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Kurzbeschreibung

Der Flächenfußabdruck untersucht die Beanspruchung von Landressourcen aus der Sicht des Verbrauchers. Diese Studie beschreibt eine neue hybride Methode zur Berechnung von Flächenfußabdrücken, basierend auf einem global konsistenten Top-down-Ansatz und der Kombination von physischen und ökonomischen Bilanzierungsansätzen. Der physische Ansatz verfolgt anhand der physischen (Tonnen von Biomasse) harmonisierten Daten der FAO die Wertschöpfungsketten von Nahrungsmitteln vom "Feld zum Teller" und von anderen Biomasseprodukten vom "Feld zur technischen Nutzung". Die ökologisch-ökonomische Bilanzierung dient der weiteren Verfolgung von Non-Food-Rohstoffen in monetären Werten bis zum Endverbrauch. Die hybride Methode wurde angewandt, um jährliche Fußabdrücke zwischen 1995 und 2010 für global 21 Märkte (einschließlich der großen Volkswirtschaften wie USA, China, Indien) zu berechnen. Die Flächenfußabdrücke des Ackerlands auf Pro-Kopf Basis und deren Zusammensetzung variiert weltweit erheblich. Detaillierte Ergebnisse für Deutschland und die EU28 heben die höhere Landnachfrage von stark auf tierischen Produkten basierenden Ernährungsweisen im Vergleich zu pflanzenbasierter Ernährung hervor. Sie zeigen die zunehmende Globalisierung der Märkte und die zunehmende Bedeutung des Non-Food-Sektors für den Flächenfußabdruck im letzten Jahrzehnt. Der Flächenfußabdruck eines Deutschen beläuft sich heute auf 2693 m² für Ackerland, etwa die Hälfte für tierische Nahrungsmittel, ein Viertel für pflanzenbasierte Ernährung und ein Viertel für Non-Food Biomasseprodukte. Zusätzliche werden für den Konsum von Produkten von Wiederkäuern pro Kopf 1655 m² Grünland beansprucht. Deutschland ist ein bedeutender und wachsender Handelspartner mit aktuellen „Nettoeinfuhren“ von 10,6 Millionen Hektar. Insgesamt stammen damit die Hälfte der 22 Millionen Hektar des Ackerland-Fußabdrucks von Anbauflächen im Inland und die andere Hälfte von Landressourcen im Ausland. Auch wenn große Unsicherheiten bei der Berechnung vom Flächenfußabdruck des Grünlands bestehen, deuten die Ergebnisse darauf hin, dass Deutschland ein bedeutender Nettoimporteur von ‚virtuellem‘ Grünland ist.

Abstract

Footprint analysis reveals the appropriation of land resources from a consumer's perspective. We here present a novel hybrid land-flow accounting method for the calculation of land footprints, employing a globally consistent top-down approach and combining physical with environmental-economic accounting. Physical accounting tracks food products from 'field to plate' and non-food from 'field to industrial use' using the large harmonized FAO data to track biomass flows and related land use in physical volumes (tons of biomass). Environmental-economic accounting is used to further track non-food commodities in monetary values to final consumption. The hybrid methodology has been applied annually between 1995 and 2010 for 21 regional markets globally and including major economies separately (e.g. USA, China, India). Per capita extents and composition of cropland footprints vary widely across the world. Detailed results for Germany and the EU28 highlight the higher land demand of livestock-based diets compared to crop-based diets, the growing integration in international markets, and the growing importance of the non-food sector since 2000. Today the land footprint of each Germany citizen appropriates on average 2693 m² cropland (about one half for livestock-based diets, one quarter for crop-based diets and one quarter for non-food products). Additional 1655 m² of grassland per capita are used for the consumption of ruminant livestock products. Germany is a major and increasing trading partner with current net 'cropland imports' of 10.6 Mha. Overall, half of Germany's 22 Mha cropland footprint relies on domestic cultivation and half on land resources abroad. Albeit large uncertainties in the calculation of grassland footprints, results point towards Germany being a significant net importer of grassland embedded in ruminant livestock products.

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Abbreviations

EE-IOA	Environmentally extended input-output analysis
EU28	European Union (28 Member States)
EXIOBASE	A detailed global multi-regional environmentally extended input-output database
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	Statistical databases of the FAO
GAEZ	Global Agro-Ecological Zones model and databases
GTAP	Global Trade Analysis Project
IIASA	International Institute for Applied Systems Analysis
IO	Input-output
IOT	Input-output table
LANDFLOW	The acronym for the applied physical accounting model developed at IIASA
Mha	Million hectares
MRIO	Multi-regional input-output models
SUA	Supply Utilization Accounts
WU	Wirtschaftsuniversität Wien (Vienna University of Economics and Business)
UN	United Nations

1 Introduction

In a globalized world with complex supply chains and trade relations, consumption patterns in one country/region may cause environmental changes including changes in land use and management elsewhere. Individual agents may not be aware of or concerned with environmental and social impacts elsewhere and indirect effects of supply chains may exacerbate effects of consumption on sustainable land use practices.

Striving for sustainable land use requires consideration of production and management of primary commodities, which is closely interlinked with consumer demand and preferences. Land footprints and their impact-oriented extensions characterize land use from a consumer perspective. The aim is to attribute human consumption patterns to land use extents and land use impacts globally.

The German Federal Environment Agency (Umweltbundesamt, UBA) has commissioned a research project in support of UBA and the German Federal Bureau of Statistics (Statistisches Bundesamt, StBA) to further develop and establish land footprint indicators for monitoring global implications of German and EU consumption on land use and related environmental impacts. The aim is to develop indicators from a consumption perspective in support of Germany's sustainability strategy. Indicators should provide an improved understanding of the interlinkages of consumption and land use globally relevant for national and international policy making towards achieving sustainable land use.

In a first step we've reviewed the current studies on land flow accounting methods and concluded with recommendations for further development (Bruckner et al. 2017). The focus of this paper is on quantifying land extents associated with consumption patterns. These are termed 'land footprints' and reported in physical area, e.g. hectares or square meters. The central theme of a related third paper is on extending area-based land footprints with land quality and impact oriented indicators with the objective to extend physical areas with describers or proxies of sustainable land use, such as land quality, nutrient use, land use change (e.g. deforestation) or irrigation water use.

Following the recommendations of the former study (Bruckner et al., 2017) we employ a hybrid accounting combining physical accounting with environmental-economic accounting. Chapter 2 is on methodology. After introducing the concept of hybrid accounting we describe in detail methodology and data for

i) the applied LANDFLOW model from IIASA for physical accounting;

ii) the environmental-economic accounting from the Economic University of Vienna; and

iii) how these two modelling systems are interlinked in hybrid land flow accounting.

Hybrid land footprints were calculated for the period 1995 to 2010 for defined 21 markets covering the world and including major economies separately (e.g. USA, China, India).

In Chapter 3 (Results) describes hybrid land footprints for Germany and the European Union. This includes details in the composition of trade and the footprints separately for crop-based food, livestock food and non-food consumption. We further present the fraction of the footprint based on cropland and grassland used domestically and the origin of land use from land use outside Germany and the European Union. In addition we briefly put Europe's cropland footprints into a global perspective.

In Chapter 4 we compare our results with land footprints from numerous other studies including those calculated at the German statistical office StBA (Mayer et al., 2014a).

Chapter 5 presents comprehensive conclusions on the methodology, an outlook for further research and main results for Germany and the European Union.

2 Methodology

2.1 Concept of the developed accounting approach

Various methods exist for quantifying the land embodied in international trade flows and consumption, i.e. the land footprint. These can be classified into

a) environmental-economic accounting approaches, applying input-output analysis and tracking supply chains in monetary values,

b) physical accounting approaches, using an accounting framework based on data in physical units, and

c) hybrid accounting, combining elements from both environmental-economic and physical accounting.

Environmental-economic accounting allows tracking land flows along monetary inter-industry transactions (supply chains) represented in an input-output (IO) table. IO tables cover the entire economy of a country but use fairly aggregate sectors to portray agriculture and forestry, potentially biasing the results. Physical accounting approaches use agricultural production data, bilateral trade statistics and overall commodity balances (Supply Utilization Accounts) compiled by the UN Food and Agriculture Organization (FAO) in physical units. These statistics provide fairly detailed and comprehensive national data for the most land-intensive sectors, i.e. crop agriculture, livestock production and forestry. However, non-food industrial uses of agricultural products and further processing of wood pulp and panels are not reported and thus cannot be accounted for based on these statistics.

In this study, we apply a hybrid accounting approach, combining elements from environmental-economic and physical accounting. Typically, hybrid accounting models apply physical accounting for raw materials and products with a low level of processing, as these data allow taking into account specific aspects with regard to different products, applied technologies and countries of origin at a very detailed product level. Processed commodities and finished goods with more complex production chains are treated with the environmental-economic accounting methodology (i.e. input-output analysis), which allows considering the full upstream resource requirements and thus illustrating all indirect effects (Buyny et al. 2009; Ewing et al. 2012; Schoer et al. 2012b; Vringer et al. 2010).

This combination of different methods is realised in various ways. Some studies integrate detailed statistics in weight units into monetary input-output tables, thereby creating mixed-unit IO tables (Buyny et al. 2009; Schoer et al. 2012a; Schoer et al. 2013). Another type of hybrid accounting sets up physical accounts to model crop flows and related embodied land flows from agricultural production to the first use stage, tracking any further flows through the economy to final consumption using input-output analysis (Weinzettel et al. 2011; Ewing et al. 2012; Steen-Olsen et al. 2012; Weinzettel et al. 2013; Weinzettel et al. 2014). This enables the application of a different sales structure for each primary product. For example, food and feed use of wheat are assigned to the food processing and to the livestock sectors according to records in agricultural statistics and irrespective of the monetary inter-sectoral flows within the IO table.

The methodology applied in this study is based on the latter approach and extends this by fully exploiting the spectrum of available international agricultural and forestry statistics reporting supply and use flows in mass units. The aim is to establish a globally consistent top-down accounting framework comprising all biomass supply chains. We therefore use a physical accounting model to track land flows embodied in food products to consumption (see Section 2.2). Flows not covered by this approach, i.e. non-food crop and animal products as well as further processed wood products, are assigned to the using sectors in an IO model and tracked further through the economy up to final consumption (see Section 2.3).

This approach is in accordance with the recommendations for the development of a robust land flow accounting method in Bruckner et al. (2017):

- The model captures *multi-cropping* and *fallow practices*.
- It uses reported global cropland *statistics* and *model estimates* for grassland and forest areas.
- It applies a *top-down* approach and avoids the domestic technology assumption, thereby maintaining global consistency of land attribution along supply chains.
- It *avoids* errors resulting from *inconsistencies* between National Accounts and land use statistics tracks land flows along *detailed physical supply chains* by using a physical accounting method for raw materials and products with a low level of processing.
- It comprises all bio-based commodities and supply chains, including highly processed *non-food commodities* by extending the physical with an environmental-economic accounting framework.
- It sets up a consistent and *balanced* representation of bilateral *trade flows* and fully considers *re-exports* and *transit trade*.
- Joint production processes are treated by the use of *economic allocation* for attributing land to *joint products*.
- It distinguishes different *categories of designated end use* such as vegetarian food, animal food, non-food commodities and waste and for the case of non-food commodities additionally provides information on the *final demand products and categories* (e.g. household consumption, government consumption and investments).

The developed methodology, however, does not consider national statistics and country details for extending or replacing international data sources in cases where national data are considered more reliable or where they can add details. For example, it does not consider differences in the import contents of domestic uses and exports as done in Mayer et al. (2014a).

The following sections provide a detailed description of the underlying accounting models:

a) the physical accounting model LANDFLOW, developed at IIASA (IIASA et al. 2006; Prieler et al. 2013)

b) and the environmental-economic accounting model EXIOBASE, developed during several EU projects (Tukker et al. 2013; Wood et al. 2015).

Furthermore we describe the interfaces we used for the integration of both into a hybrid accounting framework.

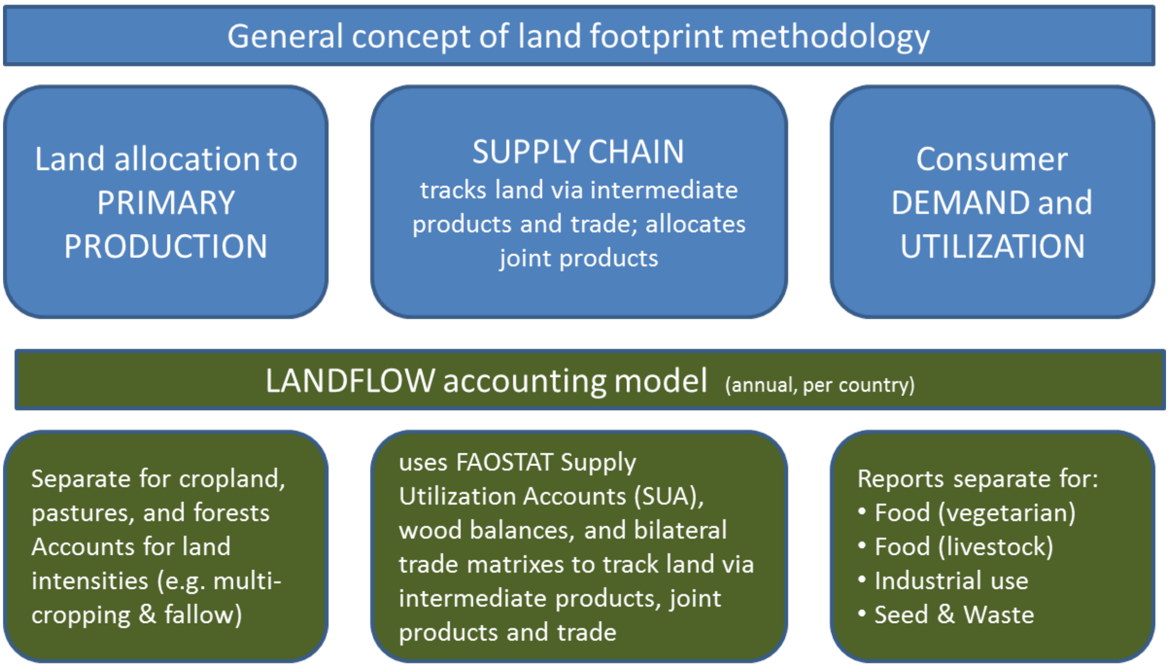
2.2 Physical accounting of land flows

2.2.1 Methodological approach and data

Figure 1 highlights the general concept of land footprint methodologies and specifies their realization in the IIASA LANDFLOW accounting model. Supply chains connect land used for the production of primary commodities with consumption. The LANDFLOW accounting model tracks physical quantities and 'total land' embodied in agricultural and forestry products from primary production in the country of origin to final utilization. The model solves for all reported agricultural and forestry commodities a system of linear equations across regions for land content of traded products. It accounts for intermediate and joint products along the agricultural and forestry processing chain and records cross-country flows of primary and secondary commodities.

LANDLFOW comprises two main steps. First, production of primary commodities is attributed to physical land separately for i) cropland (for primary food, feed and fodder crop production); ii) pastures (for ruminant livestock feed) and; iii) forest land (for roundwood harvest). Land intensities are determined by reported biomass productivity (yields) where available and supplemented by modelled biomass productivity from the Global Agro-Ecological Zones (GAEZ) database (IIASA/FAO, 2012). Cropland attribution also accounts for multi-cropping and fallow periods. Second, 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 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.

Figure 1: Land footprint accounting models and their realization in LANDFLOW



LANDFLOW operates on an annual basis per country. It uses for calculations a detailed commodity list and then generates results for aggregate commodity groups allowing a complete land balance of agricultural and forestry production. Besides land area required for agricultural production and trade, physical volumes of produced, traded and utilized (food, feed, other use and seed/waste) commodities are also recorded. In addition, flows of selected important commodities of interest can be traced separately.

LANDFLOW comprises the following main modules: i) LANDFLOW trade reconciliation; ii) LANDFLOW crop sector; iii) LANDFLOW livestock sector; iv) LANDFLOW forestry sector.

2.2.1.1 Input data

LANDFLOW uses the large harmonized 1990 - 2011 time series country data from different domains of the United Nations Food and Agriculture Organization FAOSTAT agriculture and forestry databases. They include i) primary crop and livestock production; ii) land use data; iii) crop yields; iv) animal stock numbers; v) commodity supply and utilization balances (SUA) of primary and derived products; vi) bilateral commodity trade data by country in physical units and dollar values; vii) production of raw timber materials and wood-based products. The FAOSTAT commodity list includes 683 commodities, grouped in 20 chapters. It provides a framework for collection and analysing data on production and trade and, ultimately compiles the Supply Utilization Accounts (SUA). The FAO commodity list is tailored on “commodity trees”, i.e. the primary crop and its derived products or live animals and their derived products are traceable all along the value chain of agricultural production.

Biomass productivity of pastures and forests (i.e. pasture and forest yields) for individual countries were compiled using estimates from the spatial grid data of the Global Agro-Ecological Zones database GAEZ v3.0 (IIASA/FAO, 2012) and in the case forest yields for selected countries from available published data (UN-ECE/FAO, 2000).

2.2.1.2 Output data

LANDFLOW generates annual results per country/region for the period 1990 to 2011 separately for cropland, pastures and forest land. For reporting, individual commodities are summed up and presented in terms of the following main commodity aggregates:

First, crop products from cropland include eight sub-categories: 1) Cereals; 2) Roots & tubers; 3) Sugar crops; 4) Oil crops; 5) Fruits/Veg./Spice; 6) Stimulants; 7) Industrial crops; 8) Fodder crops. Second, two sub-categories of livestock products are reported according to their feed requirements and associated land utilization. 1) Ruminants (e.g. cattle, sheep) use cropland and pastures, 2) other livestock (mainly pigs and poultry) relies on cropland for feed only. Third, forestry products from forest land include three sub-categories: 1) Wood products (sawnwood and panels); 2) Pulp and Paper; 3) Fuel wood.

For each commodity aggregate, country and year, LANDFLOW generates a balance of supply and utilization. Supply consists of production and imports. Utilization in the agricultural sector includes food use, separate for vegetarian and livestock diets, ‘other use’ (mainly industrial), exports and equivalents for seeds and wastes (from field to farm gate). In addition land embedded in stock changes is reported each year. The forestry sector utilization items include fuelwood, and wood products and pulp and paper products from industrial roundwood production. Table 1 summarizes LANDFLOW reporting categories by main utilization and associated land use type.

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. The modular structure reporting of crop products separate from livestock products reveals extents of land used for the cultivation of crops for direct food consumption (vegetarian diet) and livestock feed.

For the hybrid accounting employed in this study results of land embedded for additional sub-commodities of industrial use are transferred to the economic modelling of land flows (see 2.4).

Table 1: LANDFLOW reporting categories and associated land use embedded in utilization

Utilization (excl. exports)		Sub-categories	Cropland	Pastures	Forests
Agricultural sector: FOOD use	Vegetarian diet	Cereals			
		Roots & tubers			
		Sugar crops			
		Oil crops			
		Fruits/Vegetables/Spices			
		Stimulants (Tea, Coffee)			
	Livestock products[1]	Ruminant livestock			
		Pigs & Poultry			
Agricultural sector: Non-food INDUSTRIAL use	Crop products	Industrial crops			
		Cereals			
		Roots & tubers			
		Sugar crops			
		Oil crops			
	Livestock products	Ruminant livestock	**	**	
		Pigs & Poultry	**		
Agricultural sector – Seed & Waste[2]					
Forestry sector	Fuel wood				
	Industrial roundwood	Wood products			
		Pulp and Paper			

1 Cropland use for growing feed crops including Cereals, Roots & Tubers, Sugar crops, Oil crops (cakes), Fruits/Vegetables, and Fodder crops; Pasture use of grazing ruminant livestock herds; **2** Land associated with seed production and commodity losses through wastage between farm gate and consumption (including handling, storage and transport). Note that the waste incurred at household or restaurant level is not included; ** Includes only small areas globally.

2.2.2 Land allocation to primary production

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 & 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, sheep). Forest land is used to harvest primary roundwood for fuel and industrial processing.

FAOSTAT reports consistent land use time series for all countries including agricultural areas separately for arable land, land for permanent crops, and permanent meadows/pastures, and forest areas (Table 2). In contrast to cropland definitions for grassland and forests may differ across countries and surveying these land uses may be challenging in particular in semi-arid climates or mixed grassland-shrub-forest ecosystems. Therefore statistics for grassland and forest land are considered more uncertain compared to cropland area statistics.

Table 2: FAOSTAT land use data, definitions and LANDFLOW terminology

FAOSTAT item	FAOSTAT Definition	LANDFLOW terminology
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.	**Cropland (i.e. the sum of arable land and permanent crops)**
Permanent crops	Permanent crops are sown or planted once, and then occupy the land for some years and need not be replanted after each annual harvest, such as cocoa, coffee and rubber. 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).	Pastures
Forest area	Forest area is the land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. Forest is determined both by the presence of trees and the absence of other predominant land uses. Excludes: tree stands in agricultural production systems, for example in fruit plantations and agroforestry systems. The term also excludes trees in urban parks and gardens.	Forests

2.2.2.1 Allocation of cropland to primary crop commodities

Globally cropland comprises 1550 Mha and is concentrated on the world's most fertile areas. Cropland productivity depends on biophysical endowment, access to agro-research knowledge through extension services, availability of agro-inputs, 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 for all primary crops detailed for 170 different commodities i) Production (tons); ii) Area harvested (ha); and iii) Yields (tons/ha)[1] (FAOSTAT, 2015). Annex A-1 lists all primary crops aggregated to LANDFLOW's reporting crop groups and attributed to either annual crops or perennials cultivated on arable land or land for permanent crops respectively. In addition FAOSTAT includes a domain on fodder crops reporting production and harvested area of 16 commodities used exclusively for feed (see Annex A-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 *separate 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 define 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 a MCI of 0.9 – 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.

2.2.2.2 Biomass potentials for ruminant livestock from pasture areas

According to FAOSTAT global permanent pastures and meadows cover 3360 Mha of widely varying quality and productivity, ranging from marginal qualities in northern parts of the Sahel or Central Asia to highly productive in large parts of Europe and South America. Data on the precise areas used by grazing livestock in individual countries are difficult to survey and therefore almost never reported in statistics. FAOSTAT reports total area of 'permanent meadows and pastures' (in hectares) and number of ruminant livestock animals (in head).

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1 **Production** data refer to "the actual harvested production, excluding harvesting and threshing losses and that part of 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 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.

To enable comparison of grassland resources across countries we use an indicator of 'reference pasture productivity'. The reference productivity is obtained by comparing potential grassland productivity data to pastures with a defined reference yield of consumable biomass per hectare per year. Pasture yields for individual countries were compiled using estimates from the Agro-Ecological Zones database GAEZ v3.0 (IIASA/FAO, 2012). Estimated yields were compared to published data and adjusted accordingly if necessary. Average national pasture yields for over 200 countries were assembled ranging from less than one ton to more than 10 tons dry matter per hectare. Applying e.g. a reference productivity of 5 ton/ha, then instead of 3400 Mha of pasture, only an equivalent 1400 Mha reference pasture is globally available.

Using a dry matter content factor of 90% and a digestible energy content of 2.4 Mcal per kg of dry matter we calculate the potentially available biomass feed supply. The LANDFLOW livestock module (see 2.6) calculates feed balances, which can for ruminant animals be compared with potential biomass feed supply from pastures.

2.2.2.3 Allocation of forest area to round wood production

According to FAO's forest as a land use definition global forest area was 4027 Mha in 2011 (FAOSTAT) or 30% of the land area. Forest land use may include periods during which the land is devoid of tree cover, for example during cycles of forest harvesting and regeneration. In such cases, a land use is considered to be forest land use when management or natural processes will, within a reasonable time, restore tree cover to the point where it constitutes a forest. Above-ground forest productivity and biomass varies widely ranging from high-biomass forests in tropical and temperate climates to low-biomass montane and boreal forests.

For the allocation of forest area to round wood production we assume long term sustainable forest management and apply annual forest biomass increments (forest yields) to reported round wood production. Forest yields applied in this study were derived from the TBFRA report on Forest Resources of Europe, CIS, North America, Australia, Japan and New Zealand" (UN-ECE/FAO, 2000) for the countries included in the report. For all remaining countries a national average forest yield was estimated based on net primary productivity calculated from the spatial GAEZ grid data (IIASA/FAO, 2012).

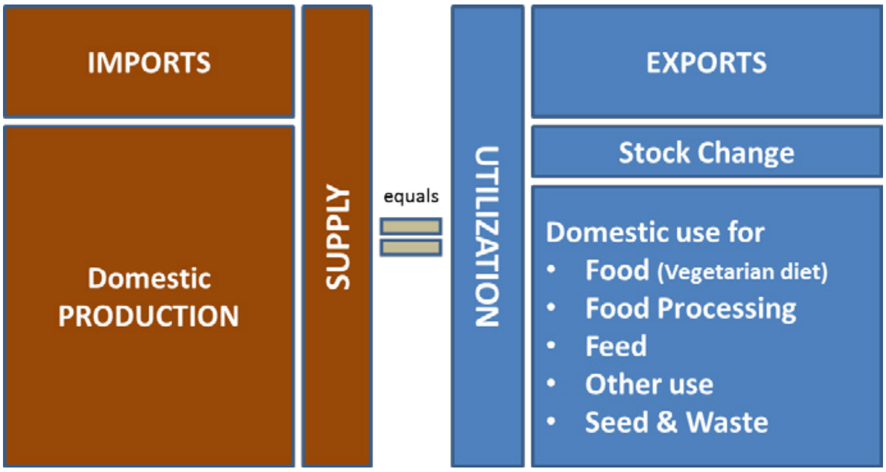
2.2.3 Supply Utilization Accounts for agricultural supply chain allocation

The FAO supply utilization accounts (SUA's) 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 2). The total quantity of agricultural commodities produced in a country, i.e. 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) and losses during storage and transportation (waste), and changes in stocks (stock change).

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 (Annex A-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 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).

Figure 2: Items in the FAO Supply Utilization Accounts (SUA)



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

Consistent tracking entails i) connecting land use intensities of primary crops to SUAs; ii) accounting for joint production; iii) solving trade flows, and iv) dealing with the livestock sector. The following sections 2.2.4 to 2.2.7 describe the main processes applied in LANDFLOWs crop and livestock sector allocation.

2.2.4 Crop sector

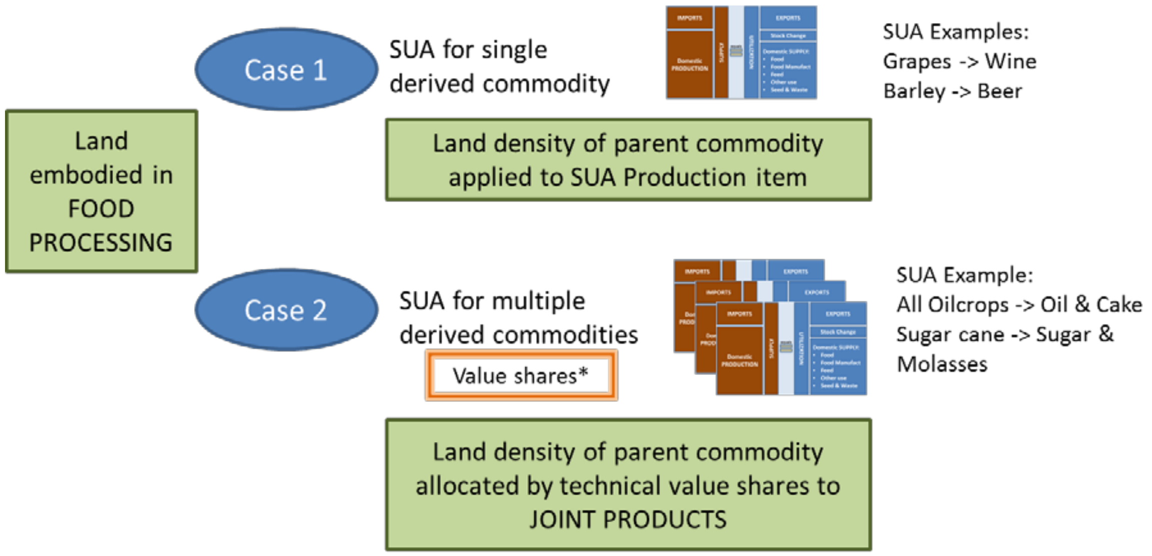
LANDFLOW covers on the one hand the entire agricultural sector and on the other hand use bottom-up detailed crop intensities for tracking embedded land areas. First cropland densities of primary production are connected to SUAs by applying land densities of the respective primary crops a to the production item in each SUA. This is achieved by aggregating primary crops (from crop production lists) to the respective SUA commodity. The sum of physical areas in imports calculated in the trade module (see section 2.2.7) and in domestic production represents the physical area in supply. We apply the land vector (ha/ton) of supply *equally* across all utilization items[3], i.e. assuming the same composition of domestic and imported crops in exports and all domestic supply items (food, livestock feed, ...).

