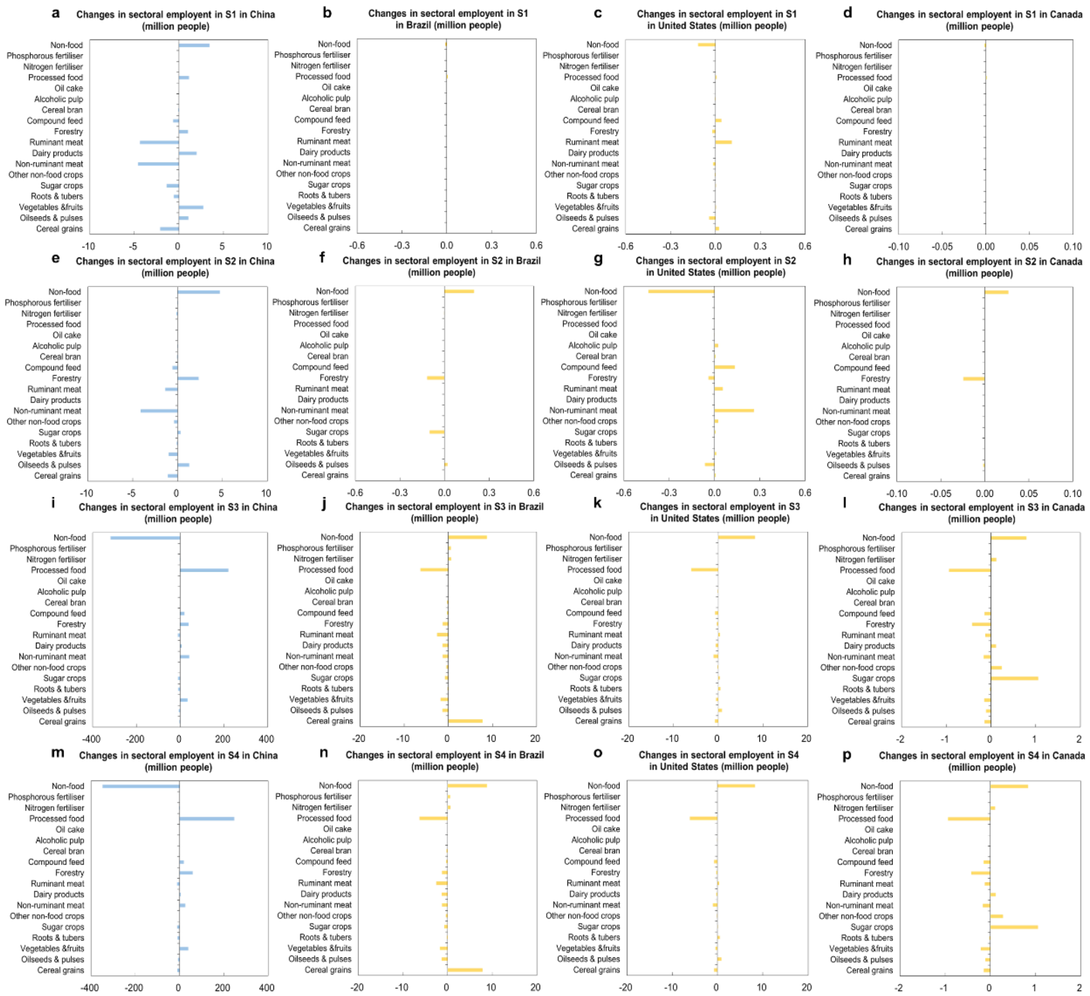
Supplementary Fig. 13 | Changes (%) in average wage across the whole economy in China and MTP in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0).



