Our Common Cropland: Quantifying Global Agricultural Land Use from a Consumption Perspective

Tramberend, Sylvia; Fischer, Günther; Bruckner, Martin; van Velthuizen, Harrij

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Supplementary information

To article: Our common cropland: Quantifying global agricultural land use from a consumption perspective

Authors:

Sylvia Tramberend[1], Günther Fischer[1], Martin Bruckner[2], Harrij van Velthuizen[1]

Affiliations:

[1] International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, 2361 Laxenburg, Austria.

[2] Institute for Ecological Economics, Vienna University of Economics and Business, Austria

Corresponding author:

Sylvia Tramberend, Water Programme, IIASA. E-mail: sylvia.tramberend@iiasa.ac.at. Tel: +43 (0) 2236 807 401

Introduction and content

In addition to the methodology overview described in the main article, Appendix 1 provides a detailed description of the underlying accounting models used in the hybrid approach. This includes the physical accounting model LANDFLOW of IIASA and the environmental-economic accounting model, EXIOBASE, processed at the Vienna Economic University. Finally, we describe the integration of both modelling frameworks into a hybrid land flow accounting model.

Appendix 2 includes selected additional results included in the sections 'Results' and 'Discussion' in the main manuscript.

Contents

Appendix 1 Methodology and data for hybrid accounting

1. LANDFLOW physical accounting

1.1 Overview and data

LANDFLOW was developed in two former projects (IIASA/GWS/SERI, 2006; Prieler et al., 2013) and extended in this project. It comprises two main steps.

First (section 1.2), the production of primary commodities is separately attributed to physical land for i) cropland (for primary food, and feed and fodder crop production); ii) grassland (for ruminant livestock feed); and iii) forest land (for roundwood harvest). Reported biomass productivity (yields) determine land intensities for cropland. Cropland attribution also accounts for multi-cropping and fallow periods.

Second (section 1.3 to 1.7), the Food and Agriculture Organization of the United Nations (FAO)'s supply utilization accounts (SUA) for agricultural products, and wood balances for the forestry sector are connected with trade matrixes to track physical quantities and embodied land areas from primary production. This is done via intermediate products (notably animal feed), joint products (e.g., livestock producing milk and meat; soybean producing soy oil and soy cake), and trade to final utilization.

LANDFLOW operates on an annual basis per country. It uses a detailed commodity list for calculations and then generates results for aggregate commodity groups allowing a complete land balance of agricultural and forestry production. Apart from the land area required for agricultural production and trade, the physical volumes of produced, traded and utilized (food, feed, other use, and seed/waste) commodities are also recorded. Flows of selected important commodities of interest can be traced separately. The model includes the following main modules: i) LANDFLOW trade reconciliation; ii) LANDFLOW crop sector; iii) LANDFLOW livestock sector; and iv) LANDFLOW forestry sector[1].

1.1.1 Input data

LANDFLOW uses the large harmonized 1990 to 2011 time series country data from different domains of the United Nations Food and Agriculture Organization FAOSTAT[2] agriculture and forestry databases (FAOSTAT, 2016). The database includes i) primary crop and livestock production; ii) land use data; iii) crop yields; iv) animal stock numbers; v) SUA of primary and derived products; and vi) bilateral commodity trade data by country in physical units and dollar values.

The FAOSTAT commodity list includes 683 commodities grouped in 20 chapters. It provides a framework for the collection and analysis of data on production and trade and, ultimately compiles the SUA. The FAO commodity list is tailored on "commodity trees", that is, the primary crop and its

[1] The forestland module has not been included in this paper and will therefore not be described further.
[2] http://www.fao.org/faostat/en/#home

derived products or live animals and their derived products are traceable all along the value chain of agricultural production.

In the case of grassland, land intensities (i.e., pasture yields) for individual countries were compiled using modelled biomass productivity estimates from the Global Agro-Ecological Zones (GAEZ[1]) database (FAO and IIASA, 2012; Fischer et al., 2012).

1.1.2 Output data

LANDFLOW generates annual results per country/region for the period 1995 to 2011 separately for cropland and pastures. For reporting and optimal linkage with the environmental-economic accounting (see section 3), individual commodities are summed up and presented in terms of the following main commodity aggregates:

Firstly, crop products from cropland include the following sub-groups:

1) Wheat; 2) rice; 3) maize; 4) other cereals; 5) roots and pulses; 6) sugar crops (primary); 7) oil crops; 8) fruits/vegetables/spice; 9) stimulants (cacao, coffee, tea); 10) tobacco; 11) rubber; 12) other industrial crops (mainly fibre); 13) fodder crops; 14) sugar, sweeteners, and molasses; 15) vegetable oil; 16) oil cakes; and 17) alcohol.

Note, sub-groups 14 to 17 are derived commodities based on other crop groups. For example, vegetable oil and oil cakes are derived from primary oil crops. Alcohol is derived from a number of crop groups including wheat, rice, maize and fruits. Fodder and oil cakes are exclusively used for livestock feed. Other crop groups have multiple uses for feed, food and other non-food industrial uses (e.g., vegetable oil for food and industrial use; maize for food and feed).

Secondly, two sub-categories of livestock products are reported according to their feed requirements and associated land utilization: first, ruminants (e.g., cattle and sheep) use cropland and pastures and second, monogastric livestock (mainly pigs and poultry) relies on cropland for feed only. Reported commodity aggregates include:

1) Ruminants, meat and offals; 2) ruminants, dairy products; 3) ruminants, fats and meals; 4) ruminants, wool, hides and skins; 5) monogastric, meat and offal; 6) monogastric eggs; 7) monogastric, fats and meals; 8) monogastric, hides and skins.

For each commodity aggregate, country and year, LANDFLOW generates a balance of supply and utilization. Supply consists of domestic production and imports. Utilization in the agricultural sector includes food use, which is separate for vegetarian and livestock diets, 'other use' (i.e., non-food industrial use), and exports and equivalents for seeds and wastes (from field to farm gate). In addition, land embedded in stock changes is reported each year.

[1] http://www.gaez.iiasa.ac.at/

Additional derived variables include self-sufficiency ratios (i.e., land in domestic production divided by land in consumption), net trade balances, and per capita utilization.

1.2 Land use allocation to primary production

1.2.1 Land use data

Tracking land in produced commodities starts from the countries of origin. Agricultural production utilizes cropland and grassland. Cropland produces annual crops (e.g., cereals, sugar crops, roots and tubers) cultivated on arable land and permanent crops (e.g., orchards, vineyards, oil palms, natural rubber) for food, feed, fibre, and other industrial uses. Grasslands provide feed for grazing and browsing ruminant livestock herds (e.g., cattle and sheep). FAOSTAT reports consistent land use time series data for all countries, including agricultural areas separately for arable land, land for permanent crops, and permanent meadows/pastures. These are defined as follows:

Arable land: Arable land is the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for “arable land” are not meant to indicate the amount of land that is potentially cultivable.

Permanent crops: Permanent crops are sown or planted once, and then occupy the land for some years. Permanent crops, such as cocoa, coffee and rubber do not need to be re-planted after each annual harvest. This category includes flowering shrubs, fruit trees, nut trees and vines, but excludes trees grown for wood or timber.

Permanent meadows and pastures: Land used permanently (five years or more) to grow herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

In LANDFLOW, arable land and permanent crops are combined under the category “cropland”. Permanent meadows and pastures are henceforth termed “grassland”.

1.2.1 Allocation of cropland to primary crop commodities

Globally, cropland comprises 1,550 million hectares and is concentrated in the world’s most fertile areas. Cropland productivity depends on biophysical endowment, access to agro-research knowledge through extension services, the availability of agro-inputs, and applied land management and local socio-economic circumstances. Biophysical endowments and agronomic land management regimes determine crop rotation schemes including multi-cropping and fallow periods. In order to connect individual crop data (harvested area and production) with aggregate data on physical cropland areas LANDFLOW allocation to primary production accounts for land use intensities.

The FAOSTAT crops primary production domain reports the following items for each primary crop: i) Production (tons); ii) area harvested (ha); and iii) yields (tons/ha)[1]. Table 1 lists all 170 primary crops aggregated to LANDFLOW's reporting crop groups and attributed to either annual crops cultivated on arable land, or perennials cultivated on land for permanent crops. In addition, FAOSTAT includes a domain on fodder crops reporting production and harvested area of 16 commodities used exclusively for feed (see Table 5).