The utilization items 'Food use' (vegetarian diet), 'Other use' (industrial), and 'Seed & Waste' (from domestic production) signify in LANDFLOW 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 either result in a single derived com-

[3] 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.

modity (e.g. grape processing produces wine; barley processing produces beer) or in multiple derived commodities (Figure 3).

Figure 3: Schematic overview of data flows for tracking land in the "Food Processing" item



* Technical value shares are calculated from physical quantity and price of the sub-products (see 2.2.5)

Examples of the latter include all vegetable oil crops, which are processed in crushing mills to vegetable oils for food and industrial use and cakes, 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 (2.2.5). Cropland areas associated with SUA feed items are tracked in the LANDFLOW livestock module as described below (2.2.7).

2.2.5 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 crushing of oil seeds, which produces jointly vegetable oils and oilcakes, both reported as SUA commodities. From the processing of sugar crops, the SUA commodities Sugar & Sweeteners and Molasses are produced. Examples of joint production in the livestock sector include ruminant animals producing milk, meat and hides & skins.

LANDFLOW achieves 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. Annex A-3 shows technical extraction rates for oil crops. From the processing of sugar crops, the SUA commodities Sugar & Sweeteners and Molasses are produced with extraction rate of about 16% and 4% respectively.

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 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 case of joint production land areas of the primary produce are best allocated by accounting for the economic value of the produce. This is justified by the vast majority of farmer's producing according to economic maximization. Alternative weighting schemes could be calorie content, physical weights, or energy content. Annex A-4 lists detailed calculation steps.

World export unit values of the year 2000 (in $/t) from FAOSTAT of the single commodities are taken as unit price for the derived commodities. To give an example, SUAs give 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.

Annex A-3 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.

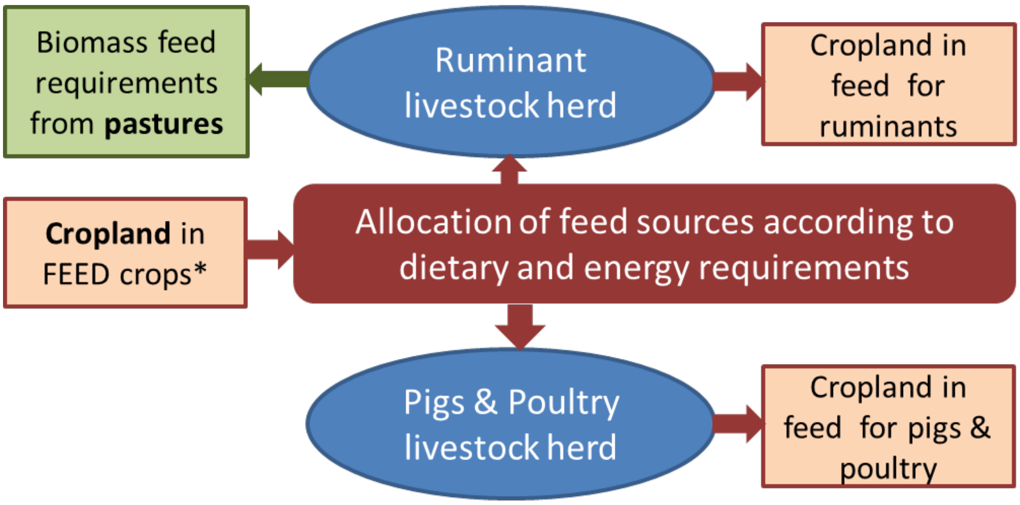
2.2.6 Livestock sector

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. Using the available data, we distinguish three types of feed sources: a) herbaceous forage from permanent pastures; b) dedicated fodder crops, and c) primary crops and crop by-products. The latter may either be produced domestically or may be imported. These 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, 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 forms the basis for attributing cropland use and pastures to the two animal groups (Figure 4).

Figure 4: Land allocation in LANDFLOW livestock module



* Feed crops cultivated on cropland include fodder crops, primary crops, crop by-products

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, the livestock unit (LU). Conversion factors were compiled by broad geographical regions. As defined in this way, each livestock unit requires 8700 Mcal of feed energy per year. With these assumptions and conversions, annual livestock energy requirements for the two livestock groups can be calculated. 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) fodder crops grown on cropland especially for animal feed
b) primary crops grown for both food and feed purposes (e.g. cereals, sugar crops, vegetables & fruits)
c) crops residues and by-products from food processing (e.g. soybean cake)
d) feeds derived from livestock products (e.g. milk, milk powder, meat offals)
e) fish products (e.g. fish meal)
f) biomass from permanent pastures

Production and harvested areas of fodder crops are reported in the FAOSTAT Primary Production domain. Due to dietary requirements, some fodder crops can only be fed to ruminants, while others are fed to both ruminants and the 'pigs & poultry' livestock group. It is assumed that all fodder crops are grown on cropland. Published conversion factors of dry matter percentage and energy content of dry matter (see Annex A-5) are used to estimate feed energy provision from fodder crops.

The SUA (see 2.2.3) trace the utilization of animal feed (Annex A-2). SUA items are generally reported in metric tons. Like with fodder crops, conversion factors are used to calculate dry matter and energy content of the feed sources.

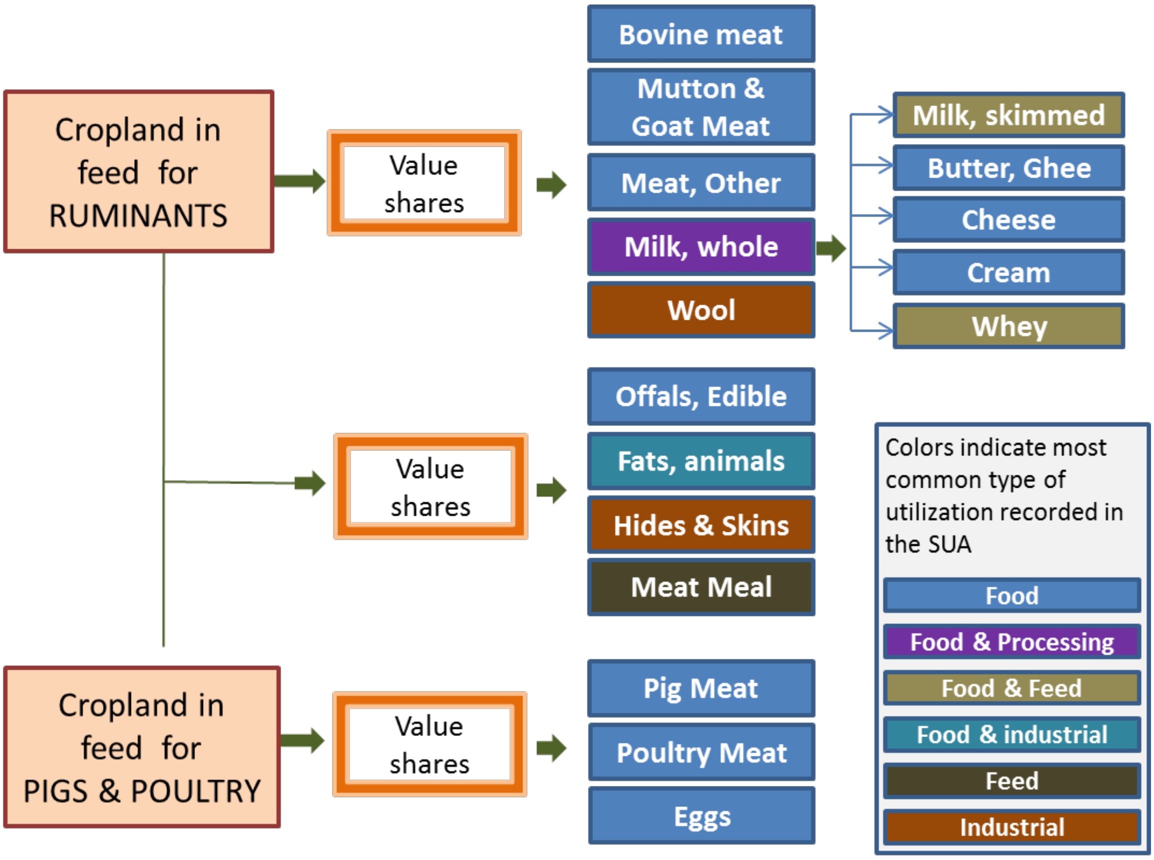
Feed sources and associated cropland areas are allocated to livestock categories in proportion to energy requirements of the respective livestock herds and according to suitability of feed sources for use in animal diets, i.e. while respecting dietary characteristics of animal types and the total amounts of recorded feed types, the feed energy balance of each animal type are 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 in section 2.2.5. Figure 5 highlights the main produces from the two animal groups including their most common type of utilization.

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 for each country the head of ruminant livestock and the total pasture areas. Information on livestock management practices (e.g. fencing, herd rotations, 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 actually utilized pasture areas 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 digestible biomass per hectare and year in a country as pasture in primary production for feeding ruminant livestock herds.

Figure 5: Allocation of cropland in feed to multiple livestock commodities using value shares



2.2.7 Cross-country trade

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 rely on primary crops from both, domestic production and imported primary crops[4].

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 purpose of land appropriation of traded agricultural commodities a relationship has been established between the trade data and their respective SUA items. For example, in the case of the primary commodity maize reported as primary equivalents in the SUA, the following items are included in the trade data base: 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.

Globally consistent natural resources allocations including land footprints require consistency between imported and exported commodities. Bilateral trade flows are reported separately by importer

[4] For example, in many European countries domestic utilization of soybean is to a large extent based on imported commodities from North and South America. Another example are European countries exporting processed tropical fruit commodities, which they do not produce themselves.

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:

g) time lags (e.g. exports reported at the end of the year could reach a destination in the following year)
h) exported quantities could be destroyed on the way to the destination
i) type of trade reported: some countries report general trade (including re-exports) while other report special trade (imports of domestic consumption)
j) data confidentiality by one of the reporters
k) customs tax avoidance by misrepresenting a commodity on import or not reporting a transhipment
l) place of origin/final destination inconsistencies (e.g. some countries may report final destination and omit intermediate trade via a third country)

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.

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 often disagree. There is no common method for reconciling difference 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've defined 28 regional markets listed in Annex A-6 including Germany as a separate market and optimized for hybrid accounting, i.e. linking with the economic accounting model used in this study (Annex A-7).

Starting from the trade matrix described by the bilateral FAO physical trade data (in tons), an iterative procedure has been applied for each commodity and year of the period 1990 to 2008 to adjust calculated trade shares and to ensure the full mutual consistency of export and import flows, i.e., whatever region i reports as export to region k must also show up as import of region k from region i.

After conversion of the extensive FAO bilateral trade data into primary equivalent and aggregation to the respective SUA commodity, 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 larger the number of defined regional markets, the higher the necessary adjustments of the original 'raw' data, to achieve a consistent trade matrix.

2.2.8 Forestry sector

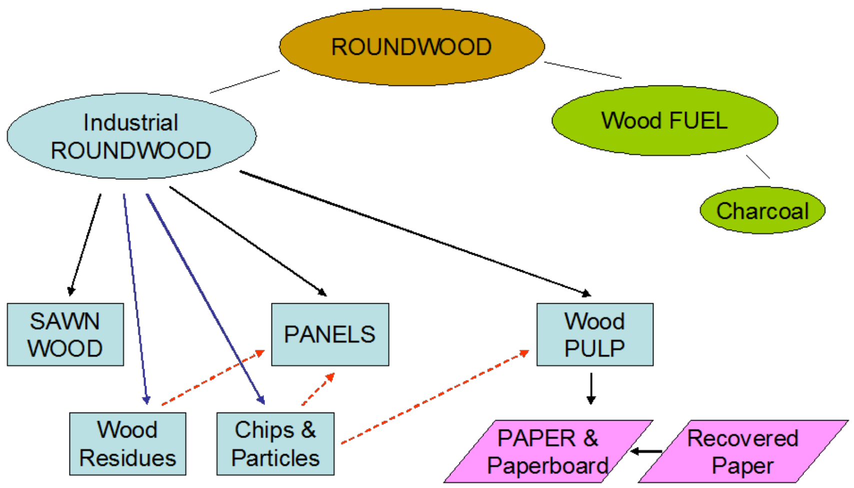
The forestry sector includes primary roundwood production as well as manufactured forest products including diverse wood and paper products. Forestry industry has become highly globalized with substantial amounts of cross-country flows of forest products. When a country imports forest commodities it also imports land resources behind these commodities and vice versa in the case of exports.

Several key economic activities utilize timber resources. The primary sector 'forestry, logging and related activities' produces timber and wood fuel. Industrial roundwood is the raw material for diverse forest manufacturing industries. They include sawmilling and the manufacture of wood to produce sawn wood, panels, veneer sheets, plywood and others as well as the manufacture of pulp, paper and paperboard. While trade in the primary sector, i.e. transport of logs is relatively small, trade of processed timber commodities (wood and paper products) may be significant.

The LANDFLOW forestry module tracks land associated with the production and trade of forestry products using supply chains based on the global FAOSTAT country databases. Following the relationships sketched in the figure 6, the LANDFLOW analysis constructs a consistent wood balance tracking the wood commodity supply chains for each country and year, taking into account domestic roundwood production volumes, trade of primary roundwood, production and trade of the derived wood products, as well as of wood pulp and paper (including recycled paper). Detailed definitions for all FAOSTAT forestry items are described in Annex A-8.

Roundwood refers to all wood in its natural state obtained from removals. It comprises industrial roundwood and wood fuel, with charcoal being a subcategory of wood fuel[5]. Industrial roundwood is the raw material to produce sawn wood, wood based panels and wood pulp with the latter being the base material for paper production. The pulp and paper sector includes national amounts of recovered paper (recycling). 'Wood residues' and 'chips and particles' are usually produced as waste material from 'logging, sawn wood or panels' production. They are used for diverse purposes including pulping and particle board and fibre board production. These two by-products are reported in roundwood equivalents and are included in the domestic industrial roundwood production (as of 1998). However, note that in the trade data these two commodities are reported separately next to the import and export of industrial roundwood.

Figure 6. LANDFLOW forestry sector supply chain based on FAO data bases



LANDFLOW calculates the extent of forest land associated with roundwood production using each country's respective estimate of forest land productivity (see 2.2.3). The wood commodity balances and associated land balances form a system of linear equations that is solved each year for all commodities and markets to obtain a vector of land intensities in a country's domestic supply by commodity and for each market. These intensities are then further applied to calculate the respective land embodied in the production and utilization of each sub-sector (e.g. sawn wood, panels, pulp and paper, etc.). In order to avoid double counting in wood and land balances, recycled paper in LANDFLOW is treated as containing no land. In other words, the land use associated with the volume of roundwood required for paper production is attributed to the first cycle of paper production and use only.

[5] However trade data report charcoal separately and charcoal is therefore not included in the amount of traded wood fuels.

2.2.9 System boundaries

Due to the domain boundaries of the FAOSTAT databases, trade of highly processed agricultural and forestry goods and hence 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 respectively shoes 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) and forestry commodities in an environmental-economic accounting of land flows, i.e. a hybrid accounting.

2.3 Hybrid accounting of land flows

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 be used for the study of food-related biomass flows and flows of basic wood products only. 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), together forming a hybrid accounting model to track upstream flows of non-food biomass commodities.

2.3.1 Environmental-economic accounting of land flows

Environmental-economic accounting approaches in the form of environmentally extended input-output analysis (EE-IOA) allow tracing 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 for each commodity or industry represented in the model all inputs required along the whole supply chain. These inputs comprise direct input requirements of the sector itself and indirect inputs from other sectors located upstream the supply chain.

Multi-regional input-output (MRIO) models link together input-output tables of several countries or regions via bilateral trade flows. These models trace global supply chains using country specific information on production technologies and economic structures (Feng et al. 2011) and thus allow taking into account the different resource intensities (e.g. yields) in different countries (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 (Tukker et al. 2013; Wood et al. 2015). For a comparison of MRIO datasets see Bruckner et al. (2015). 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 (see Annex B-1). Each country model is available in a detail of 200 commodities (see Annex B-2) such as, for example, 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 to allocate land use related with the production of agricultural commodities to the consumer of the end-products.

2.3.1.1 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,

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

The dimensions and descriptions for the model variables are given in Table 3.

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

Variable	Description	Dimension
i, j	Sectors or commodities	200
p, q	Countries and country groups	49
A	Technical coefficients matrix	9800 × 9800
x	Total output	9800 × 1
Y	Final demand	9800 × 49
Z	Intermediate use matrix	9800 × 9800

Consequently, 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:

$$x = Ax + Y \tag{1}$$

Solving for x, we obtain

$$X = (I - A)^{-1}Y \tag{2}$$

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. X

is a matrix now, showing the output of each sector and country in the rows and the countries directly or indirectly obtaining these sector outputs in the columns.

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

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

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.

2.3.2 Linking physical with environmental-economic accounting

In the standard EE-IOA approach applied to land footprint accounting (Arto et al. 2012; Bruckner et al. 2012; Yu et al. 2013; Wood et al. 2015), 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, forest land 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 to textiles, or land embodied in oil seeds is attributed to the industries and countries where they are processed to 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. We track food commodities up 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 hence 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

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

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. Aggregating F_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_c^q represents the final demand of a specific country q for a commodity c.

$$F\_total_c^q = F\_io_c^q + F\_ph_c^q \tag{5}$$

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 a a 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, i.e. 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 is rather straight forward. 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 4.

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).

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, multiplying the respective supply shares with the land use content of the non-food commodity determined beforehand with the LANDFLOW model.

Table 4: Supplying and using EXIOBASE sectors of the considered non-food commodities

Nr	Commodity	Supplying sector(s)	Using sector(s)
1	Wheat	Wheat	all non-food industries
2	Rice	Paddy rice; Processed rice	all non-food industries
3	Maize	Cereal grains nec	all non-food industries
4	Other cereals	Cereal grains nec	all non-food industries
5	Roots & Pulses	Vegetables, fruit, nuts	all non-food industries
6	Sugar crops (primary)	Sugar cane, sugar beet	all non-food industries
7	Sugar & Sweetener & Molasse	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 & 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 & Skins, monogastrics	Pigs; Products of meat pigs	Textiles; Wearing apparel, furs; Leather and leather products; Wool, silk-worm cocoons
24	Timber	Wood and products of wood and cork (except furniture), articles of straw and plaiting materials	all industries (excl. Pulp and Paper and paper products)
25	Panels	Wood and products of wood and cork (except furniture), articles of straw and plaiting materials	all industries (excl. Pulp and Paper and paper products)
26	Pulp	Pulp	all industries

3 Results

3.1 Scope, model calculations and indicator overview

Land footprints were calculated using a hybrid approach (see section 2.3), combining physical and economic accounting. The physical accounting uses the LANDFLOW model, which tracks the flow of virtual cropland and grassland along supply chains as reported in the FAO land use, agricultural and forestry production and trade data. LANDFLOW also tracks non-food uses of bio-based commodities (e.g. textiles from cotton, latex from rubber plantations, oleo-chemicals from vegetable oils, biofuels from starch crops and oil crops). The LANDFLOW output for non-food uses serves as input to the economic accounting of a multi-regional input-output model (MRIO). Note that land embodied in supply chains and trade is tracked using physical data (tons) in physical accounting while it is tracked in monetary values ($) in economic accounting.

Following the recommendations of work package 1 of this study (Bruckner et al., 2016, forthcoming), we account for differences in accuracy, sharpness and availability of land use data for the broad primary sectors crop, livestock and wood production and present land footprints separately for different land use categories. Agriculture utilizes cropland for the production of food, livestock feed and non-food commodities (e.g. fibre, tobacco, natural rubber) and uses grassland for grazing ruminant livestock herds. Accounting for differences in land use we distinguish in the livestock sector ruminant livestock (e.g. cattle, sheep) and monogastric livestock (pigs and poultry). Only ruminants feed on grassland in addition to feed from crops cultivated on cropland.

In contrast to cropland, definitions for grassland and forests may differ across countries and statistical data of these land uses are challenging in particular in semi-arid climates or mixed grassland-shrub-forest ecosystem. Moreover extents of grassland and forests actually used for human economies are not surveyed in many countries and not reported in FAO land use data. Therefore land footprint calculations would require additional assumptions and calculations, which are beyond the scope of this report.

As cropland footprints represent more reliable estimates of human utilization on land resources (compared to grassland and forest land footprints) the focus of the results section is on the presentation of cropland footprints. Furthermore, cropland is concentrated on the world's most fertile lands and area-based cropland footprints have been earmarked as important indicators or proxies for human impacts on natural ecosystems. Ruminant livestock however may rely in addition to cropland also on grassland for feed. Although a higher degree of uncertainty is attached to grassland footprints based on FAO grassland data only, we present results for Germany and the EU to provide a complete picture of the agricultural sector. A land quality based methodology for grassland footprint calculations is presented in another report of this study focused on an extension of land footprints towards a better characterisation of the sustainability of agricultural use.

Forest land footprints based on FAO land use data and the assumption that all forest land is used for timber production is considered too uncertain for footprint calculations. In the case of forest land we argue that going beyond forest land statistics and taking land quality and biomass yields into account is indispensable for sensible forestland footprint accounting. We've therefore proposed a methodology using best available forest yields together with reported roundwood production for the allocation of forestland footprints (see section 2.2.2.3 and 2.2.8).

Calculations operate on an annual basis for the period 1995 to 2011 for defined 28 (LANDFLOW) and 21 (MRIO) markets globally (Annex B-1). The markets were selected i) for providing linkage with the LANDFLOW and MRIO modelling systems; ii) for ensuring inclusion of major national economies (e.g. USA, China, India, Brazil) including Germany, and iii) for facilitating a logical hierarchy of regions and national economies (e.g. India and 'Rest of South Asia' can be aggregated to 'South Asia').

Further LANDFLOW operates with detailed commodity data, while MRIO functions on sector levels (see Annex A-1 and A-2 for LANDFLOW Annex B-2 for MRIO). Results are expressed as in economics and FAO commonly used three-years moving averages (i.e. 2010 represents 2009-2011) to smooth out short-term fluctuations or noise of random outliers and emphasize longer-term trends. We present the following indicators for area-based land footprints.

First, a key indicator is the cropland footprint, i.e. the extent of cropland used for the production of goods consumed by a country's population. It includes both commodities from crops cultivated domestically and abroad. We present the following main use categories: i) Food, crops; ii) Food, livestock; and iii) Non-food (industrial products). 'Seed and waste' refers to a fourth usually smaller part of the footprint, i.e. land equivalents attributed to seed production and waste generated at the farm level. The cropland footprint is calculated as the domestically cultivated areas ('Production') plus areas embedded in imported products ('Imports') minus the areas embedded in exported commodities ('Exports'). Estimated footprints represent different land uses (see also Table 1) and include

i) Food use of crop-based diets, e.g. from cereals (rice, corn, bread, noodles, beer), roots and pulses (potatoes, cassava), sugar crops (sugar), oil crops (vegetable oils), vegetables, fruits and spices (includes beverages and wine), stimulants (coffee, cacao, tea)

ii) Food use of livestock diets, e.g. meat, dairy products (milk, cheese,…), eggs, animal fats

iii) Non-food use, e.g. from vegetable oils (oleo-chemical industry including biodiesel), from cotton, fibres and wool (textiles), from starch crops (bioethanol, glues,…), from natural rubber (latex), from livestock skins & hides (leather products), from animal fats (for chemical and pharmaceutical industry), from timber (pulp, paper, panels, furniture,…)

Second, an important indicator for the areas appropriated of a specific national economic includes the area in domestic production plus the area in imports. Although some of these areas are used for products of export markets, i.e. areas embedded in 'Exports', it is the national economy that requires and benefits from the cropland areas embedded in 'Demand of the economy', a second indicator we present.

For policy makers and potential further studies aimed at analysing the sustainability of human consumption patterns, it is important to further detail footprint indicators by their composition of commodities. In this vein we present sub-indicators detailing results by 25 main commodity groups for different stages along the supply chain including trade and intermediate products (see Table 7).

The objective of this study is the calculation of footprints for Germany and the EU. At the same time European economies are strongly interlinked with global markets. From a perspective of global resource efficiency it is interesting to discuss European footprints in relation to global footprints and those of other markets. This is here achieved by presenting another sub-indicator, namely the footprint per capita, for Germany, the EU, world averages and selected major economies across the world. Separate sub-sections are dealing with footprint dynamics and the vegetable oil sector. Direct or indirect land use change impacts of footprints such as deforestation or a qualification of land footprints by biomass productivity are dealt with separately.

3.2 Germany

3.2.1 Overview and composition of current cropland footprints

Germany's current 2010) demand for agricultural commodities required as input for the country's food, livestock and other non-food industrial sectors is based on crops produced from 36 Mha cropland of which one third is produced domestically and two thirds is located outside Germany and 'virtually' imported via imported crops and livestock products (Table 5a). At the same time Germany's industry exports and re-exports crops and livestock commodities equivalent to 13.8 Mha. In total

Germany is a net importer of 'virtual' cropland due to imports of crop based commodities being more than double compared to exports of crop based commodities. In the livestock sector Germany is however a net exporter of cropland (Table 5b).

Table 5. Cropland embedded in production, trade and demand of crops and livestock products, 2010

a) Demand of German economy

Origin of cropland (1000 ha)		
Domestic crop production	12,088	33%
Imports	24,227	67%
Total demand	**36,315**	100%

b) TRADE

1000 ha	Crops	Livestock	Total
Imports	19,099	5,128	24,227
Exports	8,022	5,599	13,621
Net Imports	11,077	-471	10,607

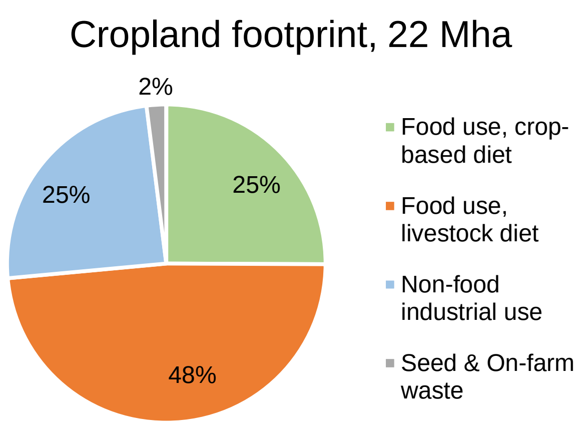
Table 6 and Figure 7 present a comprehensive summary of Germany's cropland footprint, i.e. the area associated with of German consumption. The area is estimated from total demand for cropland for German consumers, i.e. domestic crop production plus cropland embedded in imported commodities minus the cropland embedded in exported commodities. The cropland footprint consists of food use (separately for crop-based and livestock food use) and non-food commodities from crops- and livestock (e.g. cloth from cotton, biodiesel from vegetable oil, car tires from natural rubber, animal hides and wool). The seed and waste category represents cropland required for seed production and land equivalents accounting for on-farm waste from domestic crop production.

Table 6. Cropland footprint and source, Germany 2010

a) Cropland source (1000 ha)	
Domestic production	12,088
Net imports	10,607
Stock change	-336
Total	22,359

b) Cropland footprint	1000 ha	m^2 / capita
Food use, crop-based diet	5,604	675
Food use, livestock diet	10,835	1,305
Non-food industrial use	5,476	660
Seed & Waste	444	53
Total	22,359	2,693

Figure 7. Composition of Germany's cropland footprint, 2010



Almost half of Germany's cropland footprint is related to food consumption of livestock products (meat, dairy products, eggs), about one quarter to crop-based diets (vegan food) and also a quarter to non-food commodities. Germany's cropland self reliance ratio (cropland in domestic production divided by the cropland footprint) is 54%, i.e. almost half of cropland required to meet domestic consumption is located outside Germany. Each German citizen appropriates on average 2,693 square meter cropland for the consumption of food and non-food commodities.

Table 7 presents a comprehensive summary of the balances of supply and utilzation by major commodity group along the supply chains from primary production to final consumption including trade and key intermediate products, notably livestock feed and food processing. Rows represent major commodity groups, columns the different items of supply and utilization. *Supply* comprises production and imports corrected for stock changes, i.e. the demand of the national economy for respecitve goods and underlying cropland resources. *Utilization* describes the different use categories including exports, food use, food processing, livestock feed, non-food industrial use, and seed & waste. While food use and non-food use represent a category of final consumption, all use categories are intermediate items along the supply chain.

The upper section of Table 7 shows 13 commodity groups summarized as 'primary commodities'. Production here refers to cropland extents cultivated domestically and is accounting for multi-cropping and fallow land (see section 2.2.2.1). In the case of Germany cultivated cropland amounts to 12,088 kha, half of it used for the production of fodder crops. Note that commodity groups are aggregates of all categories represented in the FAO Supply Utilization Accounts. Except for production, livestock feed and 'Seed & Waste', the other categories (columns in Table 7) often include processed items. For example, import of stimulants may be in the form of primary commodities (e.g. coffee beans) or as processed commodities (e.g. coffee).

