Going global to local: achieving agri-food sustainability from a spatially explicit input-output analysis perspective

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Appendix

8 Appendix

8.1 Supporting information to chapter 2

8.1.1 Critical review methodology – selection of the literature

We searched all papers using spatially-explicit input-output (SIO) approaches published before March, 2018 and analyzed their spatial scale, method, and environmental impacts.

We use Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to search for articles using SIO approaches, on March, 2018 (Figure S 8.1) [424]. PRISMA aims to be a standard operating procedure for systematic reviews, in order give a more reliable and less biased result [425]. The systematic and explicit methods for this systematic review reduces issues with identifying, selecting, synthesizing, summarizing, collecting and analyzing data [425]. It also allows for reproducibility by providing all the information required to perform the review. We searched three scientific catalogues: Web of Science, ScienceDirect and the Leiden University Catalogue. There is a large diversity of terms in the literature describing the same, spatially-explicit concept, including "map", "mapping", and "hotspots". Of course, not all of these are synonyms, and not all of these studies are in fact spatially-explicit. In order to restrict the search further we included terms including "input-output" and "MRIO (Multi-Regional Input Output)", For example, we use the combination of ("spatial*" or "map*" or "hotspot*") and ("input output analysis" or "input output model" or "input output table" or "MRIO") in for the research topic in Web of Science. For the detailed protocol please see the Supporting Information.

The search criteria are: (1) that all papers are in English; (2) that all papers are in peer-reviewed; (3) that all papers use input-output method; (4) that all papers have spatially distributed results at a resolution higher than regional. A flow diagram of the search methodology is shown in Table S 8.1. After using search protocols, we find another 15 papers using Google Scholar, and then perform a snowball sampling of these papers, finding a further 14 eligible papers.

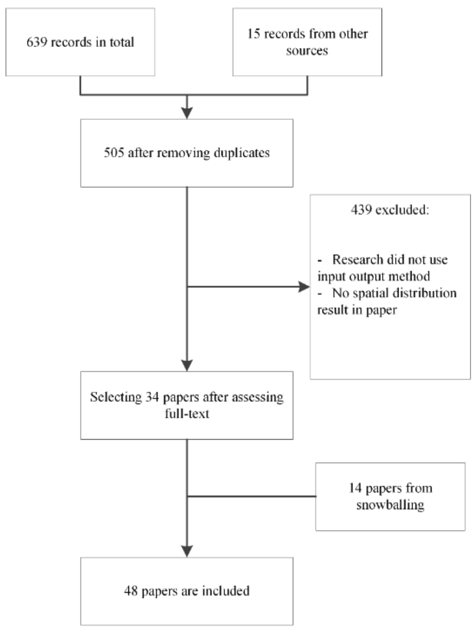

Figure S 8.1 Flow diagram of the search methodology used. After a large number of initial studies were found, these were filtered on the criteria described above to 48 analyses.

All these search terms are based on snowball sampling for each search library. Details are in Table S 8.1

Table S 8.1 Search terms used in meta-analysis for each database.

Database	Code	Search Results	After Duplicates Removed	Titles and Abstracts Screened				
Web of Science	(TS=("spatial*" OR "map*" OR "hotspot*") AND TS=("input output analysis" OR "input output model" OR "input output table" OR "MRIO")) *AND* LANGUAGE:(English)*AND* DOCUMENT TYPES:(Article OR Book OR Book Chapter OR Data Paper OR Database Review)	243	168	28				
ScienceDirect	(tak("input output analysis" OR "input output model" OR "input output table" or "MRIO")) AND (tak("spatial*" OR "map*" OR "hotspot*"))	155	110	16				
Leiden University Catalogue	(Any("input output analysis" OR "input output model" OR "input output table" OR "MRIO")) AND (Title("spatial*" OR "hotspot" OR "map*" OR "spatially-explicit")) AND Language(Englsih)	241	227	22	Full-text Assessed for Eligibility	Derived from other References	Derived from snowballing	Total
Total		639	505	66	19	15	14	48

8.1.2 **Methodological approaches in the literature**

Method 1: mapping between MRIO model and hydrological model—WaterGAP

Lutter et al. and Holland et al. combined an MRIO model (EXIOBASE in the case of Lutter et al. and GTAP8 in the case of Holland et al.), with WaterGAP model to research fresh water consumption embodied in trade almost at the same time [50,113]. Their core work is to build up mapping relationship between MRIO table and water consumption data from WaterGAP model by production sector, particularly different agricultural sectors (Table S 8.2).The difference was that Lutter et al mapped MRIO data into watershed scale, but Holland et al. mapped MRIO data into original resolution—0.5°×0.5° grid cell—of WaterGAP [113].

Table S 8.2 Example of disaggregation matrix, indicating which share of water consumption in a specific industry-region combination is originating form which watershed.

	Region 1			…	Region n		
	Ind 1	…	Ind n	…	Ind 1	…	Ind n
Watershed 1	0	…	0.95	…	0.57		0.3
…	…	…	…	…	…	…	…
Watershed m	1	…	0.05	…	0.43	…	0.7

Source: from Lutter et al.[50]

Method 2: identifying hotspots from supply chains

Kanemoto et al. developed a spatially-explicit MRIO method to identify spatially-explicit environmental impacts hotspots embodied in supply chain [95]. The core of this method is to nest spatial distribution map (R) into traditional multi-regional input-output model.

$$H_{(m)s} = \sum_r R^r \frac{\sum_i f_i^r \sum_{jt \neq s} L_{ij}^{rt} y_j^{ts}}{\sum_i d_i^r} \quad \text{(S1)}$$

$$H^{(c)s} = \sum_r R^r \frac{\sum_i f_i^r \sum_{jt} L_{ij}^{rt} y_j^{ts}}{\sum_i d_i^r} \quad \text{(S2)}$$

Table S 8.3 Variables and description of hotspots method.

Variables	Description
$H_{(m)s}$	the $PM_{2.5}$ emission hotspots H driven by imports (m) into country s
$H^{(c)s}$	the $PM_{2.5}$ emission hotspots H driven by total consumption (c) into country s
R	$PM_{2.5}$ emission maps term (R) are in absolute values
d	total emissions
f	intensity of $PM_{2.5}$

L	Leontief inverse
y	final demand
i	sector of origin and destination
j	sector of destination
r	exporting country
s	importing country
t	country of last sale in the consumption and imports terms

Method 3: integrating process-based model with input-output model

Wang et al. developed hybrid method that integrated process-based model with input-output model to analyze global water scarcity at basin level [97]. The most pivotal part of this method is

$$WSI_i^{BAU} = \frac{WW_i^{BAU}}{BA_i} \quad (S3)$$

$$WSI_i^{NT} = \frac{WW_i^{NT}}{BA_i} \quad (S4)$$

Table S 8.4 Variables and description of integrating process-based model with input-output model.

Variables	Description
WSI_i^{BAU}	Water stress index with international trade at basin ***i***
WSI_i^{NT}	Water stress index without international trade at basin ***i***
WW_i^{BAU}	Water withdraw at basin ***i*** with international trade
WW_i^{NT}	Water withdraw at basin ***i*** without international trade
BA_i	Blue water availability annually at basin ***i***

WW_i^{BAU} was calculated by downscaling production-based national water withdraws into basins based on water withdraw estimated Aqueduct Global Maps in 2010.

WW_i^{NT} was calculated by downscaling consumption-based national water withdraws, which got from MRIO model, into basins based on the same proportion of WW_i^{BAU}

Method 4: Integrating MRIO model with production-side location information.

Cazcarro et al. integrated input-output model with spatial location information to downscale grey water footprints into business level [116]. There were three steps to downscaling grey water footprints as following figure (Figure S 8.2): (1) estimating direct intensities of grey water footprints; (2) calculating grey water footprints with multi-regional input-output model; (3) downscaling grey water footprints into business level.

Mekonnen et al. estimated global agricultural grey water footprints driven by EU27 consumption with similar method of agricultural part in Cazcarro et al [115].

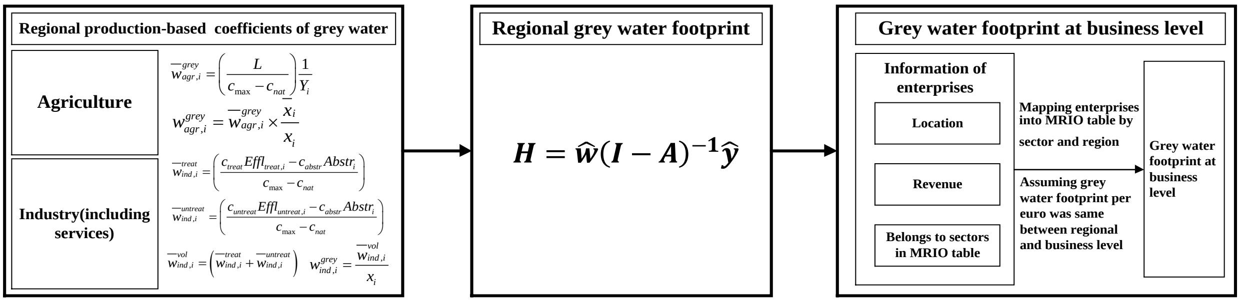

Figure S 8.2 Process of downscaling grey water footprints into business level.

Table S 8.5 Variables and description of method that downscales grey water footprints.

Variables	Description
$\overline{w}_{agr,i}^{grey}$	Agricultural physical grey water coefficient (m^3/ton) for i^{th} crop
L	Excess of nitrogen (kg/ha per year)
c_{max}	Maximum acceptable concentration
c_{nat}	Natural concentration
Y_i	Crop yield for i^{th} crop
$w_{agr,i}^{grey}$	Agricultural direct grey water coefficient (m^3/euro) for i^{th} crop
x_i	Agricultural output (euro) for i^{th} crop
$\bar{x}_i$	Agricultural production (ton) for i^{th} crop
$\overline{w}_{ind,i}^{treat}$	Amount of grey water from treated water(m^3) for sector i
$\overline{w}_{ind,i}^{untreat}$	Amount of grey water from untreated water(m^3) for sector i
c_{treat}	Concentration of treated effluent(mg/l)
c_{abstr}	Actual concentration(mg/l)
$Effl_{treat,i}$	Volume of treated effluent for sector i
$Abstr_i$	Water volume(m^3) for sector i
$c_{untreat}$	Concentration of untreated effluent(mg/l)
$Effl_{untreat,i}$	Volume of untreated effluent for sector i
$\overline{w}_{ind,i}^{vol}$	Total amount of grey water(m^3) for sector i

$w_{ind,i}^{grey}$	Direct grey water coefficient for sector *i*
$\boldsymbol{H}$	Grey water footprint matrix
$\boldsymbol{\hat{w}}$	Grey water coefficient matrix
$\boldsymbol{I}$	Identify matrix
$\boldsymbol{A}$	Technical coefficient matrix for input-output table
$\boldsymbol{\hat{y}}$	Final demand vector

Method 5: dynamic inoperability input-output model (DIIM)

Inoperability input-output model is a good tool to assess risk, and McDonald et al. integrated dynamic inoperability input-output model with volcanic locations to estimate economic loss [117].

Four steps to construct spatial map of risk by DIIM:

- splitting regional output into the finest spatial scale;
- evaluating production inoperability in each finest spatial location;
- estimating total economic impact by DIIM;
- adjusting total economic impacts based on hazard probability.

Method 6: combining data from MRIO table and demand-side subnational information.

Several researchers linked subnational information with input-output model to estimate subnational environmental impacts, the details referenced to their papers [105,108,123,126–128]. Maybe some small difference existed in their method, but the core of their method is to combine supply chain information in national input-output database or multi-regional input output database to track upstream environmental impacts with subnational consumption information to calculate subnational environmental impacts, for example consumer expenditure surveys (CESs), to calculate subnational environmental impacts.

For example, Feng et al. combined with geo-demographic data to calculate water footprints at subnational area. The core equations are as follows.

$$w_{Int} = e^{d^*}(I-A)^{-1}y + w_{hh} \tag{S10}$$

$$w_{Ext} = e^{i^*}(I-A)^{-1}y \tag{S11}$$

$$e^{d^*} = [e^d, 0] \tag{S12}$$

$$e^{i^*} = [0, e^i] \tag{S13}$$

$$y = \begin{bmatrix} y^d \\ y^i \end{bmatrix} \tag{S14}$$

Table S 8.6 Variables and description of method that combines with subnational information.

