UNISECO

UNDERSTANDING & IMPROVING THE SUSTAINABILITY OF AGRO-ECOLOGICAL FARMING SYSTEMS IN THE EU

Deliverable Report 4.1

Report on the methodological specification of the spatially-explicit modelling framework

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EXECUTIVE SUMMARY

The UNISECO project aims to provide recommendations on how the sustainability of agro-ecological farming systems (AEFS) in Europe can be promoted. These recommendations build also upon model-based upscaling to territorial level of case-study based results on various AEFS throughout the partner countries. This deliverable in detail describes the models to do this upscaling, starting with the general context, the description of the conceptual aspects of the mass- and nutrient-flow modelling as used in UNISECO, and then the detailed description of the two biophysical models employed for this.

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1 INTRODUCTION

This deliverable D4.1 (“Report on methodological specification of the spatially-explicit modelling framework”) is part of WP4 (“Assessment at territorial level”), Task 4.2. The task description for Task 4.2 reads as follows:

Environmental impacts will be calculated based on the detailed agricultural information on biomass flows from production to consumption side gathered in Task 4.1, i.e. from agricultural production systems to final consumers. It will follow IPCC approaches for the assessment of activity-based GHG emissions from agriculture and land use, including upstream emissions (from e.g. transport, fertilizer production), and systematically assess Nitrogen and Phosphorous flows and surplus/deficits. Land-use information provided by the BioBaM-SOLm model will be used to assess changes in land use patterns as well as in ecological stocks and flows. This will provide the basis to explore biodiversity pressures (using information on species-area relationships and species energy relationships from the literature), as well as assess water demand and, in combination with climate information (precipitation, water availability of rivers), water use (following standard approaches such as the water footprint). Impacts on animal health and welfare are assessed by using indicators such as expected health improvements/deteriorations from changes in livestock efficiencies and management (based on literature data) as well as access to e.g. roaming space and other possibilities to influence natural behaviours (input to D4.2 – Task 4.3). These indicators are assessed on an animal head basis and then summed to provide indications on the level of pressures/risks for deterioration or improvement of these indicators on aggregate under various scenarios. Socio-economic and other societal indicators are assessed by linking production volumes or cropping areas to per ton or hectare impacts, combined with regional pressure or risk indicators, such as for increased child labour (e.g. from the Social Hot Spot Database). This again results in indications on the level of pressures/risks for deterioration or improvement of these indicators on aggregate under various scenarios.

Task 4.2 will compile and analyse spatially explicit information on environmental and socioeconomic conditions that determine the actual and potential distribution of farming types as well as the identification and quantification of major trajectories related to European and global land use (including changes in diets, yields, feeding conversion rates, land demand, etc.). These conditions will be used to open up an option space of the European farming system (cf. sections 5 and 7.3.1) and will rely on, and extend, the well-established, existing global assessments by BioBaM and SOLm. Results from the participatory scenario development (Task 4.3) will be used to assess the feasibility and desirability of modelling variations within the option space (D4.1).

This document provides the methodological description of the modelling framework. Two biophysical models are applied in UNISECO, BioBaM and SOLm. In part I, this documentation describes how these models are used in combination to provide the territorial assessment for UNISECO. In parts II and III, the two models are each described in more detail separately.

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PART I: COUPLED MODEL

2 MODEL COUPLING

Generally, BioBam has a focus on spatially explicit mass, carbon and energy flows, being based on the embodied Human Appropriation of Net Primary Production (HANPP) framework, which are then aggregated to assess the agricultural production on the level of geographic regions, such as e.g. countries or NUTS2 regions, and using data from the CAPRI model (to a large extent based on EUROSTAT) as a core data basis for the baseline. Details on BioBaM are provided in part II, sections 3 to 6.

SOLm has a focus on the mass and nutrient flows related to global agricultural production and commodity flows at country level (or finer, such as NUTS2, if data is available). It is not spatially explicit, but covers animal production systems, manure management, nitrogen and phosphorus in more detail and also traces commodities on the food system level. The core data basis for SOLm is FAOSTAT, including the detailed TRADESTAT, etc. Details on SOLm are provided in part III, sections 7 to 9.

In this, the two models complement each other in several ways to achieve the goals of the territorial assessment in UNISECO.

First, the two models provide some input to each other that is not at all available or only available in less refined form without the calculations from the respective other model (e.g. grassland yields derived from the HANPP-framework are also used in SOLm; organic production data is more refined in SOLm).

Second, they provide partly the same basic key indicators to assess scenarios of future agroecological developments in the EU, partly using the same data (e.g. the NUTS2 data described below) and calculation procedures (e.g. (IPCC 2006) equations for GHG emissions), partly using different data sources (e.g. data from CAPRI and FAOSTAT, etc.) and calculations (e.g. feed allocation to animals). This allows for specific consistency checks of the results of the two models. When using the same data with the same equations, results for the same indicator should be identical or very close for the two models. When using different data and calculations, potential differences in results for the same indicator need to be well understood and add to improved understanding of them.