The lower section of Table 7 shows secondary commodities derived from input and processing of primary commodities separate for crops (sugar/sweetener/molasses; vegetable oil, oilseed cakes, and alcohol) and livestock products (8 sub-groups including meat, dairy products, eggs, wool/hides/skins). For example, 220 kha primary sugar crops (row 6, column food processing) are used in Germany for the production of 'sugar/sweetener/molasse' (row 15, column production). The oilseed sector is another example of linking primary commodities with derived commodities along the supply chain. In Germany, some 3373 kha of cropland is embedded in oilseeds used for crashing (i.e. 'food processing', row 7) oilseeds into vegetable oil (2078 khA) and oil cakes (1300 kha). The small difference in the sum of vegetable oil and oil cakes as compared to primary oil crops is explained by maize, which also is used to produce some vegetable oils (see section 3.1.5). Alcohol is derived from a number of primary crops including 'other cereals', fruits, and maize.

Livestock production has been related to extents of feed and fodder crops used for raising domestic livestock herds. Some 12,176 kha cropland is used domestically and abroad for the production of livestock feed. Main livestock feed commodities include domestically grown fodder crops (6,819 kha), cereals (2,939 kha) and oil cakes (1,854 kha), the latter supplied by crops cultivated domestically and abroad.

The supply utilization balance provides the basis for the calculation of the cropland footprint (Table 6) comprising of

i) Food, crop-based diets (5,604[6] kha);

ii) Food, livestock diets (10,500 + 47 + 288 = 10,835[7] kha);

iii) Non-food (4,653 crops + 823 livestock = 5,476[8] kha); and

iv) Land equivalents attributed to domestic seed production and on-farm waste (444[9] kha).

In the following we discuss commodity details and origin of cropland for the individual component of supply and utilization and derived footprints.

[6] See row 'Total, crops'; column 'Food use'

[7] See row 'Total, livestock; columns 'Food use', 'Food processing', 'Livestock feed'.

[8] See rows 'Total, crops', 'Total, livestock'; column 'Non-food'

[9] See rows 'Total, crops' + 'Total, livestock'; column 'Seed / Waste'

Table 7. Supply and utilization of cropland, Germany, 2010, by commodity group

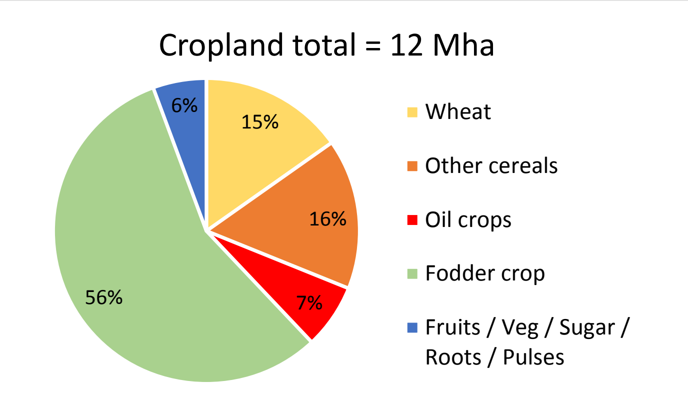
1000 hectares	SUPPLY				UTILIZATION					
	Produc-tion	Imports	From Stock	TOTAL	Exports	Food use	Food processing	Livestock Feed	Non- food	Seed / Waste
Crop sector										
Wheat	1,838	1,514	-61	3,292	1,170	781	17	1,020	173	130
Rice	0	176	-2	174	26	74	0	9	64	2
Maize	266	783	-29	1,020	80	70	65	361	427	17
Other cereals	1,659	878	30	2,567	407	185	281	1,549	41	105
Roots and pulses	200	147	-1	346	70	106	14	94	26	36
Sugar crops (primary)	216	11	0	227	0	0	220	0	7	0
Oil crops (primary)	826	3,287	-269	3,843	163	115	3,373	72	73	47
Fruit, vegetables, spices	261	1,417	6	1,683	333	1,130	144	3	12	60
Stimulants (Coffee,tea,cacao)	0	3,246	0	3,246	2,213	1,028	0	0	6	0
Tobacco	1	185	0	186	113	0	0	0	73	0
Rubber	0	582	0	582	266	0	0	0	316	0
Other industrial crops	0	672	0	673	37	0	0	0	635	0
Fodder	6,819	0	0	6,819	0	0	0	6,819	0	0
Total, primary commodities	**12,088**	12,898	-326	24,657	4,879	3,489	4,115	9,927	1,853	396
Sugar, sweetener, molasses	220	98	-6	312	84	184	27	5	13	0
Vegetable oil	2,078	3,453	2	5,534	1,925	1,154	36	390	2,029	0
Oil cakes	1,300	1,330	-6	2,625	682	0	0	1,854	89	0
Alcohol	542	1,320	0	1,863	453	731	9	0	670	0
Total, derived commodities	4,140	6,201	-10	10,334	3,143	2,069	72	2,249	2,800	0
Total, crops		19,099	-336		8,022	5,604*	4,186	12,176	4,653	396
Livestock sector										
Ruminants, meat & offals	2,044	703	0	2,747	757	1,953	2	1	27	8
Ruminants, dairy products	5,536	1,671	0	7,207	2,389	4,360	0	283	168	7
Ruminants, fats & meals	60	81	0	140	40	53	2	1	45	0
Ruminant, wool & hides & skins	151	611	0	763	381	0	0	0	381	0
Monogastric, meat & offals	3,750	1,592	0	5,342	1,780	3,497	39	0	25	0
Monogastric, eggs	288	327	0	614	65	505	0	0	13	32
Monogastric, fats & meals	290	108	0	398	173	133	4	3	86	0
Monogastric, hides & skins	58	36	0	94	15	0	0	0	78	1
Total, livestock	12,176	5,128	0	17,304	5,599	10,500	47	288	823	48

This table shows major commodity groups (each balanced by supply and utilization) for primary commodities and derived (secondary) commodities. Cultivated cropland in Germany: 12,088; Cropland embedded in utilization items: a) Feed crops for raising German livestock herds = 12,176; b) Food use, livestock products: 10,500 + 47 + 288 = 10,835; c) Food use, crop-based products: *5,604 (incl. correction for food processing not shown in the Table); d) Non-food (industrial) use: 4,653 + 823 = 5,476.

3.2.2 Cropland embedded in production and trade

More than half of Germany's domestically cultivated cropland (56%) is used for the production of fodder crops and almost one third (31%) for cereal production (Figure 8 and the column "Production, Primary commodities" in Table 7).

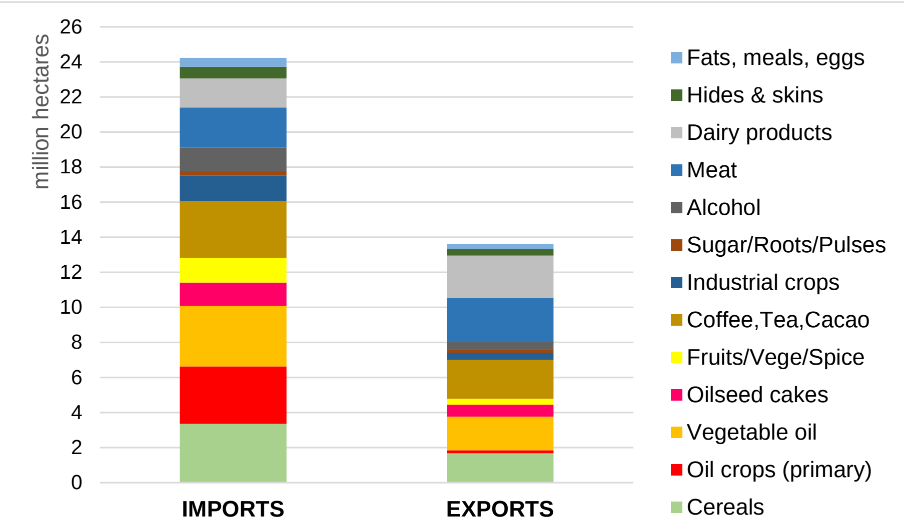
Figure 8. Composition of domestic crop production, Germany, 2010



Germany extensively trades agricultural primary and secondary commodities. Figure 9 shows major commodity groups with cropland embedded in imports and exports.

Germany's cropland embedded in imports is 24 Mha, twice the area of domestic crop cultivation. One third (33%, 8 Mha) of this virtually imported cropland is associated with the oil crop sector (see also 3.1.5). Other important commodities with large virtually imported cropland include stimulants (coffee, tea, cacao) and cereals, both with associated imported cropland of over 3 Mha, followed by meat (2.3 Mha), dairy products (1.7 Mha) and industrial crops (1.4 Mha).

Figure 9. Cropland embedded in imports and exports, by major commodity group, Germany, 2010



Germany is an important exporter for agricultural based food and industrial products, (re-)exports almost 40% of total supply (cropland embedded in domestic production and imports of crops and livestock products) or 13.6 Mha are exported or re-exported. Important export commodities are meat products (2.5 Mha), dairy products (2.4 Mha), stimulants (2.2 Mha), vegetable oils (1.9 Mha) and cereals (1.7 Mha) making up almost 80% of exported commodities.

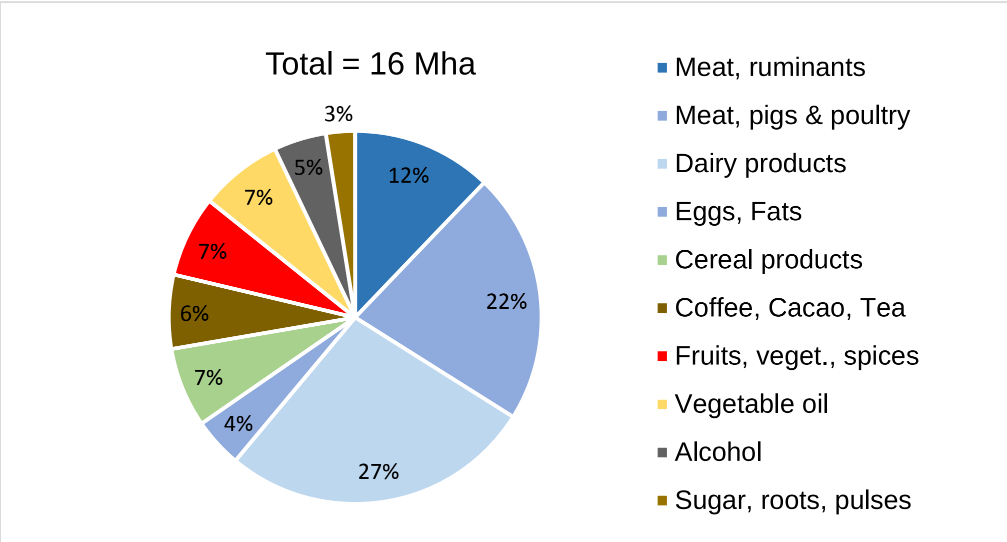
Overall, Germany is a net 'cropland importer' of 10. 6 Mha (Table 5b). However in the case of meat and dairy products, a net exporter. Thus Germany generates financial gains by exporting higher value processed livestock commodities. Significant amounts of oilseed cakes, maize and other cereals are produced on cropland outside Germany and used as animal feed to raise German's livestock herds. Similarly, Germany's virtual land imports associated with stimulants (coffee, cacao, tea) is three times its domestic use, i.e. after processing two-thirds are re-exported as higher value processed goods.

3.2.3 Cropland footprint for food consumption

Germany's cropland footprint of food consumption amounts to 16.4 Mha or 1,980 square meters per capita. The column 'Food use' in Table 7 highlights the composition by main commodity group. Two thirds of the food-related cropland footprint or 10.8 Mha (1,205 m2/capita) is due to the consumption of livestock products (Figure 10). Main components include dairy products (4.6 Mha), pig and poultry meat (3.5 Mha) and rumiant livestock (mainly beef) meat (2.0 Mha). Note that commodities from ruminant livestock (cattle, sheep, goat) require feed on grassland in addition to cropland and thus enlarge the resprective footprint (see section 3.1.7).

A much smaller amount (5.6 Mha), or about one-third of the food related footprint, is associated with food use of crop products comprising of a variety of food products. About 1.1 Mha is associated with the consumption of each of the following commodity groups: i) cereal products; ii) vegetable oil; iii) fruits, vegetables, spices; and iv) stimulants (coffee, cacao, tea).

Figure 10. Cropland footprint for food consumption, Germany, 2010



Cropland embedded in Germany's food consumption is in majority (61%) based on crops cultivated domestically (Table 8). Some 23% stems from crops cultivated in other EU28 countries. The remaining 16% comes from non-EU countries, notably South America (stimulants, fruits), Sub-Saharan Africa (Stimulants), and Southeast Asia (stimulants, vegetable oil). Although the non-EU use of cropland for livestock products consumption is relatively minor (total 0.4 Mha), it should be noted that this includes protein feed, mainly soy oilseed cakes, a key requirement in livestock's dietary composition.

Table 8. Origin of cropland for Germany's food consumption footprint, by major commodity group, 2010

1000 ha	GER	REU28	NAM	CAM	SAM	REUR	NAWA	SSAF	EAS	SAS	SEA	OCE	Total	
Crop products														
Wheat	449	284	20	1	0	17	5	0	3	0	0	3	781	5%
Rice	0	26	2	0	8	0	1	0	0	10	27	0	74	0%
Maize	30	34	1	0	2	3	0	0	0	0	0	0	70	0%
Other cereals	113	61	0	0	0	9	0	0	0	0	0	1	185	1%
Roots & Pulses	75	18	4	0	0	3	3	1	1	0	1	0	106	1%
Sugar & Sweetener	134	25	0	3	11	1	1	7	0	1	1	1	184	1%
Oil crops (primary)	4	22	13	2	33	2	10	5	6	8	10	1	115	1%
Vegetable oil	589	299	4	6	29	78	16	15	3	23	127	2	1,190	7%
Fruit, vegetables, spices	150	417	48	30	100	19	161	51	45	43	63	4	1,131	7%
Stimulants*	0	0	0	114	286	0	0	386	12	29	200	0	1,028	6%
Alcohol	421	273	4	2	8	13	2	8	1	0	0	9	740	5%
Total Crops	1,963	1,459	96	157	477	145	197	473	72	114	428	21	**5,604**	34%
Livestock products														
Ruminants, meat & offals	1,483	366	12	0	71	1	0	4	0	0	0	18	1,956	12%
Dairy products	3,674	860	2	0	0	102	1	0	0	0	0	2	4,643	28%
Ruminants, fats	40	0	2	0	0	0	0	0	0	0	0	12	55	0%
Monogastric**, meat	2,534	877	4	1	86	13	8	1	2	0	11	1	3,537	22%
Monogastric, eggs	243	233	14	1	1	3	4	0	1	3	2	0	505	3%
Monogastric, fats	116	21	0	0	0	1	0	0	0	0	0	0	139	1%
Total Livestock	8,090	2,357	35	2	158	119	14	6	4	4	13	34	**10,835**	66%
Total Crops & Livestock	**10,053**	**3,816**	**131**	**159**	**635**	**263**	**211**	**479**	**75**	**118**	**442**	**55**	**16,439**	100%
	61%	23%	1%	1%	4%	2%	1%	3%	0%	1%	3%	0%	100%	

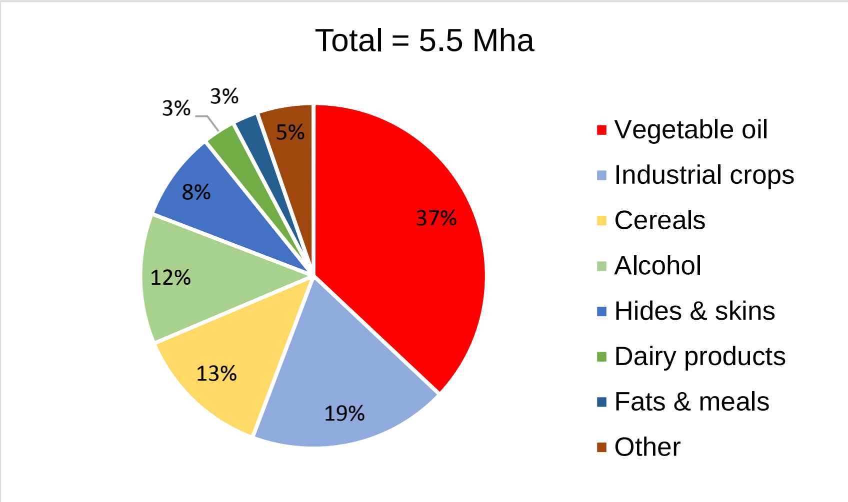
* Coffee, cacao, tea; ** Monogastric animals include pigs and poultry; Meat refers to Meat & Offals

Note, in the case of food use a more detailed regionalization is possible (compared to non-food industrial use) because results rely on LANDFLOW analysis only, which is based on the more detailed FAO database. GER Germany; REU28 Rest of EU28; NAM Northern America; CAM Central America; SAM Southern America; REUR Rest of Europe (i.e. Non-EU28) & Russia; NAWA Northern Africa & Western Asia; SSAF Sub-Saharan Africa; EAS Eastern Asia; SAS Southern Asia; SEA Southeast Asia; OCE Oceania

3.2.4 Cropland footprint for non-food products

Some 5.5 Mha or 24.5% of Germany's cropland footprint is associated with agricultural commodities used for non-food purposes, for example in the form of fuels, textiles, plastics or pharmaceuticals (henceforth termed 'non-food footprint'). Almost one fifth of Germany's non-food cropland footprint relates to industrial crops, including natural rubber, fiber crops, and tobacco, which are cultivated for the non-food purposes only. Non-food uses for all other crops and livestock commodities either compete directly with the food sector (e.g. cereals, dairy products) or are co-products in joint production (e.g. hides & skins produced together with meat; ethanol from cereal starch produced together with livestock feed). Vegetable oils are associated with 37% of the country's non-food cropland footprint, as Figure 11 reveals. These are for example used in the form of agrofuels added to fossil fuels as foreseen by the EU directive 2003/30/EC. Ethanol from sugar crops and cereals, as well as bioplastics are some other non-food uses of increasing importance. Germany's consumption of leather and fur products produced from animal hides and skins requires nearly 500,000 hectares of cropland, or 8% of Germany's non-food cropland footprint.

Figure 11. Cropland footprint for non-food use, by source of agricultural commodity, Germany, 2010



While with 61% the vast majority of cropland embodied in Germany's food consumption stems from the country itself and another 23% is sourced from other EU countries (see Table 8), for the case of non-food products only 14% of Germany's cropland footprint is based on domestic land resources or produced on land in the rest of the EU-28, respectively (see Table 9). The remaining 71.4% of cropland is imported from outside the EU-28. 26% or 1.4 Million hectares stem from Rest of Asia, including countries such as Indonesia, Malaysia, Bangladesh, Philippines and Thailand (see Annex B-1). North America, particularly the US, is supplying 12% of Germany's non-food cropland footprint, mainly in the form of maize (or starch, ethanol, etc. derived from maize).

The products of coffee, tea, cocoa and natural rubber are entirely imported from non-EU countries. The four most important non-food products are vegetable oils, non-food alcohol, fibres and fibre crops, and maize and derived products, with 37%, 12%, 12% and 8%, respectively. More than 56% of vegetable oils are imported from outside the EU-28. For non-food alcohol, fibre crops and maize, extra-EU imports account for 84%, 96% and 97% of Germany's footprint, respectively. The results reveal a considerably higher import dependency for non-food products, than for food products.

Table 9. Origin of cropland for Germany's non-food cropland footprint, by cultivating regions* and major commodity groups, 2010

1000 ha	DEU	REU28	RERU	AFR	NAM	LAM	JPAU	CHN	IND	RASI	Total	
Crop products												
Wheat	26	72	24	5	12	2	6	7	0	19	173	3%
Rice	0	1	0	1	1	3	0	5	0	54	64	1%
Maize	1	10	5	1	328	7	0	64	1	10	427	8%
Other cereals	11	8	0	18	1	2	0	0	0	1	41	1%
Roots & Pulses	0	2	1	13	0	1	0	0	0	9	26	0%
Sugar & Sweetener	0	5	1	1	0	7	0	0	0	4	19	0%
Oil crops (primary)	0	6	3	13	7	3	1	7	1	33	73	1%
Vegetable oil	525	365	112	74	52	85	5	136	43	632	2,029	37%
Oil cakes	26	6	0	0	2	38	0	5	4	7	89	2%
Fruit, vegetables, spices	0	2	2	2	0	0	0	0	0	6	12	0%
Coffee, tea, cocoa	0	0	0	5	0	0	0	0	0	0	6	0%
Tobacco	0	4	2	18	2	17	0	22	4	3	73	1%
Rubber	0	0	0	43	0	2	0	8	5	258	316	6%
Fibre crops	0	28	36	80	86	30	6	64	152	153	635	12%
Alcohol	17	92	9	57	54	218	3	24	6	191	670	12%
Total Crops	607	601	194	333	545	416	21	341	215	1,379	4,653	85%
Livestock products												
Ruminants, meat & offals	4	10	1	1	0	2	3	0	0	5	27	0%
Dairy products	69	48	18	0	28	0	2	0	0	2	168	3%
Ruminants, fats	11	7	5	0	12	1	8	0	0	1	45	1%
Ruminants, wool & hides & skins	19	61	33	20	50	12	99	12	33	42	381	7%
Monogastric, meat & offals	1	9	1	1	1	8	0	1	0	3	25	0%
Monogastric, eggs	0	2	6	0	0	0	0	3	0	2	13	0%
Monogastric, fats	36	25	9	0	7	3	1	3	0	2	86	2%
Monogastric, hides & skins	42	14	3	0	0	2	0	10	0	5	78	1%
Total Livestock	181	176	76	23	100	28	113	30	34	61	823	15%
Total Crops & Livestock	788	778	271	356	645	444	134	371	249	1,440	5,476	100%
	14%	14%	5%	6%	12%	8%	2%	7%	5%	26%	100%	

* DEU=Germany, REU28=Rest of European Union, RERU=Rest of Europe and Russia, AFR=Africa and Middle East, NAM=Northern America, LAM=Latin America, CHN=China, IND=India, RASI=Rest of Asia

3.2.5 Oilcrop sector

The oilcrop sector plays an outstanding role in Germany's demand for foreign cropland, cropland footprint and appropriation of foreign cropland resources. Table 10 summarizes production, trade and domestic use of primary oil crops and its derived commodities vegetable oil and oilseed cakes.

While less than 10% of Germany's cropland (0.8 Mha) is used for the cultivation of oil crops, the country is a major net importer (3.1 Mha). Primary oil crops are imported from several regions including other EU28 countries, South America, Southeast Asia, and other Europe and Russia. The main use of primary oil crops is for crushing (equivalent of 3.4 Mha oil crops) to produce vegetable oil and oilseed cakes as livestock feed in a ratio 60 to 40 percent (Section 2.6.6. and yellow highlight in Table 10).

Germany also imports significant amounts of vegetable oils (3.5 Mha) and oil cakes (1.3 Mha). For the oil crop sector as a whole as much as 8.1 Mha cropland are imported. Fewer amounts are exported, equivalent to 2.8 Mha, mainly as vegetable oils (2.0 Mha). In total for the oilseed sector, Germany is a cropland net-importer of 5.3 Mha, i.e. about 90% of supply is from crops cultivated on foreign cropland.

Vegetable oil based products are mainly used in the form of processed products of the oleo-chemical industry including biodiesel (2.0 Mha) and to a lesser extent in the form of food products (1.2 Mha). Some 1.8 Mha cropland is used for the production of protein feed for Germany's domestic livestock alone, about 0.7 Mha are (re-)exported.

Table 10. Cropland supply and use of oil crops and derived products, Germany, 2010

1000 hectares		Trade			Domestic Supply[1]	Domestic use/consumption			
	Production	Imports	Exports	Net Imports		Food[2]	Livestock feed[3]	Non-food	Food processing
Oil crops, primary	826	3,287	163	3,124	4,044	115	72	73	3,378[4]
Vegetable oil	2,078	3,453	1,925	1,528	3,609	1,154	390	2,029	36
Oilseed cakes	1,300	1,330	682	648	1,943	0	1,854	89	0
Total		8,070	2,770	5300		1,269	2,316	2,191	

1 Domestic supply (Production + Imports + From Stock – Exports) equals domestic use (Food + Feed + Food processing + Industrial use + Seed/Waste). Cropland equivalents for stock changes and for the production of seed and on-farm waste are relatively small and excluded from the table for reasons of clarity and comprehensibility. Therefore the sum of domestic supply slightly deviates from the sum of domestic use. **2** Food here refers to crop-based food only. **3** Feed is used for raising Germany's domestic livestock herds; **4** Food processing refers to oil crops crushed in Germany (3,378 kha) for the joint production of vegetable oil (2,078 kha) and oilseed cakes (1,300 kha).

3.2.6 Cropland footprints dynamics

While cropland cultivated in Germany has hardly changed since 1995 neither in terms of total cropland nor in terms of crop composition, volumes of commodities and associated cropland areas entering trade increased after 1995 for exports and after 2000 for imports (Figure 12, 13). Compared to 1995 imports and exports of crop and livestock products increased by 25% (+4.8 Mha) and 43% (+4.1 Mha) respectively.

At the detailed commodity level, increases in imports are dominated by cereals (+1.9 Mha), vegetable oil (+1.6 Mha), and stimulants (coffee, cacao, tea; +0.8 Mha). Imports of all other commodity groups also increased except roots and pulses, other industrial crops and hides and skins. Apparently the increasing imports of primary crops and crop products were driven by increasing demand of export markets mainly for meat of pigs and poultry (+1.6 Mha or a more than 8 fold increase) and processed products in the stimulants group (+1.2 Mha). In contrast, increasing imports in vegetable oils are mainly due to increasing demand in Germany's domestic market. Overall cropland embedded in trade increased substantially, and as a result Germany only slightly increased its net imports of 'virtual' cropland from 9.9 Mha in 1995 to 10.6 Mha in 2010.

Figure 12. Cropland embedded in Germany's imports, 1995 to 2010

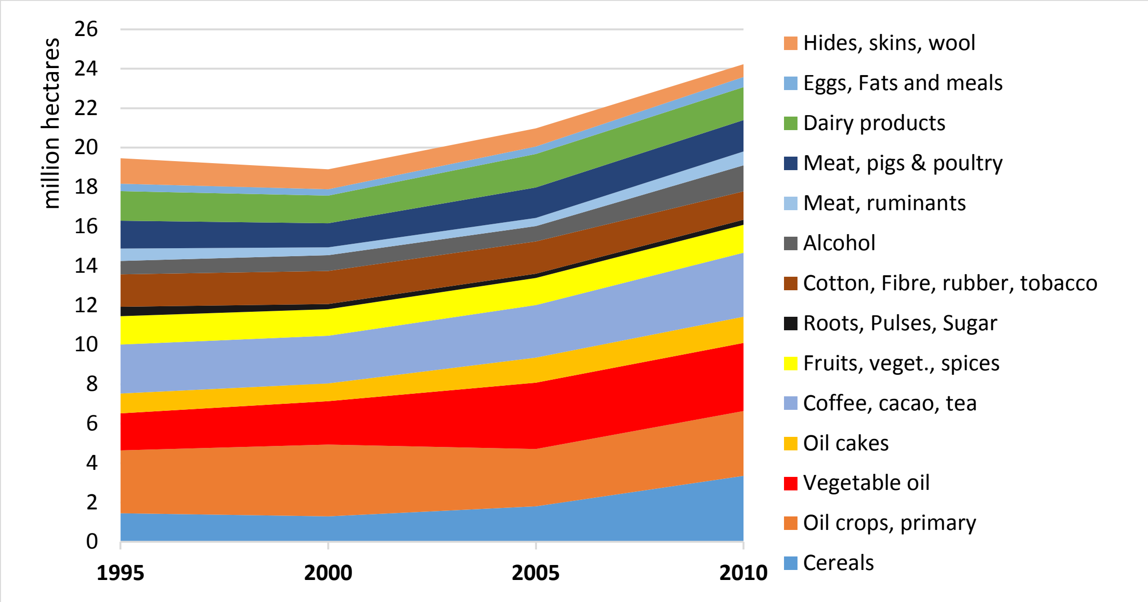
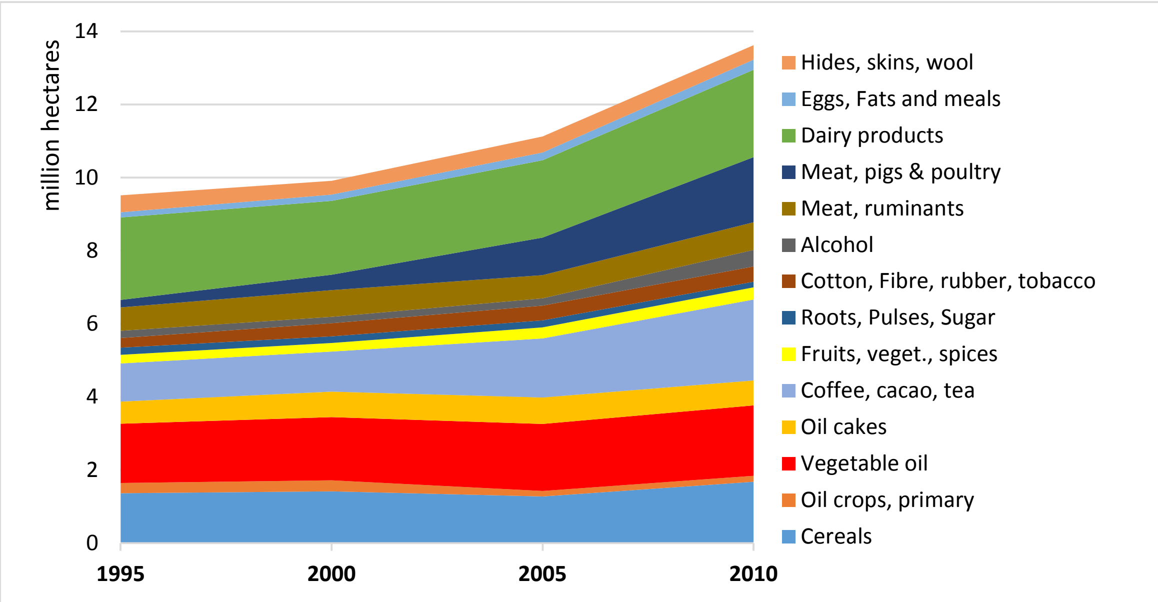


Figure 13. Cropland embedded in Germany's exports, 1995 to 2010



Compared to 1995 by 2010 Germany's economy has increased its demand for agriculturally based commodities, while extents of domestic cropland production remained constant. At the same time imports increased by 24% or 4.8 Mha. The increasing cropland demand was driven by demand from export markets. Cropland 'virtually' exported from Germany, mostly in the form of higher processed commodities, increased by 4.1 Mha (crops and livestock products). In the livestock sector, Germany developed from a net importer of 'virtual' cropland in 1995 to a net exporter in 2010 (Table 11).