Variables	Description

w_{Int}	Water footprint from domestic consumption
w_{Ext}	Water footprint from other countries
w_{hh}	Water consumption from direct household consumption
e^d	Water consumption coefficients of domestic commodities
e^i	Water consumption coefficients of commodities from other countries
y^d	Final demand from domestic and export commodities
y^i	Final demand from other countries
$\boldsymbol{I}$	Identify matrix
$\boldsymbol{A}$	Technological coefficients matrix

A is from MRIO table at country level, and replace final demand ***y*** at regional level, it would calculate water footprint at local regional scale.

Method 7: integrating MRIO with GEOS-Chem model

Lin et al. and Zhang et al. combined multi-regional input-output model with GEOS-Chem to simulate transport of emissions [98,104]. Firstly, calculating environmental impacts (or emissions) embodied in trade at country level, and then using GEOS-Chem model to simulate the spatial distribution of environmental impacts on worldwide (Figure S 8.3). Zhang et al., also link health impacts model, Integrated Exposure-Response (IER), to simulate spatial distribution of premature death driven by consumption

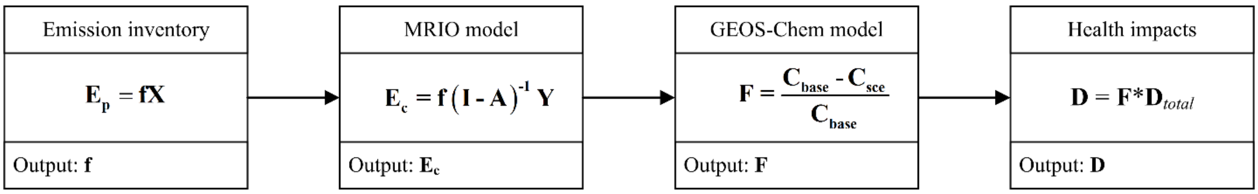

Figure S 8.3 Process of method that integrated with GEOS-Chem model.

Table S 8.7 Variables and description of method that integrated with GEOS-Chem model.

Variables	Description
$\boldsymbol{E_p}$	Emission matrix from production
$\boldsymbol{F}$	Emission intensity vector
$\boldsymbol{X}$	Total output
$\boldsymbol{E_c}$	Consumption-based emission matrix
$\boldsymbol{I}$	Identify matrix

A	Technological matrix
Y	Final demand vector
F	Spatial distribution of fractional contribution of emission derived from different scenarios
C_{base}	Emission concentration on base scenarios
C_{sce}	Emission concentration on different scenarios
D	Premature death population at grid cell driven by consumption
D_{total}	Global total premature death population using IER model at grid cell

Method 8: combing input-output model with air pollution dispersion model.

Firstly, applying regional input-output table and emission inventory data to calculate emission coefficients of different sectors, and then using these coefficients to calculate amount of emission discharging sites [93]. Finally, applying smeared concentration approximation method (SCA) to simulate spatial diffusion of these emissions (Figure S 8.4).

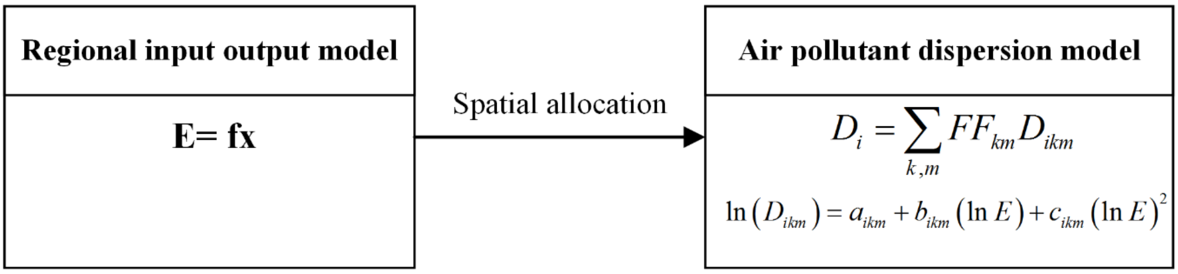

Figure S 8.4 Process of combing with air pollution dispersion model

Table S 8.8 Parameters and description of method that combines with air pollution dispersion model

Variables	Description
E	Production-based emission
F	Emission intensity
X	total output
D_i	Average concentration of emission between source and receiver
FF_{km}	Frequency of emission occur
D_{ikm}	Average contribution of concentration of emission at different situation
I	Emission classes
K	Atmospheric stability condition
M	Windspeed classes

Method 9: spatial regional econometric input–output model

Kim et al. developed spatial regional econometric input-output model through integrating regional econometric input–output model(REIM) with disequilibrium adjustment model, and they used the model to predict population and employment change of 296 municipalities in Chicago, USA [118]. The core of this method included 5 steps:

- Quantifying potential employment growth for year *t* based on exogenous national economic growth.
- Estimating information for grid cell in year *t*-1.
- Calculating employment and population at local level for year *t* based on information: (a) potential employment growth for year *t*-1 (b) information of grid cell for year *t* -1(c) their own information for year *t*-1 (d) interaction relationship between local-level employment and population.
- Updating macroeconomic variables for year *t* based on information of employment and population change with modified REIM formulation.
- Predicting information at grid cell level for year *t* via simple logic econometrics model or other more complicated simulation approach.

Method 10: Integrating MRIO model with GIS technology.

Van Der Veen et al. constructed contour map of value added based on employment data from enterprises and spatial interpolation methods with GIS platform, regarding multipliers from input-output model as the weight [121]. Similarly, Zhou et al. estimated spatial flow of chemical oxygen demand (COD) in Changzhou city, China at GIS platform [119,120,122].

Method 11 (in Trase.earth): spatially-explicit information on production to consumption systems(SEI-PCS) model

In order to trace spatial heterogeneity of environmental impacts related to production consumed by other regions within a country, especially large country, which contributes to global consumption. Godar et al. developed SEI-PCS model [109], and they used the model to analyse crops and virtual water embedded in farming commodities in Brazil at subnational scale [153,154]. The model downscales production consumed by domestic and other countries into finest scale, the municipality level, in a country. The following graph (Figure S 8.5) describes the core theory of this model, and the detail can reference to Godar et al. 2015 [109].

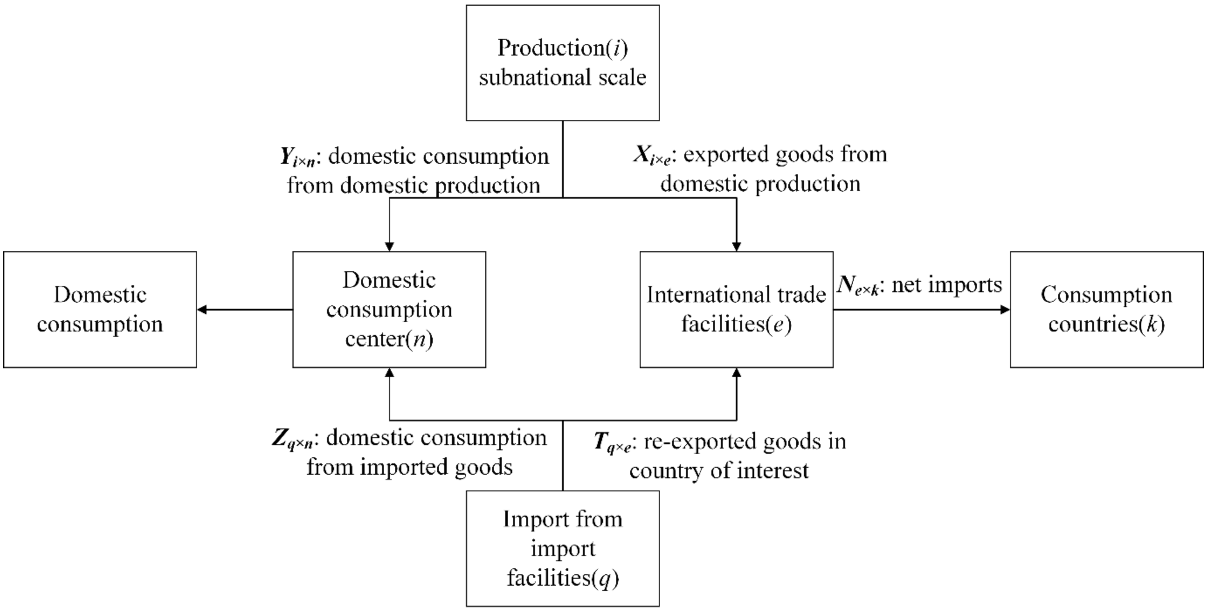

Figure S 8.5 The framework of SEI-PEC.

$$\boldsymbol{R_{i\times k} = D_{i\times e} \times L_{e\times k} \times B_{k\times k}} \tag{S5}$$

$$\boldsymbol{\bar{r}_{i,k}} \begin{cases} \boldsymbol{r_{i,k}} & \boldsymbol{if\ k \neq country\ of\ interest} \\ \boldsymbol{P_i - \sum_j r_{i,j}} & \boldsymbol{if\ country = country\ of\ interst} \end{cases} \tag{S6}$$

$$\boldsymbol{EI_k = EII_i \times \bar{R}_{i\times k}} \tag{S7}$$

$$\boldsymbol{d_{i,e} = \frac{x_{i,e}}{\sum_i x_{i,e}}} \tag{S8}$$

$$\boldsymbol{l_{e,k} = \frac{n_{e,k}}{P^k}} \tag{S9}$$

Table S 8.9 Variables and description of equation in model SEI-PCS.

Variables	**description**
$R_{i\times k}$	consumption of ***k*** countries produced by ***i*** domestic producers in country of interest
$\bar{R}_{i,k}$	The revised value of $R_{i\times k}$
$D_{i\times e}$	Share of commodities from ***i*** sub-regional producers to ***e*** trade facilities
$L_{e\times k}$	Ratio between imports from countries ***k*** and production of that country
$B_{k\times k}$	Bilateral trade flow between ***k*** countries
EI_k	Environmental impacts in ***k*** countries
EII_i	Environmental impacts intensity in subnational regions ***i***
$X_{i\times e}$	Exported commodities produced in subnational regions

$\boldsymbol{Y_{i \times n}}$	Domestic production produced in subnational regions
$\boldsymbol{T_{q \times e}}$	Re-exported commodities in country of interest
$\boldsymbol{Z_{q \times n}}$	Imported commodities were consumed in country of interest
$\boldsymbol{P^{k}}$	Production of consumption countries $\boldsymbol{k}$
$\boldsymbol{x_{i,e}}$	The elements of $\boldsymbol{X_{i \times e}}$
$\boldsymbol{d_{i,e}}$	The elements of $\boldsymbol{D_{i \times e}}$
$\boldsymbol{l_{e,k}}$	The elements of $\boldsymbol{L_{e \times k}}$
$\boldsymbol{n_{e,k}}$	The elements of $\boldsymbol{N_{e \times k}}$
$\boldsymbol{r_{i,k}}$	The elements of $\boldsymbol{R_{i \times k}}$
$\boldsymbol{\bar{r}_{i,k}}$	The elements of $\boldsymbol{\bar{R}_{i,k}}$

8.2 Supporting information to chapter 3

8.2.1 Explanatory note 1

8.2.1.1 Methods for aggregating Millet and Coffee

In the SPAM databases, there are *Millet Pearl* and *Millet Small*, and *Coffee Arabica* and *Coffee Robusta*. But there are only *Millet* and *Coffee* in FAOSTAT and so EXIOBASE as well. In order to match SPAM databases with EXIOBASE, we aggregate *Millet Pearl* and *Millet Small* into *Millet*, and aggregate *Coffee Arabica* and *Coffee Robusta* into *Coffee*. Because we use total production of primary crops in SPAM, namely a value in grid cell stands for its production quantity in metric tons, we use Raster Calculator tools in ArcGIS 10.2.2 to add two raster databases of production of *Millet Pearl* and *Millet Small* as the spatial distribution of total production of *Millet*. And the similar way for calculation for *Coffee*.

8.2.1.2 Special solution for Canada

Canada is a special case for the spatial distribution of some livestock. There is no major road further north than a latitude of 70° N; yet ducks and sheep are in relative abundance north of that. Therefore, we regard the region below 70° N within a concave hull based on a 1-degree buffer around all roads as the first-priority region for export and the second-priority region for domestic consumption, and the rest as the first-priority region for second-priority region for export and the first-priority region for domestic consumption.