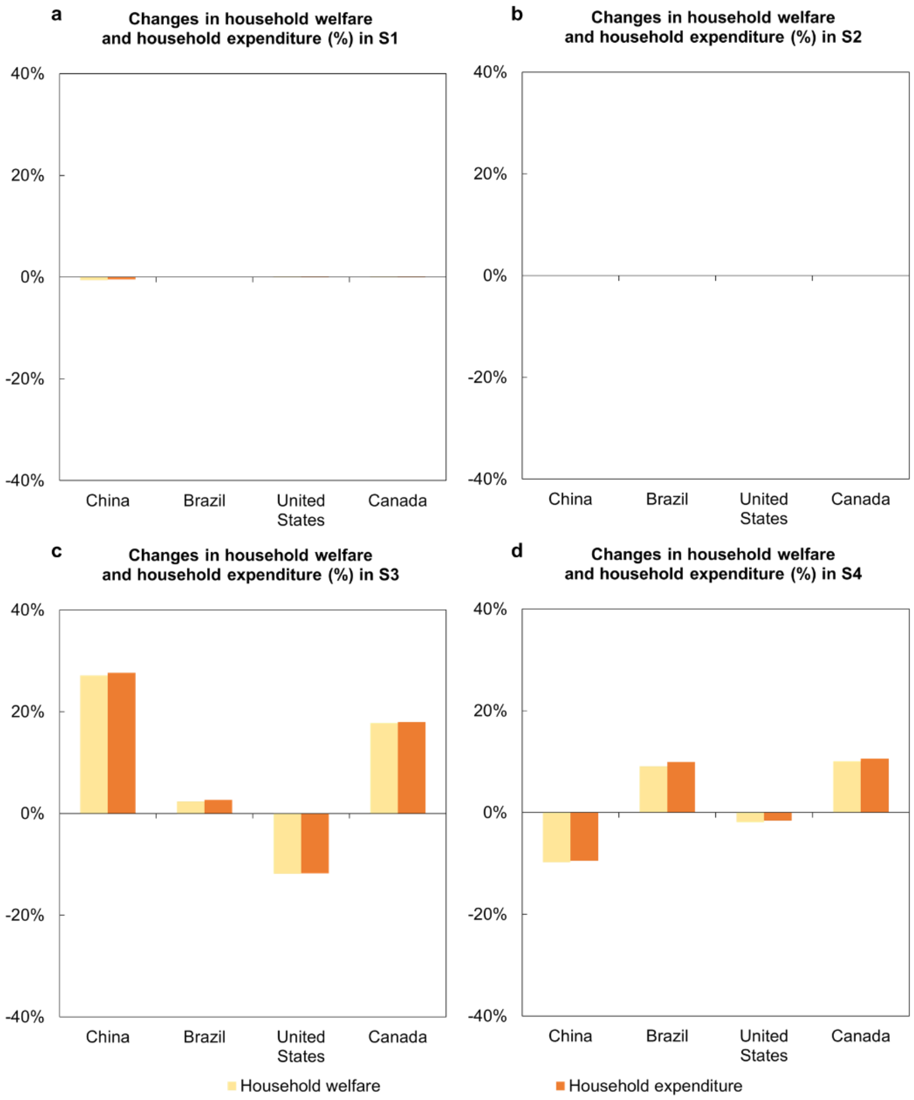
Supplementary Fig. 14 | Shares (%) of sectoral value-added in (a) China, (b) Brazil, (c) United States, and (d) Canada in scenarios.



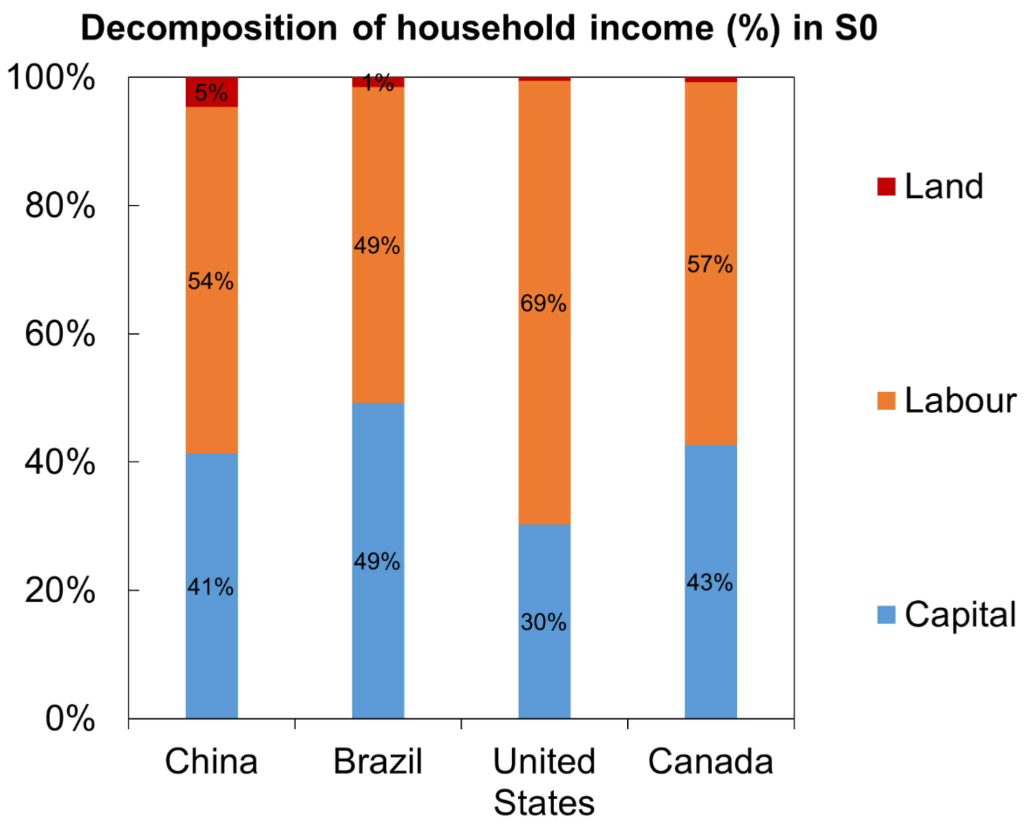
Supplementary Fig. 15 | Changes (%) in sectoral output (i.e., the value of production) in China in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0). Changes (%) in sectoral output (i.e., the value of production) in Brazil in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 with respect to the baseline (S0). Changes (%) in sectoral output (i.e., the value of production) in the United States in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 with respect to the baseline (S0). Changes (%) in sectoral output (i.e., the value of production) in Canada in scenarios (m) S1, (n) S2, (o) S3, and (p) S4 with respect to the baseline (S0).