Table 11. Cropland embedded in demand and trade, Germany, 1995 and 2010

a) Demand of German economy, 1995

Origin of cropland (1000 ha)		
Domestic crop production	12,054	38%
Imports	19,458	62%
Total demand	**31,512**	100%

b) TRADE, 1995

1000 ha	Crops	Livestock	Total
Imports	14,249	5,209	19,458
Exports	5,811	3,704	9,515
Net Imports	8,438	1,505	**9,943**

c) Demand of German economy, 2010

Origin of cropland (1000 ha)		
Domestic crop production	12,088	33%
Imports	24,227	67%
Total demand	**36,315**	100%

d) TRADE, 2010

1000 ha	Crops	Livestock	Total
Imports	19,099	5,128	24,227
Exports	8,022	5,599	13,621
Net Imports	11,077	-471	**10,607**

Almost constant extents of domestic cropland combined with only small increases in net imports has resulted in an almost similar cropland footprint for the years 1995 and 2010 (Table 12). The composition of the footprint however changed towards cropland area associated with non-food use at the expense of food use, especially of crop-based diets. The food-based cropland footprint of an average German citizen has become more land efficient in the past 15 years, the area required for the non-food sector increased at a constant rate.

Table 12. Cropland footprint, Germany, 1995 to 2010

1000 hectares	**1995**		**2000**		**2005**		**2010**	
Food use, crop products	6,532	29%	5,853	28%	5,597	26%	5,604	25%
Food use, livestock products	11,315	50%	9,929	48%	10,769	50%	10,835	49%
Other use (non-food)	4,327	19%	4,453	22%	4,796	22%	5,476	24%
Seed & Waste	462	2%	439	2%	403	2%	444	2%
Total	**22,636**		**20,674**		**21,565**		**22,359**	

3.2.7 Grassland footprint developments

Feed for ruminant livestock herds (e.g. cattle, sheep, goats) comes from cropland and from grassland (see also 2.2.6). Note that grassland actually used for livestock production is not recorded in FAO's statistics. We therefore assume here that all reported grassland in each country is part of the production cycle. Challenges and potential uncertainties arising in some countries have been discussed elsewhere (Bruckner et al., 2016, forthcoming; Fischer et al., 2016, forthcoming). Table 13 summarizes the composition and origin of Germany's grassland footprint in 1995 and 2010 respectively. Figure 14 highlights developments of grassland embedded in trade by major commodity group.

For Germany FAOSTAT reports a current 4.7 Mha 'permanent meadows and pastures' (grassland) down from 5.3 Mha in 1995. Here we assume the entire extent of reported grassland area is used for feeding Germany's ruminant livestock herds of 12.7 million cattle and 2.1 million sheep (year 2010) and is representing the grassland footprint.

Compared to domestic extents of grassland, significant amounts of grassland resources is embedded in imports of ruminant livestock products. Although significantly decreasing, virtually imported grassland in 2010 is still three times larger (15 Mha) than domestic grassland resources. Exports are small compared to imports. Germany is thus a significant net importer of virtual grassland.

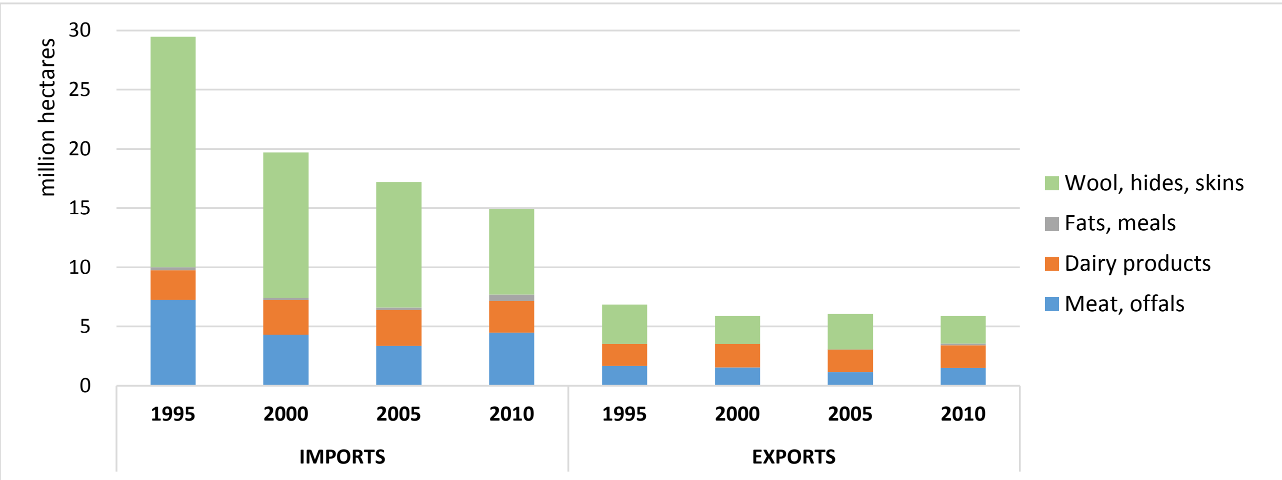
Decreases in grassland areas embedded in imported livestock commodities are mainly due to the commodity group 'wool, hides, skins'. In particular grassland embedded in higher processed commodities (e.g. textiles) is smaller compared to 1995.

As a result Germany's grassland footprint in 2010 turns out to be about half the footprint of 1995. By 2010 Germany's grassland footprint is for 55% related to food use and the remaining 45% to non-food use.

Table 13. Composition and origin of Germany's grassland footprint, 1995 and 2010

	TRADE		DOMESTIC SUPPLY			OF WHICH FOR	
MILLION HA	IMP	EXP	NET-IMPORTS	DOMESTIC PRODUCTION	FOOTPRINT	FOOD USE	INDUSTRIAL USE
1995							
MEAT & OFFALS	7,245	1,664	5,581	1,557	7,138	6,189	949
DAIRY PRODUCTS	2,510	1,847	662	3,540	4,202	3,457	746
FATS & MEALS	251	21	230	56	286	28	258
WOOL, HIDES, SKINS	19,473	3,329	16,144	123	16,267	0	16,267
TOTAL	29,479	6,862	22,617	5,275	27,892	9,674	18,219
2010							
MEAT & OFFALS	4,494	1,502	2,993	1,228	4,221	3,875	346
DAIRY PRODUCTS	2,649	1,913	736	3,325	4,061	3,492	568
FATS & MEALS	569	151	419	36	454	199	255
WOOL, HIDES, SKINS	7,226	2,311	4,915	91	5,005	0	5,005
TOTAL	14,939	5,877	9,062	4,680	13,742	7,567	6,175

Figure 14. Grassland embedded in imports and exports of livestock products, Germany, 1995-2010



3.2.8 Forestland footprint

In contrast to the presented cropland and grassland footprint calculations, where a hybrid accounting method was applied, the forestland footprint results shown below are derived based on standard

MRIO calculations applying Exiobase version 3.3 extended by land use vectors as described in chapter 2.3.1 of this report. While also for the case of wood products it would be preferable to apply a mixed-unit accounting system, the LANDFLOW model used in this project currently only covers agricultural commodities and thus is not applicable to the case of forest areas.

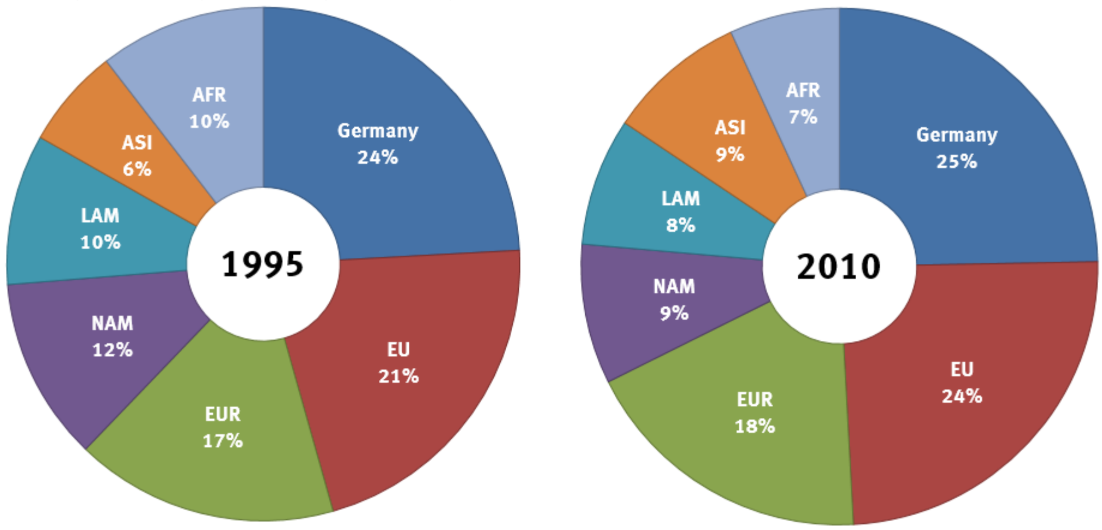
Figure 15 illustrates the development of the German forestland footprint in the time period of 1995 to 2011. Note that calculations were performed for the years 1995, 2000, 2005, and 2009 to 2011 only and years in between (marked with an asterisk) were estimated through interpolating data.

Figure 15. Forestland footprint of Germany, 1995-2011

Results reveal significant fluctuations in the overall forestland footprint of Germany. Starting at around 365 thousand km² in 1995, forestland footprint increased to almost 410 thousand km² in 2000, of which 85% were made of industrial roundwood and 15% of wood fuel. This increase was mainly driven by an increased demand for timber in the sectors of 'Manufacture of wood and of products of wood' as well as 'Manufacture of furniture'. From 2000 onwards, the forestland footprint declined to around 290 thousand km² in 2009, before turning again upwards and reaching 310 thousand km² in 2011. According to the model calculations, the significant decline by more than 30% in the period 2000-2009 was driven by footprint reductions in all main wood-based product groups: 'Manufacture of wood and of products of wood', 'Manufacture of furniture', 'Paper' as well as 'Publishing and printing'. Also the direct and indirect inputs of wood into construction activities decreased from the year 2000 onwards. In contrast, consumption of wood fuel was not effected by that development and remained relatively constant at levels between 58 and 62 thousand km².

As the EXIOBASE model allows specifying the geographical location of land use, Germany's forestland footprint can also be disaggregated by countries and regions (Figure 16).

Figure 16. Geographical composition of Germany's forestland footprint, 1995 and 2010



Note: AFR = Africa, ASI = Asia, LAM = Latin America, NAM = North America, EUR = non-EU Europe incl. Russia, EU = European Union excluding Germany; Please note that the classification of regions used here differs from that applied to figures showing cropland and grassland footprints due to different country classifications of the footprint accounting models.

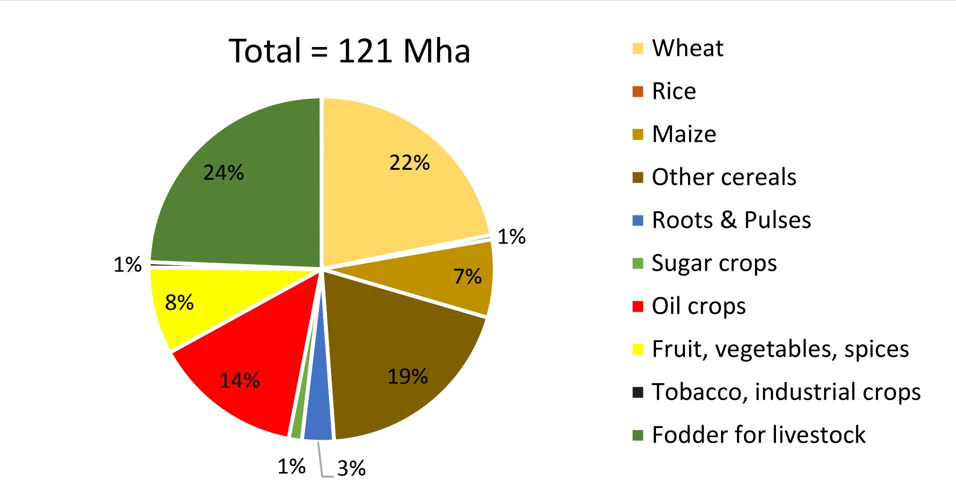
The composition of the origin of the German forestland footprint slightly shifted between 1995 and 2010. While Germany sourced around a quarter of the wood required to satisfy final demand within its own territory across the whole observed time period, the share of imports from other European countries increased from 38% in 1995 (of which 21% stemmed from EU countries) to 42% in 2010 (EU: 24%). Timber harvested outside Europe decreased its share from 38% in 1995 to 32% in 2010, with the Americas contributing the largest non-European amounts of wood. Both, in 1995 and 2010, the major source country of woodland for German imports was Russia with about 15% of the total German forestland footprint.

3.3 European Union

3.3.1 Cropland footprint developments

Cropland in the countries of the European Union has been continuously decreasing during the last decades. In 2010 farmers in the EU28 (henceforth EU) cultivate 121 Mha cropland compared to 131 Mha in 1995. The decline took place for all crops except oil crops, where cultivation increased by 2.7 Mha over the 15 year period. The group 'other cereals' showed the strongest decreases (-4.6 Mha), followed by roots and pulses (-3 Mha), 'fruits, vegetables, spices' (-1.9 Mha), and dedicated fodder crops cultivated for livestock feed only (-1.1 Mha).About half of current cropland in the EU is used for growing cereals, namely wheat, rice, maize, and the aggregate group 'other cereals' (e.g. barley, rye, oat), one quarter for dedicated fodder crops (e.g. clover, alfalfa), and 14% oil crops (Figure 17).

Figure 17. Composition of cultivated crops on EU cropland, 2010



During the same period overall trade volumes and embedded cropland resources increased. Imports and exports increased by 24% and 43% and amounted to 136 Mha and 101 Mha in 2010 respectively. However cropland extents of net trade remained fairly constant amounting to between 35 and 39 Mha. Less cultivation of EU cropland is therefore the main reason for the decreases in the EU cropland footprint from 170 Mha in 1995 to 157 Mha in 2010. The main trend in the composition of the cropland footprint is a decreasing proportion of the use of food in favour of a higher proportion of the non-food sector (Table 14a).

Per capita the cropland footprint decreased by 11% from 3506 m² per capita to a current 3111 m² per capita. The decline is due to decreases in extents of cropland required domestically and abroad for EU food consumption. In contrast, the cropland area for the consumption of non-food industrial products has increased from 463 m² per capita in 1995 to a current 540 m² per capita (Table 14b).

Since 1995 the crop-based industrial footprint has increased significantly and contributes today some 14% to the cropland footprint. The increase in the crop-based non-food footprint is to a large extent due to vegetable oil and maize for production of biodiesel and ethanol respectively. Apparently the increase in biofuel consumption in the EU is reflected in the increasing cropland footprint for non-food industrial products.

Comparing extents of cropland footprint with cropland cultivated in the EU reveals a fairly constant cropland self-reliance ratio over time of between 74 to 78% (Table 14c). In other words, currently more than one fifth or 36 Mha of the cropland embedded in the EU consumption of food and industrial products is located outside the EU territory. The remaining four fifth stem from crops cultivated within the EU.

Table 14. Development of the EU28 cropland footprint, 1995 to 2010

Table 14a. Composition of cropland footprint (1000 hectares)

1000 hectares	1995		2000		2005		2010	
Food use, crops	55,658	33%	53,265	33%	51,572	31%	49,550	31%
Food use, livestock	82,973	49%	79,211	48%	78,288	47%	73,392	47%
Non-food, crops	14,500	9%	16,771	10%	21,669	13%	22,594	14%
Non-food, livestock	8,578	5%	7,117	4%	7,594	5%	5,604	4%
Seed & On-farm waste	8,351	5%	7,423	5%	6,530	4%	6,297	4%
Total	**170,060**		**163,787**		**165,653**		**157,437**	

Table 14b. Per capita cropland footprint (m²)

	1995	2000	2005	2010
Food use	2858	2715	2613	2430

Non-food industrial use	476	490	589	557
Total (includes seed & waste)	3506	3356	3333	3111

Table 14c. EU cropland self-reliance (%)

	1995	2000	2005	2010
Domestic cropland	131,309	128,102	123,251	120,698
Self-reliance ratio	77%	78%	74%	77%

3.3.2 Cropland footprint of food consumption

Some 60% of the EU footprint of food use is associated with livestock diets, of which more than half for meat consumption and about one third for dairy products. Cropland use for crop-based diets is for a variety of food products with the largest extents associated with products from cereals, vegetable oils and fruits, vegetables and stimulants (Figure 18).

Figure 18. Composition of EU cropland footprint of food consumption, 2010

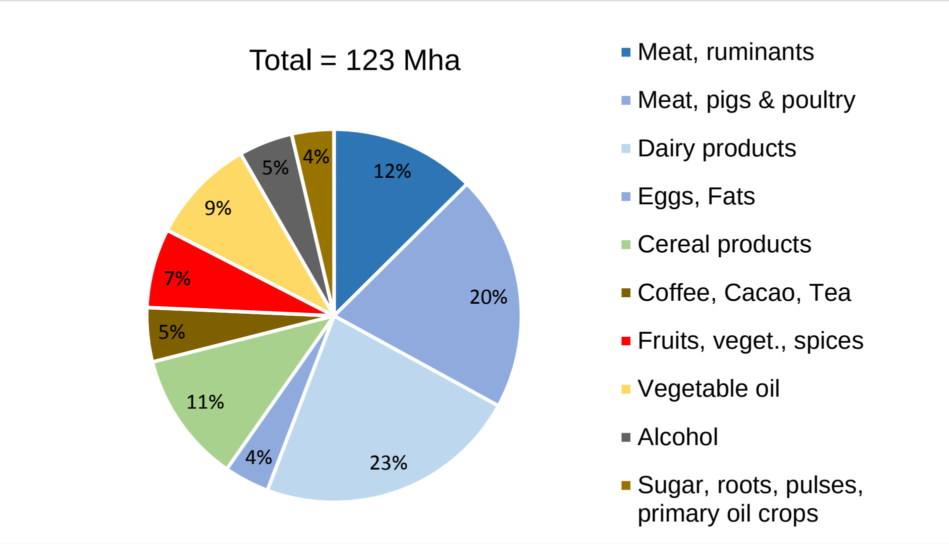


Table 15 highlights the origin of cropland embedded in different food commodities. The majority (106 Mha or 86%) of cropland embedded in EU food consumption is from crops cultivated within the EU. The remaining 17 Mha (14%) are sourced from cropland outside the EU. Main regions of origin include Southern America (3.6 Mha) and Sub-Saharan Africa (3.5 Mha). From both regions a variety of crops and food commodities is imported. The dominant crops include coffee, cacao, and tea, followed by fruits and vegetables. Other important regions include 'Rest of Europe and Russia (REUR) (2.3 Mha, e.g. vegetable oil), Southeast Asia (2.2 Mha), Northern Africa and Western Asia (NAWA) (1.2 Mha) and Northern America (1.2 Mha).

Table 15. Origin of cropland embedded in EU28 food consumption, by major commodity group, 2010

1000 ha	EU28	NAM	CAM	SAM	REUR	NAWA	SSAF	EAS	SAS	SEA	OCE	Total	
Crop products													
Wheat	9,915	505	20	6	395	38	1	90	4	0	75	11,048	9.0%
Rice	384	16	0	53	1	6	0	2	86	180	0	728	0.6%
Maize	553	6	0	26	38	0	3	0	0	0	0	626	0.5%
Other cereals	1,484	0	0	0	37	0	0	0	0	0	4	1,525	1.2%
Roots & Pulses	1,615	110	10	64	55	28	36	56	3	25	10	2,012	1.6%
Sugar & Sweetener	1,111	2	96	246	22	9	114	2	10	16	26	1,654	1.3%
Oil crops (primary)	404	29	14	120	11	28	39	30	75	59	5	814	0.7%
Vegetable oil	8,303	33	15	443	1,142	414	147	8	90	624	13	11,232	9.1%
Fruit, vegetables, spices	5,760	195	188	622	76	606	326	166	215	255	23	8,432	6.9%
Coffee, cacao, tea	0	0	494	1,296	0	3	2,766	47	207	949	1	5,763	4.7%
Alcohol	5,497	18	19	37	44	10	28	4	2	2	55	5,716	4.6%
Total Crops	**35,026**	**914**	**856**	**2,913**	**1,821**	**1,142**	**3,460**	**405**	**692**	**2,110**	**212**	**49,551**	**40%**
Livestock products													
Ruminants, meat	14,647	121	1	302	20	3	32	3	3	3	265	15,400	12.5%
Dairy products	27,511	26	1	2	424	15	1	2	2	1	35	28,020	22.8%
Ruminants, fats	226	13	0	1	0	0	0	0	0	0	68	308	0.3%
Monogastric**, meat	24,488	46	10	405	32	52	9	11	0	107	6	25,166	20.5%
Monogastric, eggs	3,616	30	1	4	20	12	1	1	6	5	1	3,697	3.0%
Monogastric, fats	781	2	0	1	12	0	0	0	1	3	1	798	0.7%
Total Livestock	**71,269**	**238**	**13**	**715**	**508**	**82**	**43**	**17**	**11**	**119**	**376**	**73,392**	**60%**
Total Crops & Livestock	**106,295**	**1,152**	**869**	**3,628**	**2,329**	**1,224**	**3,503**	**422**	**705**	**2,228**	**588**	**122,942**	100%
	86.5%	0.9%	0.7%	3.0%	1.9%	1.0%	2.8%	0.3%	0.6%	1.8%	0.5%	100%	

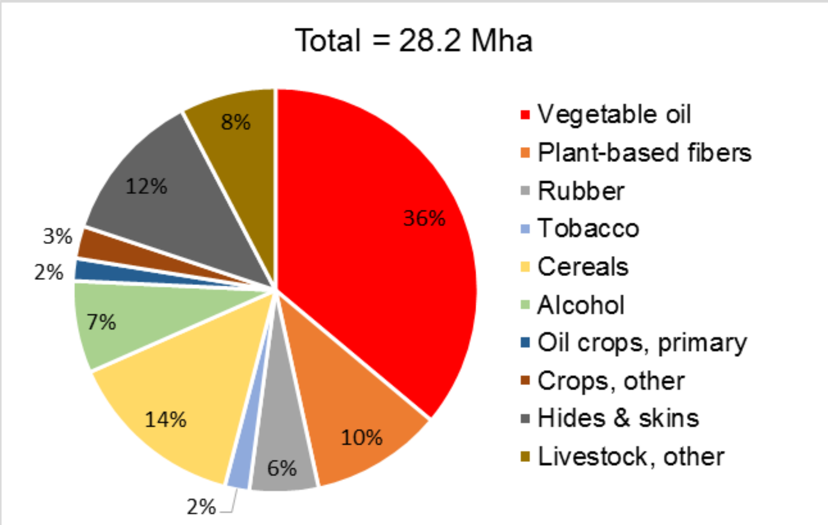
* Monogastric animals include pigs and poultry

Note, in the case of food use a more detailed regionalization is possible (compared to non-food industrial use) because results rely on LANDFLOW analysis only, which is based on the more detailed FAO database. EU28 = European Union; NAM = Northern America; CAM = Central America; SAM = Southern America; REUR = Rest of Europe (i.e. Non-EU28) & Russia; NAWA = Northern Africa & Western Asia; SSAF = Sub-Saharan Africa; EAS = Eastern Asia; SAS = Southern Asia; SEA = Southeast Asia; OCE = Oceania

3.3.3 Cropland footprint for industrial use

28.2 Mha of the EU-28's cropland footprint is associated with agricultural commodities used for non-food purposes, comprising among others vegetable oils (36%), fibre crops (10%), ruminant hides and skins (10%), non-food alcohol (7%), maize (7%) and natural rubber (6%). This corresponds to 18% of the EU's overall cropland footprint (see Figure 19). With 36%, more than a third of the EU's non-food cropland footprint relates to vegetable oils, mainly used as fuels. Cereals, such as maize and wheat, used for example to produce ethanol or bioplastics, account for 14% of the EU's non-food footprint, accompanied by 7% non-food alcohol. Germany's consumption of leather and fur products produced from animal hides and skins requires nearly 3.5 Mha of cropland, or 12% of the EU's non-food cropland footprint, while textiles produced from fibre crops account for about 3 Mha or 10%.

Figure 19. Cropland footprint for non-food consumption, EU28, 2010, by commodity group



While with 86.5% the vast majority of cropland embodied in the EU's food consumption stems from the EU itself (see Table 15), for the case of non-food products only 35% is based on domestic land resources (see Table 16). The remaining 65% of the cropland is imported from outside the EU-28. 21% or 5.9 Mha stem from the aggregate region 'Rest of Asia', including countries such as Indonesia, Malaysia, Bangladesh, Philippines and Thailand (see Annex B-1), supplying Europe particularly with vegetable oils, rubber, plant fibres and non-food alcohol. China is a major supplying country accounting for 10% of the EU's non-food cropland footprint, mainly in the form of vegetable oils, maize, and fibre crops (or derived products). North America plays an important role as an exporter of maize for industrial uses (e.g. in the form of starch or ethanol) and adding up to 10% of the EU's non-food cropland footprint, followed by Africa and Middle East with 7%.

As for Germany, also for the overall EU the four most important non-food products are vegetable oils, fibre crops, non-food alcohol, and maize (and derived products), with 36%, 10%, 7% and 7%, respectively. More than 56% of vegetable oils are imported from outside the EU-28. For fibre crops, non-food alcohol and maize, imports to the EU account for 93%, 69% and 92% of the EU's footprint, respectively.

On a per-capita basis, the rest of the EU-28 uses considerably less non-food alcohol and fibres, while requiring more hides and skins, as compared to Germany. Non-food alcohol is mainly used as a fuel. The results thus indicate higher per capita bioethanol consumption for Germany as compared to other EU countries, which could be caused by a higher blending rate. Overall, import dependency for land embodied in non-food products are similar with 71% for Germany and 65% for the total EU.