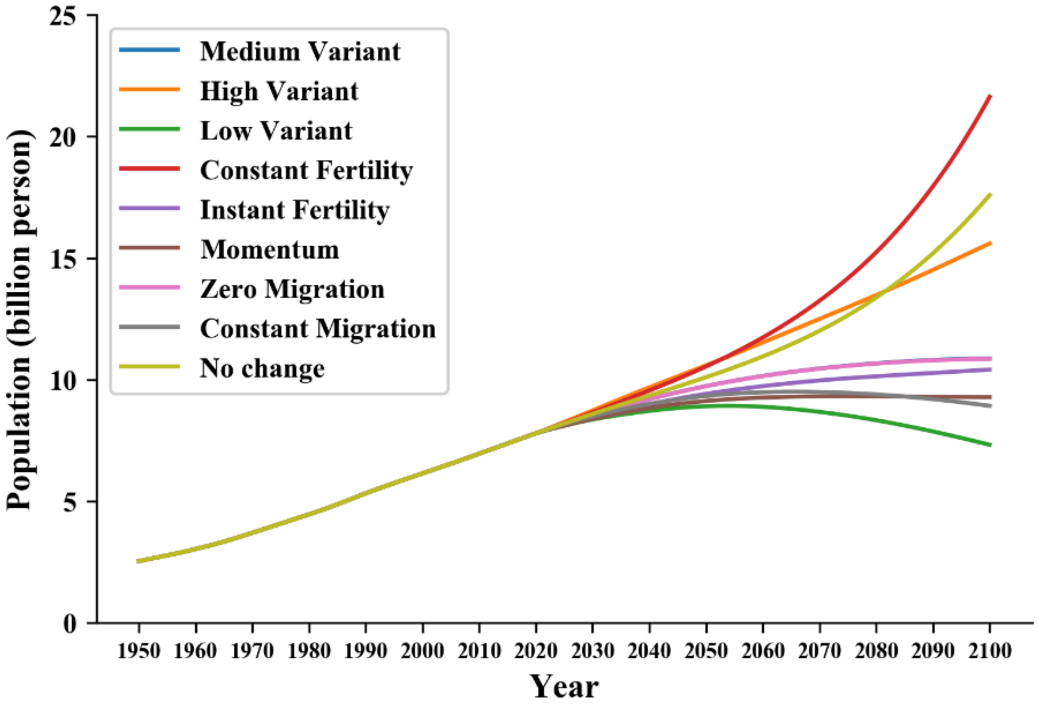

Figure S 8.6. World Population from 1950 to 2100. Source: World Population Prospects: The 2019 Revision.

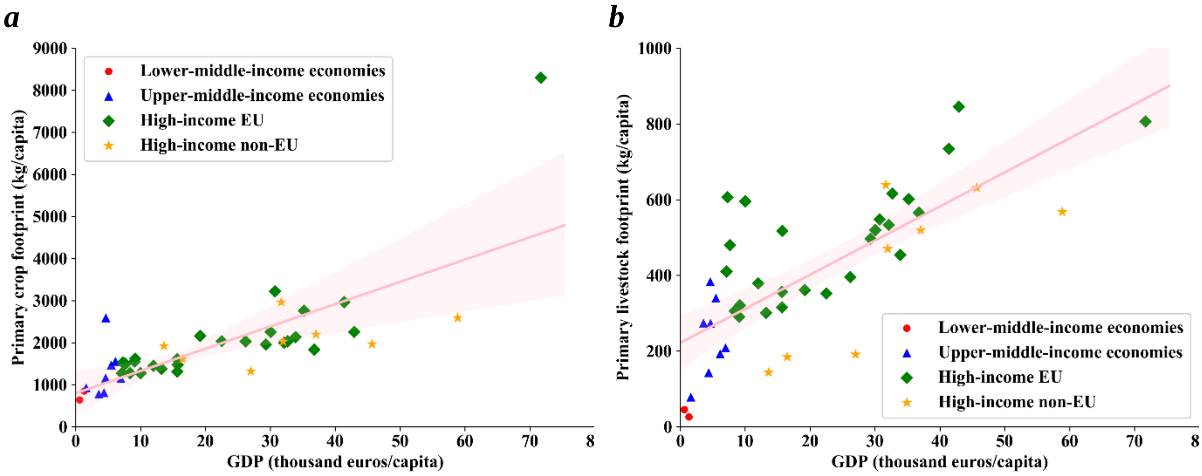

Figure S 8.7. Per-capita embodied primary crop (a) and livestock (b) consumption and per-capita GDP for 44 countries in EXIOBASE.

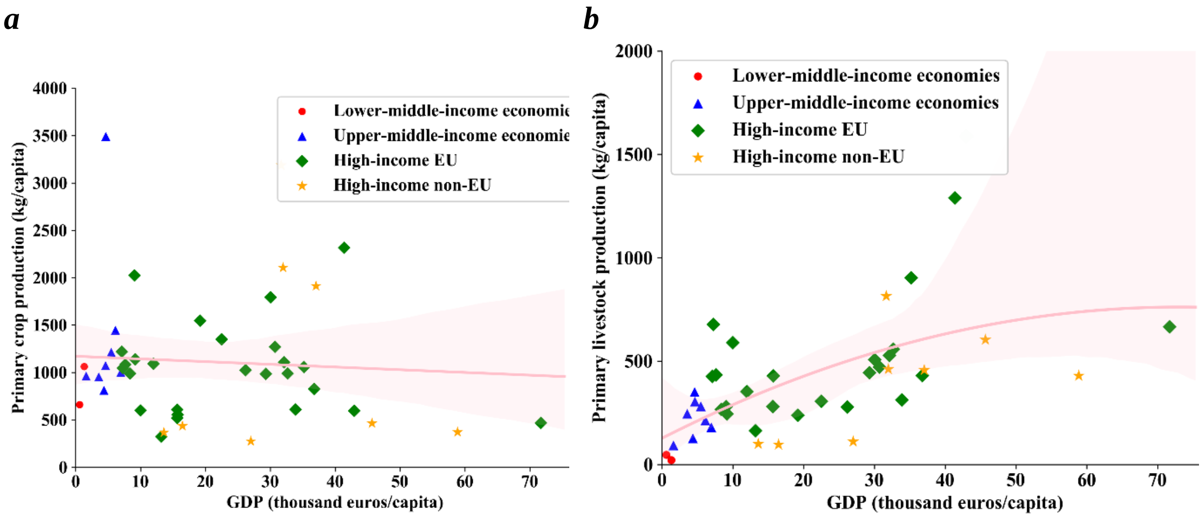

Figure S 8.8. Per-capita primary crop (a) and livestock (b) production and per-capita GDP for 44 countries in EXIOBASE.

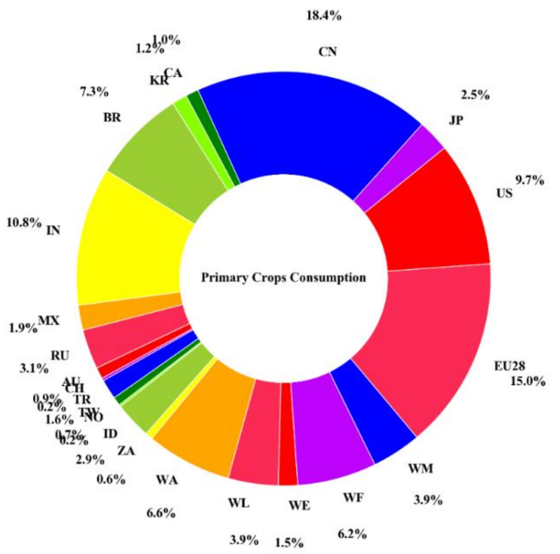

Figure S 8.9. Embodied primary crop consumption for each region in EXIOBASE

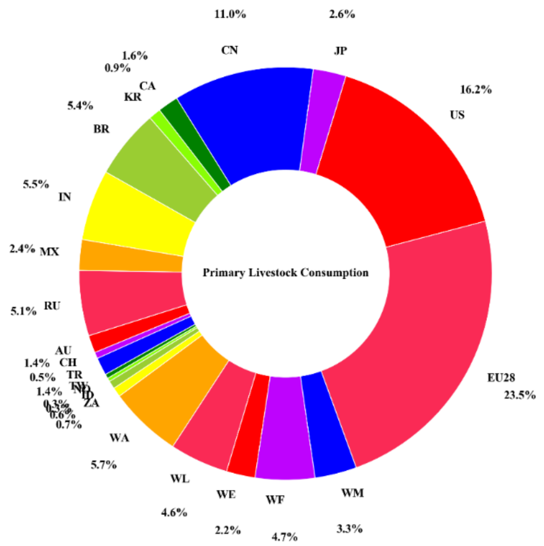

Figure S 8.10. Embodied livestock for each region in EXIOBASE

a *b*

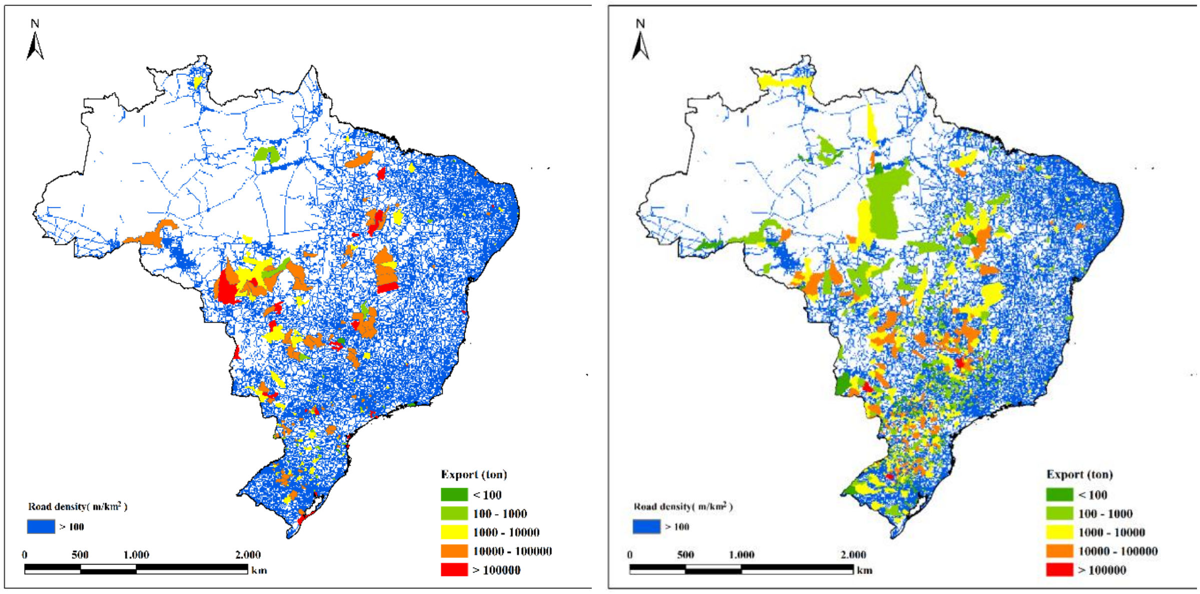

Figure S 8.11. Soybean export from official statistics data (a) and Trase.earth calculation (b) in 2006 at municipality level.