For the physical land balance maintained in the LANDFLOW model, the task is to go beyond harvested areas and to estimate the physical land base used (in the particular year, management regime and country) for the production of individual crops. We assume that physical cropland can be allocated to individual cultivated primary crops by accounting for the *entire* country's land use intensity, *separately for annual crops and perennials*[2].

Calculation of Multi-Cropping Index: The intensity of using physical land in time, accounting for both sequential cropping and fallow periods, is indicated by the multi-cropping index (MCI). It reflects the cropping intensity on a given piece of land and is defined as the ratio of harvested area of all crops in a defined region over the actual underlying physical cropland area. Whereas annual crops are sown or planted each year and, weather permitting, may be harvested more than once a year, perennial crops occupy the land for long periods and are usually harvested only once a year. Taking into account the differences in land requirements between annual and perennial crops, we calculate separate MCIs. In the case of annual crops, we calculate an average MCI over all annual crops cultivated in the particular year and country:

$$MCI_{annuals} = \frac{\sum ac_{Harv}}{arable\ land}$$

$MCI_{annuals}$	Multi-Cropping Index for annual crops
ac_{Harv}	Harvested area of annual crops

For perennial crops an MCI of 0.9 to 1.0 is assumed.

The physical extent of cropland for individual primary crops is then derived by dividing the harvested area by the respective MCI.

[1] **Production** data refer to "the actual harvested production, excluding harvesting and threshing losses, as well as the part of a crop not harvested for any reason". **Area harvested** is defined as "land area from which a crop is gathered". Areas, on which no harvest takes place due to damage or failure, are excluded. In cases of successive cropping, the area is counted as many times as it is harvested. **Yields** represent "the harvested production per unit of harvested area for crop products".

[2] Applying a country's aggregate annual and perennial land intensities evenly to individual crops is also a necessary assumption due to lacking data on specific crop rotation patterns.

Group	FAO primary crops
Cereals	*Annual crops:* Wheat; rice, paddy; maize; barley; rye; oats; millet; sorghum; buckwheat; quinoa; fonio; triticale; canary seed; mixed grain; cereals not elsewhere specified (nes)
Roots and pulses	*Annual crops:* Potatoes; sweet potatoes; cassava; yautia; taro (cocoyam); yams; roots and tubers nes; beans, dry; broad beans, dry; peas, dry; chick-peas; cow peas, dry; pigeon peas; lentils; bambara beans; vetches; lupins; pulses nes
Sugar crops	*Annual crops:* Sugarcane; sugar beets; sugar crops nes
Oil crops	*Annual crops:* Soyabeans; groundnuts in shell; castor beans; sunflower seed; rapeseed; safflower seed; sesame seed; mustard seed; poppy seed; melon seed; tallow tree seeds; seed cotton; cottonseed; linseed; hempseed; oilseeds nes *Perennials:* Coconuts; oil palm fruit; palm kernels; palm oil; olives; karite nuts (sheanuts); tung nuts; jojoba seeds; kapok fruit; kapok seed in shell; kapok seed shelled
Vegetables, fruits, nuts and spices	*Annual crops:* Cabbages; artichokes; asparagus; lettuce; spinach; cassava leaves; tomatoes; cauliflower; pumpkins, squash gourds; cucumbers; eggplants; chillies and peppers, green; onions & shallots; onions, dry; garlic; leeks & other allium veget.; beans, green; peas, green; broad beans, green; string beans; carrots; okra; green corn; mushrooms; chicory roots; carobs; fresh vegetables nes; strawberries; watermelons; Cantaloupes & other mel.; anise, badian, fennel, coriander. *Perennials:* Brazil nuts; cashew nuts; chestnuts; almonds; walnuts; pistachios; kolanuts; hazelnuts; areca nuts (betel); nuts nes. Bananas; plantains; oranges (Tangerines, mandarins, clementines, satsumas); lemons and limes; grapefruit and pomelos; citrus fruit nes; apples; pears; quinces; apricots; sour cherries; cherries; peaches and nectarines; plums; stone fruit nes, Fresh; raspberries; gooseberries; currants; blueberries; cranberries; berries nes; grapes; figs; mangoes; avocados; pineapples; dates; persimmons; cashew apple; kiwi fruit; papayas; tropical fresh fruit nes; fresh fruit nes; mate; tea nes; hops; pepper (white/long/black); pimento, allspice; vanilla; cinnamon (canella); cloves; nutmeg, mace, cardamom; ginger; spices nes; peppermint
Stimulants	*Perennials:* Coffee, green; cocoa beans; tea
Industrial crops	*Annual crops:* Cotton lint; flax fibre; hemp; jute; jute-like fibres; fibre crops nes; tobacco leaves *Perennials:* Pyrethrum, dried flowers; kapok fibre; ramie; sisal; agave fibres nes; abaca (manila hemp); coir; natural rubber; natural gums
Fodder crops	*Annual crops:* Rye grass, forage and silage (For&Sil); grasses nes, For&Sil; clover for For&Sil; alfalfa for For&Sil; leguminous fodder crops nes, forage & silage; mixed grasses & legumes; fodder crops for livestock; maize for For&Sil; sorghum for For&Sil; green oilseeds for fodder; cabbage for fodder; turnips for fodder; beets for fodder; carrots for fodder; swedes for fodder; forage products nes; vegetables & roots for fodder

Table 1: FAOSTAT primary crop list aggregated to main crop groups

1.3 SUAs for agricultural supply chain allocation

The FAO SUAs time series data, deal with statistics on supply and utilization, which are kept physically together to allow the matching of food availability with food use (Figure 1). The total quantity of agricultural commodities produced in a country, that is, domestic production added to the total quantity imported and adjusted to any change in stocks that may have occurred since the beginning of the reference period, gives the supply available during that period. The utilization side distinguishes between the quantities exported, food supplies available for human consumption (food), fed to livestock (feed), put to manufacture for food use (processing), other uses (other use), used for seed production (seed), losses during storage and transportation (waste), and changes in stocks (stock change).

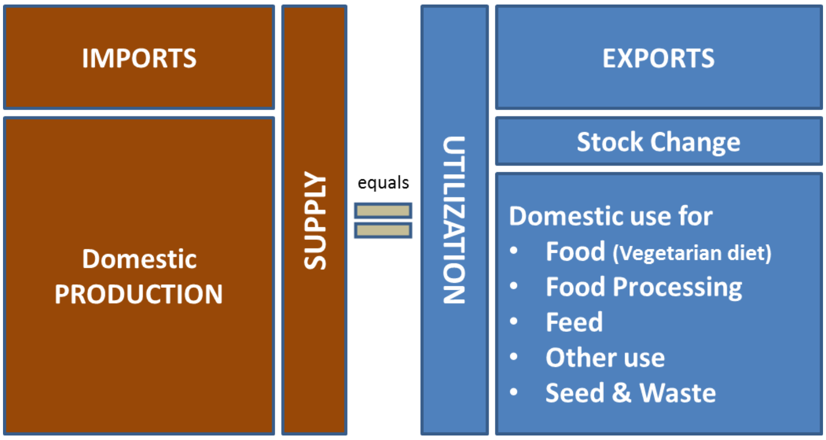


Figure 1: Items in the FAO Supply Utilization Accounts (SUA)

The SUA database structure of agricultural statistics is designed to cover each country's entire agricultural sector. Over 200 different primary and processed crop and livestock commodities (Table 2) are linked by a consistent commodity tree structure and balanced annually for each country. Intermediate or processed commodities may be included in a particular SUA commodity in their primary equivalent. For example, the SUA commodity wheat includes in its supply of imports not only the import of primary wheat, but also all imported wheat products converted into primary wheat equivalent.

LANDFLOW utilizes SUAs for tracking physical quantities and embedded agricultural land areas along supply chains. Land areas associated with the utilization of crops are estimated by applying country specific yields to domestic production following the procedures described below, adding imports (using relevant yields in country of origin), and subtracting exports of individual commodities (using land content of both domestic production and imports).

In addition, LANDFLOW generates supply utilization accounts for alcohol by combining the food processing information of commodities used for alcohol production (grapes, barely, maize) with data from the SUAs on different types of alcohol (e.g., beverages, alcohol; and alcohol, non-food).