Table 16. Origin of cropland for the EU's industrial cropland footprint, by cultivating regions* and major commodity groups, 2010

1000 ha	DEU	REU28	RERU	AFR	NAM	LAM	JPAU	CHN	IND	RASI	Total	
Crop products												
Wheat	46	947	116	35	91	10	34	53	0	119	1,451	5%
Rice	0	9	0	9	3	14	0	36	2	302	375	1%
Maize	2	164	30	5	1,196	45	0	494	3	51	1,990	7%
Other cereals	13	73	1	120	3	9	0	0	0	4	223	1%
Roots & Pulses	1	32	4	84	2	5	1	0	0	50	179	1%
Sugar & Sweeteners	1	77	5	9	0	41	1	0	1	28	163	1%
Oil crops (primary)	0	86	21	90	56	16	4	54	4	178	509	2%
Vegetable oil	751	3,758	799	400	260	478	20	1,098	207	2,407	10,178	36%
Oil cakes	32	12	0	0	11	98	0	38	24	41	256	1%
Fruit, vegetables, spices	0	50	6	11	1	3	0	1	1	20	93	0%
Coffee, tea, cocoa	0	0	0	34	0	1	0	0	0	2	37	0%
Tobacco	1	84	16	114	15	117	0	155	29	21	552	2%
Rubber	0	0	0	210	0	8	0	61	18	1,257	1,554	6%
Fibre crops	0	218	109	425	346	134	30	442	672	583	2,959	10%
Alcohol	24	608	28	162	119	503	9	63	26	528	2,070	7%
Total Crops	871	6,118	1,135	1,708	2,103	1,482	99	2,495	987	5,591	22,589	80%
Livestock products												
Ruminants, meat	7	111	6	3	2	10	14	1	0	35	189	1%
Dairy products	116	530	89	3	109	1	10	0	1	14	873	3%
Ruminants, fats	15	99	30	2	50	3	47	1	1	3	251	1%
Ruminants, hides and skins	67	1,017	161	156	392	56	619	76	127	236	2,907	10%
Monogastric**, meat	7	173	4	5	5	39	0	12	0	19	264	1%
Monogastric, eggs	0	22	19	1	0	0	0	22	0	11	75	0%
Monogastric, fats	65	314	44	2	32	11	6	25	0	12	511	2%
Monogastric, hides and skins	48	358	10	4	2	11	2	76	1	23	535	2%
Total Livestock	325	2,624	363	176	592	131	698	213	130	353	5,605	20%
Total Crops & Livestock	1,196	8,742	1,498	1,884	2,695	1,613	797	2,708	1,117	5,944	28,194	100%
	4%	31%	5%	7%	10%	6%	3%	10%	4%	21%	100%	

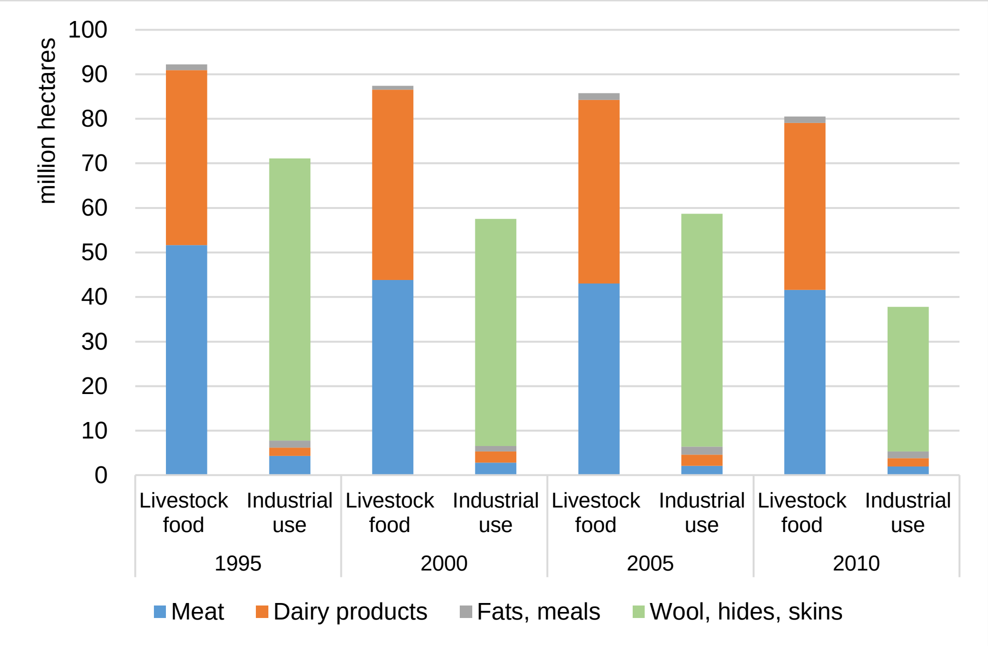
* DEU=Germany, REU28=Rest of European Union, RERU=Rest of Europe and Russia, AFR=Africa and Middle East, NAM=Northern America, LAM=Latin America, CHN=China, IND=India, RASI=Rest of Asia

3.3.4 Grassland footprint developments

Extents of grassland in the EU are slightly more than half of EU cropland amounting to a current 67.8 Mha, down from 73 Mha in 1995. In comparison to domestic grassland use the EU grassland footprint is much larger, 118 Mha in 2010 and 172 Mha in 1995. Since 1995 the grassland self-reliance ratio has steadily decreased to a current 57% (2010); i.e. 43% or 50 Mha of the footprint is from grassland outside the EU.

Figure 20 highlights the composition of the EU grassland footprint between 1995 and 2010. The food related part of the footprint remained fairly constant over time with slightly more than half of it attributed to meat consumption and the majority of the remainder to dairy products. Grassland embedded in the consumption of higher processed industrial goods decreased over time, primarily due to the decreasing extents attributable to products from 'wool, hides, skins' (e.g. textiles, shoes).

Figure 20. Composition of the EU grassland footprint, 1995 to 2010



Three fourth of the current food-related grassland footprint (80 Mha) is sourced from grassland located in the EU28 and one fourth from other regions, mainly imported as meat products from Southern America (Brazil) (Table 17).

Table 17. Origin of the EU grassland footprint, 2010

1000 hectares	Meat & offals	Dairy products	Fats & meals	Total	Share
EU28	22,951	35,869	364	59,184	74%
Northern America	476	92	56	624	1%
Central America	29	15	0	44	0%
Southern America	12,409	45	30	12,484	15%
Rest Europe & Russia	28	523	0	551	1%
North.Africa & Western Asia	60	263	0	323	0%
Sub-Saharan Africa	1,675	50	0	1,725	2%
Eastern Asia	88	59	4	151	0%
Southern Asia	3	2	0	5	0%
Southeastern Asia	7	5	0	12	0%
Oceania	3,876	566	942	5,384	7%
Total	41,601	37,489	1,396	**80,487**	

3.3.5 Forestland footprint

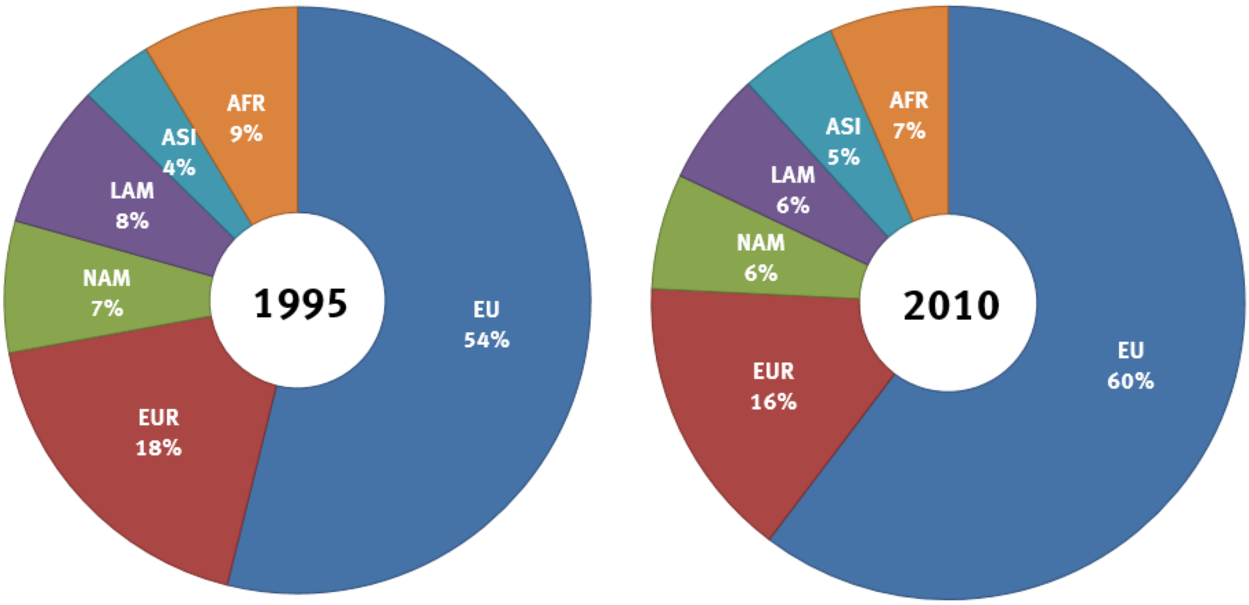
In parallel to the calculations of Germany's forestland footprint (see chapter 3.2.8 above), the EXIOBASE model was also applied on the level of the EU-28. Figure 21 illustrates the development of the EU-28 forestland footprint in the time period of 1995 to 2011. Note again that calculations were performed for 1995, 2000, 2005, and 2009-2011 only and years in between (marked with an asterisk) were estimated through interpolating data.

Figure 21. Forestland footprint of the EU28, 1995-2011

In the year 1995, almost 2.5 million km² were required world-wide to satisfy the final demand for wood and wood-based products in the EU-28. In the period from 1995 to 2000, the EU forestland footprint increased by almost 20% to 2.9 million km². This growth in demand was mainly driven by the sectors of 'Construction', 'Manufacture of furniture' as well as 'Paper'. Overall levels remained constant between 2000 and 2005. Although Figure 21 shows that demand for industrial roundwood already fell, while wood fuel increased its share in the total forestland footprint to almost a quarter in 2005. Both types of wood demand decreased significantly in the period of 2005 to 2009, with the footprint dropping in sectors across the whole economy. In absolute numbers, the sectors 'Manufacture of wood and of products of wood', 'Paper', 'Publishing and printing', 'Manufacture of furniture' as well as 'Construction' contributed most to the decline. Between 2009 and 2011, the EU-28 forestland footprint remained relatively stable at around 2.3 million km².

Figure 22 illustrates the geographical origin of the EU-28 footprint.

Figure 22. Geographical composition of Europe's forestland footprint, 1995 and 2010



Note: AFR = Africa, ASI = Asia, LAM = Latin America, NAM = North America, EUR = non-EU Europe incl. Russia, EU = European Union; Please note that the classification of regions used here differs from that applied to figures showing cropland and grassland footprints due to different country classifications of the footprint accounting models.

As described for the case of Germany above, an increased share of wood stemming from European sources can also be observed for the forestland footprint of the EU-28. Industrial roundwood and fuel wood extracted within the EU-28 itself had a share of 54% in 1995 and increased to 60% in 2010. Other European countries, most dominantly Russia, contributed 18% and 16%, respectively. The share of non-European wood that directly and indirectly serves EU-28 final demand decreased from 28% in 1995 to 24% in 2010.

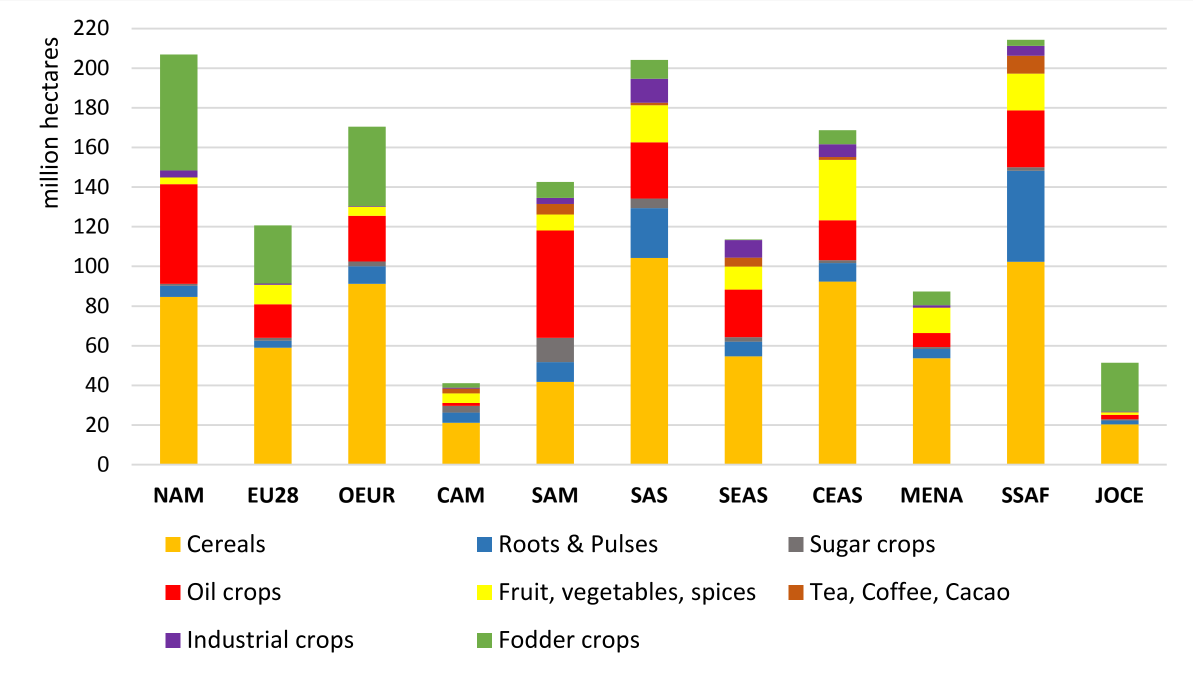
3.4 Global cropland footprints

Today, globally some 1521 Mha are cultivated for crop production including the world's most fertile lands. Based on reported harvested areas and cultivated cropland, we account in for multi-cropping and fallow periods and report cultivation of cropland area by major region and crop group (Figure 23).

Almost half (48%) of global cropland is used to produce cereals cultivated across the world. The second most important crop group is oil crops (17%) produced in Southern America, Northern America and to a lesser extent in Sub-Saharan Africa, Southeast Asia, Other Europe and Russia. Significant amount of cropland areas are used for the production of oil crops (17%), dedicated fodder crops (12%), roots and pulses (8%) and fruits, vegetables, spices (8%).

The largest cropland areas occur in Sub-Saharan Africa, Northern America, and Southern Asia. It should be noted that productivity differs significantly across regions.

Figure 23. Distribution of global cropland, by region and major crop group, 2010



NAM = Northern America; EU28 = European Union; OEUR = Rest of Europe (i.e. Non-EU28) & Russia; CAM = Central America; SAM = Southern America; SAS = Southern Asia; SEAS = Southeast Asia; CEAS = Central and Eastern Asia; MENA = Middle East and Northern Africa; SSAF = Sub-Saharan Africa; JOCE = Japan & Oceania

Cropland availability per capita is a core land indicator to reflect the relative abundance of a country's land resources. For example the World Bank and the FAO regularly report arable land (or termed cultivated land) per capita and their development over time. The indicator is used to describe developments in food security or as general environmental or land indicator. We argue that in addition to cropland per capita it is important to describe the cropland footprint per capita, i.e. the reliance of cropland from a consumer perspective.

At a global average humans use half of cropland extents for food consumption of crop products, almost one third for food consumption of livestock products, some 12% for non-food industrial consumption, and a remainder of 8% is required for seed production and land equivalents for on-farm waste generated during harvest (Figure 24). Per capita human consumption of today's 6.9 billion people is based on 2192 m² cropland, one fifth lower compared to 1995 when 5.7 billion people relied on 2630 m² per capita.

Today almost one third of global cropland (472 Mha) embedded in agricultural products enters cross-country trade. In this way significant cropland land resources are cultivated in one region but derived commodities are consumed in another region.

Figure 24. Global cropland footprint, 2010

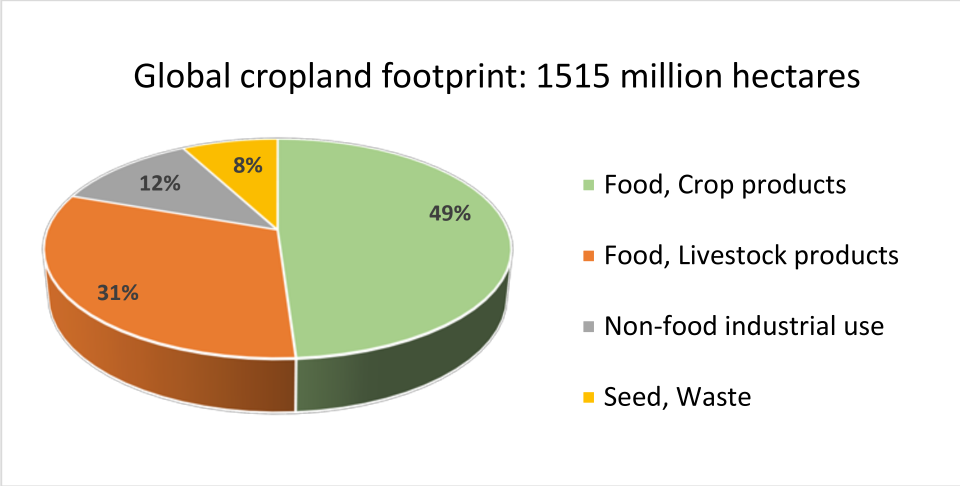


Figure 25 (with data shown in Table 18) highlights regional heterogeneity in extents and composition of cropland footprints. The per capita cropland footprint of the European Union and in Germany is 42% and 23% above the world average of 2192 m^2. Their composition however differs. At the global level half of cropland is used for crop-based diets while in the EU and Germany these are only 31% and 25% respectively.

The lowest per capita cropland footprints occur in densely populated Asian countries including China (1139 m^2), India, (1350 m^2) and Indonesia (1557 m^2). In these regions multi-cropping is common. Despite of their restricted per capita cropland resources India and Indonesia are net exporters of cropland with self-sufficiency ratio of 104% and 120% respectively. China is a net importer of cropland resources with a self-sufficiency ratio of 78%.

The largest cropland footprints over 7000 m^2 per capita are found in Australia and Canada, both at the same time crop net exporting regions, and Russia (Figure 25, right). The large footprints in these countries result from extensive cropland management applying fallow periods on relatively large extents of cropland (Australia, 46 Mha; Canada, 48 Mha; Russia, 122 Mha). At the same time population numbers are comparatively low (Australia, 20 million; Canada, 34 million; Russia, 144 million).

Figure 25. Composition of per capita cropland footprint, 2010

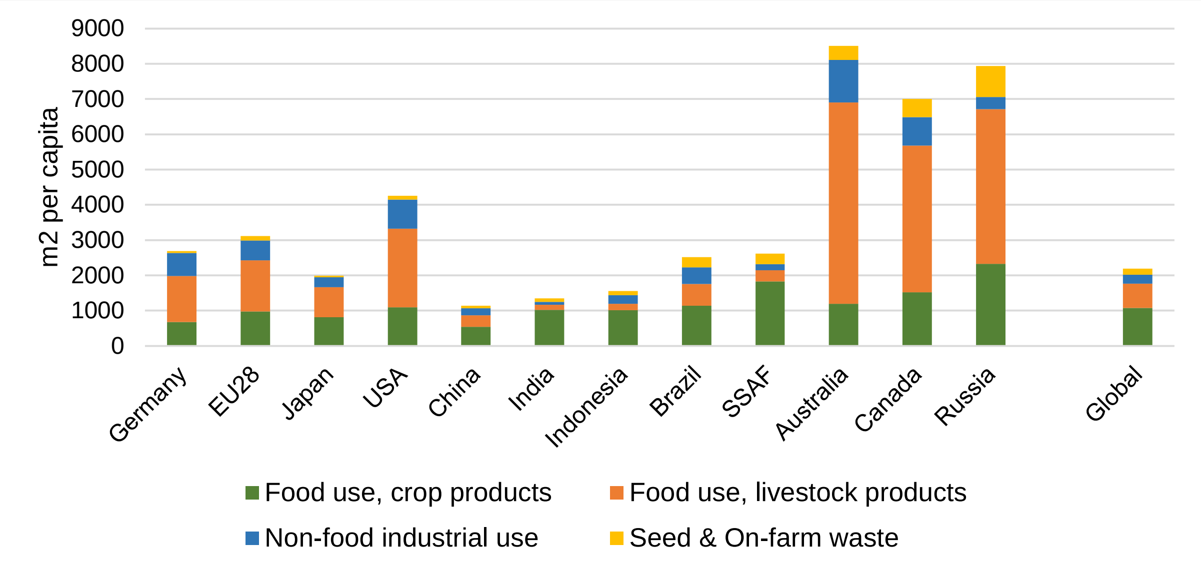


Table 18. Composition of per capita cropland footprint, 2010

square meters per capita	Food use, Crop products	Food use, Livestock products	Non-food industrial use	Seed & on-farm waste	Total
Germany	675	1305	660	53	2693
European Union (EU28)	979	1450	557	124	3111
Japan	810	858	281	43	1993
United States	1094	2231	823	109	4257
China	543	325	202	68	1139
India	1019	149	76	105	1350
Indonesia	1009	188	238	122	1557
Brazil	1143	610	477	291	2521
Sub-Saharan Africa	1829	317	168	303	2617
Australia	1192	5710	1208	396	8506
Canada	1519	4161	810	512	7002
Russia	2328	4388	344	873	7934
Global	**1073**	**690**	**258**	**172**	**2192**

4 Comparison to other studies

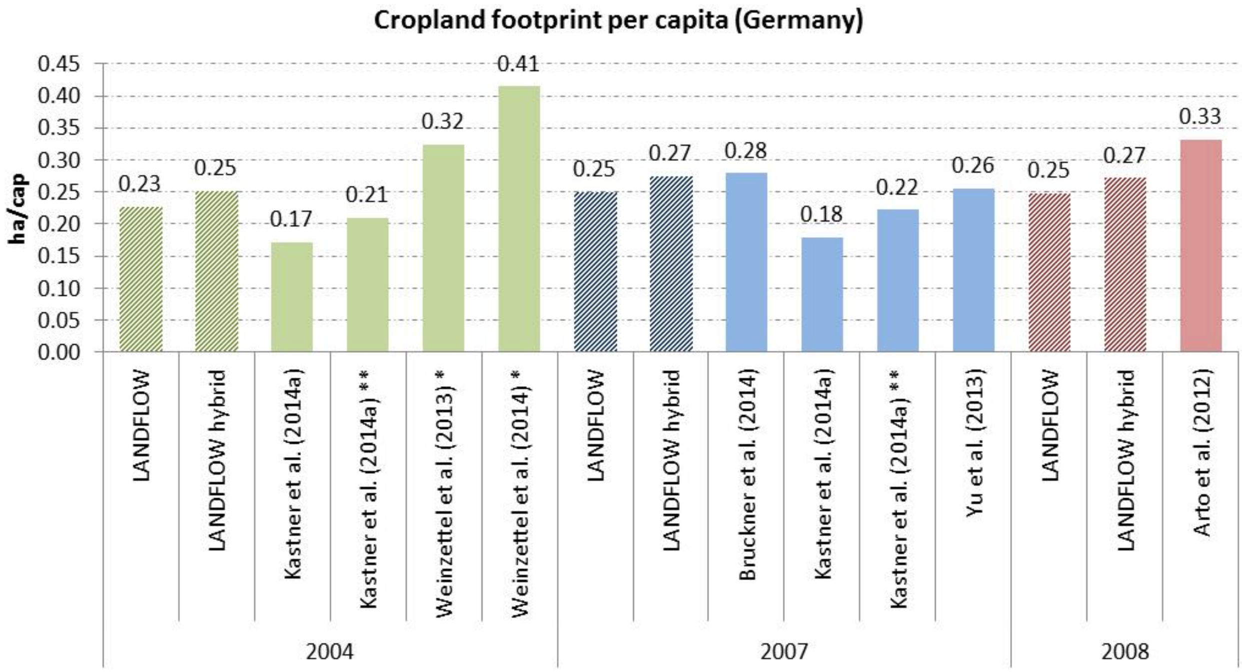
As presented in the report of work package 1 of this study (Bruckner et al. 2017), within recent years various studies have published results on land footprints applying different approaches (see also Bruckner et al. 2015). While in Bruckner et al. (2017) the characteristics and resulting advantages and disadvantages of those methodologies (physical accounting, environmental-economic accounting and hybrid accounting) were analysed, in the following section available land footprint results from the literature are compared with those achieved from applying the LANDFLOW model as well as the hybrid approach described in Chapter 2 (in the following referred to as LANDFLOW hybrid). This comparison is focusing on cropland, initially by illustrating differences in results for Germany and the EU in detail, later by looking at per-capita results and net trade of selected countries, and finally by comparing the footprints of all regions available in the hybrid accounting model.

4.1 Variations in land footprint results for Germany

4.1.1 Comparison of cropland footprints

Figure 26 illustrates cropland footprints per capita for Germany. While the results of the underlying project provide a time range of 1995-2010, the results from nearly all other studies are restricted to certain years. The only exception is Kastner et al. (2014a), providing a time range of 1986-2009. Only for the base years 2004, 2007 and 2008, at least three studies were available for a comparison. The results from these studies range from a minimum of 0.17 ha/cap to a maximum of 0.41 ha/cap for the cropland footprint of Germany (Weinzettel et al. 2014; Weinzettel et al. 2013; Kastner et al. 2014a; Yu et al. 2013; Bruckner et al. 2014; Arto et al. 2012).

Figure 26. Cropland footprints per capita in Germany, different studies and model years



* Please note: Data for Weinzettel et al. (2013) have been published in global hectares, and had to be converted to hectares by applying country-specific conversion factors. An explanation of the conversion procedure can be found in Chapter 4.4.2.
** Please note: The input data on cropland use applied in the study by Kastner et al. (2014a) differ greatly from those of the other studies. In order to improve comparability, data has been adapted (see Chapter 4.4.2). Figure 22 displays both, the original and the adapted results by Kastner et al. (2014a).

Results obtained by the LANDFLOW hybrid method are about 10 – 11% higher than those of the LANDFLOW model, showing that Germany's final demand required more land for non-food purposes, than the amount processed by German industries, as determined without further tracking of non-food supply chains.

The hybrid input-output model by Weinzettel et al. (2013) and Weinzettel et al. (2014), as well as the environmental-economic model by Arto et al. (2012) produce the highest results, while Kastner et al.

(2014a) – even for the harmonized version –present the lowest numbers. This can be in part explained by the fact, that the latter study does not include fodder crops reported by FAOSTAT[10], which in the case of Germany account for 59% of total harvested area in 2010 (FAOSTAT 2016). See Chapter 4.4.2 for more details on this issue. Furthermore, environmental-economic models are known to generate higher results for developed countries than physical accounting models for several reasons, as elaborated in detail by Bruckner et al. (2017), most importantly the coverage of non-food products and the price-wealth correlation for commodity imports (see also Bruckner et al. 2015).

4.1.2 Cropland for food purposes: Comparison with Mayer et al. (2014a)

In 2014, the Federal Bureau of Statistics (Destatis) published a detailed study of the German land footprint (see Mayer et al. 2014a). This study could not be included in the comparison, because it narrows its focus on food products only, while all other studies present aggregate numbers for food and non-food products. With the LANDFLOW model, it is possible to report separately for food and non-food products and their related land requirements. In this chapter, we therefore compare just these two approaches.

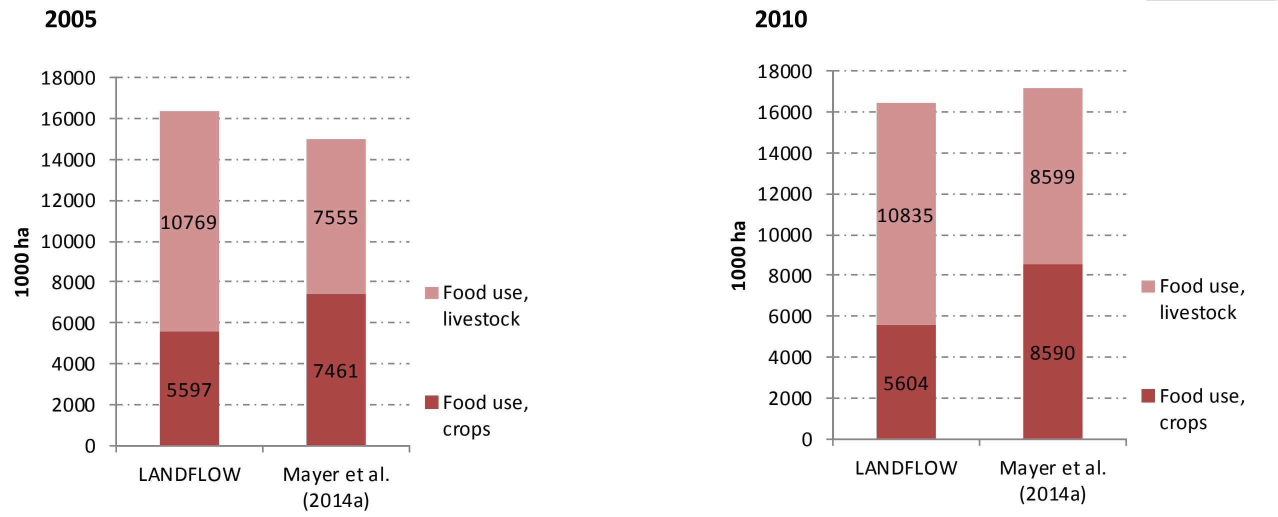
However, we come across another limitation for the comparison. The Destatis study does not report separately for cropland, but rather aggregates this with grazing land to the total agricultural area required for Germany's food consumption. Therefore, we estimate the share of cropland in Germany's land use and imports, using the data on the share of grassland in the land required for domestically produced and imported animal products from the supplementary information provided in Mayer et al. (2014b). Figure 27 contrasts results obtained with the LANDFLOW model on cropland used for food purposes with those estimates derived from the numbers published in Mayer et al. (2014a).