Table S 8.10. Mapping relationship between resource extensions about crop accounts in EXIOBASE with SPAM

Extensions in EXIOBASE	unit	SPAM code	name in SPAM	Sector in EXIOBASE
Domestic Extraction Used - Primary Crops – Abaca	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops - Agave Fibres nes	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops – Almonds	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Anise, Badian, Fennel	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops – Apples	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Apricots	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Arecanuts	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Artichokes	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Asparagus	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Avocados	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Bambara beans	kt	19	other pulses	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Bananas	kt	37	banana	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Barley	kt	4	Barley	Cereal grains nec
Domestic Extraction Used - Primary Crops - Beans, dry	kt	14	Bean	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Beans, green	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Berries nec	kt	40	temperate fruit	Vegetables, fruit, nuts

Domestic Extraction Used - Primary Crops – Blueberries	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Brazil nuts, with shell	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Broad beans, horse beans, dry	kt	19	other pulses	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Buckwheat	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops – Cabbages	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Canary Seed	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops – Carobs	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Carrots	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Cashew nuts, with shell	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Cashewapple	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Cassava	kt	12	cassava	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Cassava leaves	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Castor oil seed	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops – Cauliflower	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Cereals nec	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops – Cherries	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Chestnuts	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Chick peas	kt	15	chickpea	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Chicory Roots	kt	41	vegetables	Vegetables, fruit, nuts

Domestic Extraction Used - Primary Crops - Chillies and peppers, dry	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops - Chillies and peppers, green	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Cinnamon	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops - Citrus Fruit nec	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Cloves	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops - Cocoa Beans	kt	34	Cocoa	Crops nec
Domestic Extraction Used - Primary Crops – Coconuts	kt	22	coconut	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Coffee, Green	kt	32	arabica coffee	Crops nec
Domestic Extraction Used - Primary Crops – Coir	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops - Cotton Lint	kt	30	Cotton	Plant-based fibers
Domestic Extraction Used - Primary Crops – Cottonseed	kt	30	Cotton	Oil seeds
Domestic Extraction Used - Primary Crops - Cow peas, dry	kt	16	cowpea	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Cranberries	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Cucumbers and Gherkins	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Currants	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Dates	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Eggplants	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Fibre Crops nes	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops – Figs	kt	39	tropical fruit	Vegetables, fruit, nuts

Domestic Extraction Used - Primary Crops - Flax Fibre and Tow	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops – Fonio	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops - Fruit Fresh Nes	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Fruit, tropical fresh nes	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Garlic	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Ginger	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops – Gooseberries	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Grapefruit and Pomelos	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Grapes	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Groundnuts in Shell	kt	21	groundnut	Oil seeds
Domestic Extraction Used - Primary Crops – Hazelnuts	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Hemp Fibre and Tow	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops – Hempseed	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops – Hops	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops - Jojoba Seeds	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops - Jute and Jute-like Fibres	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops - Kapok Fibre	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops - Karite Nuts	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops - Kiwi Fruit	kt	40	temperate fruit	Vegetables, fruit, nuts

Domestic Extraction Used - Primary Crops – Kolanuts	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Leeks and other Alliac. Veg.	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Leguminous vegetables, nes	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Lemons and Limes	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Lentils	kt	18	Lentil	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Lettuce	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Linseed	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops – Lupins	kt	19	other pulses	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Maize	kt	3	Maize	Cereal grains nec
Domestic Extraction Used - Primary Crops - Maize, green	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Mangoes, mangosteens, guavas	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Mate	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops – Melonseed	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops – Millet	kt	5	pearl millet	Cereal grains nec
Domestic Extraction Used - Primary Crops - Mixed Grain	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops – Mushrooms	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Mustard Seed	kt	25	rapeseed	Oil seeds
Domestic Extraction Used - Primary Crops - Natural Rubber	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops - Nutmeg, mace and cardamoms	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops - Nuts, nes	kt	42	rest of crops	Vegetables, fruit, nuts

Domestic Extraction Used - Primary Crops – Oats	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops - Oil Palm Fruit	kt	23	oilpalm	Oil seeds
Domestic Extraction Used - Primary Crops - Oilseeds nec	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops – Okra	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Olives	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops – Onions	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Onions, dry	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Oranges	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Other Bastfibres	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops - Other melons	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Papayas	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Peaches and Nectarines	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Pears	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Peas, dry	kt	19	other pulses	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Peas, Green	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Pepper	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops – Peppermint	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops – Persimmons	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Pigeon peas	kt	17	pigeonpea	Vegetables, fruit, nuts

Domestic Extraction Used - Primary Crops – Pineapples	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Pistachios	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Plantains	kt	38	plantain	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Plums	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Pome fruit, nes	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Poppy Seed	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops – Potatoes	kt	9	Potato	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Pulses nec	kt	19	other pulses	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Pumpkins, Squash, Gourds	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Pyrethrum, Dried Flowers	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops – Quinces	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Quinoa	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops – Ramie	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops – Rapeseed	kt	25	rapeseed	Oil seeds
Domestic Extraction Used - Primary Crops – Raspberries	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Rice	kt	2	Rice	Paddy rice
Domestic Extraction Used - Primary Crops - Roots and Tubers, nes	kt	13	other roots	Cereal grains nec
Domestic Extraction Used - Primary Crops – Rye	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops - Safflower Seed	kt	27	other oil crops	Oil seeds

Domestic Extraction Used - Primary Crops - Sesame Seed	kt	26	sesameseed	Oil seeds
Domestic Extraction Used - Primary Crops – Sisal	kt	31	other fibre crops	Plant-based fibers
Domestic Extraction Used - Primary Crops – Sorghum	kt	7	sorghum	Cereal grains nec
Domestic Extraction Used - Primary Crops - Sour Cherries	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Soybeans	kt	20	soybean	Oil seeds
Domestic Extraction Used - Primary Crops - Spices nec	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops – Spinach	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Stone Fruit nec,	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Strawberries	kt	40	temperate fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - String beans	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Sugar Beets	kt	29	sugarbeet	Sugar cane, sugar beet
Domestic Extraction Used - Primary Crops - Sugar Cane	kt	28	sugarcane	Sugar cane, sugar beet
Domestic Extraction Used - Primary Crops - Sugar Crops nes	kt	42	rest of crops	Sugar cane, sugar beet
Domestic Extraction Used - Primary Crops - Sunflower Seed	kt	24	sunflower	Oil seeds
Domestic Extraction Used - Primary Crops - Sweet Potatoes	kt	10	sweet potato	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops - Tallowtree Seeds	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops - Tang. Mand Clement. Satsma	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Taro	kt	13	other roots	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Tea	kt	35	Tea	Crops nec
Domestic Extraction Used - Primary Crops - Tea nes	kt	35	Tea	Crops nec

Domestic Extraction Used - Primary Crops - Tobacco Leaves	kt	36	tobacco	Crops nec
Domestic Extraction Used - Primary Crops – Tomatoes	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Triticale	kt	8	other cereals	Cereal grains nec
Domestic Extraction Used - Primary Crops - Tung Nuts	kt	27	other oil crops	Oil seeds
Domestic Extraction Used - Primary Crops – Vanilla	kt	42	rest of crops	Crops nec
Domestic Extraction Used - Primary Crops - Vegetables Fresh nec	kt	41	vegetables	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Vetches	kt	19	other pulses	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Walnuts	kt	42	rest of crops	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Watermelons	kt	39	tropical fruit	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Wheat	kt	1	Wheat	Wheat
Domestic Extraction Used - Primary Crops – Yams	kt	11	Yams	Vegetables, fruit, nuts
Domestic Extraction Used - Primary Crops – Yautia	kt	13	other roots	Vegetables, fruit, nuts

Table S 8.11. Mapping relationship between EXIOABSE account with FAOSTAT product of livestock

EXIOBASE sector number	EXIOBASE name	FAOSTAT product names
11	Poultry	Eggs, hen, in shell
14	Raw milk	Milk, whole fresh cow; Milk, whole fresh goat; Milk, whole fresh sheep
43	Products of meat cattle	Hides, cattle, fresh; Meat indigenous, cattle
44	Products of meat pigs	Meat indigenous, pig.
45	Products of meat poultry	Meat indigenous, chicken; Meat indigenous, duck
46	Meat products nec	Meat indigenous, goat; Skins, goat, fresh; Meat indigenous, sheep; Skins, sheep, fresh.

Table S 8.12. Mapping relationship between countries in FAOSTAT with regions in EXIOABSE for livestock

FAOSTAT countries	EXIOBASE regions	Region abbreviation in EXIOBASE
Austria	Austria	AT
Belgium	Belgium	BE
Bulgaria	Bulgaria	BG
Cyprus	Cyprus	CY
Czechia	Czech Republic	CZ
Germany	Germany	DE
Denmark	Denmark	DK
Estonia	Estonia	EE
Spain	Spain	ES
Finland	Finland	FI
France	France	FR
Greece	Greece	GR
Croatia	Croatia	HR
Hungary	Hungary	HU
Ireland	Ireland	IE
Italy	Italy	IT
Lithuania	Lithuania	LT
Luxembourg	Luxembourg	LU
Latvia	Latvia	LV
Malta	Malta	MT
Netherlands	Netherlands	NL
Netherlands Antilles (former)	Netherlands	NL
Poland	Poland	PL
Portugal	Portugal	PT

Romania	Romania	RO
Sweden	Sweden	SE
Slovenia	Slovenia	SI
Slovakia	Slovakia	SK
United Kingdom	United Kingdom	GB
United States of America	United States	US
Japan	Japan	JP
China, Hong Kong SAR	China	CN
China, mainland	China	CN
Canada	Canada	CA
Republic of Korea	South Korea	KR
Brazil	Brazil	BR
India	India	IN
Mexico	Mexico	MX
Russian Federation	Russia	RU
Australia	Australia	AU
Switzerland	Switzerland	CH
Turkey	Turkey	TR
China, Taiwan Province of	Taiwan	TW
Norway	Norway	NO
Indonesia	Indonesia	ID
South Africa	South Africa	ZA
New Caledonia	RoW Asia and Pacific	WA
Afghanistan	RoW Asia and Pacific	WA
American Samoa	RoW Asia and Pacific	WA
Armenia	RoW Asia and Pacific	WA

Azerbaijan	RoW Asia and Pacific	WA
Bangladesh	RoW Asia and Pacific	WA
Bhutan	RoW Asia and Pacific	WA
Brunei	RoW Asia and Pacific	WA
Cambodia	RoW Asia and Pacific	WA
Cook Islands	RoW Asia and Pacific	WA
Democratic People's Republic of Korea	RoW Asia and Pacific	WA
Fiji	RoW Asia and Pacific	WA
French Polynesia	RoW Asia and Pacific	WA
Georgia	RoW Asia and Pacific	WA
Guam	RoW Asia and Pacific	WA
Kazakhstan	RoW Asia and Pacific	WA
Kyrgyzstan	RoW Asia and Pacific	WA
Lao People's Democratic Republic	RoW Asia and Pacific	WA
Malaysia	RoW Asia and Pacific	WA
Micronesia (Federated States of)	RoW Asia and Pacific	WA
Mongolia	RoW Asia and Pacific	WA
Myanmar	RoW Asia and Pacific	WA
Nepal	RoW Asia and Pacific	WA
New Zealand	RoW Asia and Pacific	WA
Niue	RoW Asia and Pacific	WA
Norfolk Island	RoW Asia and Pacific	WA
Pakistan	RoW Asia and Pacific	WA
Papua New Guinea	RoW Asia and Pacific	WA
Philippines	RoW Asia and Pacific	WA
Samoa	RoW Asia and Pacific	WA

Singapore	RoW Asia and Pacific	WA
Solomon Islands	RoW Asia and Pacific	WA
Sri Lanka	RoW Asia and Pacific	WA
Tajikistan	RoW Asia and Pacific	WA
Thailand	RoW Asia and Pacific	WA
Timor-Leste	RoW Asia and Pacific	WA
Tonga	RoW Asia and Pacific	WA
Turkmenistan	RoW Asia and Pacific	WA
Uzbekistan	RoW Asia and Pacific	WA
Vanuatu	RoW Asia and Pacific	WA
Viet Nam	RoW Asia and Pacific	WA
Wallis and Futuna Islands	RoW Asia and Pacific	WA
Antigua and Barbuda	RoW America	WL
Argentina	RoW America	WL
Bahamas	RoW America	WL
Barbados	RoW America	WL
Belize	RoW America	WL
Bermuda	RoW America	WL
Bolivia	RoW America	WL
British Virgin Islands	RoW America	WL
Cayman Islands	RoW America	WL
Chile	RoW America	WL
Colombia	RoW America	WL
Costa Rica	RoW America	WL
Cuba	RoW America	WL
Dominica	RoW America	WL