SUA item	Produce	Feed	SUA item	Produce	Feed
1 CEREALS			**4 OIL CROPS**		
Wheat	A	F	Soybeans	A	F
Barley	A	F	Groundnuts	A	
Maize	A	F	Sunflower seed	A	F
Rice	A	F	Rape and mustard seed	A	F
Rye	A	F	Cottonseed	A	F
Oats	A	F	Coconuts	P	F
Millet	A	F	Sesame seed	A	F
Sorghum	A	F	Palmkernels	P	F
Cereals, other	A	F	Olives	P	
Brans	D	F	**4.1 VEGETABLE OIL**		
Beer	D		Soybean oil	D	F
Maize germ oil	D		Groundnut oil	D	F
Rice bran oil	D		Sunflower seed oil	D	F
Infant food	D		Rape and mustard seed oil	D	F
2 ROOTS & TUBERS			Cottonseed oil	D	F
Potatoes	A	F	Palmkernel oil	D	F
Cassava	P	F	Palm oil	D	
Sweet potatoes	A	F	Coconut oil	D	
Roots, other	A	F	Sesame seed oil	D	F
Yams	A/P	F	Olive oil	D	F
Beans, dry	A	F	Oilcrops oil, other	D	
Peas, dry	A	F	**4.2 OIL CAKES**		
Pulses, other	A	F	Soybean cake	D	F
3 SUGAR CROPS			Groundnut cake	D	F
Sugarcane	P	F	Sunflower seed cake	D	F
Sugar beets	A	F	Rape and Mustard cake	D	F
Sugar, non-centrifugal	D	F	Cottonseed cake	D	F
Sugar (raw equivalent)	D	F	Palm kernel cake	D	F
Sugar crops, nes	A/P		Copra cake	D	F
Sweeteners, other	D	F	Sesame seed cake	D	F
Molasses	D	F	Oilseed cakes, other	D	F

Note: SUA items were grouped in annual (A), perennial (P) crops, derived products (D) and commodities used for feed (F)

Table 2: Commodities of the Supply Utilization Accounts (SUAs)

(Table 2 continued)

SUA item	Produce	Feed	SUA item	Produce	Feed
5 VEGTABLES; FRUITS; NUTS; SPICES			**7 INDUSTRIAL CROPS**		
Nuts	P		Cotton lint	A	
Tomatoes	A	F	Jute	A	
Onions dry	A	F	Jute-like fibres	A	
Vegetables, other	P	F	Soft fibres, other	A/P	
Oranges, mandarins	P	F	Sisal	P	
Lemons, limes	P		Abaca, manila hemp	P	
Grapefruit	P		Hard fibres, other	A/P	
Citrus, other	P		Tobacco leaves	A	
Bananas	P	F	Natural rubber	P	
Plantains	P	F	**8 FODDER CROPS**		
Apples	P	F	Fodder crops	A/P	F
Pineapples	P		**9 LIVESTOCK PRODUCTS**		
Dates	P	F	Bovine meat	D	F
Grapes	P	F	Pig meat	D	
Fruits, other	P	F	Poultry meat	D	
Pepper	P		Meat, other	D	F
Pimento	P		Mutton and goat meat	D	
Cloves	P		Offal, edible	D	
Spices, other	A/P		Meat, meal	D	F
Wine	D		Eggs	D	F
Beverages fermented	D		Milk, excl. butter	D	F
Beverages, alcoholic	D		Milk, whole	D	F
6 STIMULANTS			Milk, skimmed	D	F
Coffee green	P		Cheese	D	
Cocoa beans	P		Butter, ghee	D	F
Tea	P		Cream	D	
			Whey	D	F
			Fats, animals, raw	D	F
			Hides and skins	D	
			Honey	D	
			Silk	D	
			Wool	D	

Note: SUA items were grouped in annual (A), perennial (P) crops, derived products (D) and commodities used for feed (F)

Table 3: Commodities of the Supply Utilization Accounts (SUAs)

Consistent tracking of cropland from primary production to final utilization entails, i) solving trade flows; ii) connecting the land use intensities of primary crops to SUAs; iii) accounting for joint production; and iv) dealing with the livestock sector.

The following sections 1.4 to 1.7 describe the main processes applied in LANDFLOWs crop and livestock sector allocation.

1.4 Cross-country trade reconciliation

LANDFLOW tracks the extents of land associated with exported and imported primary and processed agricultural commodities to provide consistent accounts of land use from farm production, to international trade, and to final use. Exported agricultural products may come from domestic production or may derive from imported primary or processed commodities. Processed agricultural commodities are derived from primary crops from both domestic production and imported primary crops[1].

LANDFLOW tracks traded commodities and their land content based on annual bilateral FAOSTAT trade data. The commodity list includes nearly 600 different products covering a country's entire trade of the agricultural sector. For the land appropriation of traded agricultural commodities, a relationship has been established between the trade data and their respective SUA items. In the case of the primary commodity maize reported as primary equivalents in the SUA, for example, the following items are included in the trade database: Maize primary; germ of maize; flour of maize; and bran of maize. Processed commodities of the trade domain are converted to primary equivalents using technical coefficients (FAO, 2015).

The LANDFLOW methodology links countries through bilateral trade, based on a large time series data set of more than ten thousand bilateral trade flows of agricultural commodities, published in FAOSTAT. Globally consistent natural resource allocations, including land footprints, require consistency between imported and exported commodities. Bilateral trade flows are reported separately by importer and exporter, often resulting in large discrepancies in reported trade flows for a variety of reasons (Gelhar, 1996). FAOSTAT lists the following reasons for inconsistencies in their trade matrix data: i) time lags (e.g., exports reported at the end of the year could reach a destination in the following year); ii) exported quantities could be destroyed on the way to the destination; iii) type of trade reported–some countries report general trade (including re-exports), while others report special trade (imports of domestic consumption); iv) data confidentiality by one of the reporters; v) customs tax avoidance by misrepresenting a commodity on import, or not reporting a transhipment; vi) place of origin/final destination inconsistencies (e.g., some countries may report the final destination and omit intermediate trade via a third country).

[1] For example, in many European countries domestic utilization of soybean is largely based on imported commodities from North and South America. Another example are European countries exporting processed tropical fruit commodities that they do not produce themselves.

LANDLFOW trade reconciliation procedures: For various reasons, some of which have been discussed above, when two trading partners report trade, the export figures and the corresponding import figures may not correspond. There is no common method for reconciling differences in counterpart trade statistics. LANDFLOW reconciles imports and exports for defined countries or regional aggregates to achieve consistency for all partner pairs by ensuring that primary equivalents in the trade data, equal reported imports and exports in the supply utilization accounts. For this purpose, countries were grouped into defined regional markets. For this study, we defined 28 regional markets optimized for hybrid accounting (i.e., linked with the economic accounting model MRIO used in this study) (Table 3).

After conversion of the extensive FAO bilateral trade data into a primary equivalent, and aggregation to the respective SUA commodity, an iterative procedure is applied for each commodity and year. The reconciliation process applies the following rules: In case of missing reporting, the value from the trade partner who is reporting trade is accepted. When a country pair reports different quantities for the same commodity, the larger quantity is used. The iterative process adjusts calculated trade shares to ensure the full mutual consistency of export and import flows, that is, whatever region i reports as export to region k, must also show up as import of region k from region i. The larger the number of defined regional markets, the higher the necessary adjustments of the original 'raw' data, to achieve a consistent trade matrix.