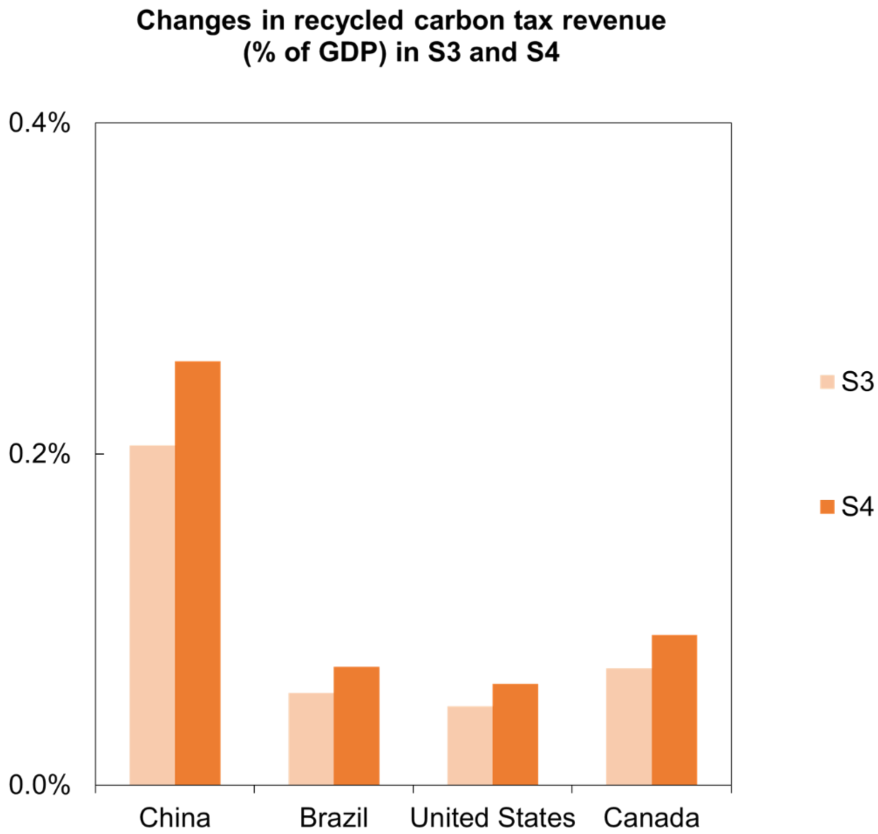
Supplementary Fig. 16 | Changes (million people) in sectoral employment in China in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0). Changes (million people) in sectoral employment in Brazil in scenarios (e) S1, (f) S2, (g) S3, and (h) S4 with respect to the baseline (S0). Changes (million people) in sectoral employment in the United States in scenarios (i) S1, (j) S2, (k) S3, and (l) S4 with respect to the baseline (S0). Changes (million people) in sectoral employment in Canada in scenarios (m) S1, (n) S2, (o) S3, and (p) S4 with respect to the baseline (S0).



Supplementary Fig. 17 | Changes (%) in household welfare and household expenditure in China and MTP in scenarios (a) S1, (b) S2, (c) S3, and (d) S4 with respect to the baseline (S0).



Supplementary Fig. 18 | Decomposition of household income (%) in the baseline (S0).



Supplementary Fig. 19 | Changes (% of GDP) in recyled carbon tax revenue in scenarios 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 a less animal-based diet closing 20% of the gap between current food consumption and the Chinese Dietary Guidelines (CDG) 2022 [23]	No afforestation policy in China	No global uniform carbon tax
Land scenario (S2): An afforestation policy in China	No dietary shift in China	An afforestation policy in China based on the National Forest Management Plan (2016-2050) [17] to expand forest land in China by 23 Mha (4% of China's agricultural land) by 2030	No global uniform carbon tax
Climate scenario (S3): A global uniform carbon tax with carbon tax revenue recycling	No dietary shift in China	No afforestation policy in China	Implementing a global uniform carbon tax to achieve a 25% reduction in net total GHG emissions in China and MTP by 2030, aligned with the 2 °C climate stabilisation target [25] outlined in the Paris Agreement [26]
Combined scenario (S4): S1 + S2 + S3	A dietary shift in China	An afforestation policy in China	Implementing a global uniform carbon tax to achieve a 25% reduction in net total GHG emissions in China and MTP by 2030, aligned with the 2°C climate stabilisation target [25] outlined in the Paris Agreement [26]

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

[a] It directly 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 directly 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
Other 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 production quantities of cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, sugar crops, other non-food crops, non-ruminant meat, dairy products, ruminant meat, nitrogen fertiliser, and phosphorous fertiliser are obtained from FAO [35]. Here, physical production quantities of cereal grains waste, oilseeds & pulses waste, vegetables & fruits waste, and roots & tubers waste are excluded, which are quantified separately for each type of food product by multiplying primary food products after processing by China-specific food waste fractions [36] following the FAO methodology [37].

[b] The physical production quantity of compound feed is calculated according to the weighted averages of crops included in the compound feed at the regional level.