Dominican Republic	RoW America	WL
Ecuador	RoW America	WL
El Salvador	RoW America	WL
Falkland Islands (Malvinas)	RoW America	WL
French Guiana	RoW America	WL
Greenland	RoW America	WL
Grenada	RoW America	WL
Guadeloupe	RoW America	WL
Guatemala	RoW America	WL
Guyana	RoW America	WL
Haiti	RoW America	WL
Honduras	RoW America	WL
Jamaica	RoW America	WL
Martinique	RoW America	WL
Montserrat	RoW America	WL
Nicaragua	RoW America	WL
Panama	RoW America	WL
Paraguay	RoW America	WL
Peru	RoW America	WL
Puerto Rico	RoW America	WL
Saint Kitts and Nevis	RoW America	WL
Saint Lucia	RoW America	WL
Saint Pierre and Miquelon	RoW America	WL
Saint Vincent and the Grenadines	RoW America	WL
Suriname	RoW America	WL
Trinidad and Tobago	RoW America	WL

United States Virgin Islands	RoW America	WL
Uruguay	RoW America	WL
Venezuela (Bolivarian Republic of)	RoW America	WL
Albania	RoW Europe	WE
Belarus	RoW Europe	WE
Bosnia and Herzegovina	RoW Europe	WE
Faroe Islands	RoW Europe	WE
Iceland	RoW Europe	WE
Liechtenstein	RoW Europe	WE
Montenegro	RoW Europe	WE
Republic of Moldova	RoW Europe	WE
Serbia	RoW Europe	WE
The former Yugoslav Republic of Macedonia	RoW Europe	WE
Ukraine	RoW Europe	WE
Algeria	RoW Africa	WF
Angola	RoW Africa	WF
Benin	RoW Africa	WF
Botswana	RoW Africa	WF
Burkina Faso	RoW Africa	WF
Burundi	RoW Africa	WF
C+¦te d'Ivoire	RoW Africa	WF
Cabo Verde	RoW Africa	WF
Cameroon	RoW Africa	WF
Central African Republic	RoW Africa	WF
Chad	RoW Africa	WF
Comoros	RoW Africa	WF

Congo	RoW Africa	WF
Democratic Republic of the Congo	RoW Africa	WF
Djibouti	RoW Africa	WF
Equatorial Guinea	RoW Africa	WF
Eritrea	RoW Africa	WF
Ethiopia	RoW Africa	WF
Gabon	RoW Africa	WF
Gambia	RoW Africa	WF
Ghana	RoW Africa	WF
Guinea	RoW Africa	WF
Guinea-Bissau	RoW Africa	WF
Kenya	RoW Africa	WF
Lesotho	RoW Africa	WF
Liberia	RoW Africa	WF
Libya	RoW Africa	WF
Madagascar	RoW Africa	WF
Malawi	RoW Africa	WF
Mali	RoW Africa	WF
Mauritania	RoW Africa	WF
Mauritius	RoW Africa	WF
Morocco	RoW Africa	WF
Mozambique	RoW Africa	WF
Namibia	RoW Africa	WF
Niger	RoW Africa	WF
Nigeria	RoW Africa	WF
Reunion	RoW Africa	WF

Rwanda	RoW Africa	WF
Saint Helena, Ascension and Tristan da Cunha	RoW Africa	WF
Sao Tome and Principe	RoW Africa	WF
Senegal	RoW Africa	WF
Seychelles	RoW Africa	WF
Sierra Leone	RoW Africa	WF
Somalia	RoW Africa	WF
Sudan (former)	RoW Africa	WF
Swaziland	RoW Africa	WF
Togo	RoW Africa	WF
Tunisia	RoW Africa	WF
Uganda	RoW Africa	WF
United Republic of Tanzania	RoW Africa	WF
Western Sahara	RoW Africa	WF
Zambia	RoW Africa	WF
Zimbabwe	RoW Africa	WF
Bahrain	RoW Middle East	WM
Egypt	RoW Middle East	WM
Iran (Islamic Republic of)	RoW Middle East	WM
Iraq	RoW Middle East	WM
Israel	RoW Middle East	WM
Jordan	RoW Middle East	WM
Kuwait	RoW Middle East	WM
Lebanon	RoW Middle East	WM
Occupied Palestinian Territory	RoW Middle East	WM
Oman	RoW Middle East	WM

Qatar	RoW Middle East	WM
Saudi Arabia	RoW Middle East	WM
Syrian Arab Republic	RoW Middle East	WM
United Arab Emirates	RoW Middle East	WM
Yemen	RoW Middle East	WM

8.3 Supporting information to chapter 4

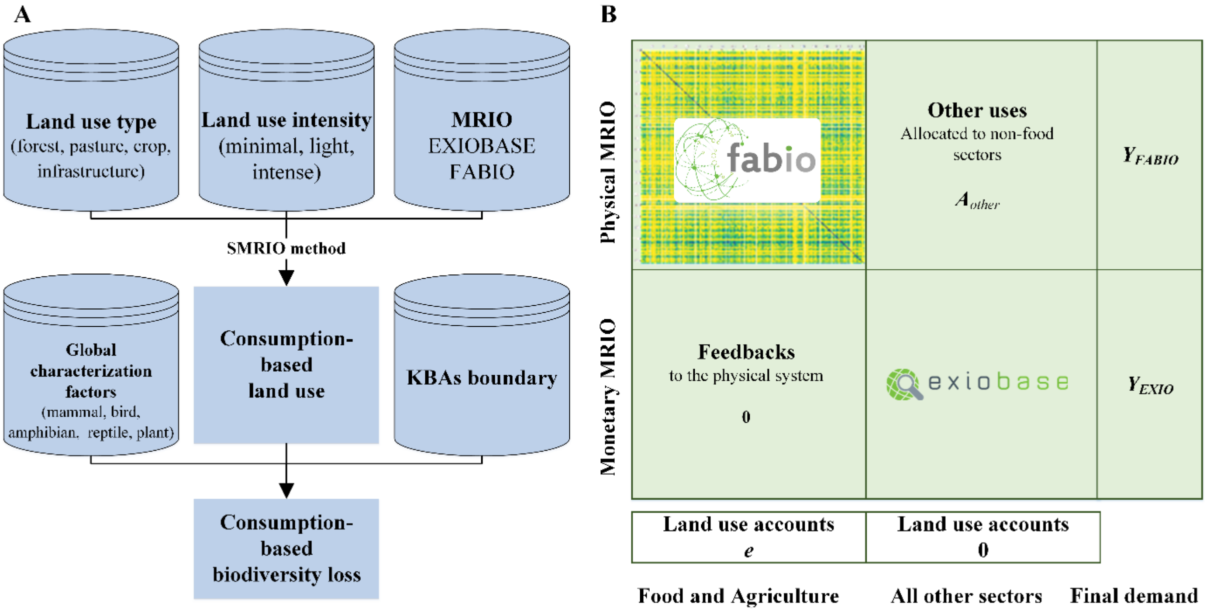

Figure S 8.12. Schematic of the methodology in general (a), and of linking FABIO and EXIOBASE (b).

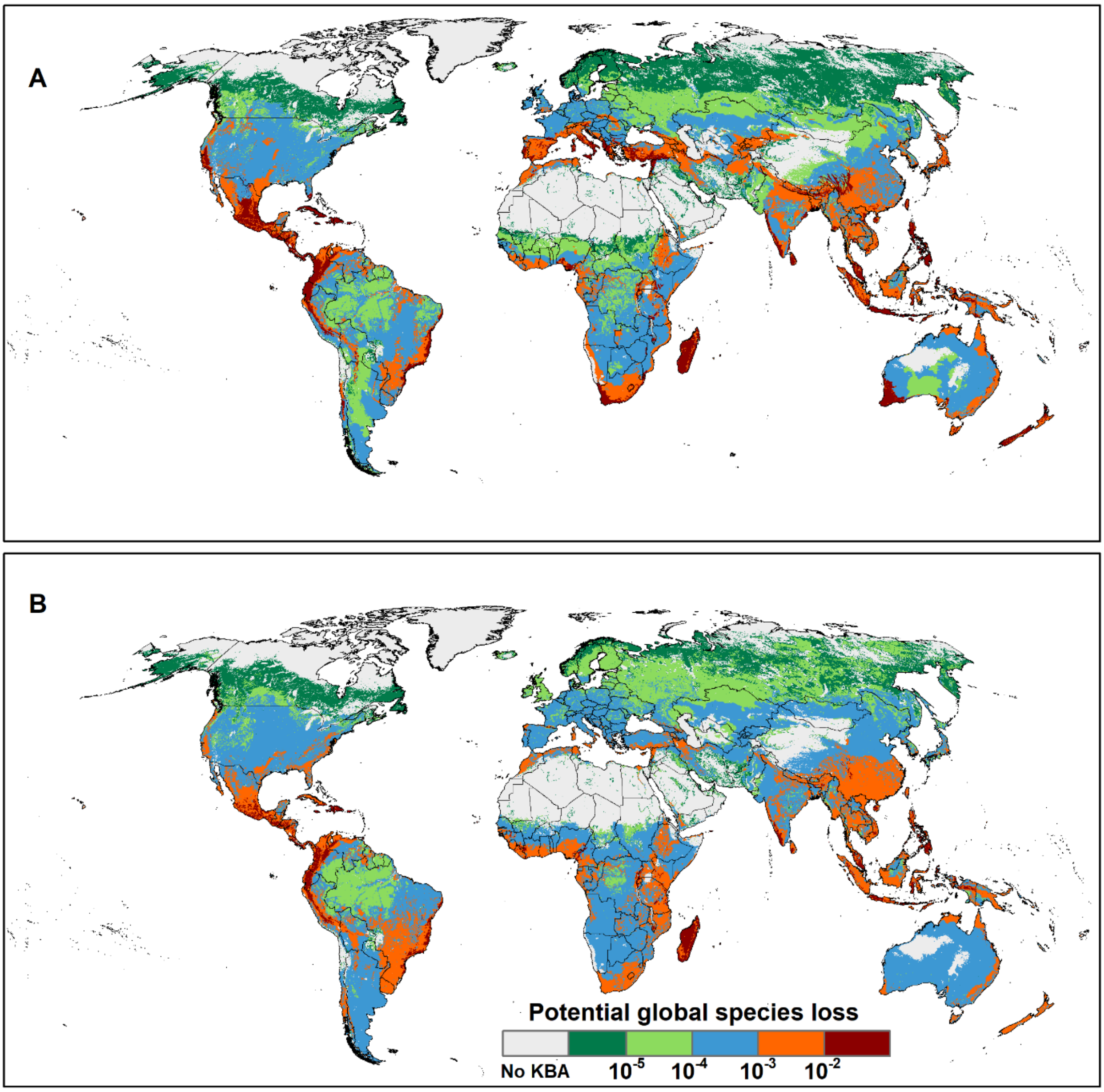

Figure S 8.13. Spatial distribution of potential global species loss driven by land use inside and outside KBAs for a) plants, and b) vertebrates (mammals + birds + amphibians + reptiles). The spatial resolution is 5 arc min.