LANDFLOW[1]	**MRIO[2]**	**Major region[3]**	**Country listing**
CAN	CAN	NAM	Canada
USA	USA	NAM	United States
MEX	MEX	LAM	Mexico
RCAM	RLAM	LAM	Antigua, Bahamas, Barbados, Bermuda, Aruba, Belize, Cayman Is, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Martinique, Neth. Antilles, Nicaragua, Panama, St Kitts Nevis, St Lucia, St Vincent/Grenada, Trinidad/Tobago
ARG	RLAM	LAM	Argentina
BRA	BRA	LAM	Brazil
RSAM	RLAM	LAM	Bolivia, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
AUT	AUT	EU28	Austria
DEU	DEU	EU28	Germany
REU1	REU1	EU28	Belgium, Luxembourg, Denmark, Finland, France, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, United Kingdom
REU2	REU2	EU28	Bulgaria, Croatia, Cyprus, Czech Republic, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia

LANDFLOW[1]	MRIO[2]	Major region[3]	Country listing
RUS	RUS	OEUR	Russia
REUR	REUR	OEUR	Albania, Belarus, Bosnia & Herzegovina, Rep. Moldova, Macedonia, Norway, Serbia and Montenegro, USSR, Ukraine, Switzerland, Yugoslav SFR
EGY	MEA	MEA	Egypt
TUR	TUR	MEA	Turkey
RCEA	RASI	MEA	Afghanistan, Armenia, Azerbaijan, Rep. Georgia, Kazakhstan, Korea DR, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan
RWEA	RMIE	MEA	Iran, Islamic Rep of Iraq, Israel, Jordan, Kuwait, Lebanon, Palestine O.T., Saudi Arabia, United Arab Emirates, Yemen
NAFR	RAFR	AFR	Algeria, Libyan Arab Jamahiriya, Morocco, Syrian Arab Republic, Tunisia
ZAF	ZAF	AFR	South Africa
SSAF	RAFR	AFR	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Republic of, Cote d'Ivoire, Djibouti, Ethiopia, Ethiopia PDR, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome & Principe, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania Unit.Rep, Togo, Uganda, Zambia, Zimbabwe
CHN	CHN	CHN	China, Mainland; China, Hong Kong SAR; China, Macao SAR
JPN	JPN	JPN	Japan
IND	IND	IND	India
RSAS	RASI	RASI	Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka
IDN	IDN	RASI	Indonesia
RSEA	RASI	RASI	Cambodia, Korea Republic of, Laos, Malaysia, Myanmar, Philippines, Taiwan China Province, Thailand, Timor-Leste, Viet Nam
AUS	AUS	AUS	Australia
ROCE	RASI	RASI	Fiji Islands, French Polynesia, Kiribati, New Caledonia, New Zealand, Samoa, Solomon Islands, Vanuatu

1 LANDLFOW acronyms, e.g. RCAM = Rest of Central America; RSAM = Rest of Southern America

2 MRIO Multi-Regional Input Output model

3 Major Region Codes: **NAM** Northern America; **LAM** Latin America; **EU28** European Union; **OEUR** Other Europe and Russia; **MEA** Middle East and Western Asia; **AFR** Africa; **CHN** China; **IND** India; **JP** Japan**; AUS** Australia; **RASI** Rest of Asia

Table 4: Regionalization applied for hybrid accounting and aggregation to major region

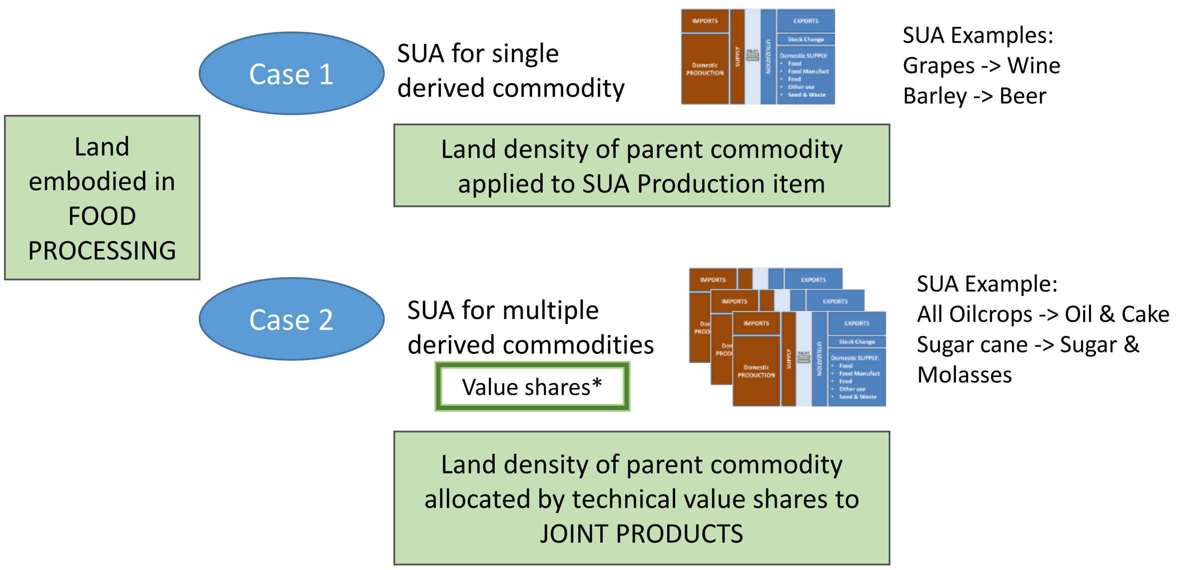
1.5 Crop sector

LANDFLOW covers the entire agricultural sector and uses bottom-up detailed crop intensities for tracking embedded land areas. First, cropland densities of primary production are connected to SUAs by applying the land densities of the respective primary crops to the production item in each SUA. This is achieved by aggregating primary crops (from crop production lists) to the respective SUA commodity. The physical area in supply is represented by the sum of physical areas in imports calculated in the trade module (see section 1.4) and in domestic production.

We apply the land vector (ha/ton) of supply *equally* across all utilization items[1], that is, assuming the same composition of domestic and imported crops in exports and all domestic supply items (food, livestock feed, etc.).

In LANDFLOW, the utilization items 'Food use' (i.e., crop-based vegetarian diet), 'Other use' (industrial), and 'Seed and waste' (from domestic production), signify end-points of the supply chain. Potential limitations of denoting 'Other use' (i.e., use of agricultural commodities in the non-food processing industry as end-point in the supply chain) are discussed in section 2.2.9.

In contrast, 'Food processing' and 'Feed' are further tracked along the supply chain. Processed items may result either in a single derived commodity (e.g., grape processing produces wine; barley processing produces beer), or in multiple derived commodities (Figure 2).



* Physical quantity and price of the sub-products determine technical value shares (see 1.6)

Figure 2: Schematic overview of data flows for tracking land in the "Food processing" item

[1] This assumption is also necessary because FAOSTAT does not record the amount of crops from imports entering re-exports and the amount of crops from domestic production used for exports or other domestic supply items.

Examples of the latter include all vegetable oil crops that are processed in crushing mills to produce vegetable oils for food, industrial use and cakes, which is an important protein animal feed (see 2.2.6). In the case of single derived commodities, the land vector of utilization of the 'parent' commodities is applied to the derived commodity. For multiple derived commodities, LANDFLOW solves for joint production as described below (1.6). Cropland areas associated with SUA feed items are tracked in the LANDFLOW livestock module as described below (1.7).

1.6 Treatment of joint production

Tracking embodied land along supply chains requires solving for joint production. In the crop sector, joint production occurs with oil crops and sugar products. The processing of oil crops involves the crushing of oil seeds that produces vegetable oils and oilcakes, both of which are reported as SUA commodities. From the processing of sugar crops, the SUA commodities sugar and sweeteners, and molasses are produced. Examples of joint production in the livestock sector include ruminant animals producing milk, meat, and hides and skins.

LANDFLOW achieves the allocation of land to joint products by value shares using published technical extraction rates (FAO, 2015) and accounting for the economic value of the multiple produces as described below. As simple conversion of joint commodities by their extraction rates to primary equivalent would lead to double counting of physical land, a weighting of the technical coefficient is needed.

The LANDFLOW approach to weighting in case of joint production is to compare the monetary values (prices) of the joint products, and to use their share in total value of output to weight extraction rates of the corresponding commodities. LANDFLOW thus assumes that in cases of joint production, the land areas of the primary produce are best allocated by accounting for the economic value of the produce. This is justified by the fact that the vast majority of farmers produce according to a process of economic maximization. Alternative weighting schemes could be calorie content, physical weights, or energy content.