[c] Physical production quantities of cereal bran, alcoholic pulp, and oil cake are estimated by multiplying the production quantities of primary food products by FAO technical conversion factors for various by-products [38]. Here, physical production quantities of discard biomass of cereal bran, alcoholic pulp, and oil cake are excluded, based on discarded share data reported by Fang, et al. [39].

[d] The physical production quantity of processed food is calculated according to the weighted averages of crops included in the processed food at the regional level.

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

	Cropland (Mha)	Pastureland (Mha)	Accessible forest land (Mha) [b]	Total land (Mha)
China	132	393	113	638
Brazil	63	172	154	388
United States	159	258	216	632
Canada	38	20	100	158
Total	391	842	582	1816

[a] Physical area of cropland, pastureland, and forest land is obtained from FAO [35]. Following the GTAP land use and land cover database [32,40,41], 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.
[b] Accessible forest land is calculated based on the country-specific shares of accessible forest area, using data provided by Sohngen, et al. [9] and Baldos and Corong [41].

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)	Other non-food crops (Mha)	Total cropland use (Mha)
China	43.68	6.30	66.33	6.92	8.07	0.32	132
Brazil	15.18	15.87	20.90	2.18	3.43	5.15	63
United States	54.49	27.71	55.27	5.76	4.14	11.43	159
Canada	10.01	8.12	14.27	1.47	0.47	3.88	38
Total	123	58	157	16	16	21	391

[a] The FAO [35] crop categories are aggregated based on the crop sector aggregation scheme (see Appendix Table 1) in the GTAP database to determine cropland use by crop sectors at the regional level.

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	151.64	241.19	393
Brazil	61.66	110.34	172
United States	114.77	142.91	258
Canada	9.23	10.47	20
Total	337	505	842

[a] The FAO [35] livestock categories are aggregated based on the livestock sector aggregation scheme (see Appendix Table 1) in the GTAP database to determine pastureland use by livestock sectors at the regional level. 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)	Other non-food crops (Tg)	Total nitrogen fertiliser use (Tg)
China	23.02	1.62	10.83	1.47	0.97	1.93	39.84
Brazil	0.51	0.16	0.09	0.01	0.29	0.31	1.37
United States	5.40	0.25	0.21	0.07	0.06	1.64	7.63
Canada	1.73	1.42	0.03	0.03	0.0017	0.12	3.34
Total	30.66	3.45	11.15	1.58	1.33	4.01	52.17

[a] Data on nitrogen fertiliser use by crop type and country are derived from Ludemann, et al. [42].

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)	Other non-food crops (Tg)	Total phosphorous fertiliser use (Tg)
China	9.24	0.81	5.91	0.65	0.32	0.62	17.54
Brazil	0.49	1.44	0.07	0.03	0.13	0.26	2.42
United States	4.14	1.36	0.16	0.10	0.09	0.32	6.18
Canada	0.05	0.05	0.001	0.001	0.0001	0.01	0.11
Total	13.91	3.67	6.14	0.78	0.53	1.21	26.24

[a] Data on phosphorous fertiliser use by crop type and country are derived from Ludemann, et al. [42].

Supplementary Table 8 | The economic and mass allocation of food processing main and by-products. [a]

	Main and by-products	By-product group	Economic share (%)	Mass share (%)
Cereal flour production [a]	Cereal flour	-	93%	86%
	Cereal bran	Cereal bran	7%	14%
Maize ethanol production	Maize ethanol	-	83%	49%
	Distiller's grain from maize ethanol	Alcoholic pulp	17%	51%
Barley beer production	Barley beer	-	98%	82%
	Brewer's grain from barley beer	Alcoholic pulp	2%	18%
Liquor production	Liquor	-	97%	25%
	Distiller's grain from liquor	Alcoholic pulp	3%	75%
Vegetable oil production	Soybean oil	-	44%	23%
	Soybean oil cake	Oil cake	56%	77%
	Other oil	-	66%	43%
	Other oil cake	Oil cake	34%	57%

[a] Data source: Haque, et al. [43], Mackenzie, et al. [44], Nyhan, et al. [45], and Pourmehdi and Kheiralipour [46]

Supplementary Table 9 | Estimated mean energy (kcal kg^{-1}) contents of food sub-groups in China and its main food and feed trading partners. [a]

	Cereal grains	Oilseeds & pulses	Vegetables & fruits	Roots & tubers	Sugar crops	Non-ruminant meat	Dairy products	Ruminant meat
China	3496	8136	372	780	3871	1910	612	1692
Brazil	3496	8332	563	780	3871	2036	612	2334
United States	3496	8352	430	780	3871	2008	612	2342
Canada	3496	7515	375	780	3871	2015	612	2300

[a] The values are weighted averages of food types included in the groups at the regional level. Data are sourced from Willett, et al. [47].

Supplementary Table 10 | Food consumption (kcal capita^{-1} day^{-1}) in scenarios S0-S1in China, the recommended targets in the Chinese Dietary Guidelines (CDG) 2022 diet, and changes (%) to close 20% of the gap in food consumption in China in S0 and the recommended targets in the CDG diet.