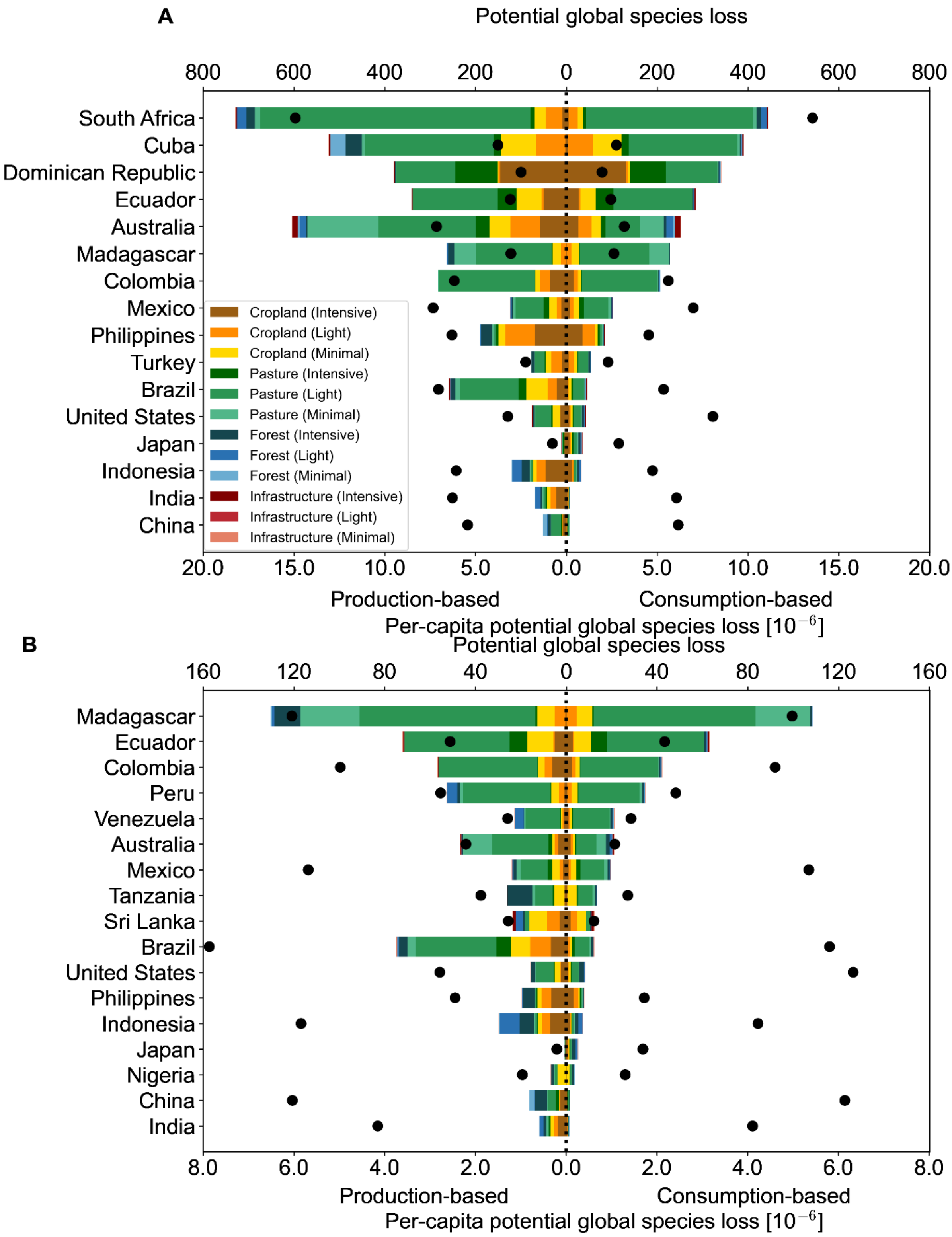

Figure S 8.14. The potential global species loss from land use inside and outside KBAs for plants (a) and vertebrates (b) (mammals, birds, amphibians, and reptiles). On each *x*-axis (bottom and top of figures), the production-based perspective is shown to the left of zero and the consumption-based perspective to the right. The *y*-axis lists the top 15 countries/regions with the largest consumption-based or production-based biodiversity loss from land use within and outside KBAs at the national level. The bar shows the per-capita value of biodiversity loss per land type and land use intensity. The circles show the total national biodiversity loss with a value shown by the upper *x*-axes on the top of each plot.

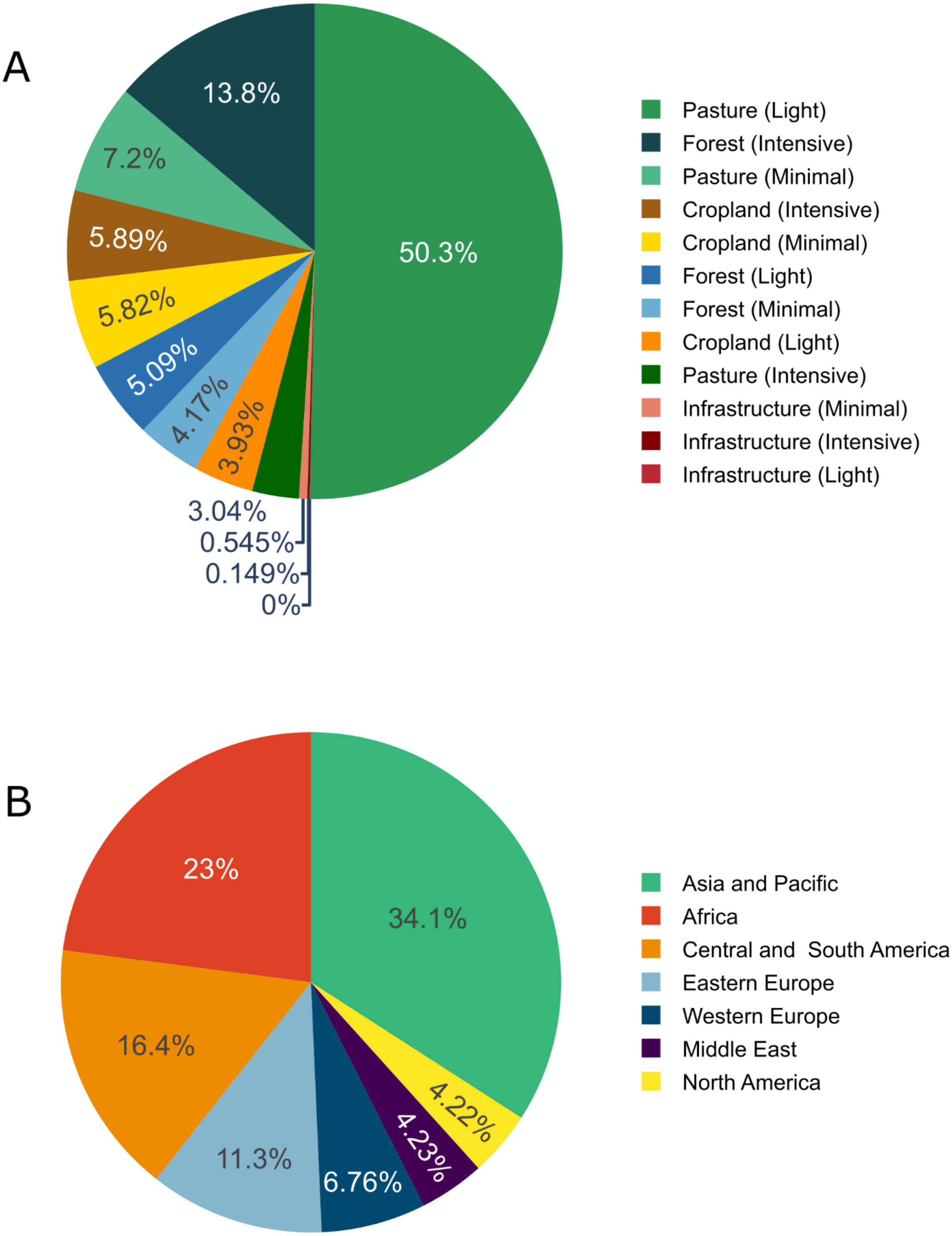

Figure S 8.15. Land use within KBAs with different land use types and land use intensities (a) and in different regions (b).

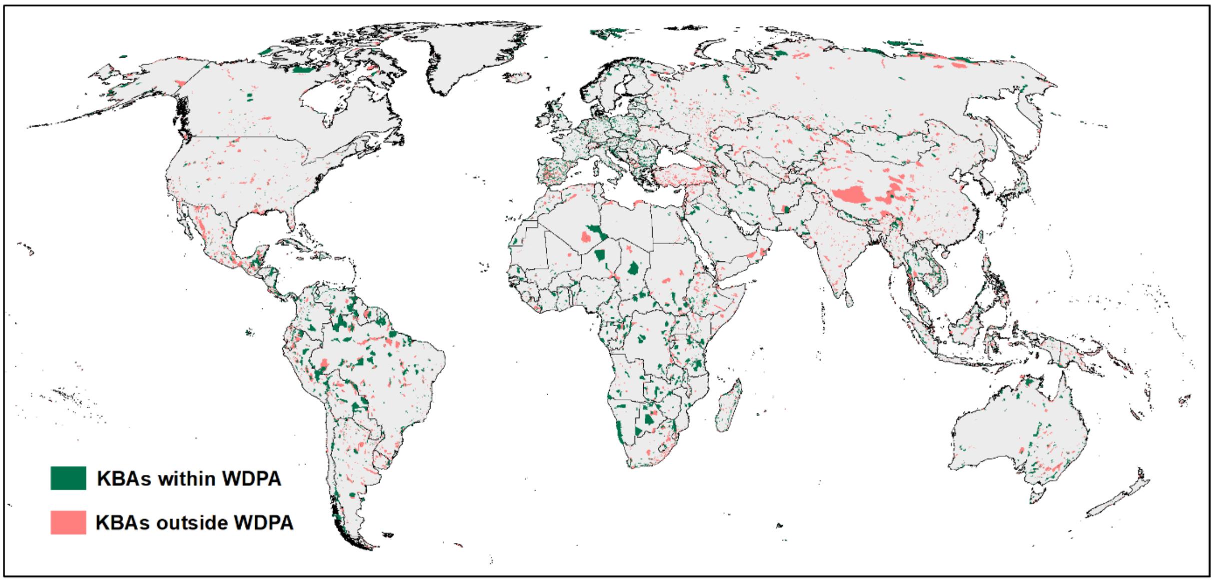

Figure S 8.16. Intersections between KBAs and the World Database on Protected Areas (WDPA).

8.4 Supporting information to chapter 5

8.4.1 **Supplementary Methods**

Biomass carbon and soil organic carbon in current vegetation

The calculation of aboveground biomass carbon (AGBC) and belowground biomass carbon (BGBC) is based on the latest harmonized carbon density map in the year 2010 developed by Spawn et al[358]. For herbaceous crops, Spawn et al. employed gridded crop maps from EarthStat [35], and we used the latest crop maps from Spatial Production Allocation Model (SPAM) [390] in 2010 and method from Spawn et al. [358]to get the latest AGBC and BGBC maps of herbaceous crops. For woody crops and pasture, we extract AGBC and BGBC from the latest harmonized carbon density maps directly.

Primary crops and fodder:

The production and harvested area of 163 types of primary crops and 16 types of fodder crops in 2010 come from FAOSTAT [357]. The fodder crops are not available in FAOSTAT now, and are provided by one of developers of The Food and Agriculture Biomass Input-Output model (FABIO) [36]. We then use the SPAM [390] to build a spatially-explicit picture of crop production. SPAM employs a cross-entropy approach to make estimates of 42 crop maps in 2010 at 5 arc min resolution. Since "Pearl Millet" and "Small Millet" are not split in FAOSTAT, we aggregate them into millet; similarly "Arabica Coffee" and "Robusta Coffee" are not split and we aggregate them into "Coffee". These 40 crops are aggregated from an average of 163 types of primary crops contained in the FAOSTAT database between 2009 and 2011. Therefore, we used national data from FAOSTAT in 2010 to calibrate the SPAM for each country. However, since SPAM does not include fodder crop maps, we use EarthStat fodder maps [35] at 5 arc min resolution in 2000. We aggregate the 16 fodder maps into one fodder map for ease of analysis.

Pasture

There are many ways to estimate pasture for grazing. Ramankutty et al. created a map in which they estimate the percentage of pasture per grid cell at 5 min resolution [35] in 2000. Sloat et al., updated this map to the year 2010 at 500 meters resolution [393]. They considered a grid cell to be pasture if it fell into a livestock category on the global livestock production systems (GLPS) map and also contained at least 30% pasture by area [393]. Marques et al.,[12] used pasture map from Ramankutty et al.,[35] as permanent pasture, and excluded non-productive area (below NPP over 20 g C m^{-2} yr^{-1}) is used to feed livestock in the year 2000. In the end, we employed the pasture map developed by Sloat et al. [393] because their dataset is the latest and the time is in line with our research. We assume pasture layer was capped if all land-use types (cropland, infrastructure, and forest) fill 100% of the grid cell. For forest, we employed fractional tree cover from MODIS in 2010 [426]. We linearly stretched values such that 80% was treated as complete tree cover (100%), since MODIS tree cover estimates saturate at around 80%, following Spawn et al.[358]. For infrastructure, we used ESA CCI Land cover Maps at 300 meters resolution in 2010 [427].