Detailed calculation steps of the applied economic allocation are listed below. Let us assume that we have two joint products A and B, which are both obtained from the processing of commodity Q. Product A with quantity Q_A has an extraction rate of ε_A, while product B with quantity Q_B has an extraction rate of ε_B. The following identities hold:

$$\varepsilon_A = \frac{Q_A}{Q} \quad \text{and} \quad \varepsilon_B = \frac{Q_B}{Q}$$

Knowing the unit price of commodities A and B, say P_A and P_B, their respective value V_A and V_B may be calculated:

$$V_A = Q_A \cdot P_A \quad \text{and} \quad V_B = Q_B \cdot P_B$$

The value share of commodity A is defined as:

$$v_A = \frac{V_A}{V_A + V_B}$$

And vA follows as: $v_A = \frac{\varepsilon_A \cdot P_A}{\varepsilon_A \cdot P_A + \varepsilon_B \cdot P_B}$

The value share of commodity B is then given by: $v_B = 1 - v_A$

The world export unit values of the single commodities (in $/t) from FAOSTAT for the year 2000 are taken as the unit price for the derived commodities. To give an example, SUAs report the quantity of oilseeds delivered to food processing industries, represented in SUAs through the utilization item 'Food processing'. The output of this crushing industry is vegetable oil and oilcakes, both being converted to their corresponding land area (as explained above).

A separate SUA balances vegetable oils and further details its utilization (primarily as 'Food' and in the case of industrial use as 'Other use'). Another SUA balances oilcakes, which are primarily utilized as 'Feed' for livestock. LANDFLOW accounts the respective land areas under the corresponding utilization items.

Table 4 summarizes extraction rates (technical coefficients) for oil crops and the calculated value shares, which are applied to split the land content of the primary products to the land content of the derived produces. The same logic and calculation procedure are applied for sugar crops, carob, cotton and their derived products. From the processing of sugar crops, the SUA commodities sugar and sweeteners, and molasses are produced with extraction rates of about 16 % and 4 % respectively.

Oil crops	Oilseed cakes		Vegetable oil	
	Extraction rates	Value share	Extraction rates	Value share
Soybeans	0.79	64.00%	0.18	36.00%
Groundnuts in shell	0.38	19.05%	0.3	80.95%
Coconuts	0.08	10.36%	0.13	89.64%
Palm kernels	0.52	15.83%	0.46	84.17%
Olives			0.22	100%
Sunflower seed	0.47	17.83%	0.41	82.17%
Rapeseed	0.6	27.45%	0.38	72.55%
Sesame seed	0.51	8.75%	0.43	91.25%
Cottonseed	0.51	40.51%	0.16	59.49%
Karite nuts (sheanuts)			0.25	100%
Castor beans			0.4	100%
Mustard seed	0.58	20.84%	0.36	79.16%
Tung nuts			0.16	100%
Jojoba seeds			0.35	100%
Safflower seed	0.63	29.70%	0.35	70.30%
Tallow tree seeds			0.3	100%
Kapok fruit	0.37	21.94%	0.3	78.06%
Linseed	0.63	37.30%	0.35	62.70%

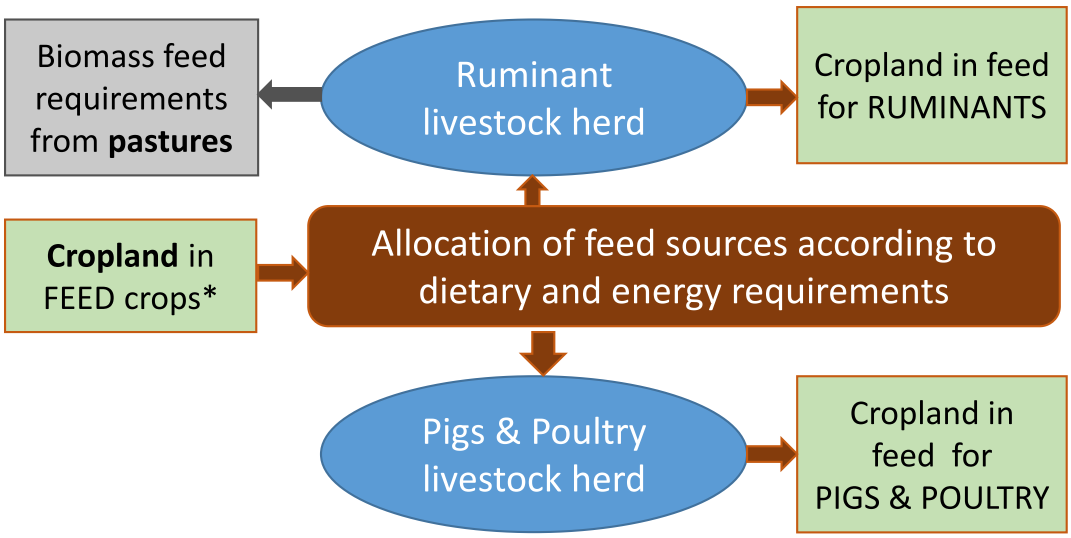
Table 5: Extraction rates and value shares of major oil crops

1.7 Livestock sector

LANDFLOW estimates the feed area used to produce the feed required for a country's domestic livestock herd. FAOSTAT reports time series of a country's number of heads of live animals for some 15 different animal categories. Feed sources are obtained from two types of land use, namely permanent pastures and cropland. Corresponding to their feed composition and land requirements, we differentiate two broad groups of animals, namely 'ruminants' and 'pigs and poultry':

1. *Ruminants:* cattle, sheep, goats, horses, asses, mules, camels, and other camelids
2. *Pigs and poultry:* pigs, chickens, ducks, geese, turkeys, rabbits, and other rodents

Ruminants utilize herbaceous forage from grazing pastures, as well as fodder and feed crops cultivated on cropland. Feed sources for pigs and poultry originate solely from cropland. Feed requirements, together with feed sources form the basis for attributing cropland use and pastures to the two animal groups (Figure 3).



* Feed crops cultivated on cropland include fodder crops, primary crops, crop by-products, and cropland embedded in feed derived from livestock products

Figure 3: Land allocation in LANDFLOW livestock module

The allocation of feed crops and associated cropland areas to the two animal groups is estimated according to the energy requirements of the livestock herd as compared to energy supply provided by the different feed sources. First, energy requirements for both animal groups are calculated. For this purpose, reported livestock species (in animal heads) are converted to a common reference unit, namely the livestock unit (LU). Conversion factors were compiled by broad geographical regions. As defined in this way, each livestock unit requires 8,700 Mcal of feed energy per year. With these assumptions and conversions, annual livestock energy requirements for the two livestock groups can be calculated for each country. Energy required for the livestock herd is then compared with energy supply from various feed sources.

Feed in livestock production systems include many categories and vary greatly between countries. Integrating different FAOSTAT databases allows tracing of the following types of feed sources:

A. Feed originating from cropland
   a) dedicated fodder crops cultivated especially for animal feed (Table 5)
   b) primary crops grown for both food and feed purposes (e.g., cereals and sugar crops)
   c) crop residues and by-products from food processing (e.g., oil cakes)
   d) feed derived from livestock products (e.g., milk, milk powder, eggs, and animal fats)
   e) fish products (e.g., fish meal)
B. Biomass from grazing on permanent pastures

Note that b), c) and d) may be produced domestically or may be imported. The column ‘Feed’ in Table 2 lists all commodities used for livestock feed.

The FAOSTAT Primary Production domain reports harvested areas of fodder crops. Due to dietary requirements, some fodder crops can only be fed to ruminants, while others are fed to both ruminants and monogastric (pigs and poultry) livestock. We assume that all fodder crops grow on cropland. Published conversion factors of dry matter percentage and energy content of dry matter (Table 5) are used to estimate feed energy provision from fodder crops.

Fodder crops reported in FAOSTAT Primary Production	Dry matter (DM) [%]	Energy content in DM [Mcal/kg]
Fodder crops suitable for ruminants only		
Rye grass, forage and silage	32	2.56
Grasses nes*, forage and silage	26	2.65
Clover for forage and silage	23	2.82
Alfalfa for forage and silage	26	2.69
Leguminous fodder crops nes, forage and silage	23	2.82
Mixed grasses and legumes	24	2.80
Fodder crops suitable for ruminants and monogastric livestock		
Maize for forage and silage	26	2.87
Sorghum for forage and silage	30	2.65
Green oilseeds for fodder	21	2.70
Cabbage for fodder	12	3.31
Turnips for fodder	9	3.75
Beets for fodder	13	3.54
Carrots for fodder	12	3.66
Swedes for fodder	11	3.75
Forage products nes	25	2.55
Vegetables and roots for fodder	11	3.50

Table 6: Fodder crops conversion factors

The SUA (see 1.3) trace the utilization of animal feed (Table 2). SUA items are generally reported in metric tons. Like with fodder crops, conversion factors are used to calculate the dry matter and energy content of the feed sources.