	CDG 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 20% of the gap (%)
Cereal grains	874	1156	1100	-4.88
Oilseeds & pulses	399	263	290	10.31
Vegetables &fruits	277	214	227	5.90
Roots & tubers	59	111	100	-9.46
Sugar crops	194	779	662	-15.03
Non-ruminant meat	171	397	352	-11.40
Dairy products	184	51	78	51.88
Ruminant meat	12	36	31	-13.26
Total	2169	3007	2839	-5.58

[a] Food consumption in scenarios S0 and S1 in China are calculated by our AGE model. [b] The Chinese Dietary Guidelines (CDG) 2022 recommendations are based on Chinese Nutrition Society [23]. We estimate changes in the processed food sector by applying a weighted average across crop types, using their primary content in processed food as weights, and find that its demand increases by 1.78% under the dietary shift (S1) scenario.

Supplementary Table 11 | 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. [4].

Supplementary Table 12 | 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. [4]. These values are the same for China, Brazil, the United States, and Canada.

Supplementary Table 13 | 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	84.56	15.50	0.52
Brazil	146.26	26.81	12.76
United States	135.69	24.88	1.88
Canada	152.27	27.92	4.21

[a] Data source: Nguyen, et al. [16] and China's National Forest Management Plan (2016-2050) [17]. Annual forestry carbon sequestration intensities are distributed evenly over a depreciation period of 20 years, as suggested by IPCC [14] and BSI [15]. 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. Accordingly, annual forestry carbon sequestration intensity is calculated as the weighted average of sequestration intensities from cropland-to-forest and pastureland-to-forest conversions, with weights corresponding to the respective shares of cropland and pastureland in total agricultural land.

Supplementary Table 14 | Annual land-use change greenhouse gas mitigation (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 anual land-use change greenhouse gas mitigation contributed by China and its trading partners under different carbon tax rates, relative to the global total.

Supplementary Table 15 | Material intensity coefficients (kg USD^{-1}) of each commodity in China and its main food and feed trading partners in 2014. [a]

	cer	osd	vf	rt	sgr	ocr	oap	rmk	ctl	cof	bran	pulp	cake	otf	nfe	pfe
China	2.70	3.20	1.47	4.24	4.14	18.59	0.58	1.72	0.27	1.74	3.35	8.47	283.36	1.37	3.11	3.83
Brazil	3.35	4.03	1.57	8.43	83.57	1.22	1.20	1.87	0.28	1.64	1.48	61.74	7209.48	1.13	1.22	1.99
United States	7.63	4.32	0.99	3.16	3.67	1.18	0.46	1.46	0.15	1.64	4.77	12.87	19.54	1.13	4.50	3.22
Canada	6.99	5.37	0.35	6.12	0.17	0.03	0.45	1.00	0.12	1.64	6.14	14.06	33.07	1.13	1.88	2.70

[a] Data source: Calculated by our study. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=other non-food crops. oap=non-ruminant meat. rmk=dairy products. ctl=ruminant meat. cof=compound feed. bran=cereal bran. pulp=alcoholic pulp. cake=oil cake. otf=processed food. nfe=nitrogen fertiliser. pfe=phosphorous fertiliser.

Supplementary Table 16 | Energy intensity coefficients (kcal USD^{-1}) of food sub-groups in China and its main food and feed trading partners in 2014. [a]

	Cereal grains	Oilseeds & pulses	Vegetables & fruits	Roots & tubers	Sugar crops	Non-ruminant meat	Dairy products	Ruminant meat
China	10110	26467	1031	4043	16034	1104	1053	465
Brazil	11723	33618	885	6574	1672	2437	1144	660
United States	26657	36103	426	2467	14208	924	893	347
Canada	6253	40319	132	4776	670	898	609	287

[a] Data source: Calculated by our study.

Supplementary Table 17 | Changes (%) in global crop-based food, animal-based food, processed food, and average food price in scenarios with respect to the baseline (S0). [a]

	Crop-based food price	Animal-based food price	Processed food price	Average food price
S1	0.14%	0.09%	0.08%	0.12%
S2	0.02%	-0.10%	0.03%	-0.02%
S3	179%	155%	98%	162%
S4	225%	263%	126%	227%

[a] Crop-based food price is the average price of cereal grains, oilseeds & pulses, vegetables & fruits, roots & tubers, and sugar crops. Animal-based food is the average price of non-ruminant meat, dairy products, and ruminant meat. Average food price is the average price of crop-based food, animal-based food, and processed food.

Supplementary Table 18 | Changes (%) in household income without/with carbon tax recycling and household expenditure with trade balance adjustment in China and its main food and feed trading partners in scenarios with respect to the baseline (S0).

		S1	S2	S3	S4
Household income without carbon tax revenue recycling	China	0.00	0.00	-42.49	-57.90
	Brazil	0.00	0.00	-3.11	-5.43
	United States	0.00	0.00	-6.12	-6.47
	Canada	0.00	0.00	-7.31	-9.29
Household income with carbon tax revenue recycling [a]	China	0.00	0.00	-9.14	-17.47
	Brazil	0.00	0.00	6.57	6.99
	United States	0.00	0.00	2.14	4.10
	Canada	0.00	0.00	4.75	6.16
Household expenditure with trade balance adjustment	China	-0.46	0.00	27.65	-9.50
	Brazil	0.06	0.00	2.68	9.96
	United States	0.12	0.00	-11.77	-1.55
	Canada	0.10	0.00	17.97	10.59

[a] Note: In scenarios S3 and S4, the carbon tax revenue is recycled to households as a lump-sum transfer to household income (see equation 48). Recycling carbon tax revenue as climate dividends can greatly mitigate, and even offset, the risk of increased food insecurity induced by the carbon tax.