GHG emissions

For animal-specific sectors, this includes: "Enteric Fermentation", "Manure Management", "Manure applied to Soils", and "Manure left on Pasture". For crop-specific sectors, this includes: "Rice Cultivation", "Crop Residues", and "Burning - Crop Residues". There are two outstanding, high-emission sectors: "Synthetic Fertilizers", and "Energy Use" which are not allocated to specific agricultural sectors. In FAOSTAT, GHG emission of "Synthetic Fertilizers" is only derived from nitrogen fertilizers, so we first classify their GHG emissions into 28 countries/regions, and 13 crop groups based on the amount of nitrogen fertilizer use from the International Fertilizer Association (IFA) in 2010 [428]. Mapping relationship of countries and crops between FABIO and IFA see Tables S5 and S6. We then allocate GHG emission of “Synthetic Fertilizers” of 28 countries/regions, and 13 crop groups into separated countries and agricultural sectors in FABIO based on the monetary value of crops in each group from FAOSTAT [357]. Similarly, we allocate CO_2, CH_4, and N_2O from the “Energy Use” sector into 49 countries/regions and 14 agricultural sectors based on the combustion emissions of CO_2, CH_4, N_2O in EXIOBASE v3.6. Mapping relationship of countries and sectors between FABIO and EXIOBASE see Supplementary Tables S7 and S8. We then allocate these cases from “Energy Use” into agricultural sectors and countries using FABIO and based on the monetary value of crops from FAOSTAT in every group.

8.4.2 **Supplementary Discussion**

Potential opportunities for carbon sequestration.

Climate-smart agriculture may provide another opportunity to increase carbon benefits [429]. For example, novel plants like intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkworth & D.R.Dewey) is an emerging cool-season perennial grain (the name for commercialized grain is “Kernza”) and forage dual-use grass, and its extensive root system can improve belowground carbon fixing and reduce soil erosion [430]. Intermediate wheatgrass is becoming commercially available to farmers for some areas in the US [431]. A further opportunity is biochar. While carbon stocks will saturate when the land restores to mature and stable vegetation, biochar can break the biophysical limits of carbon sequestration[379]. Feedstocks for biochar come from residues of forest/crop/pasture, animal manure, and food waste[379]. Removing forest residue can reduce risks of wildfire, but may disturb habitats of some fungi and wildlife, along with other ecosystem services [379]. This represents a tradeoff among carbon sequestration and other ecosystem services [379]. New technologies in agricultural production can also help to mitigate climate change. For example, 3-nitrooxypropanol (3NOP), a methane inhibitor, can persistently decrease enteric methane emissions by 30% under industry-relevant conditions without affecting animal productivity negatively [432], and has been approved as a feed additive in the European Union [433].

Potential carbon offset.

Here, we focus on dietary change in high-income countries where most food supply is higher than the recommendation in the EAT diet, and the dietary change could increase carbon sequestration and reduce CO2 emission. However, the carbon benefit may be offset by population growth and malnutrition in some low- and middle-income countries in the long term [327]. For example, most low- and middle-income countries face a severe double burden of malnutrition which means simultaneous manifestation of both undernutrition and overweight and obesity [434]. The obesity in low- and middle-income countries is due to overconsumption of cheap ultra-processed food and beverages which is an unhealthy diet [434]. The EAT diet is not suitable in low-income countries because they cannot afford it, and it estimated at least 1.58 billion people are not able to pay for the cost of the EAT diet in the world [397]. People will consume more food with income growth, especially animal products in low- and middle-income countries [45]. In addition population growth low- and middle-income countries will increase food needs further. For example, population is projected to increase by 199% (1026·04 million in 2017 to 3071·21 million in 2100) in Sub-Saharan Africa [420]. The increasing food demand in low- and middle-income countries will offset carbon benefit from dietary change in high-income countries.

Another carbon offset is food waste in high-income countries. EAT diet recommends per-capita food intake instead of food purchase. Pre-capita food waste is positively related to per-capita income, and most food waste occurs in consumption stage in high-income countries because of overstocking, and too much cooking or serving [435]. In addition, healthier diets would cause more food waste because healthier diets need more consumption of perishable produce such as fruit and vegetables, which has substantial hidden costs from food waste [436]. Therefore, it is very necessary to halt food waste and loss. It is estimated about one third of global food is lost or wasted [222]. If reducing 50% of global food waste and loss, another 0.9 Pg CO_2e yr^{-1} would be mitigated [437].

Recently, organic food consumption and organic agriculture production are surging in high-income countries because they are more environmentally friendly (e.g. less fertilizer or pesticide input, and fewer biodiversity losses) also higher price compared to conventional farming [438,439]. However, organic production has lower yield which means it needs more land use to satisfy the same food demand [438,439]. The high quality and environmentally friendly food consumption is at the expense of carbon benefit.

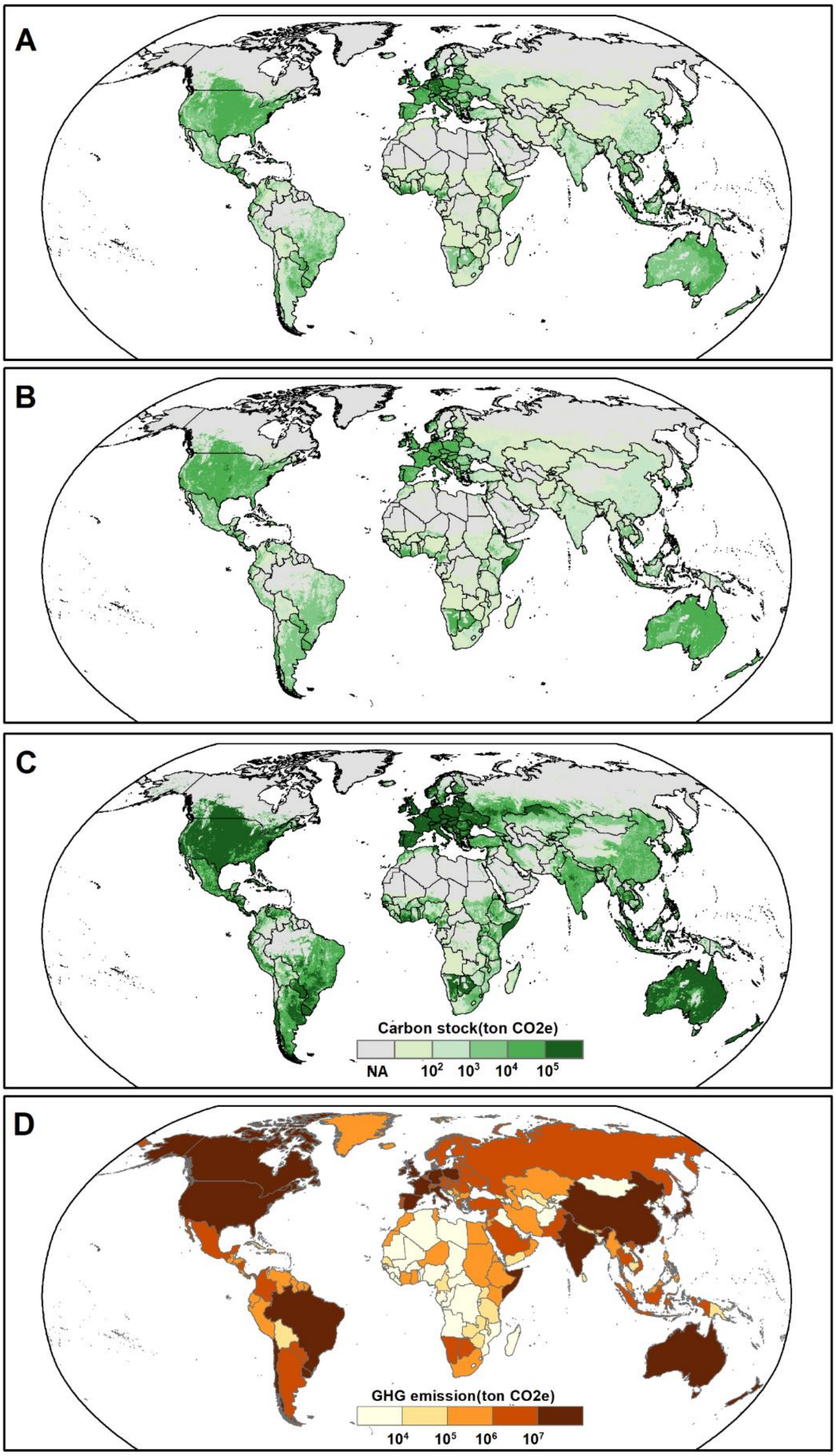

Figure S 8.17. Aboveground biomass carbon (AGBC, A), belowground biomass carbon (BGBC, B), soil organic carbon (SOC, C) and GHG emission (D) embodied in current national average diets of high-income countries.

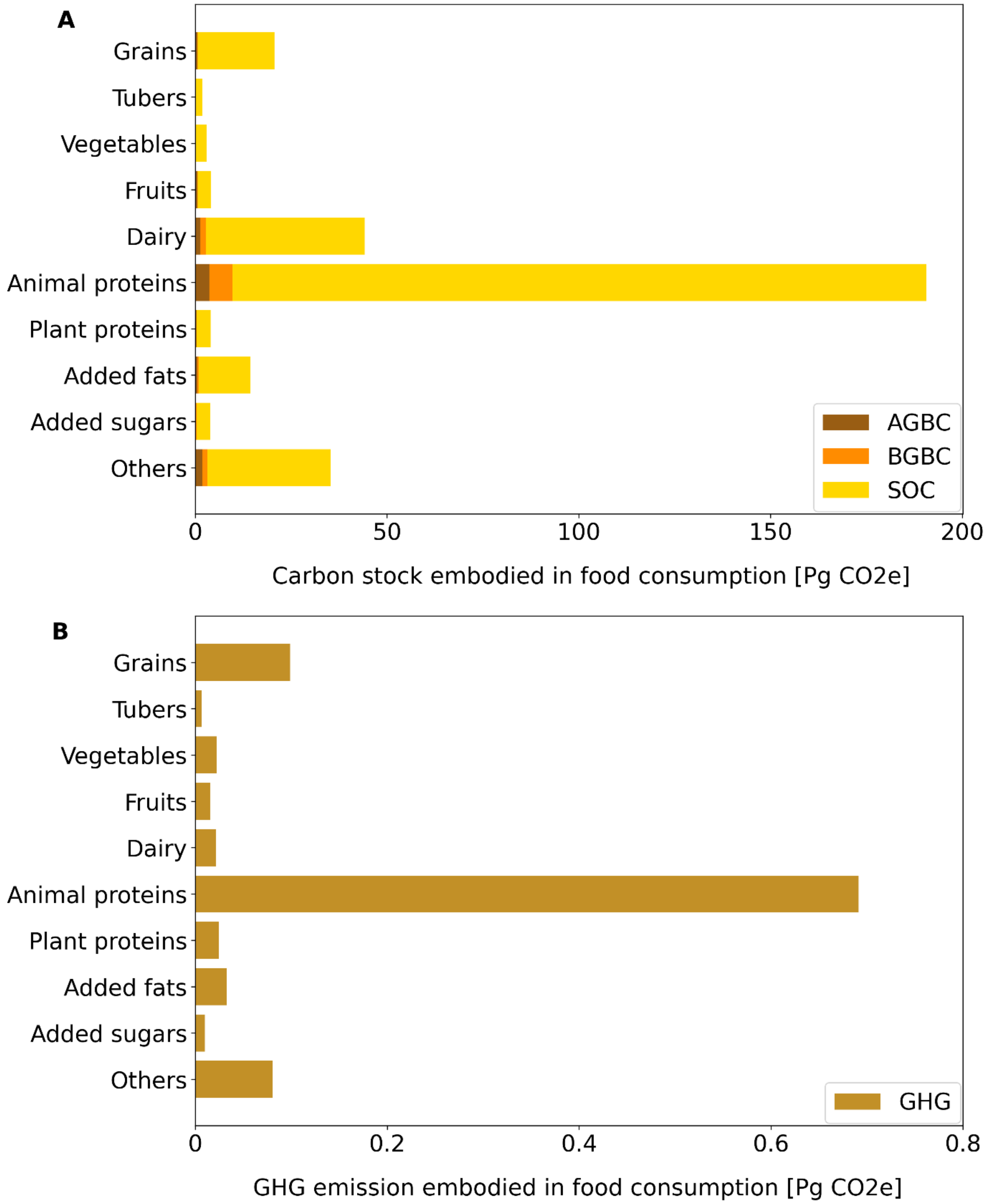

Figure S 8.18. Embodied carbon stocks (A) and GHG emission flows (B) in national average diets for high-income countries by food category. Carbon stock means aboveground biomass carbon (AGBC), belowground biomass carbon (BGBC), and soil organic carbon (SOC) in present agricultural production related vegetation (primary crops, fodder, and pasture) used for human food consumption.