Feed sources and associated cropland areas are allocated to livestock categories in proportion to the energy requirements of the respective livestock herds, and according to the suitability of feed sources for use in animal diets. This means that, while respecting the dietary characteristics of animal types and the total amounts of recorded feed types, the feed energy balance of each animal type is satisfied as closely as possible.

Once cropland areas are allocated to the two animal groups, land areas are attributed to multiple derived products using value shares as described for joint production (section 1.6). Figure 4 highlights examples of main produces from the two animal groups including their most common type of utilization.

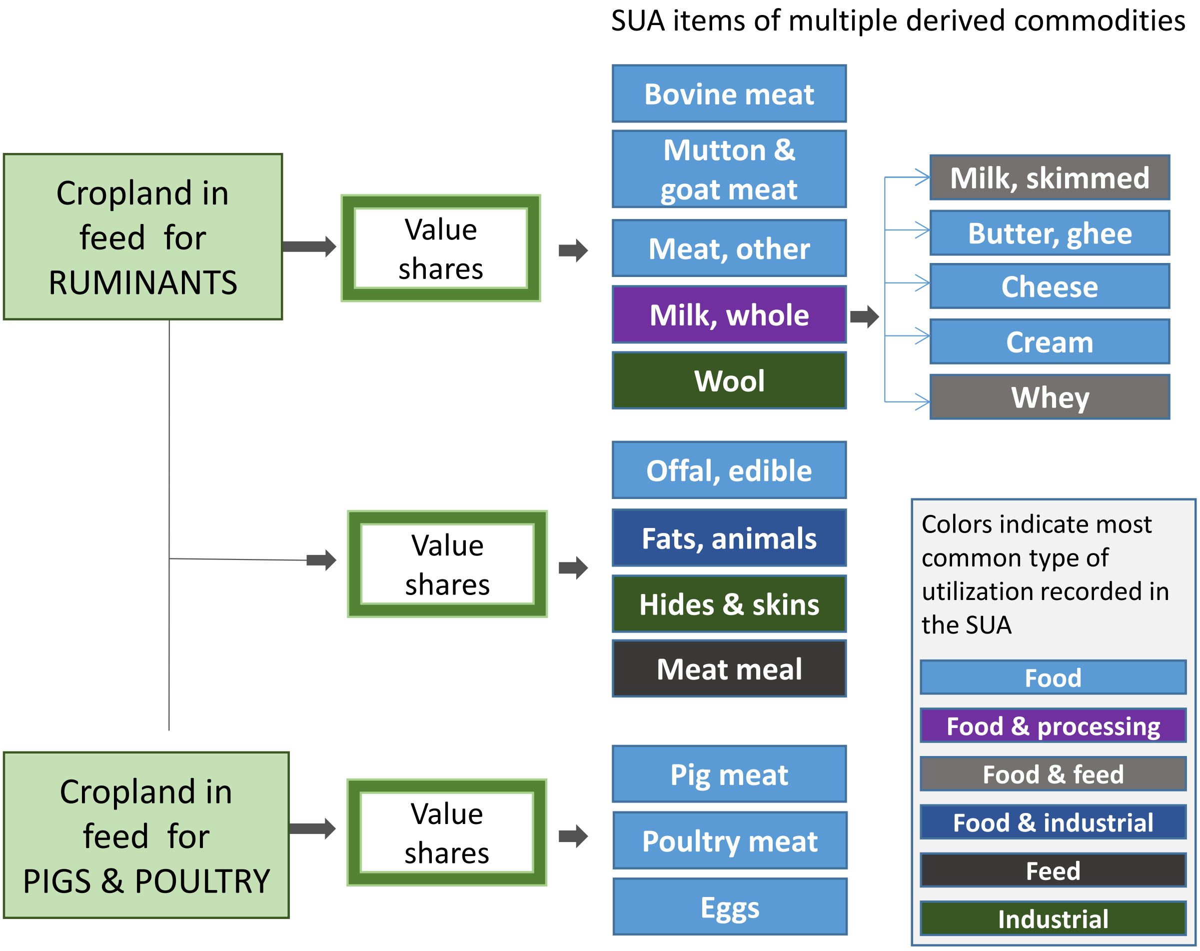


Figure 4. Allocation of cropland in feed to multiple livestock commodities using value shares

Grassland for ruminant livestock

Finally, LANDFLOW records potential feed energy gaps for the ruminant livestock herd in each country. These are compared with potential biomass supply from pastures. FAO statistics report the heads of ruminant livestock and the total pasture areas for each country. Information on livestock management practices (e.g., fencing, herd rotations, and improved pastures) is rare. Nor are there statistical records on the actual pasture areas utilized for livestock grazing. In view of these large uncertainties in allocating ruminant livestock to pasture areas that are actually utilized, LANDFLOW:

i) reports embodied cropland areas separate from pastures;

ii) tracks both total reported pastures and reference pasture areas normalized to 5 t biomass yield per hectare; and

iii) calculates ruminant livestock feed balances.

As a first approximation and lacking information on actual pasture utilization, LANDFLOW allocates the entire reference pasture area, normalized to 5 tons of digestible biomass per hectare and year in a country, as pasture in primary production for feeding ruminant livestock herds.

1.8 LANDFLOW system boundaries

Due to the domain boundaries of the FAOSTAT databases, the trade of highly processed agricultural and forestry goods, and hence the ultimate final uses of such highly processed commodities, cannot be tracked within the LANDFLOW system. LANDFLOW analysis tracks the trade of raw materials to the destination of industrial use (as reported for the agricultural sector in the SUA “other use”), but cannot track the trade of highly processed industrial commodities. For instance, once animal fats enter the industrial sector to produce cosmetics, or tanned leather from skins and hides are turned into leatherwear or shoes, the trade of cosmetics or shoes respectively, is not recorded in the FAOSTAT data. Other examples of trade that cannot be tracked include biofuels produced from vegetable oils, clothes produced from fibres (e.g., cotton), or furniture made from wood.

This study goes beyond these system boundaries by a further analysis of the reported utilization items of industrial agricultural (i.e., non-food processing) commodities in an environmental-economic accounting of land flows (i.e., a hybrid accounting).

Due to the FAO’s focus on food security, information on international commodity flows captured in the SUAs is limited to food products. Non-food uses of bio-based commodities, such as fibre crops for textiles and vegetable oils for biofuels, are lumped into the utilization category ‘other use’. Therefore, the physical accounting model tracks these commodities and the embodied land use only to their industrial use stages.

The physical land flow accounting model (LANDFLOW) thus, can only be used for the study of food-related biomass flows and flows of basic wood products. The untraceable non-food commodities amount to about 10 to 30 % of a country’s total land footprint. For the comprehensive analysis of all biomass flows, in this study the physical system is joined with an environmental-economic accounting model (i.e., a monetary input-output model), forming a hybrid accounting model to track upstream flows of non-food biomass commodities.

2. Environmental-economic accounting of land flows

Environmental-economic accounting approaches in the form of environmentally extended input-output analysis (EE-IOA) allow the tracing of land flows along monetary, inter-industry transactions (supply chains) represented in an input-output (IO) table. This technique has become an increasingly popular tool for national and international environmental assessments, driven by constantly improving data availability and computational power in the past 15 years. The Leontief inverse of an IO model shows all inputs required along the whole supply chain for each commodity or industry represented in the model. These inputs comprise the direct input requirements of the sector itself, and indirect inputs from other sectors located upstream in the supply chain. The methodology described here was developed during several EU projects (Tukker et al., 2013; Wood et al., 2015), and was extended in this project.

2.1 Multi-regional input-output (MRIO) models

Multi-regional input-output (MRIO) models link the input-output tables of several countries or regions together via bilateral trade flows. These models trace global supply chains using country specific information on production technologies and economic structures (Feng et al., 2011), thus allowing the different resource intensities (e.g., yields) in different countries to be taken into account (Tukker et al., 2013). MRIO analysis is considered an appropriate methodological approach for the analysis of environmental and wider sustainability impacts of traded goods and services (Wiedmann et al., 2011). In recent years, a range of scientific publications have validated the suitability of this approach, among others, for assessing the human footprint of nations on biologically productive areas (Weinzettel et al., 2013), tracing global flows of embodied land (Yu et al., 2013), and examining consumption-related biodiversity impacts (Lenzen et al., 2012).