Results on the overall cropland footprint of Germany for food purposes are similar for both studies, with the LANDFLOW model obtaining slightly higher results (about 9%) for the year 2005 and slightly lower results (about 4.6%) for 2010. However, Mayer et al. (2014a) reports about half of the required cropland consumed in the form of plant and animal products, respectively, while LANDFLOW identifies a considerably larger proportion being related with the consumption of livestock products. These variations may be partly explained by differences in the employed land use data (see discussion in Chapter 4.4.2).

A more detailed comparison is not sensible at the moment, as the uncertainties introduced by separating cropland from grassland for the results by Mayer et al. (2014a) may significantly bias any conclusions derived from a comparison.

[10] Not to be confused with other types of feed, e.g. crops and vegetables used for feed. Fodder crops refer to roughage fodder such as grasses, forages and silages.

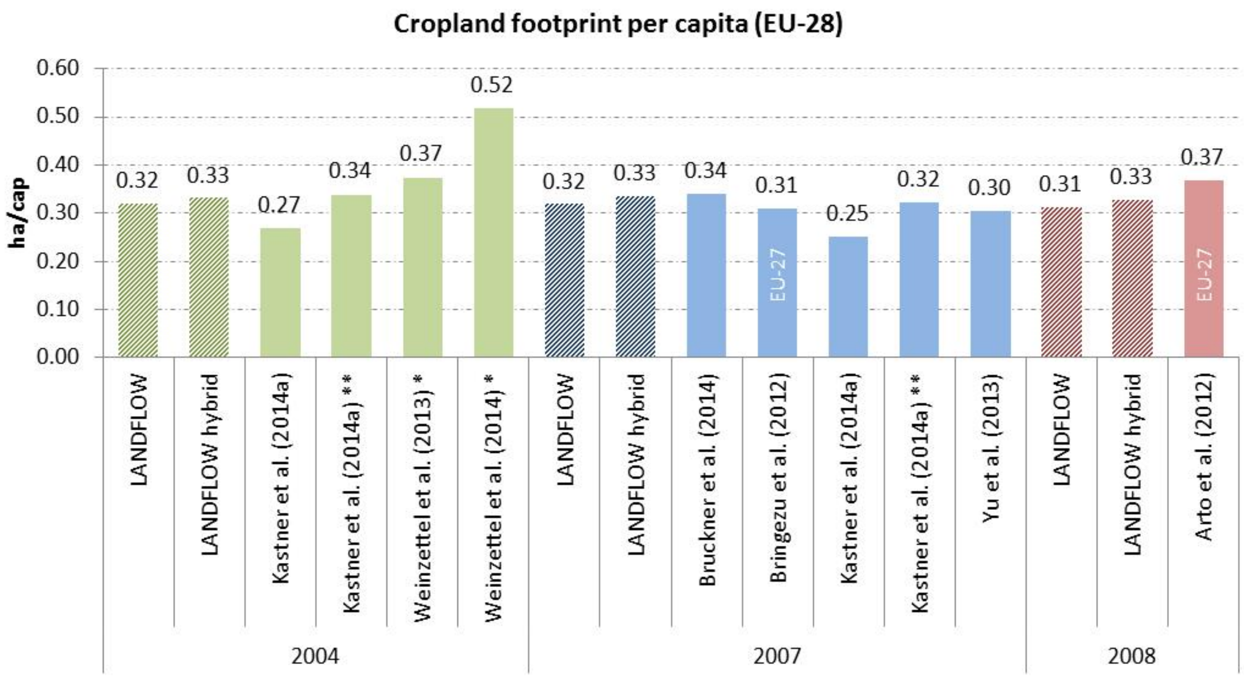
Figure 27. Cropland footprint for food purposes in Germany, 2005 and 2010



4.2 Variations in land footprint results for the EU-28

Figure 28 illustrates cropland footprints per capita for the EU-28 for the base years 2004, 2007 and 2008. Compared for years, the results range from a minimum of 0.25 ha/cap to a maximum of 0.52 ha/cap. Results obtained by the hybrid approach are about 4 to 5% higher than those of the standard LANDFLOW model.

Figure 28. Cropland footprints per capita in the EU-28 area, different studies and model years



*/** Please note: Data has been converted as explained for Figure 22.

The observed differences are similar to those identified for Germany, although the results by Kastner et al. (2014a) in this case are closer to those of the LANDFLOW model.

4.3 Variations in results for selected countries

4.3.1 Comparison of per-capita footprints

Figure 29 and Figure 30 illustrate the per-capita results for nine selected countries and the EU-28 area for the years 2004 and 2007. In both cases, footprints from two studies are shown in contrast to those from the LANDFLOW model and the hybrid accounting approach.

Figure 29. Comparison of cropland footprints per capita in selected countries, year 2004

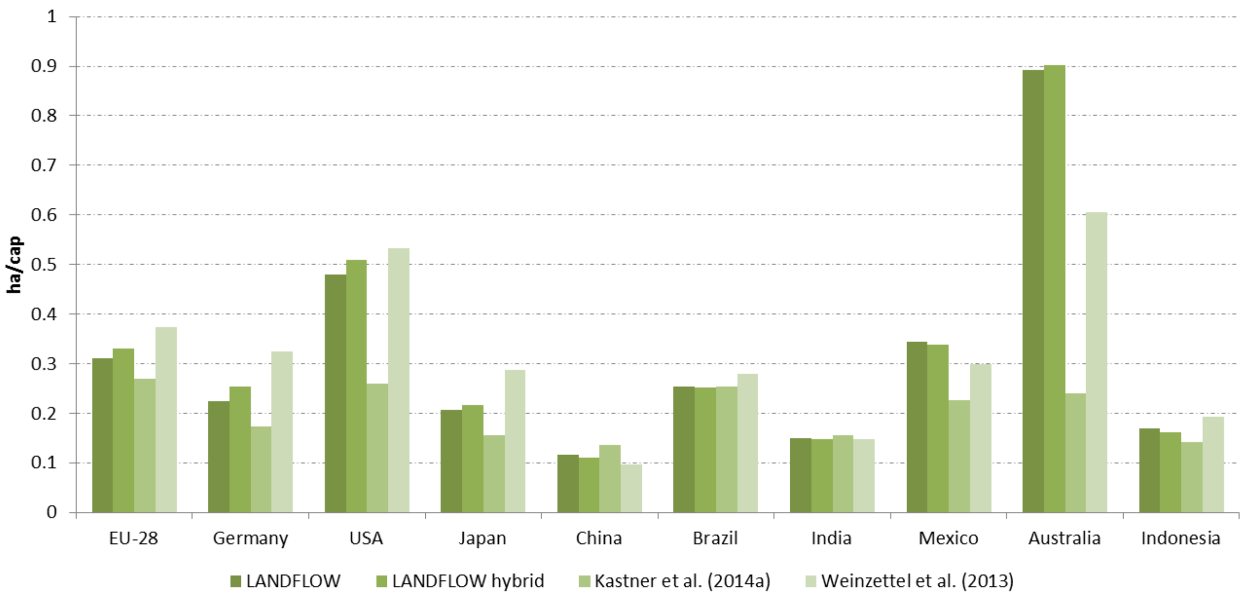
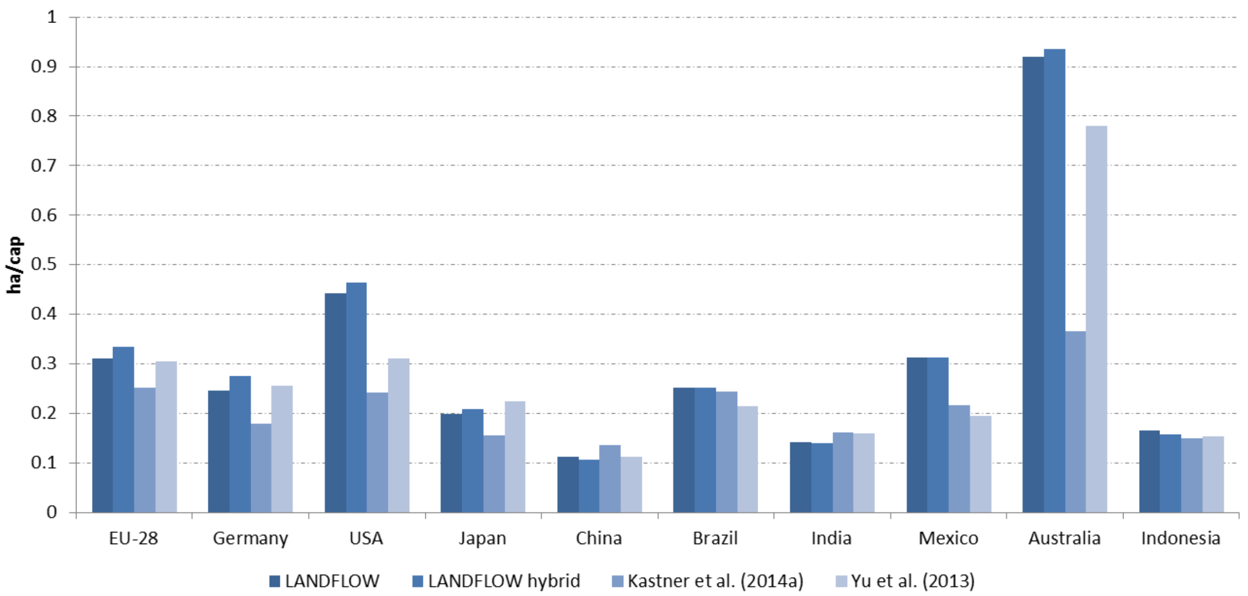


Figure 30. Comparison of cropland footprints per capita in selected countries, year 2007



For the year 2004, across all four considered studies, the results for industrialized countries/regions seem to be subject to higher differences than the results for developing and emerging economies like China, Brazil, India and Indonesia (Figure 29). Except for the latter ones, the results from the underlying project are (in some cases considerably) higher than those from Kastner et al. (2014a), while in most cases being below those from Weinzettel et al. (2013). The outlier for Australia can be explained by differing land use data, as Australia reports huge areas for fodder crop production, which are neglected by Kastner et al. (2014a). Weinzettel et al. (2013) use a hybrid accounting approach similar to LANDFLOW hybrid, but relying to a greater extent on environmental-economic accounting and to a smaller extent on the physical data on supply and utilization from FAO's commodity balance sheets. Therefore, it applies less detail for secondary products than LANDFLOW hybrid, which is mentioned by Weinzettel et al. (2014) as a major shortcoming that needs further improvement. The LANDFLOW hybrid approach developed in this study tries to overcome this shortcoming.

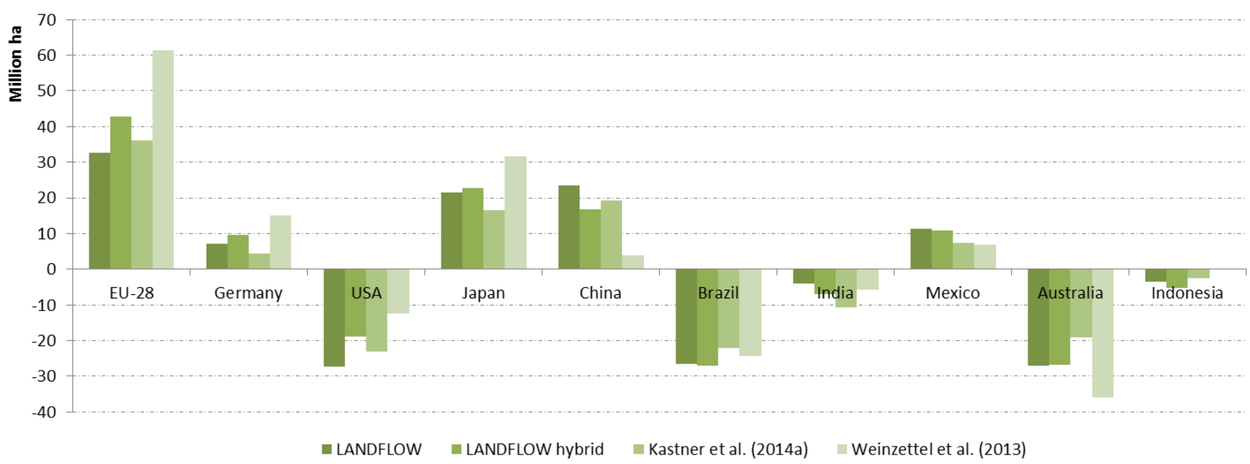
For the year 2007, the pattern of differences in results is similar, showing larger differences for industrialized economies than for developing and emerging countries (Figure 30), and with Kastner et al. (2014a) being below the LANDFLOW results for developed countries such as Germany, the USA, Japan, or Australia. However, for some of these countries, results by Yu et al. (2013) are rather similar to the LANDFLOW and the associated hybrid approach, while in case of the USA and Mexico they are rather similar to those from Kastner et al. (2014a).

4.3.2 Differences in net trade

This chapter illustrates the results for net trade for the same selection of countries as in the previous section. While the differences between land footprints can be mainly attributed to the characteristics of the various applied approaches of trade modelling (see Bruckner et al. 2017), they also stem from different assumptions and methodologies regarding the input data, i.e. the amount of land area used for crop production in each country which has to be allocated (see also 4.4.2). Therefore, a certain part of the footprint of a country is determined by its own land supply indicated in the production data. This makes it reasonable to examine the other part, i.e. the resulting net trade of countries obtained by different calculation approaches.

These net trade results underlie high variations to such an extent that some countries are presented as net exporters of cropland by one study and as net importers by another (as the case for China in 2007, see Figure 32). A comparison for the year 2004 (Figure 31) reveals that results obtained with the LANDFLOW model, the LANDFLOW hybrid approach and from the study by Kastner et al. (2014a) are rather similar for most countries. For Germany and the EU-28, particularly the results by LANDFLOW and Kastner et al. (2014a) are very similar. At the same time, those of Weinzettel et al. (2013) are significantly higher for some industrial countries and regions such as the EU-28, Germany, the USA, Japan, or Australia, while rather similar for developing and emerging countries like Brazil, India and Mexico, and significantly lower for China.

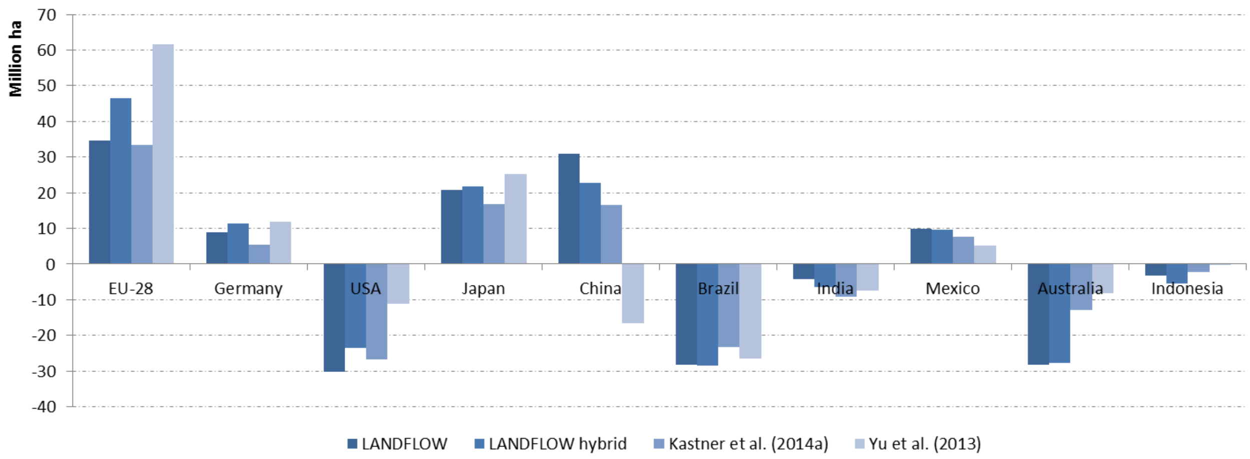
Figure 31. Comparison of net trade of embodied cropland for selected countries, year 2004 (positive values indicate net imports, while negative values indicate net exports)



Unlike presented in Kastner et al. (2014b), the converted values for Weinzettel et al. (2013) present China as a net importer of cropland, however with considerable differences to the results from the three other accounting approaches. Note that in the present report the trade matrix of Weinzettel et al. (2013) has been adjusted to the amount of land area defined and reported as "arable land and permanent crops", similar to the LANDFLOW approach, while the results of Kastner et al. (2014b) have been adjusted to the land area defined as "area harvested" (see 4.4.2).

While the extent of net trade differs between the different studies, all studies agree on the fact, whether a country is an importer or exporter. The only exception is China: As already illustrated by Kastner et al. (2014b), it is presented as a net exporter of cropland by Yu et al. (2013) for the year 2007 with a net export value of around 16.5 Mha, while Kastner et al. (2014b) determine net imports of 16.5 Mha and the LANDFLOW model obtains net imports of about 31 Mha (Figure 32).

Figure 32. Comparison of net trade of embodied cropland for selected countries, year 2007 (positive values indicate net imports, while negative values indicate net exports)



4.4 Comparison of all model regions

In correspondence with the limited availability of comprehensive results published by studies on a global scale, the comparison has been conducted for two points in time (2004 and 2007), for which such data was abundant. This is mainly because of work from Weinzettel et al. (2013), Weinzettel et al. (2014) and Yu et al. (2013) being based on GTAP data, which are only available for these years. Trade matrices for all studies have been aggregated to the model regions used in the LANDFLOW hybrid model.

4.4.1 Inter-model comparison for the base years 2004 and 2007

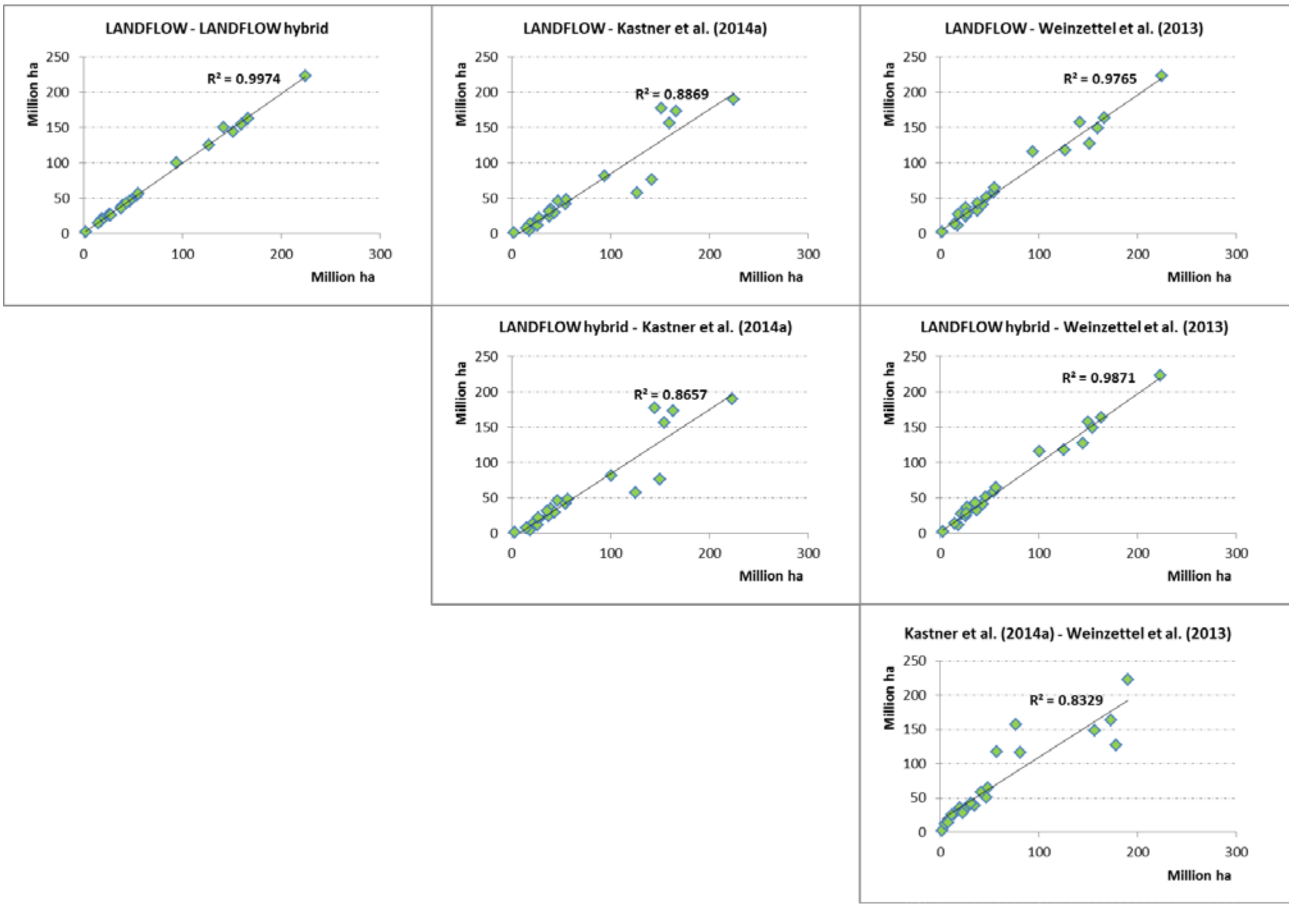
In Figure 33 and Figure 34 the coefficient of determination R^2 is used as a proxy for the correlation between the results for all aggregated model regions[11]. While Figure 33 compares the available cropland footprints for 2004, Figure 34 refers to the base year 2007.

Figure 33 illustrates that in general the correlation between the results of most studies is very high. The difference between results by the LANDFLOW model and the hybrid approach are highly correlated. It can be assumed that even though the proportion of cropland footprints used for non-food purposed is significantly different for certain regions, it is still comparatively small to the overall

[11] As we compare two samples of results in each plot, R squared is simply defined as the square of the sample correlation coefficient.

footprint and also restricted to particular regions. For example, for the EU-28 the results on cropland for other use change by about 50% for 2010 by applying the hybrid approach, but within the total footprint that change accounts for only 5%.

Figure 33. Correlation of footprints results for all model regions, year 2004

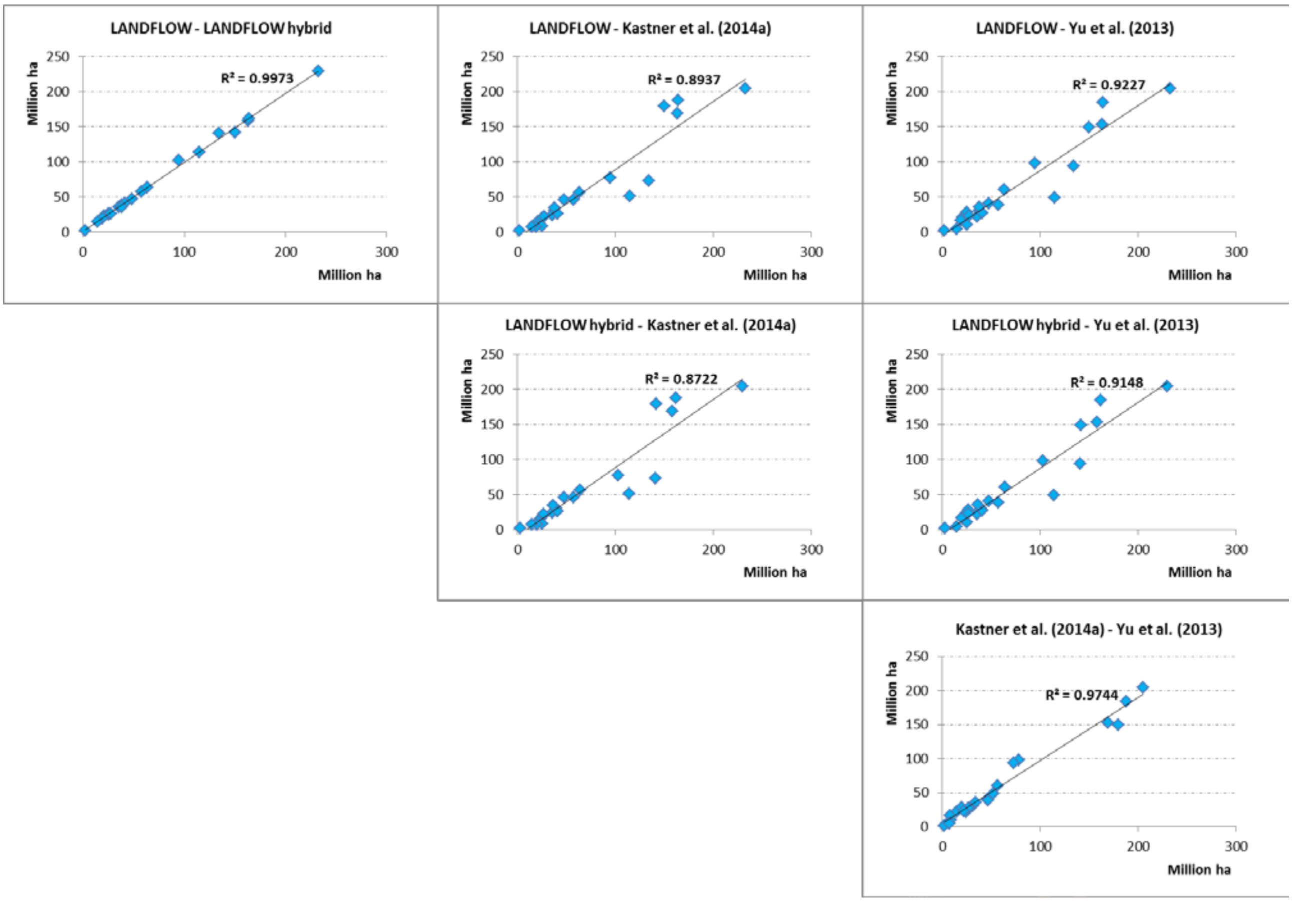


Moreover, results from both LANDFLOW approaches correlate highly with those from Weinzettel et al. (2013). Interestingly, results by Kastner et al. (2014a) show less correlation with any of the other three studies compared to the correlation among those. While a rather good fit can be observed for the smaller countries and regions with footprints up to 50 Mha, deviations increase for those between 50 and 200 Mha.

A recently published study by Schaffartzik et al. (2015) compared different study outcomes on the land footprint. The applied disaggregation of countries was higher which resulted in less correlation between the numbers, for example with an R^2 of only 0.51 between Kastner et al. (2014a) and Yu et al. (2013), compared to the 0.97 in our findings (see Figure 34). Schaffartzik et al. (2015) applied an aggregation of 101 countries compared to 21 regions in the present report. This finding indicates that current land footprint accounting methods are rather robust on an aggregate level, while producing highly varying results on a detailed country level.

The insights drawn from results for the year 2007 are similar to 2004. However, it can be seen that Kastner et al. (2014a) and Yu et al. (2013), although using very different methods and data, correlate considerably high compared to the R^2 of other study pairs. However, as described before, the comparison might be biased by the high region aggregation.

Figure 34. Correlation of footprints results for all model regions, year 2007



4.4.2 Divergences due to differing input data

As already mentioned earlier, the considered studies apply different data for the land areas used for crop production. These variations are mostly related to differences in accounting for multi-cropping and fallow land (Bruckner et al. 2017). The utilization of differing land use data directly results in differences in the footprints calculated with each model.

Land use data used by Yu et al. (2013) and Kastner et al. (2014a), for example, have been calculated from crop production (in tonnes) and yield data (both from FAOSTAT), and do not include fallow land. Multi-cropped areas, however, are double-counted. Moreover, land use for the production of fodder crops from cropland (including, for example, forages and silages) were excluded from the calculations in these two studies.

For the LANDFLOW calculations in this study, fallow land was added to harvested areas according to FAOSTAT and adapted for multi-cropping. The land use data used in this study, and thus also the resulting land footprints, thus are significantly higher than those in the compared studies.