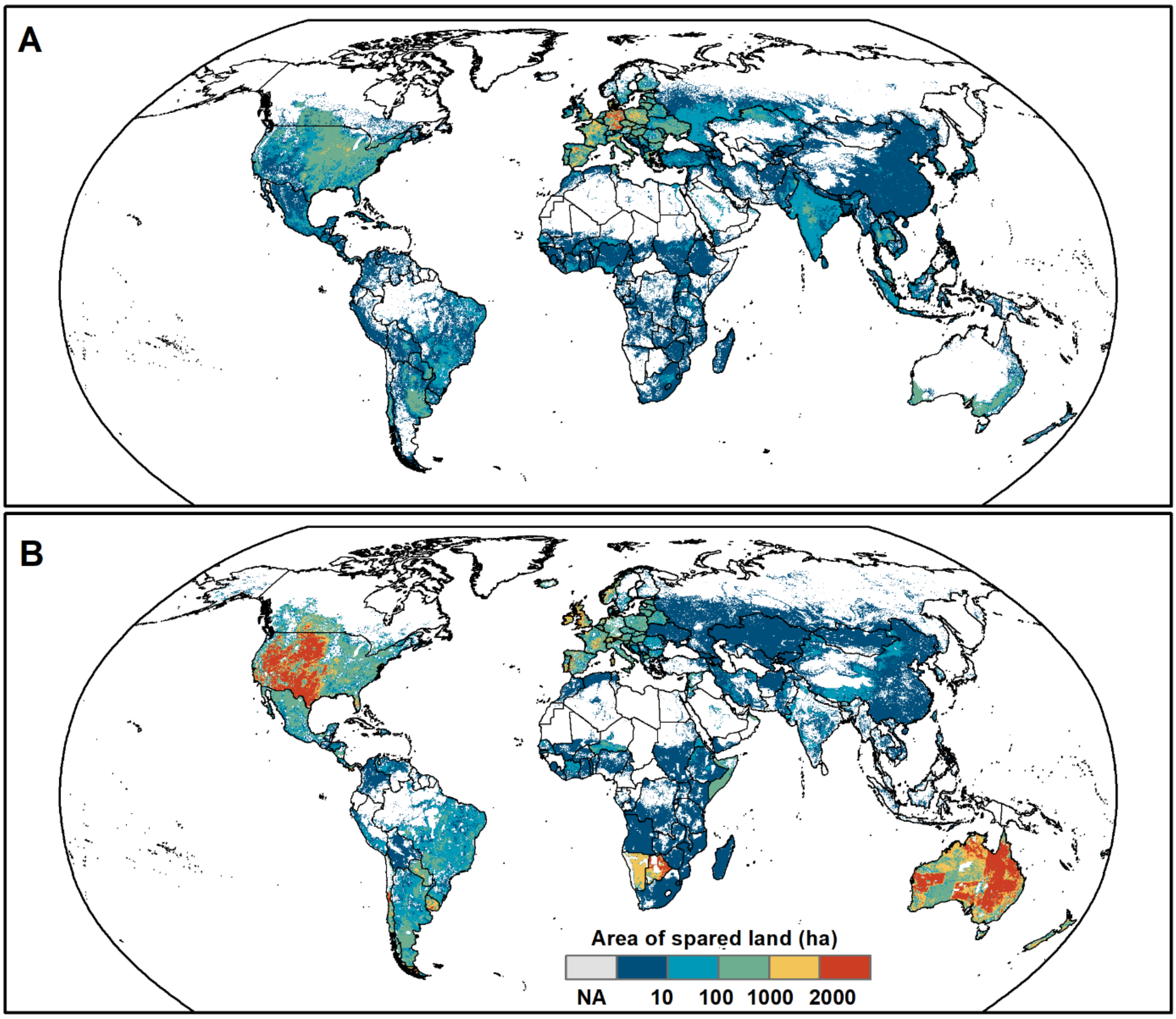

Figure S 8.19. Area of spared land due to dietary shift from national average diets to EAT diet in high-income countries for cropland (A) and pastureland (B).

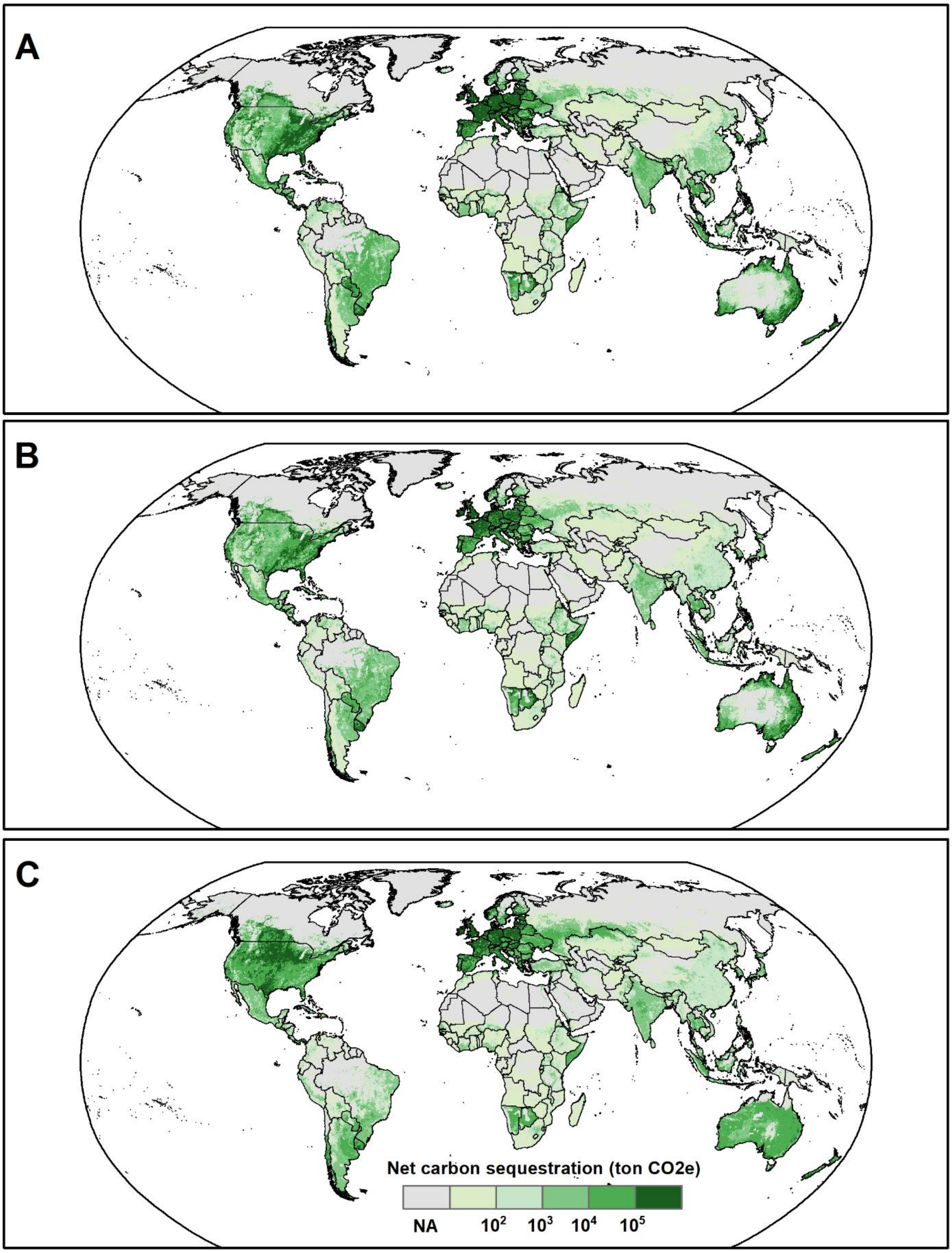

Figure S 8.20. Net carbon sequestration due to dietary shift from national average diets to EAT diet in high-income countries. Increasing amount of carbon sequestration in spared land due to dietary change for AGBC (A), BGBC (B), SOC (C).

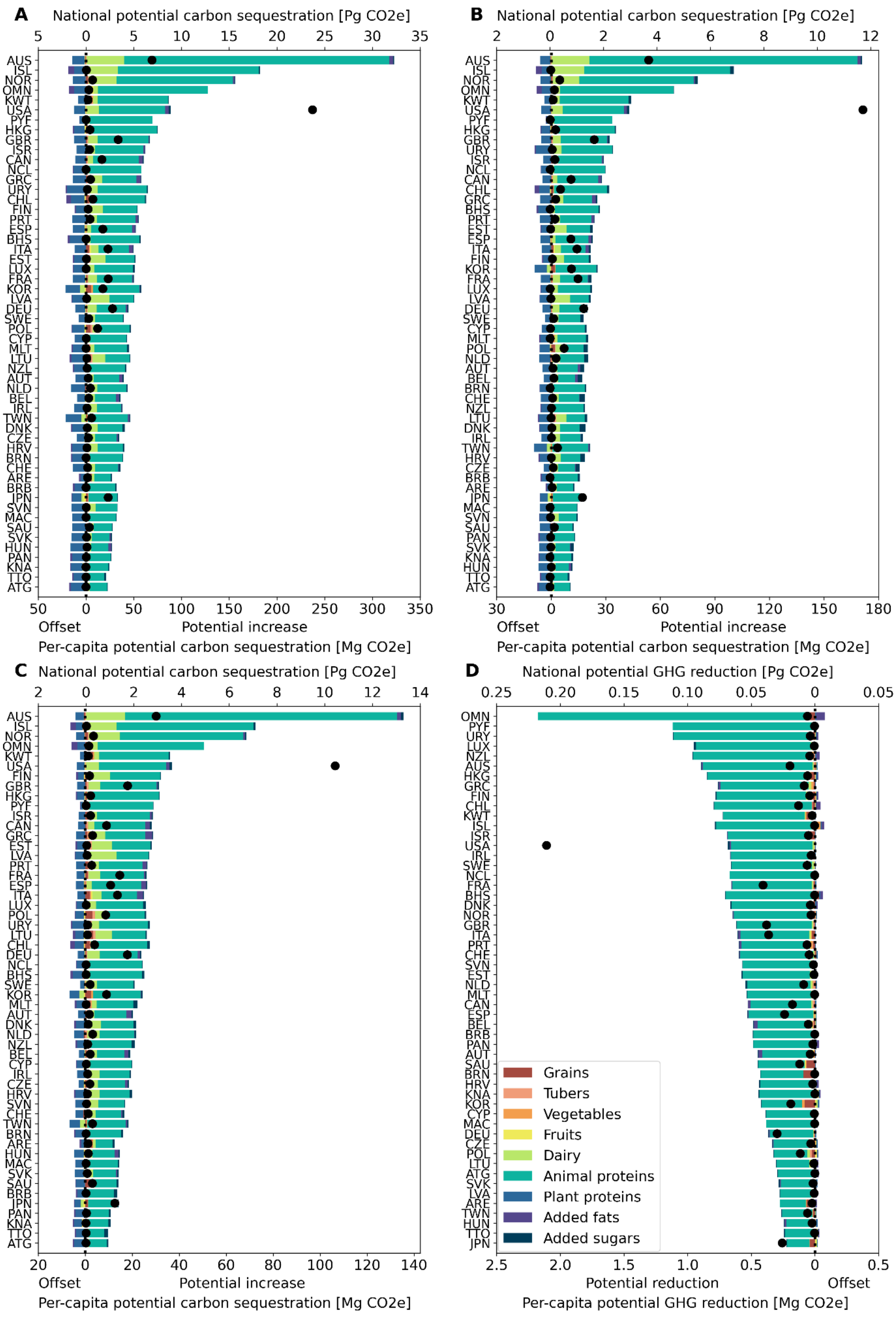

Figure S 8.21. National and Per-capita net carbon benefit due to dietary shift from national average diets to EAT diet in individual high-income country by food category. Increasing amount of carbon sequestration due to dietary change for AGBC (A), BGBC (B), SOC (C), and reducing amount of GHG emission (D) by food category. The bar means per-capita carbon sequestration and GHG emission change by food categories, and the dot means national net carbon sequestration and GHG emission change. The potential increase of carbon sequestration means carbon sequestration in potential natural vegetation minus that of current agricultural vegetation. The offset of carbon sequestration means carbon sequestration in potential natural vegetation minus that of increased agricultural vegetation. The carbon reduction of GHG emission means the GHG reduction due to reduction of food categories, and the offset means the GHG increase due to increase of food categories.