In this study, we apply the MRIO model from EXIOBASE version 3.1 (Stadler et al., 2018). We select EXIOBASE among a range of available MRIO databases (see, e.g., Andrew and Peters, 2013; Dietzenbacher et al., 2013; Lenzen et al., 2013) due to its consistently detailed sector classification for food and agriculture sectors, which are of particular interest for this study. Moreover, EXIOBASE is the only MRIO database with dedicated biofuel sectors. For a comparison of MRIO datasets we refer to other studies (Arto et al., 2014; Bruckner et al., 2015; Inomata and Owen, 2014; Lenzen et al., 2017; Moran and Wood, 2014; Owen et al., 2014).

EXIOBASE 3 provides a multi-regional input-output table with global coverage comprising information on domestic and international intra- and inter-sectoral flows, so called intermediary flows, and global production and final demand for 49 countries or country groups. Each country model is available in a detail of 200 commodities including, wheat, raw milk, bovine meat products, dairy products, sugar, beverages, textiles, chemical products, motor vehicles, financial services, and so on. These data enable us to trace flows of goods and services (in monetary terms) from their production along global supply chains through to final consumption, which in turn allows us to allocate land use related to the production of agricultural commodities to the consumer of the end-products.

2.2 Environmentally extended MRIO methodology based on EXIOBASE 3

In input-output analysis, the economy is represented by the simple equation $x = Z + Y$, stating the identity of total economic output x with intermediate use Z and final demand Y (Miller and Blair, 2009). The technical coefficient matrix A shows the direct input-requirements per unit of output and is calculated by $A = Z/x$, or element-wise by $a_{ij}^{pq} = z_{ij}^{pq}/x_j^q$, where a_{ij}^{pq} represents the inter-sector monetary flow from sector i in country p to sector j in country q, and x_j^q is the total output of sector j in country q. Y is a final demand matrix with y_i^{pq} representing the final demand of country p for products from sector i in country q. x is a vector of total outputs for all sectors in all countries. More specifically,

$$A = \begin{bmatrix} a^{11} & a^{12} & \dots & a^{1n} \\ a^{21} & a^{22} & \dots & a^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a^{n1} & a^{n2} & \dots & a^{nn} \end{bmatrix}; \qquad Y = \begin{bmatrix} y^{11} & y^{12} & \dots & y^{1m} \\ y^{21} & y^{22} & \dots & y^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ y^{n1} & y^{n2} & \dots & y^{nm} \end{bmatrix}; \qquad x = \begin{bmatrix} x^1 \\ x^2 \\ \vdots \\ x^n \end{bmatrix}.$$

Table 6 shows the dimensions and descriptions for the model variables and their indices. We use capital letters for matrices and small letters for vectors, scalars and indices.

Variable/Indices	Description	Dimension
$i,\ j$	Sectors or commodities	1…200
$p,\ q$	Countries and country groups	1…49
x	Total output vector	9800 × 1
Y	Final demand matrix	9800 × 49
Z	Intermediate use matrix	9800 × 9800
A	Technical coefficients matrix	9800 × 9800
F	Footprint matrix	9800 × 49
e	Environmental extension vector	9800 × 1

Table 7: Variables and indices of the EXIOBASE 3 MRIO model and their dimensions

Consequently, the total output of the economy can be set up as the sum of all intermediate uses, expressed by the multiplication of A with x, and final demands:

$$x = Ax + Yi \quad (1)$$

We use i to represent a column vector of 1's (of appropriate dimension – here m). This is known as a summation vector. Solving for x, we obtain

$$x = (I - A)^{-1}Yi \quad (2)$$

where $(I - A)^{-1}$ is the Leontief inverse (Leontief and Ford, 1970). This matrix captures both direct and indirect inputs to satisfy one unit of final demand in monetary values. I is the identity matrix.

To allocate an environmental input to final demand, that is, to calculate an environmental footprint embodied in goods and services, the MRIO model is extended with environmental data, using the equation

$$F = \hat{e}(I - A)^{-1}Y \quad (3)$$

where $\hat{e}$ is a diagonalised vector of environmental inputs per unit of economic output and F is a matrix of the resulting footprint indicator for all goods and services ultimately serving final demand (i.e., private and government consumption, investments and changes in inventories). The sum of each column vector of matrix F represents the footprint of a specific country q.

3. Linking physical LANDFLOW with environmental-economic MRIO accounting

In the standard EE-IOA approach applied to land footprint accounting (Arto et al., 2012; Bruckner et al., 2012; Wood et al., 2015; Yu et al., 2013), the economic MRIO model is extended by data on land use in primary production. In other words, land use data from agricultural statistics are attributed to the agricultural sectors of an IO table, and forestland data to the forestry sectors.

In the case of hybrid accounting approaches that combine physical data from agricultural and forestry statistics with IO models (Ewing et al., 2012; Weinzettel et al., 2014), environmental inputs are allocated to the IO model at a later stage of the supply chain in order to relax the uncertainties introduced by the homogeneity and proportionality assumptions of environmental IOA. For example, land embodied in fibre crops is attributed to the manufacturing industries and countries where the crops are processed into textiles, or land embodied in oil seeds is attributed to the industries and countries where they are processed into food or non-food commodities, or fed to livestock.

The methodology applied in this study extends the approach presented by Ewing et al. (2012) by fully exploiting the spectrum of available international agricultural and forestry statistics reporting supply and use flows in mass units. Using LANDFLOW, we track food commodities to final consumption along physical supply chains and attribute only the remaining non-food commodities to the manufacturing industries of the IO model. For example, land embodied in vegetable oils is attributed to the industries where the vegetable oils are used for non-food purposes. Thereby, we establish a very detailed globally consistent top-down accounting framework comprising all biomass supply chains.

The environmental extension consequently represents the intermediate consumption of non-food crop and animal products, as well as pulp and wood products distinguished by region of origin. A list of non-food commodities allocated to the IO model is provided in Annex B-3. We track the flows of commodity c from the country of a recorded non-food use in the SUAs to final demand in country q using the equation

$$F\_io_c^q = \hat{e}_c (I - A)^{-1} \hat{y}_q \quad (4)$$

where $\hat{e}_c$ is a diagonalised vector of land use inputs per unit of economic output for the non-food commodity c assigned to the consuming sectors, and $\hat{y}_q$ is the diagonalised final demand of country q. By aggregating $F\_io_c^q$ over all sectors for each country, we get a matrix with the dimension 20 × 20, representing the flows of commodity c from country p to country q. The sum of each column vector of matrix $F\_io_c^q$ represents the final demand of a specific country q for a commodity c.

$$F\_total_c^q = F\_io_c^q + F\_ph_c^q \quad (5)$$

The results from eq. 4 have to be added to the footprint results for the products covered by the physical approach $F\_ph_c^q$ to give the total consumption of commodity c by country q.

The most intricate task when linking physical with economic accounts is to define the supply shares of each commodity to the consuming economic sectors, in other words, to construct the environmental extensions $\hat{e}_c$ to the IO model. The using sectors are identified based on educated guesses, which in many cases are rather straightforward. For example, fibre crops are supplied to the 'Textiles' sector, while tobacco leaves are further processed by the sector 'Tobacco products'.

In most cases, however, a clear user allocation is not possible. Therefore, we used the information from the multi-regional IO table, in particular from the transaction matrix Z, to allocate commodities to using sectors according to monetary inter-industry flows. For this approach, we first specify the supplying sectors using the detailed CPA-based sector definition of EXIOBASE. We find between one and six supplying sectors for the considered commodities listed in Table 7.

We then identify the potential using sectors based on the supply flows from these sectors. We narrow the scope of potential receivers of non-food commodities supplied by food sectors to non-food industries, based on the rationale that non-food commodities are rather directed towards non-food industries, while food commodities are supplied either to food and food processing industries, or to final demand (esp. households). More than half of the 200 sectors listed in EXIOBASE can be classified as non-food industry. Important sectors that use agricultural commodities as input for non-food industries include 'biodiesels', 'other liquid biofuels', 'biogasoline', 'chemicals nec', 'lubricants', 'pulp', 'paper and paper products'.

For example, imagine the case of 5,000 ha of land embodied in the vegetable oils used in a specific country for non-food purposes. This number is derived by the physical accounting model and then handed over to the IO model. We can assume that vegetable oils are supplied by the EXIOBASE sector ‘Products of vegetable oils and fats’. From the IO table we can see that the sector supplies, among others, the chemical industry and biofuel sectors with its outputs.