Third, each of the two models provides a range of indicators that are not covered in the other, thus complementing each other in these results indicators (e.g. HANPP-flows for BioBaM, Phosphorus or water use in SOLm).

Generally, the two models are run in parallel, starting from the scenario assumptions, as needed for each of the models to capture the same scenario. Certain results are then exchanged to further refine results, such as e.g. using embodied HANPP values from BioBaM in SOLM to link this indicator to commodities' trade on food system level.

2.1 Land use in UNISECO

An important common data base for BioBaM and SOLm is land use and production on the European NUTS2 level (EU28 excluding Cyprus and Malta), covering 227 NUTS1 and NUTS2 regions for the year

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2012. This year was chosen as the most recent where most relevant input data was available. We constructed a consistent and comprehensive biomass flow and land-use dataset that covers the entire agricultural production, i.e. cropland and grassland areas and production. Data for forest area and harvest (despite partly being part of agricultural production), as well as land areas under non-agricultural use (other land, urban and infrastructure areas) are not considered in UNISECO.

2.2 FADN data

A second common data basis is FADN data, to be used for 1) downscaling NUTS2 data to the level of clusters of farms and 2) model certain impacts on social, economic and environmental parameters. While officially available FADN provides average data per farming system and economic size of the farm at NUTS2 level, the implementation of agro-ecological farming innovations needs more disaggregated data, i.e. at sub-nuts2 level, or spatially explicit data, about the distribution of farms within NUTS2 regions. Examples here would be the number and types of farms that manage high natural value farmlands, as well as detailed (biophysical) data on livestock and cropland management. Only then, BioBaM and SOLm can assess the feasibility and impacts of AEFS innovations for land use patterns and land cover, biodiversity, and GHG emissions. The feasibility of using FADN data will be explored in a scoping exercise only in 2020 due to the late access to the database that was only granted in late 2019.

PART II: BIOBAM

3 INTRODUCTION BIOBAM

3.1 Conceptual background and framework of BioBaM

The methodological framework followed to establishing the database are the economy-wide Material and Energy flow analysis framework (Haberl et al. 2004a; Krausmann et al. 2004; Fischer-Kowalski et al. 2011) and its pendant in land system science, the embodied Human Appropriation of Net Primary Production (HANPP) framework (Erb et al. 2009c; Haberl et al. 2016, 2014, 2009). This framework is built upon first principles and accounts for all material (including biomass) flows between society and natural systems as well as between social systems, following the law of mass conservation.

Material and Energy flow accounting aims to provide a biophysical representation of society-nature interactions that complements monetary economic accounting systems. It quantifies all material flows into and out of a socioeconomic system, accounting for solid, gaseous and liquid materials excluding water and air (Mayer et al. 2016), and tracing material flows from the production to the consumption side of the economy. However, MEFA only accounts for socioeconomic flows and does not quantify flows that occur in ecosystems, for instance. Ecological Productivity, e.g. measured in terms of net primary production (NPP, the difference between gross primary production – GPP - and plant respiration), is key for agricultural production and essential material services provided by ecosystems to society. NPP represents the origin of all biomass consumed by humans. Therefore, the inclusion of ecological processes and flows is key for the analysis of agricultural systems, or, more generally, of the land systems and their dynamics (Haberl et al. 2014; Mayer et al. submitted). The HANPP framework considers this and quantifies the effect of land use on the availability of energy in

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ecosystems.

The HANPP framework aims at integrating two effects of land-use: a) it accounts for the effect of changes in NPP induced by the replacement of natural ecosystems, such as forests and grasslands, with ecosystems utilized by humans (e.g. settlement areas, agricultural ecosystems and managed forests). The NPP of these ecosystems often differs significantly from that of natural ecosystems, accounted for as HANPPluc in the HANPP framework (where the luc stand for land use change); b) HANPP accounts for the amount of biomass that is extracted from ecosystems in the form of harvest of biomass (denoted as HANPPharv; harv for harvested). The sum of these two processes result in the overall HANPP, which can be measured as biomass flows in dry matter, in t dm/yr, or in percent of the potential (i.e. prevailing in the hypothetical absence of land use) NPP.

As such, HANPP represents a framework to assess land-use intensity and which allows to consistently integrate data for accounts of society-nature interactions (Plutzar et al. 2016). HANPP assessments study the impact of land-use with a spatial unit, from the plot to the national or global scale (Bartels et al. 2017; Gingrich et al. 2015; Haberl et al. 2007a; Krausmann et al. 2013b). Its suitability for UNISECO is based on the systematic and unambiguous classification of relevant biomass flows, e.g. discerning primary products such as cereals, used and unused residues, above- and belowground flows, etc. These biomass flows are consistently linked to spatially-explicit land-use data (e.g. specific cropland area). The HANPP framework allows for assessments across all land uses, which renders it highly suitable for trade-off analyses (Erb et al. 2009b). However, society does not only affect the ecosystems that belong to its territory (Erb et al. 2009c; Fischer-Kowalski and Erb 2016). Via trade, a group, population or nation also affects and appropriates ecological energy flows that occur in distant places. The concept of embodied HANPP (eHANPP) combines the HANPP and the material flow approaches and accounts for the amount of HANPP that is associated with the consumption of final biomass products, within and outside the territory. A prerequisite to provide consistent accounts is the comprehensive differentiation of socioeconomic compartments through which biomass is flowing, such as the one presented in Figure 1.