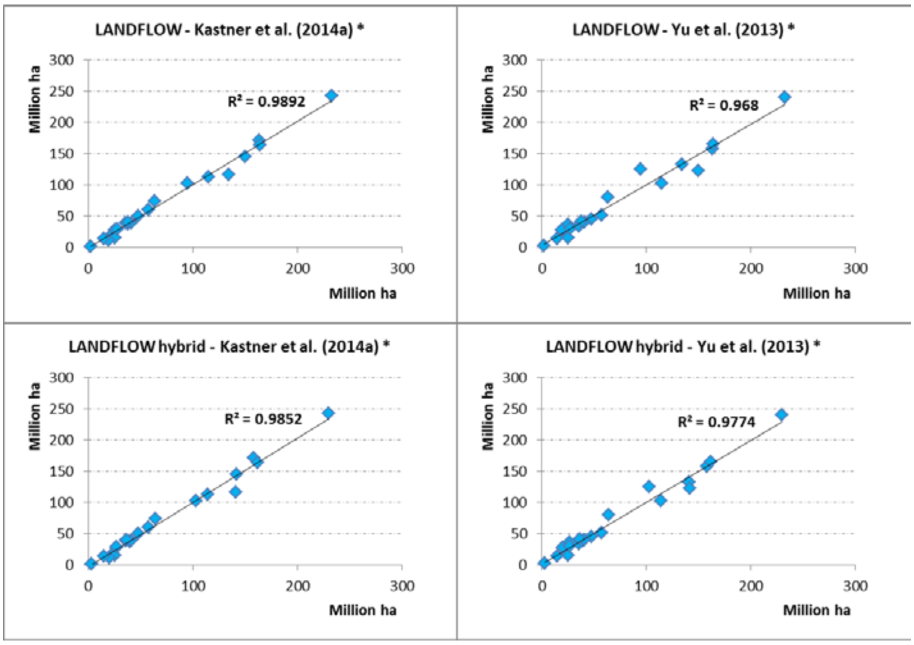
Weinzettel et al. (2013) converted the land use data into 'global hectares', a unit used for the calculation of the Ecological Footprint, which scales each hectare of land to the global average productivity. A hectare with double productivity therefore counts for two global hectares. A hectare with only half the global average productivity consequently counts 0.5 hectares.

For the purpose of enhancing comparability, we adjusted the respective trade matrices provided in the supplementary information of Kastner et al. (2014a), Weinzettel et al. (2013) and Yu et al. (2013)

by applying country-specific factors[12], thus up- or downscaling the land input to the overall cropland area available for production as reported by FAOSTAT. The conversion has been applied to the available trade matrices for the model years 2004 and 2007.

It should be noted that the adjustments made to the various trade matrices are only an approximation and do introduce an additional source of uncertainty. Nevertheless, we argue that this step enhances comparability. The correlation between results increases considerably for nearly all comparisons (Figure 35) as compared to the correlation of unadjusted study results (see Chapter 4.4.1), ranging between an R^2 of 0.97 and 0.99.

Figure 35. Correlation of results for regions by different studies, with adjusted land use data for Kastner et al. (2014a) and Yu et al. (2013), year 2007



* Please note: Data has been converted as described above

Additionally, robustness of data reported to FAO on the production of fodder crops (e.g. grasses, forages and silages) must be contested, as for some countries, the reported fodder crop area exceeds the available cropland area. This seems to be particularly relevant for the data reported for Australia, but can also be seen for the case of Germany. The discrepancies between harvested area and actually available cropland suggest that the responsible FAO rapporteurs also report grassland products under FAO item codes such as "grasses nec" which by definition are exclusively designated for field crops from temporary cropping systems. As a result, land footprint calculations for Germany and Australia based on FAO data will overestimate the cropland share while indicating a reduced grassland share, as compared to studies relying on national statistics.

[12] These factors represent the ration between the amount of land input for each country in the respective studies and the land input for each country as applied in the LANDFLOW model which uses the land available for production as reported by FAOSTAT. This approach provides approximate results as if each study had used the same land input.

5 Conclusions

The study has successfully developed and applied a hybrid approach for land flow accounting, combining elements from both physical and environmental-economic accounting. The key advantage of the hybrid approach is that the applied detailed physical data allow to compensate the disadvantages normally faced with input-output analysis, in particular the problems of aggregation and economic allocation. This especially enhances the assessment of products with a low level of manufacturing (Schaffartzik et al. 2009; Schoer et al. 2012a; Wiedmann 2011). Food products typically undergo only a few processing steps, thus, using global agricultural statistics, i.e. detailed data by country on crop production, trade, processing and utilization, the physical accounting method is particularly relevant for land footprint calculations. At the same time, the advantages of input-output analysis, in particular its complete coverage of economic sectors are beneficial for products with a higher level of manufacturing. Therefore, hybrid approaches are most promising for the analysis of land flows associated with non-food products such as textiles, leather, paper and wood products, biofuels, cosmetics, pharmaceuticals, and lubricants.

Land flow accounting tracks land use from primary production to final consumption along global supply chains for the calculation of land footprints, i.e. extents of domestic and foreign land associated with a country's consumption pattern. Physical accounting tracks biomass flows (and related land use) in physical volumes (tons of biomass), while they are tracked in monetary values ($ of commodity flows) in environmental-economic accounting. Land footprints reveal the extents of land resources required all over the world for satisfying a country's food and non-food consumption and they provide comparable statistics across countries. Tracking biomass in physical volumes along supply chains and accounting for processing activities by using relevant technical conversion coefficients (available from FAO) is transparent and intuitive. Yet, tracking biomass and land use in relation to monetary transactions between economic sectors, as applied in environmental-economic accounting, is still a necessity in order to overcome the product chain limitations of available global agricultural statistics in particular for highly processed non-food commodities such as for instance textiles or leather products. Currently, efforts are being put into the development of a physical multiregional input-output table with high product detail and global coverage of all crop and livestock commodities.

In the present study, we apply a hybrid methodology combining LANDFLOW physical accounting with environmental-economic accounting based on MRIO data, which makes best use of available data including a) the high commodity detail and technical conversion information of FAO data for the food sector, and b) the full coverage of all global supply chains of industrial non-food commodities in environmental-economic accounting models.

Nevertheless, uncertainties remain due to gaps and inconsistencies in reporting of applied input data. These include foremost the bilateral trade data provided by FAO, which currently rely on country reports but are not harmonized across countries towards consistent bilateral trade flows. For instance, what country A reports as exports to country B should also be recorded as imports of country B from country A. Harmonization is achieved in this study following rules described in section 2.2.7. This approach suggests limiting the number of markets distinguished in the analysis to reduce the need for adjustment of the reported data. Environmental-economic accounting models often apply the RAS technique, an iterative proportional fitting procedure, in order to trade-link national economies and balance global trade flows.

Harmonization of bilateral trade data carried out centrally by FAO could improve the robustness of results and would allow applying the physical accounting part of the hybrid model on a higher level of regional detail. The number of markets included in the hybrid modelling presented here is also limited by the regional coverage of the monetary IO model. While some IO models with global coverage include a larger number of countries, albeit at coarse sectoral resolution, we use EXIOBASE because of its high product detail.

The resulting model covers all food and feed processing activities in terms of mass flows. In the case of production processes resulting in joint products (e.g. vegetable oil and protein cake in oilseed crushing), we include a physical as well as an economic element in order to allocate inputs to derived products according to their value shares. For example land allocation of soybean production to soybean oil and cake is achieved by using both the respective physical extraction rates and international price weights for the produces, i.e. allocation of joint products takes place proportional to the value shares of the derived products. Alternatively, land allocation could be implemented according to mass flows, energy or nutrient contents. Value shares are used here, because they represent economic drivers behind production processes and allocate burden according to the driving force exerted by a consumption activity.

Further improvements of land footprint accounting methods could be achieved by a more detailed reporting of livestock related data. In particular reliable estimates of extents of grassland actually used for grazing ruminant livestock could greatly improve estimation of grassland utilization and footprints. Also, more detailed reporting of the use of feed and fodder crops for specific livestock categories could replace the current estimation method (see 2.2.6). Finally, completeness and robustness of data reported to FAO on the production of fodder crops (e.g. grasses, forages and silages) must be scrutinized and requires clear distinction and consistent definition of the physical resources involved (i.e. arable land or pasture land). National applications of the land footprint accounting method developed here should therefore also make use of available national statistical knowledge and expertise, in order to fill data gaps and avoid errors from data misinterpretations.

A comparison with various previous studies has identified the utilization of different land use data, for example regarding the cultivation of fodder crops, the treatment of multi-cropping (i.e. multiple use of land within a year) and the attribution of fallow land as major sources of variation in the determination of land footprints. There is a need to define 'best practices' in dealing with these factors, both from a scientific point of view and in terms of policy relevance, to improve the comparability of estimates.

The EU's Roadmap to a Resource Efficient Europe aims to transform Europe's economy towards sustainability. Efficient use of limited land resources to meet human demand is one element and the roadmap calls for 'tools to monitor and measure progress on resource efficiency'. The here presented land footprints provide a consumption-based land use indicator with a high level of commodity detail. With the proposed methodology, the extents of land appropriated for different human consumption patterns are sufficiently differentiated and made transparent and comparable across countries/regions. The indicator can be used to show the land footprints associated, for example, with different elements of food and nutrition and may serve as one element for discussing criteria and measures toward sustainable consumption.

The here presented area-based land footprint confirms prior research revealing the higher land demand of livestock-based diets as compared to crop-based diets, and extends available knowledge by information on the geographical location of the required land and the involved global supply chains. This may lead to a more general discussion about sustainability, composition and fairness of per capita human consumption footprints in view of planetary boundaries and the resource needs of future generations. Or formulated more casually, what are the characteristics of a 'sustainable footprint'?

As shown in section 3.3 there is a wide regional variety of current extents and composition of per capita cropland footprints. From a fairness and equity perspective one may argue for a more balanced per capita use of global cropland resources. The largest cropland footprints of over 4000 m^2 per capita currently occur in countries where cropland resources are abundant (Australia, Russia, Canada, USA). Except for Russia, these countries are also major net exporters of cropland embedded in agricultural products thus using their domestic cropland resource already to supply other countries. Lowest per capita footprints can be found in highly populated Asian countries including India and China with 1139 and 1350 m^2, which is significantly less than the global average of about 2200 m^2.

Strategies to reduce land footprints may consider increasing yields and overall land use efficiency in agriculture and forestry production, reducing food and non-food consumption of biomass, and shifting diets towards more land efficient commodities. Equally important as reducing land footprints, however, is fostering sustainability of land management (input use, prevention of soil degradation, soil and water pollution) in agriculture and forestry. This requires a wide field of aspects and indicators to be discussed and analysed and is beyond the scope of this report. Additionally, footprints based only on area extents do not reflect the existing large variety in land quality and capability due to climate, soil and terrain, nor do they provide an understanding of environmental risks and impacts. We refer to a related publication (Fischer et al., 2016, forthcoming) where first steps towards extending footprints considering land quality and environmental impacts are presented.

Closely related to sustainability is land intensity and productivity, i.e. the output of products achievable and actually achieved per hectare. Integrated farming, ecological farming or integrated forest management, all strive for sustainable management of the commodity produced on a piece of land with the central aim to optimize operations for both the farmers and the environment. In this regard an interesting point for further research is to assess across regions the differences in land quality and regional heterogeneity of land productivity as well as prevailing yield gaps (i.e. the difference between achievable sustainable yield potential and actually achieved productivity). Thus reporting next to the area-based cropland, grassland and forestland footprints (in hectares), as well the respective output achieved per hectare, presents another potential indicator required for a meaningful discussion of the sustainability of human consumption and the efficiency of land use.

The hybrid land flow accounting developed in this study has global coverage and was applied annually between 1995 and 2010 with results generated for 21 regional and national markets including Germany as a separate market. The objective of this study was to elaborate detailed results for Germany and the EU28 with main findings presented below.

Current demand (year 2010) of the German economy for agricultural food and non-food products amounts to 36.3 Mha cropland and 19.6 Mha grassland, of which 12.1 Mha cropland and 4.7 Mha grassland are of domestic origin. Of the total cropland in demand, more than a third, some 13.6 Mha, is exported or re-exported, resulting in a net cropland import of 10.6 Mha. More than half of Germany's cultivated cropland (56%) is used for the production of fodder crops and almost one third (31%) for cereal production.

Germany is a major and increasing trade partner for a variety of agricultural commodities. Cropland embedded in imports is about twice the amount compared to cropland embedded in exports, and it is about three times higher for grassland. Germany is thus a net importer of 'virtual' cropland and grassland amounting to 10.6 Mha and 9.0 Mha respectively. Germany's cropland self reliance ratio is 54%, i.e. almost half of cropland required to meet domestic demand is located outside Germany. The grassland self-reliance ratio is 34%. As discussed above, in addition to land self-reliance, Germany's self-reliance ratio on the basis of physical volumes (e.g. aggregated to the international price weight GK$), would provide another indicator for providing a full picture of Germany's self-reliance in agricultural products. Productivity compared to 1995, cropland embedded in imports and exports of crop and livestock products increased by 25% (+4.8 Mha) and 45% (+4.2 Mha) respectively.

The oil crop sector has played an outstanding role in imports accounting for one third of total cropland embedded in imports. Only less than 10% of Germany's cropland (0.8 Mha) is used for the cultivation of oil crops; about 90% of land in oil crop supply is imported. Thus, Germany's oil crop sector is a net cropland importer of 5.3 Mha. This is closely linked to Germany being a major livestock producer. The sector is dependent on imported soybeans and soybean cake as protein source for feeding animals. Furthermore, the increasing importance of biodiesel, based in part on imported oil crops (mainly rape seed) and vegetable oil, has put additional momentum to this trend.

Today each German citizen appropriates on average 2,693 m² cropland for the consumption of crop- and livestock-based food and non-food commodities. Two thirds of the food-related cropland footprint or 10.8 Mha (1,205 m²/capita) is due to the consumption of livestock products alone. Cropland embedded in Germany's food consumption is in majority (61%) based on crops cultivated domestically. Some 23% stems from crops cultivated in other EU28 countries, and the remaining 16% comes from non-EU countries. Non-food products account for nearly a quarter of Germany's cropland footprint, particularly highlighting the importance of biofuels and textiles, but also leather and rubber products, which considerably contribute to the country's overall land footprint. In contrast to the food sector, the majority (86%) of cropland attributed to the non-food sector is located outside Germany. In addition, Germany's grassland footprint due to consumption of ruminant livestock products (i.e. meat, dairy products, hides & skins from cattle, sheep and goats) amounts to 1,655 m²/capita.

Overall extents of Germany's cropland footprint remained almost constant in the past 15 years, its composition however changed. The food-related cropland footprint of a German citizen has on average become more land efficient in the past 15 years, i.e. less land is required per unit of consumed food product. It decreased from 2,146 m²/capita in 1995 to 1,980 m²/capita in 2010. However, at the same time the non-food cropland footprint increased from 520 m²/capita (1995) to 660 m²/capita (2010). Grassland footprint dynamics since 1995 reveal a decrease in grassland extents embedded in imports, primarily due to a reported halving of the imports of the non-food commodity group 'hides, skins and wool'.

Results for the European Union show a clear downward trend in domestic cropland and grassland of about 7% for 1995 to 2010 to current extents amounting to 121 Mha cropland and 68 Mha grassland. Like Germany, the European Union as a whole is a net importer of 'virtual' cropland and grassland. Net cropland imports remained fairly stable over time amounting to between 35 and 38 Mha annually. Net grassland imports decreased steadily from 98 Mha in 1995 to 50 Mha in 2010. The EU today relies to a significant extent on agricultural land outside its territory. Current self-reliance ratio for cropland and grassland is 77% and 57% respectively. In relative terms usage of crops from outside the EU is higher for non-food products compared to food products. While 14% of the food related cropland footprint is based on crops produced outside the EU, more than two thirds (67%) of crops embedded in non-food products is produced outside the EU.

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Annex A-1. FAOSTAT primary crop list, aggregated to main crop groups

		Annual crops	Perennials
1	Cereals	Wheat; Rice, Paddy; Barley; Maize; Pop Corn; Rye; Oats; Millet; Sorghum; Buckwheat; Quinoa; Fonio; Triticale; Canary Seed; Mixed Grain; Cereals nes	
2	Roots & Pulses	Potatoes; Sweet Potatoes; Cassava; Yautia (Cocoyam); Taro (Coco Yam); 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	
3	Sugar crops	Sugar Cane; Sugar Beets; Sugar Crops nes	
4	Oil crops	Soyabeans; Groundnuts in Shell; Castor Beans; Sunflower Seed; Rapeseed; Safflower Seed; Sesame Seed; Mustard Seed; Poppy Seed; Melonseed; Tallowtree Seeds; Seed Cotton; Cottonseed; Linseed; Hempseed; Oilseeds nes	Coconuts; Oil Palm Fruit; Palm Kernels; Palm Oil; Olives; Karite Nuts (Sheanuts); Tung Nuts; Jojoba Seeds; Kapok Fruit; Kapokseed in Shell; Kapokseed Shelled
5	Vegetables, Fruits, Nuts & Spices	Cabbages; Artichokes; Asparagus; Lettuce; Spinach; Cassave Leaves; Tomatoes; Cauliflower; Pumpkins, Squash, Gourds; Cucumbers and Gherkins; Eggplants; Chillies&Peppers, Green; Onions+Shallots, Green; Onions, Dry; Garlic; Leeks and Oth.Alliac.Veg; Beans, Green; Peas, Green; Broad Beans, Green; String Beans; Carrots; Okra; Green Corn (Maize); Mushrooms; Chicory Roots; Carobs; Vegetables Fresh nes; Strawberries; Watermelons; Cantaloupes&oth Melons; Anise, Badian, Fennel	Brazil Nuts; Cashew Nuts; Chestnuts; Almonds; Walnuts; Pistachios; Kolanuts; Hazelnuts (Filberts); Areca Nuts (Betel); Nuts nes; Bananas; Plantains; Oranges; Tang.Mand.Clement.Satsma; 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; Cashewapple; Kiwi Fruit; Papayas; Fruit Tropical Fresh nes; Fruit Fresh nes; Mate; Tea nes; Hops; Pepper,White/Long/Black; Pimento, Allspice; Vanilla; Cinnamon (Canella); Cloves, Whole+Stems; Nutmeg, Mace, Cardamons; Ginger; Spices nes; Peppermint
6	Stimulants		Coffee, Green; Cocoa Beans; Tea
7	Industrial crops	Cotton Lint; Flax Fibre and Tow; Hemp Fibre and Tow; Jute; Jute-Like Fibres; Fibre Crops nes; Tobacco Leaves	Pyrethrum, Dried Flowers; Kapok Fibre; Ramie; Sisal; Agave Fibres nes; Abaca (Manila Hemp); Coir; Natural Rubber; Natural Gums
8	Fodder crops	Rye Grass, Forage and Silage; Grasses nes, Forage and Silage; Clover for Forage and Silage; Alfalfa for Forage and Silage; Leguminous fodder crops nes, Forage and Silage; Mixed Grasses and Legumes; Fodder crops suitable for ruminants and other livestock; Maize for Forage and Silage; Sorghum for Forage and Silage; Green Oilseeds for Fodder; Cabbage for Fodder; Turnips for Fodder; Beets for Fodder; Carrots for Fodder; Swedes for Fodder; Forage Products nes; Vegetables and Roots for Fodder	

Annex A-2. Commodities of the Supply Utilization Accounts (SUAs)

SUA group	SUA item	Produce	Feed
1 Cereals	Wheat	A	F
	Barley	A	F
	Maize	A	F
	Rice	A	F
	Rye	A	F
	Oats	A	F
	Millet	A	F
	Sorghum	A	F
	Cereals, Other	A	F
	Brans	D	F
	Beer	D	
	Maize Germ Oil	D	
	Rice Bran Oil	D	
	Infant Food	D	
2 Roots and Pulses	Potatoes	A	F
	Cassava	P	F
	Sweet Potatoes	A	F
	Roots, Other	A	F
	Yams	A/P	F
	Beans, Dry	A	F
	Peas, Dry	A	F
	Pulses, Other	A	F
3 Sugar crops	Sugar Cane	P	F
	Sugar Beets	A	F
	Sugar, Non-Centrifugal	D	F
	Sugar (Raw Equivalent)	D	F
	Sugar Crops, nes	A/P	
	Sweeteners, Other	D	F
	Molasses	D	F
4 Oilcrops	Soybeans	A	F
	Groundnuts	A	
	Sunflowerseed	A	F
	Rape and Mustardseed	A	F
	Cottonseed	A	F
	Coconuts	P	F
	Sesameseed	A	F
	Palmkernels	P	F
	Olives	P	
	Oilcrops, Other	A/P	F

4.1 Vegetable oils	Soybean Oil	D	F
	Groundnut Oil	D	F
	Sunflowerseed Oil	D	F
	Rape and Mustardseed Oil	D	F
	Cottonseed Oil	D	F
	Palmkernel Oil	D	F
	Palm Oil	D	
	Coconut Oil	D	
	Sesameseed Oil	D	F
	Olive Oil	D	F
	Oilcrops Oil, Other	D	
4.2 Oil cakes	Soyabean Cake	D	F
	Groundnut Cake	D	F
	Sunflowerseed Cake	D	F
	Rape and Mustard Cake	D	F
	Cottonseed Cake	D	F
	Palmkernel Cake	D	F
	Copra Cake	D	F
	Sesameseed Cake	D	F
	Oilseed Cakes, Other	D	F
5 Vegetables, Fruit, Nuts, Spices	Nuts	P	
	Tomatoes	A	F
	Onions Dry	A	F
	Vegetables, Other	P	F
	Oranges, Mandarines	P	F
	Lemons, Limes	P	
	Grapefruit	P	
	Citrus, Other	P	
	Bananas	P	F
	Plantains	P	F
	Apples	P	F
	Pineapples	P	
	Dates	P	F
	Grapes	P	F
	Fruits, Other	P	F
	Pepper	P	
	Pimento	P	
	Cloves	P	
	Spices, Other	A/P	
	Wine	D	
	Beverages Fermented	D	
	Beverages, Alcoholic	D	
6 Stimulants	Coffee Green	P	

	Cocoa Beans	P	
	Tea	P	
7 Industrial crops	Cotton Lint	A	
	Jute	A	
	Jute-Like Fibres	A	
	Soft Fibres, Other	A/P	
	Sisal	P	
	Abaca, Manila Hemp	P	
	Hard Fibres, Other	A/P	
	Tobacco Leaves	A	
	Natural Rubber	P	
8 Fodder crops	Fodder crops	A/P	F
9 LIVESTOCK Products	Bovine Meat	D	F
	Pigmeat	D	
	Poultry meat	D	
	Meat, Other	D	F
	Mutton & Goat Meat	D	
	Offals, Edible	D	
	Meat, Meal	D	F
	Eggs	D	F
	Milk, excl. butter	D	F
	Milk, Whole	D	F
	Mil, Skimmed	D	F
	Cheese	D	
	Butter, Ghee	D	F
	Cream	D	
	Whey	D	F
	Fats, Animals, Raw	D	F
	Hides & Skins	D	
	Honey	D	
	Silk	D	
	Wool	D	
	Fish products*		F

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

Annex A-3. Extraction rates and value shares of major oil crops

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%
Tallowtree Seeds			0.3	100%
Kapok Fruit	0.37	21.94%	0.3	78.06%
Linseed	0.63	37.30%	0.35	62.70%

Note: Extraction rates from FAO (2015).

Annex A-4. Calculation steps for allocation of joint production

The LANDFLOW approach to weighting in case of joint production is to compare the monetary values of the joint products and to use their share in total value of output to weight extraction rates of the corresponding commodities. Let us assume that we have two joint products A and B, both obtained from the processing of commodity Q. Product A with quantity Q_A has an extraction rate of ε_A, product B with quantity Q_B an extraction rate of ε_B. The following identities hold:

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

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:

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

The value share of commodity A is defined as:

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

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

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

Annex A-5. Fodder crops conversion factors

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 other 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

* nes: not elsewhere specified

Annex A-6. LANDFLOW regionalization for hybrid accounting

Country / Region code	Country / Region name	Major region code*	Countries
CAN	Canada	NAM	Canada
USA	United States	NAM	United States
MEX	Mexico	CAM	Mexico
RCAM	Rest of Central America	CAM	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 Nev, St Lucia, St Vincent/Grenad., Trinidad/Tobago
BRA	Brazil	SAM	Brazil
ARG	Argentina	SAM	Argentina
RSAM	Rest of South America	SAM	Bolivia, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
DEU	Germany	EU28	Germany
AUT	Austria	EU28	Austria
REU1	Rest of former EU15	EU28	Belgium, Luxembourg, Denmark, Finland, France, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, United Kingdom
REU2	Rest of EU except EU15	EU28	Bulgaria, Croatia, Cyprus, Czech Republic, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia
RUS	Russia	EURR	Russia
REUR	Rest of Europe	EURR	Albania, Belarus, Bosnia & Herzegovina, Rep. Moldova, Macedonia, Norway, Serbia & Montenegro, USSR, Ukraine, Switzerland, Yugoslav SFR
TUR	Turkey	NAWA	Turkey
EGY	Egypt	NAWA	Egypt
NAFR	Northern Africa	NAWA	Algeria, Libyan Arab Jamahiriya, Morocco, Syrian Arab Republic, Tunisia
RCEA	Rest of Central Asia	NAWA	Afghanistan, Armenia, Azerbaijan, Rep. Georgia, Kazakhstan, Korea DR, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan
RWEA	Rest of Western Asia	NAWA	Iran, Islamic Rep of, Iraq, Israel, Jordan, Kuwait, Lebanon, Palestine O.T., Saudi Arabia, United Arab Emirates, Yemen
ZAF	South Africa	SSAF	South Africa
SSAF	Rest of Sub-Saharan Africa	SSAF	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	China	EAS	China, Mainland; China, Hong Kong SAR; China, Macao SAR
JPN	Japan	JOCE	Japan
IND	India	SAS	India
RSAS	South Asia	SAS	Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka
IDN	Indonesia	SEA	Indonesia
RSEA	Rest of Southeast Asia	SEA	Cambodia, Korea Republic of, Laos, Malaysia, Myanmar, Philippines, Taiwan China Province, Thailand, Timor-Leste, Viet Nam
AUS	Australia	JOCE	Australia
ROCE	Ret of Oceania	JOCE	Fiji Islands, French Polynesia, Kiribati, New Caledonia, New Zealand, Samoa, Solomon Islands, Vanuatu

* see next page

Annex A-6. Continued

LANDFLOW: Names of major region codes

NAM = Northern America; EU28 = European Union; OEUR = Rest of Europe (i.e. Non-EU28) & Russia; CAM = Central America; SAM = Southern America; SAS = Southern Asia; SEAS = Southeast Asia; = CEAS Central and Eastern Asia; MENA = Middle East and Northern Africa; SSAF = Sub-Saharan Africa; JOCE = Japan & Oceania

Annex A-7. Linkage of regions between LANDFLOW and MRIO

LANDFLOW	MRIO	Countries
CAN	CAN	Canada
USA	USA	United States
MEX	LAM	Mexico
RCAM	LAM	Antigua, Bahamas, Barbados, Bermuda, Aruba, Belize, Cayman Is, Costa Rica, Cuba, Dominica, Dominican Rep., El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Martinique, Neth. Anti., Nicaragua, Panama, St Kitts Nev, St Lucia, St Vinc./Gren., Trinidad/Tob
BRA	LAM	Brazil
ARG	LAM	Argentina
RSAM	LAM	Bolivia, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
DEU	DEU	Germany
AUT	AUT	Austria
REU1	REU1	Belgium, Luxembourg, Denmark, Finland, France, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, United Kingdom
REU2	REU2	Bulgaria, Croatia, Cyprus, Czech Republic, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia
RUS	RUS	Russia
REUR	REUR	Albania, Belarus, Bosnia & Herzegovina, Rep. Moldova, Macedonia, Norway, Serbia & Montenegro, USSR, Ukraine, Switzerland, Yugoslav SFR
TUR	TUR	Turkey
EGY	MEA	Egypt
RWEA	MEA	Iran, Islamic Rep of, Iraq, Israel, Jordan, Kuwait, Lebanon, Palestine O.T., Saudi Arabia, United Arab Emirates, Yemen
NAFR	RAFR	Algeria, Libyan Arab Jamahiriya, Morocco, Syrian Arab Republic, Tunisia
ZAF	ZAF	South Africa
SSAF	RAFR	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	China, Mainland; China, HongKong SAR; China, Macao SAR
IND	IND	India
IDN	IDN	Indonesia
AUS	AUS	Australia
JPN	JPN	Japan
RCEA	RASI	Afghanistan, Armenia, Azerbaijan, Rep. Georgia, Kazakhstan, Korea DR, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan
RSEA	RASI	Cambodia, Korea Republic of, Laos, Malaysia, Myanmar, Philippines, Taiwan China Province, Thailand, Timor-Leste, Viet Nam
RSAS	RASI	Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka
ROCE	RASI	Fiji Islands, French Polynesia, Kiribati, New Caledonia, New Zealand, Samoa, Solomon Islands, Vanuatu

Annex A-8. Items definition in the FAOSTAT forest products database

Roundwood (1861)	Wood in its natural state as removed from forests and from trees outside forests; wood in the rough. - Wood in its natural state as felled, with or without bark. It may be round, split, roughly squared or in other forms.
Industrial roundwood (1865)	Roundwood that is used for industrial purposes, either in its round form (e.g. as transmission poles or piling) or as raw material to be processed into industrial products such as sawn wood, panel products or pulp. - The commodities included in this category are sawlogs or veneer logs, pulpwood and other industrial roundwood. In the case of trade, chips and particles and wood residues are also included.
Wood fuel (1864)	Wood that will be used "in the rough" as fuel for purposes such as cooking, heating or power generation; and wood that will be used for charcoal production.
Charcoal (1630)	Wood carbonized by partial combustion or application of heat from an external source. It is used as a fuel or for other uses.
Sawn wood (1872)	Wood (including sleepers) sawn lengthwise or produced by a profile-chipping process, and planed wood. – Sawn products produced from logs.
Wood-based panels (1873)	An aggregate term including the following commodities: veneer sheets, plywood, particle board and fibreboard. Particle board includes varieties such as oriented strand board (OSB) and flakeboard. Fibreboard includes hardboard, medium-density fibreboard (MDF) and insulation fibreboard.
Wood pulp (1875)	Wood pulp is the most common material used to make paper. It generally comes from softwood trees such as spruce, pine, fir, larch and hemlock, but also some hardwoods such as eucalyptus and birch. Wood pulp comprises all wood based pulp, including mechanical, semi-chemical, chemical and dissolving wood pulp.
Wood residues* (1620)	Miscellaneous wood residues. Wood residues which have not been reduced to small pieces. They consist principally of industrial residues, e.g. sawmill rejects, slabs, edgings and trimmings, veneer log cores, veneer rejects, sawdust, bark (excluding briquettes), residues from carpentry and joinery production, etc.
Chips and Particles* (1619)	Wood chips and particles. Wood that has been deliberately reduced to small pieces from wood in the rough or from industrial residues, suitable for pulping, for particle board and fibreboard production, for fuelwood or for other purposes.
Paper and paperboard (1876)	The following commodities are included in this aggregate: newsprint, printing and writing paper, other paper and paperboard. (It excludes manufactured paper products such as boxes, cartons, books and magazines.)
Recovered paper (1669)	Used paper and paperboard or residues from paper conversion that are collected for reuse as a raw material for the manufacture of paper, paperboard or other products.