The environmental extension of a specific commodity is then constructed by multiplying the respective supply shares with the land use content of the non-food commodity, which is determined beforehand with the LANDFLOW model.

No	LANDFLOW Commodity	MRIO Supplying sector(s)	MRIO Using sector(s)
1	Wheat	Wheat	all non-food industries
2	Rice	Paddy rice; processed rice	all non-food industries
3	Maize	Cereal grains not earlier classified (nec)	all non-food industries
4	Other cereals	Cereal grains nec	all non-food industries
5	Roots and pulses	Vegetables, fruit, and nuts	all non-food industries
6	Sugar crops (primary)	Sugarcane and sugar beet	all non-food industries
7	Sugar, sweeteners, molasses	Sugar	all non-food industries
8	Oil crops (primary)	Oil seeds	all non-food industries
9	Vegetable oil	Products of vegetable oils and fats	all non-food industries
10	Oil cakes	Products of vegetable oils and fats	all non-food industries
11	Fruit, vegetables, spices	Vegetables, fruit, nuts	all non-food industries
12	Stimulants	Crops nec	all non-food industries (excl. tobacco products and rubber and plastic products)
13	Tobacco	Crops nec	Tobacco products
14	Rubber	Crops nec	Rubber and plastic products
15	Other industrial crops	Plant-based fibers	Textiles
16	Alcohol, non-food	Additives/blending components; biogasoline; biodiesel; other liquid biofuels; chemicals nec	all industries
17	Fodder	Crops nec	all non-food industries (excl. tobacco products and rubber and plastic products)
18	Meat, ruminants	Cattle; meat animals nec; products of meat cattle; meat products nec;	all non-food industries (excl. textiles; wearing apparel, furs; leather and leather products; wool, silk-worm cocoons)
19	Milk	Raw milk; dairy products	all non-food industries
20	Hides and skins, wool, ruminants	Cattle; meat animals nec; animal products nec; products of meat cattle; meat products nec; food products nec	Textiles; wearing apparel, furs; leather and leather products; wool, silk-worm cocoons
21	Meat, monogastrics	Pigs; poultry; products of meat pigs; products of meat poultry	all non-food industries (excl. textiles; wearing apparel, furs; leather and leather products; wool, silk-worm cocoons)
22	Eggs	Poultry; animal products nec	all non-food industries
23	Hides and skins, monogastrics	Pigs; products of meat pigs	Textiles; wearing apparel, furs; leather and leather products; wool, silk-worm cocoons

592 ***Table 8: Supplying and using EXIOBASE sectors of the considered non-food commodities***

Appendix 2 Additional information for results and discussion

2.1 Cropland embedded in net trade of crop and livestock products

The table shows extents of cropland embedded in net imports (imports – exports) by major regions and main commodity group. Negative and positive numbers refer to net exporting and importing regions respectively. Colours indicate larger extents over 3 million hectares.

million hectares	NAM	EU28	OEUR	LAM	CHN	IND	RASI	JPAU	MEA	AFR	
Cereals											
Wheat	-17.7	-1.5	-14.2	3.8	0.7	0.0	11.4	-6.2	12.7	10.9	0
Rice	-0.1	0.7	0.1	0.2	0.3	-1.0	-5.3	0.3	1.8	2.9	0
Maize	-8.8	2.5	-1.7	-1.4	-0.9	-0.9	3.9	2.5	3.4	1.4	0
Other cereals	-1.9	-1.0	-3.8	1.2	0.8	-0.2	0.7	-1.1	4.6	0.8	0
Other crops											
Roots and pulses	-3.2	0.6	-0.3	0.2	1.0	2.1	-0.4	-0.7	0.9	-0.3	0
Sugar crops (primary)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Sugar and molasses	0.8	0.6	0.2	-4.0	0.3	0.0	0.5	0.0	0.8	0.7	0
Oil crops (primary)	-21.9	8.6	-1.3	-15.1	22.2	-1.1	3.7	2.4	4.0	-1.4	0
Vegetable oil	0.9	5.7	-4.5	-4.2	2.5	1.9	-8.4	1.1	3.6	1.4	0
Oil cakes	-2.2	8.0	-0.6	-11.3	0.1	-2.7	4.7	1.2	1.7	1.2	0
Fruit, veget., spices	1.9	2.5	1.0	-2.8	-0.4	0.2	-1.1	0.6	-0.4	-1.6	0
Coffee, cacao, tea	4.2	5.7	1.5	-4.6	-0.1	-0.4	-2.6	1.3	0.8	-5.7	0
Tobacco	0.1	0.4	0.2	-0.4	-0.4	-0.1	0.1	0.1	0.2	-0.3	0
Rubber	1.6	1.6	0.2	0.5	1.5	0.1	-6.2	0.7	0.4	-0.3	0
Other industrial crops	-0.8	2.5	0.4	-0.1	2.1	-3.6	-0.1	0.2	1.3	-2.0	0
Alcohol	0.6	0.4	0.2	-1.1	0.2	0.0	-0.9	0.5	0.3	-0.1	0
Ruminants (cattle, sheep, goats):											
Meat and offal	-0.3	0.4	0.7	0.2	0.8	-0.7	2.8	-5.2	1.0	0.3	0
Dairy products	-1.5	-1.5	-1.3	1.0	0.7	0.1	2.2	-1.8	0.9	1.2	0
Fats and meals	-0.1	0.2	-0.1	0.1	0.0	0.0	0.2	-0.4	0.0	0.1	0
Hides and skins	-1.3	0.9	-0.2	0.1	3.2	0.0	0.5	-3.2	0.3	-0.3	0
Pigs and poultry											
Meat and offal	-3.4	-1.8	1.5	-3.4	1.8	0.0	1.2	1.8	1.5	0.9	0
Eggs	0.0	0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.1	-0.1	0
Fats and meals	-0.4	-0.3	-0.1	0.2	0.2	0.0	0.2	0.0	0.1	0.1	0
Hides and skins	0.1	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0
TOTAL	**-53.4**	**35.2**	**-22.3**	**-41.0**	**36.5**	**-6.2**	**7.2**	**-5.9**	**40.2**	**9.7**	0

Table 2.1: Net imports of cropland embedded in trade of crop and livestock products by region and commodity group, 2010

2.2 Average grassland yields, reported grassland areas and reference grassland areas normalized to 5 t/ha, 2000, selected countries

1000 hectares	Grassland yield[1] [tons/ha]	Reported grassland[2] [Mha]	Reference grassland[3] [Mha equivalent]
Germany	6.5	5	6.6
France	6	10	12
Russia	2	91	36
Kazakhstan	0.84	185	31
Brazil	5	196	196
Argentina	3	100	60
Uruguay	7.5	13	20
United States	3	236	142
Nigeria	2	39	16
Sudan	1.7	117	40
Saudi Arabia	0.02	170	0.7
China	1	400	80
Mongolia	0.67	129	17
Australia	1	408	82
Indonesia	9	11	20
WORLD	**2.06**	**3,400**	**1,400**

1 Source GAEZ average over all grid-cells with grassland land use; **2** Source: FAOSTAT; **3** Normalized to 5 tons/hectare; i.e. Reference grassland area = Reported grassland area * grassland yield / 5

2.3 Cropland, irrigation and land quality weights, 2010, selected countries

	Reported cropland [Mha]	Irrigation share	Land quality weight[1]	Land quality weighted cropland[2] [Mha equivalent]
Germany	12.1	5%	0.814	9.8
EU28	121			99
Russia	122	4%	0.670	81.6
Canada	48.4	2%	0.682	33.0
USA	158	12%	1.079	171
Australia	45.7	6%	0.638	29.1
India	169	39%	1.285	218
China	122	55%	1.0	122
Indonesia	44.9	15%	1.184	53.2
Brazil	78.1	7%	1.049	81.9
Argentina	37.3	6%	1.095	40.9
Egypt	3.7	99.7%	1.647	6.0
World	**1,521**	**21%**	**0.98**	**1,497**

1: Land quality calculations are derived from the GAEZ databases. We normalize to the median of land quality across current (year 2010) global rain-fed and irrigated cropland; **2** Cropland weighted by land quality = Cropland * Land quality weight

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