Supplementary Table 19 | Changes ($ billion) in household expenditure with trade balance adjustment in China and its main food and feed trading partners in scenarios with respect to the baseline (S0).

		Crop	Livestock	Forestry	Processed food	Non-food	Household expenditure
S1	China	10	-131	0	77	-116	-161
	Brazil	0	0	0	0	8	9
	United States	0	2	0	4	136	143
	Canada	0	0	0	0	9	9
	Total	10	-129	0	82	37	0
S2	China	0.0	1.1	0.1	-0.6	-1.4	-0.8
	Brazil	0.0	0.6	0.1	-0.1	-0.3	0.3
	United States	0.0	2.6	0.5	-0.1	-2.7	0.2
	Canada	0.0	0.1	0.1	-0.1	-0.3	-0.1
	Total	0.0	4.4	0.7	-0.8	-4.7	-0.5
S3	China	12	769	17	1853	7011	9661
	Brazil	-67	-88	10	138	373	365
	United States	-170	-454	45	-46	-13128	-13754
	Canada	-7	13	11	127	1539	1683
	Total	-232	240	83	2071	-4205	-2044
S4	China	6	-131	16	77	-3288	-3320
	Brazil	3	-40	20	463	909	1354
	United States	-16	-129	102	1469	-3235	-1808
	Canada	10	8	17	214	743	992
	Total	2	-292	155	2223	-4870	-2782

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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
Other 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] The value flow from the "Food products nec (ofd)" sector to monogastric and ruminant livestock in the original GTAP database after splitting out the economic values of cereal bran and distiller's grains from maize ethanol production is assumed to be compound feed. Cereal bran and distiller's grains from maize ethanol production are split from the "Food products nec (ofd)" sector based on their shares of economic values in the "Food products nec (ofd)" sector. Economic values of cereal bran and distiller's grains from maize ethanol production are determined by multiplying their region-specific physical production quantities (tons) by the corresponding regional prices (USD ton^{-1}). These prices are determined by dividing the export trade value (USD) by the export trade weight (tons) at the regional level, using data from the UN Comtrade Database [48]. The value flow from the "Beverages and Tobacco products (b_t)" sector to monogastric livestock in the original GTAP database are assumed to be distiller's grains from liquor production and brewer's grains from barley beer production. The value flow from the "Vegetable oils and fats (vol)" sector to monogastric livestock in the original GTAP database is assumed to be oil cake.

[b] The nitrogen and phosphorus fertilisers are taken from the original "Manufacture of chemicals and chemical products" sector following the method of Sturm [49] and Bartelings, et al. [50].

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	3495	5560	0	11363	1372	67	0	81831	0	0	0	61825	-2016	192727
osd	0	0	0	0	0	0	1002	89	141	0	8312	0	0	182	42993	0	0	0	5092	-34661	23150
vf	0	0	0	0	0	0	5685	577	918	0	18959	0	0	0	98059	0	0	0	145756	-139	269815
rt	0	0	0	0	0	0	595	60	96	0	1986	0	0	0	10270	0	0	0	15265	-15	28259
sgr	0	0	0	0	0	0	192	199	316	0	1280	0	0	0	6619	0	0	0	24553	-903	32256
ocr	0	0	0	0	0	0	664	101	161	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	24530	-187	24343
ctl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39016	-297	38719
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	2879	4579	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	3953	6287	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	9493	15099	44792	7946	959	155	8	89845	4413	1579	1534347	-2059463	0	0
CAP	34602	2905	35711	3725	4455	151	23777	3496	5561	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	24343	38719	65675	58884	3398	402	205	432823	12721	4551	2918771	0	0	4287021

[a] Data source: GTAP [51]. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=other 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	978	1751	0	1195	928	35	0	12745	0	0	0	11640	2	30237
osd	0	0	0	0	0	0	25	40	71	0	1102	0	0	3	6475	0	0	0	315	16623	24655
vf	0	0	0	0	0	0	199	245	438	0	3198	0	0	0	18783	0	0	0	8628	-91	31400
rt	0	0	0	0	0	0	21	26	46	0	335	0	0	0	1967	0	0	0	904	-9	3289
sgr	0	0	0	0	0	0	9	14	24	0	15	0	0	0	88	0	0	0	7820	839	8809
ocr	0	0	0	0	0	0	42	51	91	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	19510	-27	19484
ctl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34906	-43	34864
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	2998	5365	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	1483	2654	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	5157	9227	4683	1172	910	36	1	23213	236	374	597428	-672325	0	0
CAP	17088	14949	19817	2071	4940	4842	6868	8493	15197	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	19484	34864	9183	8425	2664	104	5	87776	665	1051	1152686	0	0	1438941