Note: Numbers in brackets indicate commodity numbers used in the FAOSTAT database; * Until 1998 chips and particles and wood residues are only included in trade data. Source: FAO Yearbook of Forest Products (2000).

Annex B-1. Countries and country groups in EXIOBASE 3 and concordance with LANDFLOW

Country name	ISO code	EXIOBASE region name	EXIOBASE region code	LANDFLOW region code
Australia	AUS	Australia	AU	AUS
Brazil	BRA	Brazil	BR	BRA
China	CHN	China	CN	CHN
Germany	DEU	Germany	DE	DEU
Indonesia	IDN	Indonesia	ID	IDN
India	IND	India	IN	IND
Japan	JPN	Japan	JP	JPN
Mexico	MEX	Mexico	MX	MEX
Russia	RUS	Russia	RU	RUS
Turkey	TUR	Turkey	TR	TUR
United States of America	USA	United States	US	USA
South Africa	ZAF	South Africa	ZA	ZAF
Afghanistan	AFG	RoW Asia and Pacific	WA	CEA
Kazakhstan	KAZ	RoW Asia and Pacific	WA	CEA
Kyrgyz Republic	KGZ	RoW Asia and Pacific	WA	CEA
Tajikistan	TJK	RoW Asia and Pacific	WA	CEA
Turkmenistan	TKM	RoW Asia and Pacific	WA	CEA
Uzbekistan	UZB	RoW Asia and Pacific	WA	CEA
Armenia	ARM	RoW Asia and Pacific	WA	CEA
Azerbaijan	AZE	RoW Asia and Pacific	WA	CEA
Georgia	GEO	RoW Asia and Pacific	WA	CEA
Hong Kong SAR, China	HKG	RoW Asia and Pacific	WA	CHN
Macao SAR, China	MAC	RoW Asia and Pacific	WA	CHN
Taiwan	TWN	Taiwan	TW	CHN
Bahrain	BHR	RoW Middle East	WM	MIEA
Iran, Islamic Rep.	IRN	RoW Middle East	WM	MIEA
Iraq	IRQ	RoW Middle East	WM	MIEA
Israel	ISR	RoW Middle East	WM	MIEA
Jordan	JOR	RoW Middle East	WM	MIEA
Kuwait	KWT	RoW Middle East	WM	MIEA
Lebanon	LBN	RoW Middle East	WM	MIEA
Oman	OMN	RoW Middle East	WM	MIEA

Palestine	PAL	RoW Middle East	WM	MIEA
Qatar	QAT	RoW Middle East	WM	MIEA
Saudi Arabia	SAU	RoW Middle East	WM	MIEA
Syrian Arab Republic	SYR	RoW Middle East	WM	MIEA
United Arab Emirates	ARE	RoW Middle East	WM	MIEA
Yemen, Rep.	YEM	RoW Middle East	WM	MIEA
Egypt, Arab Rep.	EGY	RoW Middle East	WM	MIEA
Algeria	DZA	RoW Africa	WF	NAF
Libya	LBY	RoW Africa	WF	NAF
Morocco	MAR	RoW Africa	WF	NAF
Tunisia	TUN	RoW Africa	WF	NAF
Western Sahara	ESH	RoW Africa	WF	NAF
Anguilla	AIA	RoW America	WL	R-CAM
Antigua and Barbuda	ATG	RoW America	WL	R-CAM
Aruba	ABW	RoW America	WL	R-CAM
Bahamas, The	BHS	RoW America	WL	R-CAM
Barbados	BRB	RoW America	WL	R-CAM
Belize	BLZ	RoW America	WL	R-CAM
Bonaire, Saint Eustatius and Saba	BES	RoW America	WL	R-CAM
Cayman islands	CYM	RoW America	WL	R-CAM
Costa Rica	CRI	RoW America	WL	R-CAM
Cuba	CUB	RoW America	WL	R-CAM
Curaçao	CUW	RoW America	WL	R-CAM
Dominica	DMA	RoW America	WL	R-CAM
Dominican Republic	DOM	RoW America	WL	R-CAM
El Salvador	SLV	RoW America	WL	R-CAM
Grenada	GRD	RoW America	WL	R-CAM
Guadeloupe	GLP	RoW America	WL	R-CAM
Guatemala	GTM	RoW America	WL	R-CAM
Haiti	HTI	RoW America	WL	R-CAM
Honduras	HND	RoW America	WL	R-CAM
Jamaica	JAM	RoW America	WL	R-CAM
Martinique	MTQ	RoW America	WL	R-CAM
Montserrat	MSR	RoW America	WL	R-CAM
Nicaragua	NIC	RoW America	WL	R-CAM
Panama	PAN	RoW America	WL	R-CAM

Puerto Rico	PRI	RoW America	WL	R-CAM
Sint Maarten (Dutch part)	SXM	RoW America	WL	R-CAM
St. Kitts and Nevis	KNA	RoW America	WL	R-CAM
St. Lucia	LCA	RoW America	WL	R-CAM
St. Vincent and the Grenadines	VCT	RoW America	WL	R-CAM
Trinidad and Tobago	TTO	RoW America	WL	R-CAM
Turks and Caicos islands	TCA	RoW America	WL	R-CAM
Virgin islands (British)	VGB	RoW America	WL	R-CAM
Virgin islands (US)	VIR	RoW America	WL	R-CAM
Korea, Democratic People's Re-public of	PRK	RoW Asia and Pacific	WA	R-EAS
Mongolia	MNG	RoW Asia and Pacific	WA	R-EAS
South Korea	KOR	South Korea	KR	R-EAS
Romania	ROM	Romania	RO	R-EU28
Slovakia	SVK	Slovakia	SK	R-EU28
Bulgaria	BGR	Bulgaria	BG	R-EU28
Austria	AUT	Austria	AT	AUT
Belgium	BEL	Belgium	BE	R-EU28
Croatia	HRV	Croatia	HR	R-EU28
Denmark	DNK	Denmark	DK	R-EU28
Estonia	EST	Estonia	EE	R-EU28
Finland	FIN	Finland	FI	R-EU28
France	FRA	France	FR	R-EU28
Greece	GRC	Greece	GR	R-EU28
Ireland	IRL	Ireland	IE	R-EU28
Italy	ITA	Italy	IT	R-EU28
Latvia	LVA	Latvia	LV	R-EU28
Lithuania	LTU	Lithuania	LT	R-EU28
Luxembourg	LUX	Luxembourg	LU	R-EU28
Malta	MLT	Malta	MT	R-EU28
Netherlands	NLD	Netherlands	NL	R-EU28
Portugal	PRT	Portugal	PT	R-EU28
Slovenia	SVN	Slovenia	SI	R-EU28
Spain	ESP	Spain	ES	R-EU28
Sweden	SWE	Sweden	SE	R-EU28
United Kingdom	GBR	United Kingdom	GB	R-EU28
Cyprus	CYP	Cyprus	CY	R-EU28

Czech Republic	CZE	Czech Republic	CZ	R-EU28
Hungary	HUN	Hungary	HU	R-EU28
Poland	POL	Poland	PL	R-EU28
Norway	NOR	Norway	NO	R-EUR
Albania	ALB	RoW Europe	WE	R-EUR
Andorra	AND	RoW Europe	WE	R-EUR
Belarus	BLR	RoW Europe	WE	R-EUR
Bosnia and Herzegovina	BIH	RoW Europe	WE	R-EUR
Channel Islands	CHI	RoW Europe	WE	R-EUR
Faeroe Islands	FRO	RoW Europe	WE	R-EUR
Gibraltar	GIB	RoW Europe	WE	R-EUR
Iceland	ISL	RoW Europe	WE	R-EUR
Isle of Man	IMY	RoW Europe	WE	R-EUR
Kosovo	KSV	RoW Europe	WE	R-EUR
Liechtenstein	LIE	RoW Europe	WE	R-EUR
Macedonia, FYR	MKD	RoW Europe	WE	R-EUR
Moldova	MDA	RoW Europe	WE	R-EUR
Monaco	MCO	RoW Europe	WE	R-EUR
Montenegro	MNE	RoW Europe	WE	R-EUR
San Marino	SMR	RoW Europe	WE	R-EUR
Serbia	SRB	RoW Europe	WE	R-EUR
Svalbard and Jan Mayen Islands	SJM	RoW Europe	WE	R-EUR
Ukraine	UKR	RoW Europe	WE	R-EUR
Vatican City State (Holy See)	VAT	RoW Europe	WE	R-EUR
Switzerland	CHE	Switzerland	CH	R-EUR
Canada	CAN	Canada	CA	R-NAM
Bermuda	BMU	RoW America	WL	R-NAM
Greenland	GRL	RoW America	WL	R-NAM
St. Pierre and Miquelon	SPM	RoW America	WL	R-NAM
American Samoa	ASM	RoW Asia and Pacific	WA	R-OCE
Christmas Island	CXR	RoW Asia and Pacific	WA	R-OCE
Cook islands	COK	RoW Asia and Pacific	WA	R-OCE
Fiji	FJI	RoW Asia and Pacific	WA	R-OCE
French Polynesia	PYF	RoW Asia and Pacific	WA	R-OCE
Guam	GUM	RoW Asia and Pacific	WA	R-OCE
Kiribati	KIR	RoW Asia and Pacific	WA	R-OCE
Marshall Islands	MHL	RoW Asia and Pacific	WA	R-OCE

Micronesia, Fed. Sts.	FSM	RoW Asia and Pacific	WA	R-OCE
Nauru	NRU	RoW Asia and Pacific	WA	R-OCE
New Caledonia	NCL	RoW Asia and Pacific	WA	R-OCE
New Zealand	NZL	RoW Asia and Pacific	WA	R-OCE
Niue	NIU	RoW Asia and Pacific	WA	R-OCE
Norfolk Island	NFK	RoW Asia and Pacific	WA	R-OCE
Northern Mariana Islands	MNP	RoW Asia and Pacific	WA	R-OCE
Palau	PLW	RoW Asia and Pacific	WA	R-OCE
Papua New Guinea	PNG	RoW Asia and Pacific	WA	R-OCE
Pitcairn	PCN	RoW Asia and Pacific	WA	R-OCE
Samoa	WSM	RoW Asia and Pacific	WA	R-OCE
Solomon Islands	SLB	RoW Asia and Pacific	WA	R-OCE
Tokelau	TKL	RoW Asia and Pacific	WA	R-OCE
Tonga	TON	RoW Asia and Pacific	WA	R-OCE
Tuvalu	TUV	RoW Asia and Pacific	WA	R-OCE
United States Minor Outlying Islands	UMI	RoW Asia and Pacific	WA	R-OCE
Vanuatu	VUT	RoW Asia and Pacific	WA	R-OCE
Wallis and Futuna Islands	WLF	RoW Asia and Pacific	WA	R-OCE
British Indian Ocean Territory	IOT	RoW Asia and Pacific	WA	ROW
Cocos (Keeling) Islands	CCK	RoW Asia and Pacific	WA	ROW
Heard and McDonald Islands	HMD	RoW Asia and Pacific	WA	ROW
French Guiana	GUF	RoW America	WL	R-SAM
Argentina	ARG	RoW America	WL	R-SAM
Bolivia	BOL	RoW America	WL	R-SAM
Chile	CHL	RoW America	WL	R-SAM
Colombia	COL	RoW America	WL	R-SAM
Ecuador	ECU	RoW America	WL	R-SAM
Falkland Islands (Malvinas)	FLK	RoW America	WL	R-SAM
Guyana	GUY	RoW America	WL	R-SAM
Netherlands Antilles	ANT	RoW America	WL	R-SAM
Paraguay	PRY	RoW America	WL	R-SAM
Peru	PER	RoW America	WL	R-SAM
Suriname	SUR	RoW America	WL	R-SAM
Uruguay	URY	RoW America	WL	R-SAM
Venezuela, RB	VEN	RoW America	WL	R-SAM
Bangladesh	BGD	RoW Asia and Pacific	WA	R-SAS

Bhutan	BTN	RoW Asia and Pacific	WA	R-SAS
Maldives	MDV	RoW Asia and Pacific	WA	R-SAS
Nepal	NPL	RoW Asia and Pacific	WA	R-SAS
Pakistan	PAK	RoW Asia and Pacific	WA	R-SAS
Sri Lanka	LKA	RoW Asia and Pacific	WA	R-SAS
Myanmar	MMR	RoW Asia and Pacific	WA	R-SEA
Brunei Darussalam	BRN	RoW Asia and Pacific	WA	R-SEA
Cambodia	KHM	RoW Asia and Pacific	WA	R-SEA
Lao PDR	LAO	RoW Asia and Pacific	WA	R-SEA
Malaysia	MYS	RoW Asia and Pacific	WA	R-SEA
Philippines	PHL	RoW Asia and Pacific	WA	R-SEA
Singapore	SGP	RoW Asia and Pacific	WA	R-SEA
Thailand	THA	RoW Asia and Pacific	WA	R-SEA
Timor-Leste	TMP	RoW Asia and Pacific	WA	R-SEA
Vietnam	VNM	RoW Asia and Pacific	WA	R-SEA
Sudan	SDN	RoW Africa	WF	R-SSAF
Angola	AGO	RoW Africa	WF	R-SSAF
Benin	BEN	RoW Africa	WF	R-SSAF
Botswana	BWA	RoW Africa	WF	R-SSAF
Burkina Faso	BFA	RoW Africa	WF	R-SSAF
Burundi	BDI	RoW Africa	WF	R-SSAF
Cameroon	CMR	RoW Africa	WF	R-SSAF
Cape Verde	CPV	RoW Africa	WF	R-SSAF
Central African Republic	CAF	RoW Africa	WF	R-SSAF
Chad	TCD	RoW Africa	WF	R-SSAF
Comoros	COM	RoW Africa	WF	R-SSAF
Congo, Dem. Rep.	COD	RoW Africa	WF	R-SSAF
Congo, Rep.	COG	RoW Africa	WF	R-SSAF
Cote d'Ivoire	CIV	RoW Africa	WF	R-SSAF
Djibouti	DJI	RoW Africa	WF	R-SSAF
Equatorial Guinea	GNQ	RoW Africa	WF	R-SSAF
Eritrea	ERI	RoW Africa	WF	R-SSAF
Ethiopia	ETH	RoW Africa	WF	R-SSAF
Gabon	GAB	RoW Africa	WF	R-SSAF
Gambia, The	GMB	RoW Africa	WF	R-SSAF
Ghana	GHA	RoW Africa	WF	R-SSAF
Guinea	GIN	RoW Africa	WF	R-SSAF

Guinea-Bissau	GNB	RoW Africa	WF	R-SSAF
Kenya	KEN	RoW Africa	WF	R-SSAF
Lesotho	LSO	RoW Africa	WF	R-SSAF
Liberia	LBR	RoW Africa	WF	R-SSAF
Madagascar	MDG	RoW Africa	WF	R-SSAF
Malawi	MWI	RoW Africa	WF	R-SSAF
Mali	MLI	RoW Africa	WF	R-SSAF
Mauritania	MRT	RoW Africa	WF	R-SSAF
Mauritius	MUS	RoW Africa	WF	R-SSAF
Mayotte	MYT	RoW Africa	WF	R-SSAF
Mozambique	MOZ	RoW Africa	WF	R-SSAF
Namibia	NAM	RoW Africa	WF	R-SSAF
Niger	NER	RoW Africa	WF	R-SSAF
Nigeria	NGA	RoW Africa	WF	R-SSAF
Reunion	REU	RoW Africa	WF	R-SSAF
Rwanda	RWA	RoW Africa	WF	R-SSAF
Sao Tome and Principe	STP	RoW Africa	WF	R-SSAF
Senegal	SEN	RoW Africa	WF	R-SSAF
Seychelles	SYC	RoW Africa	WF	R-SSAF
Sierra Leone	SLE	RoW Africa	WF	R-SSAF
Somalia	SOM	RoW Africa	WF	R-SSAF
South Sudan	SSD	RoW Africa	WF	R-SSAF
St. Helena	SHN	RoW Africa	WF	R-SSAF
Swaziland	SWZ	RoW Africa	WF	R-SSAF
Tanzania	TZA	RoW Africa	WF	R-SSAF
Togo	TGO	RoW Africa	WF	R-SSAF
Uganda	UGA	RoW Africa	WF	R-SSAF
Zambia	ZMB	RoW Africa	WF	R-SSAF
Zimbabwe	ZWE	RoW Africa	WF	R-SSAF

Annex B-2. Commodities in EXIOBASE 3

Nr	Code	Product group
1	p01.a	Paddy rice
2	p01.b	Wheat
3	p01.c	Cereal grains nec
4	p01.d	Vegetables, fruit, nuts
5	p01.e	Oil seeds
6	p01.f	Sugar cane, sugar beet
7	p01.g	Plant-based fibers
8	p01.h	Crops nec
9	p01.i	Cattle
10	p01.j	Pigs
11	p01.k	Poultry
12	p01.l	Meat animals nec
13	p01.m	Animal products nec
14	p01.n	Raw milk
15	p01.o	Wool, silk-worm cocoons
16	p01.w.1	Manure (conventional treatment)
17	p01.w.2	Manure (biogas treatment)
18	p02	Products of forestry, logging and related services
19	p05	Fish and other fishing products; services incidental of fishing
20	p10.a	Anthracite
21	p10.b	Coking Coal
22	p10.c	Other Bituminous Coal
23	p10.d	Sub-Bituminous Coal
24	p10.e	Patent Fuel
25	p10.f	Lignite/Brown Coal
26	p10.g	BKB/Peat Briquettes
27	p10.h	Peat
28	p11.a	Crude petroleum and services related to crude oil extraction, excluding surveying
29	p11.b	Natural gas and services related to natural gas extraction, excluding surveying
30	p11.b.1	Natural Gas Liquids
31	p11.c	Other Hydrocarbons
32	p12	Uranium and thorium ores
33	p13.1	Iron ores
34	p13.20.11	Copper ores and concentrates
35	p13.20.12	Nickel ores and concentrates
36	p13.20.13	Aluminium ores and concentrates
37	p13.20.14	Precious metal ores and concentrates
38	p13.20.15	Lead, zinc and tin ores and concentrates
39	p13.20.16	Other non-ferrous metal ores and concentrates
40	p14.1	Stone

41	p14.2	Sand and clay
42	p14.3	Chemical and fertilizer minerals, salt and other mining and quarrying products n.e.c.
43	p15.a	Products of meat cattle
44	p15.b	Products of meat pigs
45	p15.c	Products of meat poultry
46	p15.d	Meat products nec
47	p15.e	products of Vegetable oils and fats
48	p15.f	Dairy products
49	p15.g	Processed rice
50	p15.h	Sugar
51	p15.i	Food products nec
52	p15.j	Beverages
53	p15.k	Fish products
54	p16	Tobacco products
55	p17	Textiles
56	p18	Wearing apparel; furs
57	p19	Leather and leather products
58	p20	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials
59	p20.w	Wood material for treatment, Re-processing of secondary wood material into new wood material
60	p21.1	Pulp
61	p21.w.1	Secondary paper for treatment, Re-processing of secondary paper into new pulp
62	p21.2	Paper and paper products
63	p22	Printed matter and recorded media
64	p23.1.a	Coke Oven Coke
65	p23.1.b	Gas Coke
66	p23.1.c	Coal Tar
67	p23.20.a	Motor Gasoline
68	p23.20.b	Aviation Gasoline
69	p23.20.c	Gasoline Type Jet Fuel
70	p23.20.d	Kerosene Type Jet Fuel
71	p23.20.e	Kerosene
72	p23.20.f	Gas/Diesel Oil
73	p23.20.g	Heavy Fuel Oil
74	p23.20.h	Refinery Gas
75	p23.20.i	Liquefied Petroleum Gases (LPG)
76	p23.20.j	Refinery Feedstocks
77	p23.20.k	Ethane
78	p23.20.l	Naphtha
79	p23.20.m	White Spirit & SBP
80	p23.20.n	Lubricants
81	p23.20.o	Bitumen
82	p23.20.p	Paraffin Waxes
83	p23.20.q	Petroleum Coke

84	p23.20.r	Non-specified Petroleum Products
85	p23.3	Nuclear fuel
86	p24.a	Plastics, basic
87	p24.a.w	Secondary plastic for treatment, Re-processing of secondary plastic into new plastic
88	p24.b	N-fertiliser
89	p24.c	P- and other fertiliser
90	p24.d	Chemicals nec
91	p24.e	Charcoal
92	p24.f	Additives/Blending Components
93	p24.g	Biogasoline
94	p24.h	Biodiesels
95	p24.i	Other Liquid Biofuels
96	p25	Rubber and plastic products
97	p26.a	Glass and glass products
98	p26.w.1	Secondary glass for treatment, Re-processing of secondary glass into new glass
99	p26.b	Ceramic goods
100	p26.c	Bricks, tiles and construction products, in baked clay
101	p26.d	Cement, lime and plaster
102	p26.d.w	Ash for treatment, Re-processing of ash into clinker
103	p26.e	Other non-metallic mineral products
104	p27.a	Basic iron and steel and of ferro-alloys and first products thereof
105	p27.a.w	Secondary steel for treatment, Re-processing of secondary steel into new steel
106	p27.41	Precious metals
107	p27.41.w	Secondary preciuos metals for treatment, Re-processing of secondary preciuos metals into new preciuos metals
108	p27.42	Aluminium and aluminium products
109	p27.42.w	Secondary aluminium for treatment, Re-processing of secondary aluminium into new aluminium
110	p27.43	Lead, zinc and tin and products thereof
111	p27.43.w	Secondary lead for treatment, Re-processing of secondary lead into new lead
112	p27.44	Copper products
113	p27.44.w	Secondary copper for treatment, Re-processing of secondary copper into new copper
114	p27.45	Other non-ferrous metal products
115	p27.45.w	Secondary other non-ferrous metals for treatment, Re-processing of secondary other non-ferrous metals into new other non-ferrous metals
116	p27.5	Foundry work services
117	p28	Fabricated metal products, except machinery and equipment
118	p29	Machinery and equipment n.e.c.
119	p30	Office machinery and computers
120	p31	Electrical machinery and apparatus n.e.c.
121	p32	Radio, television and communication equipment and apparatus
122	p33	Medical, precision and optical instruments, watches and clocks
123	p34	Motor vehicles, trailers and semi-trailers
124	p35	Other transport equipment

125	p36	Furniture; other manufactured goods n.e.c.
126	p37	Secondary raw materials
127	p37.w.1	Bottles for treatment, Recycling of bottles by direct reuse
128	p40.11.a	Electricity by coal
129	p40.11.b	Electricity by gas
130	p40.11.c	Electricity by nuclear
131	p40.11.d	Electricity by hydro
132	p40.11.e	Electricity by wind
133	p40.11.f	Electricity by petroleum and other oil derivatives
134	p40.11.g	Electricity by biomass and waste
135	p40.11.h	Electricity by solar photovoltaic
136	p40.11.i	Electricity by solar thermal
137	p40.11.j	Electricity by tide, wave, ocean
138	p40.11.k	Electricity by Geothermal
139	p40.11.l	Electricity nec
140	p40.12	Transmission services of electricity
141	p40.13	Distribution and trade services of electricity
142	p40.2.a	Coke oven gas
143	p40.2.b	Blast Furnace Gas
144	p40.2.c	Oxygen Steel Furnace Gas
145	p40.2.d	Gas Works Gas
146	p40.2.e	Biogas
147	p40.2.1	Distribution services of gaseous fuels through mains
148	p40.3	Steam and hot water supply services
149	p41	Collected and purified water, distribution services of water
150	p45	Construction work
151	p45.w	Secondary construction material for treatment, Re-processing of secondary construction material into aggregates
152	p50.a	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories
153	p50.b	Retail trade services of motor fuel
154	p51	Wholesale trade and commission trade services, except of motor vehicles and motorcycles
155	p52	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods
156	p55	Hotel and restaurant services
157	p60.1	Railway transportation services
158	p60.2	Other land transportation services
159	p60.3	Transportation services via pipelines
160	p61.1	Sea and coastal water transportation services
161	p61.2	Inland water transportation services
162	p62	Air transport services
163	p63	Supporting and auxiliary transport services; travel agency services
164	p64	Post and telecommunication services
165	p65	Financial intermediation services, except insurance and pension funding services

166	p66	Insurance and pension funding services, except compulsory social security services
167	p67	Services auxiliary to financial intermediation
168	p70	Real estate services
169	p71	Renting services of machinery and equipment without operator and of personal and household goods
170	p72	Computer and related services
171	p73	Research and development services
172	p74	Other business services
173	p75	Public administration and defence services; compulsory social security services
174	p80	Education services
175	p85	Health and social work services
176	p90.1.a	Food waste for treatment: incineration
177	p90.1.b	Paper waste for treatment: incineration
178	p90.1.c	Plastic waste for treatment: incineration
179	p90.1.d	Intert/metal waste for treatment: incineration
180	p90.1.e	Textiles waste for treatment: incineration
181	p90.1.f	Wood waste for treatment: incineration
182	p90.1.g	Oil/hazardous waste for treatment: incineration
183	p90.2.a	Food waste for treatment: biogasification and land application
184	p90.2.b	Paper waste for treatment: biogasification and land application
185	p90.2.c	Sewage sludge for treatment: biogasification and land application
186	p90.3.a	Food waste for treatment: composting and land application
187	p90.3.b	Paper and wood waste for treatment: composting and land application
188	p90.4.a	Food waste for treatment: waste water treatment
189	p90.4.b	Other waste for treatment: waste water treatment
190	p90.5.a	Food waste for treatment: landfill
191	p90.5.b	Paper for treatment: landfill
192	p90.5.c	Plastic waste for treatment: landfill
193	p90.5.d	Inert/metal/hazardous waste for treatment: landfill
194	p90.5.e	Textiles waste for treatment: landfill
195	p90.5.f	Wood waste for treatment: landfill
196	p91	Membership organisation services n.e.c.
197	p92	Recreational, cultural and sporting services
198	p93	Other services
199	p95	Private households with employed persons
200	p99	Extra-territorial organizations and bodies

Annex B-3. Non-food commodities tracked with the MRIO model

Nr	Commodity
1	Wheat
2	Rice
3	Maize
4	Other cereals
5	Roots & Pulses
6	Sugar crops (primary)
7	Sugar & Sweetener & Molasse
8	Oil crops (primary)
9	Vegetable oil
10	Oil cakes
11	Fruit, vegetables, spices
12	Stimulants
13	Tobacco
14	Rubber
15	Other industrial crops
16	Alcohol, non-food
17	Fodder
18	Meat, ruminants
19	Milk
20	Hides & Skins, Wool, ruminants
21	Meat, monogastrics
22	Eggs
23	Hides & Skins, monogastrics
24	Timber
25	Panels
26	Pulp

Note: Non-food commodities are listed here with the names of the SUA items they are derived from.