[a] Data source: GTAP [51]. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=other 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	13224	16467	0	2821	110	372	0	17774	0	0	0	2807	1734	58074
osd	0	0	0	0	0	0	33	53	66	0	1821	0	0	1914	8828	0	0	0	1309	15210	29234
vf	0	0	0	0	0	0	137	150	187	0	4813	0	0	0	23337	0	0	0	35913	57	64593
rt	0	0	0	0	0	0	14	16	20	0	504	0	0	0	2444	0	0	0	3761	6	6765
sgr	0	0	0	0	0	0	47	413	514	0	1461	0	0	0	7085	0	0	0	5666	67	15252
ocr	0	0	0	0	0	0	29	36	45	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	63881	184	64065
ctl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79482	293	79775
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	9338	11628	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	4565	5684	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	22825	28423	8398	20576	803	2738	222	165696	1043	1046	7536888	-7888997	0	0
CAP	17334	9055	21379	2226	4054	3299	11316	13446	16743	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	64065	79775	29986	48023	1517	5198	2271	386971	2030	2037	10716468	0	0	11603490

[a] Data source: GTAP [51]. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=other 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	875	993	0	492	13	18	0	2408	0	0	0	2150	279	7399
osd	0	0	0	0	0	0	13	33	38	0	427	0	0	146	1756	0	0	0	314	2828	5554
vf	0	0	0	0	0	0	27	43	49	0	449	0	0	0	1846	0	0	0	6214	172	8801
rt	0	0	0	0	0	0	3	4	5	0	47	0	0	0	193	0	0	0	651	18	922
sgr	0	0	0	0	0	0	3	34	39	0	142	0	0	0	585	0	0	0	2553	-2	3354
ocr	0	0	0	0	0	0	62	89	101	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	7812	29	7841
ctl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8848	47	8895
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	1592	1806	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	349	396	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	2543	2885	6755	2434	64	91	15	15010	762	43	465567	-508975	0	0
CAP	3091	2069	3853	397	1618	520	1946	2277	2583	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	7841	8895	19032	6303	136	197	181	39360	1968	112	817823	0	0	937805

[a] Data source: GTAP [51]. cer=cereal grains. osd=oilseeds & pulses. vf=vegetables & fruits. rt= roots & tubers. sgr=sugar crops. ocr=other 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)
Land-use change [b]	• Net forest conversion (CO_2)	• -	• -
Non-agriculture [c]	• 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. [42]. Manure data by animals are derived from FAO [35]. Allocation of manure for each crop is assumed to be consistent with the allocation of N fertiliser for each crop.

[b] Emissions from land-use change refer to emissions associated with net forest conversion (i.e., changes in forest carbon stocks).

[c] 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	276.61	2.51	23.16	1.66	82.63	1.44	13.19	1.58
Oilseeds & pulses	8.33	0.08	2.97	0.21	1.94	0.03	4.98	0.60
Vegetables &fruits	54.88	0.50	1.55	0.11	1.69	0.03	0.09	0.01
Roots &tubers	7.46	0.07	0.11	0.01	0.60	0.01	0.11	0.01
Sugar crops	4.58	0.04	5.81	0.42	0.51	0.01	0.01	0.001
Other non-food crops	15.55	0.14	6.13	0.44	14.13	0.25	0.47	0.06
Non-ruminant meat	79.36	0.72	17.26	1.24	39.43	0.69	7.09	0.85
Dairy products	38.67	0.35	52.54	3.76	43.51	0.76	4.88	0.59
Ruminant meat	206.36	1.87	385.50	27.62	186.37	3.25	27.49	3.29
Land-use change	-709.55	-6.43	266.89	19.12	-417.89	-7.28	135.81	16.28
Compound feed	25.39	0.23	1.12	0.08	13.09	0.23	1.82	0.22
Cereal bran	0.00752	0.00007	0.00094	0.00007	0.00174	0.00003	0.00020	0.00002
Alcoholic pulp	0.0001148	0.0000010	0.0000096	0.0000007	0.0000210	0.0000004	0.0000012	0.0000001
Oil cake	0.01580	0.00014	0.00542	0.00039	0.00718	0.00013	0.00161	0.00019
Processed food	204.54	1.85	12.05	0.86	107.28	1.87	11.49	1.38
Nitrogen fertiliser	324.09	2.94	4.78	0.34	53.71	0.94	21.80	2.61
Phosphorus fertiliser	24.53	0.22	2.12	0.15	6.63	0.12	0.31	0.04
Non-food	10476.56	94.92	613.60	43.97	5606.80	97.67	604.72	72.49
Total	11037	100.00	1396	100.00	5740	100.00	834	100.00

[a] Data source: Climate Analysis Indicators Tool (CAIT) [52]. Greenhouse gas (GHG) emissions in our model follow the IPCC National GHG Emission Guidelines [53]. Emissions of food processing by-products (i.e., cereal bran, alcoholic pulp, oil cake) are derived from Mackenzie, et al. [44].

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	11.71	0.13	4.85	0.72	7.34	0.09	6.47
Oilseeds & pulses	0.29	0.86	0.04	1.47	0.03	0.36	0.08	5.40
Vegetables &fruits	1.89	5.63	0.02	0.77	0.03	0.31	0.00	0.10
Roots &tubers	0.26	0.77	0.00	0.05	0.01	0.11	0.00	0.12
Sugar crops	0.16	0.47	0.08	2.88	0.01	0.09	0.00	0.01
Other non-food crops	0.54	1.60	0.08	3.04	0.26	2.59	0.01	0.51
Non-ruminant meat	5.22	15.53	0.34	12.84	2.29	23.29	0.24	17.42
Dairy products	0.17	0.50	0.07	2.74	0.07	0.69	0.01	0.44
Ruminant meat	2.04	6.08	0.18	6.80	0.68	6.86	0.05	3.39
Land-use change [b]	-	-	-	-	-	-	-	-
Compound feed	0.04	0.13	0.00	0.11	0.01	0.13	0.00	0.19
Cereal bran	0.000328	0.0010	0.000041	0.0015	0.000076	0.0008	0.000009	0.0006
Alcoholic pulp	0.00000067	0.0000020	0.00000006	0.0000021	0.00000012	0.0000012	0.00000001	0.0000005
Oil cake	0.00080	0.0024	0.00028	0.0104	0.00037	0.0037	0.00008	0.0057
Processed food	0.35	1.05	0.03	1.22	0.11	1.08	0.02	1.18
Nitrogen fertiliser	0.0009	0.003	0.0003	0.010	0.0029	0.029	0.0003	0.023
Phosphorus fertiliser	0.0007	0.002	0.0007	0.026	0.0020	0.021	0.0002	0.014
Non-food	18.71	55.67	1.68	63.18	5.62	57.09	0.91	64.72
Total	33.61	100.00	2.67	100.00	9.85	100.00	1.40	100.00

[a] Data source: Liu, et al. [54], Huang, et al. [55], and Dahiya, et al. [56]. Emissions of food processing by-products (i.e., cereal bran, alcoholic pulp, oil cake) are derived from Mackenzie, et al. [44]. [b] Note: There are no emissions of acidification pollutants for land-use change.

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	10.47	0.02	1.97	0.03	0.92	0.01	0.97
Oilseeds & pulses	0.15	1.48	0.02	1.85	0.01	0.36	0.02	2.39
Vegetables &fruits	0.88	8.83	0.01	0.71	0.03	0.74	0.00	0.35
Roots &tubers	0.12	1.20	0.00	0.05	0.01	0.24	0.00	0.36
Sugar crops	0.02	0.20	0.01	0.50	0.00	0.02	0.00	0.01
Other non-food crops	0.01	0.10	0.01	0.80	0.00	0.06	0.00	0.24
Non-ruminant meat	0.58	5.88	0.07	6.06	0.26	6.98	0.05	7.08
Dairy products	0.22	2.23	0.18	15.09	0.29	7.82	0.09	12.97
Ruminant meat	1.41	14.23	0.53	42.93	0.75	20.09	0.18	27.29
Land-use change [b]	-	-	-	-	-	-	-	-
Compound feed	0.17	1.70	0.01	0.50	0.05	1.47	0.01	1.03
Cereal bran	0.0000147	0.0001	0.0000019	0.0002	0.0000034	0.0001	0.0000004	0.0001
Alcoholic pulp	0.00000029	0.0000030	0.00000002	0.0000020	0.00000005	0.0000015	0.00000000	0.0000005
Oil cake	0.000037	0.00038	0.000013	0.00107	0.000017	0.00047	0.000004	0.00054
Processed food	1.35	13.66	0.07	5.34	0.45	12.09	0.04	6.49
Nitrogen fertiliser	0.0002	0.002	0.0001	0.004	0.0005	0.015	0.0001	0.008
Phosphorus fertiliser	0.0002	0.002	0.0002	0.016	0.0006	0.016	0.0001	0.010
Non-food	3.97	40.02	0.30	24.18	1.83	49.17	0.27	40.80
Total	9.92	100.00	1.23	100.00	3.72	100.00	0.67	100.00

[a] Data source: Hamilton, et al. [57]. Emissions of food processing by-products (i.e., cereal bran, alcoholic pulp, oil cake) are derived from Mackenzie, et al. [44]. [b] Note: There are no emissions of acidification pollutants for land-use change.

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
Other non-food crops	7923	760	1244	293
Non-ruminant meat	445	1107	494	851
Dairy products	1589	2697	679	623
Ruminant meat	5330	11057	2336	3090
Land-use change [b]	-	-	-	-
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: Emission intensities of greenhouse gases for land-use change are reflected in the annual forestry carbon sequestration intensities, as reported in **Supplementary Table 13**.

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
Other non-food crops	273.39	10.05	22.44	4.46
Non-ruminant meat	29.26	21.95	28.72	29.37
Dairy products	6.84	3.74	1.07	0.79
Ruminant meat	52.81	5.20	8.47	5.36
Land-use change [b]	-	-	-	-
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: Emission intensities of acidification pollutants are not applicable for land-use change.

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
Other non-food crops	5.31	1.21	0.20	1.01
Non-ruminant meat	3.27	4.77	3.25	5.72
Dairy products	9.07	9.49	4.53	11.14
Ruminant meat	36.45	15.09	9.36	20.66
Land-use change [b]	-	-	-	-
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: Emission intensities of eutrophication pollutants are not applicable for land-use change.