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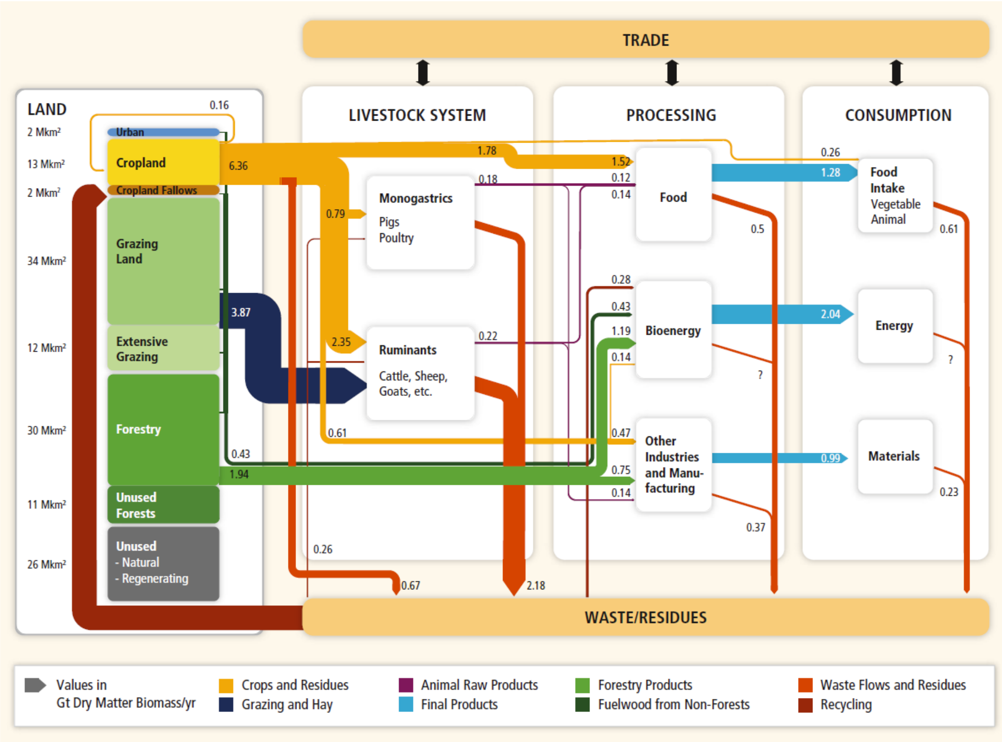

Figure 1. Schematic representation of a comprehensive account of socioecological biomass flows from production to consumption, example of global carbon flows. Source: (Smith et al. 2014). A conceptually similar account, albeit at much higher thematic resolution for agriculture (app. 40 cultivars on cropland, 20 livestock subgroups, for instance) and less focus on other sectors is established for all NUTS-2 regions in the biophysical database documented here.

Such accounts provide the basis for the territory-level scenario analyses in UNISECO. They are the basis for a description of the current biophysical status of the European biomass flow and land use system that will be used for assessing the effects of the implementation of agro-ecological innovations in Europe and abroad. However, we only use the concept presented in Figure 1 as a starting point for establishing data at NUTS-2 level. Thus, land that is currently used for forestry is not part of the database, albeit afforestation or vegetation regrowth on eventually freed-up land due to lower demand in the future will be included in BioBaM.

3.2 Data sources for the reference year 2012

This section describes the baseline data used in BioBam.

3.2.1 The European biomass flow and HANPP database: area, potential and actual NPP

Data on current and potential NPP flows (NPP) was taken from a spatially explicit HANPP assessment database (Plutzar et al. 2016) and was aggregated to the European NUTS2 level (Mayer et al., under review). This database

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contains land use intensities for the year 2006 which were applied to current (i.e. 2012) land use and biomass flows. This approach was not considered to be problematic due to the following reasons: First, the existing HANPP database is characterized by a high degree of internal consistency between all discerned biomass flows that renders it highly suitable for the work envisaged in UNISECO and overcompensates for the inconsistency introduced by another base year. Second, the aim of the database is to provide a solid basis for modelling the changes induced by innovations at the farm level on basis of an extension of the BioBaM model (Erb et al. 2009, 2016). Thus, the focus of the study will be the consistent and robust quantification of changes between different scenarios for the base year 2050 induced by innovations in livestock farming systems. The aim is not to quantify as precise as possible the situation in a recent basis year. This strategic orientation results in a standardization of results towards the base year by isolating effects induced by farming innovations, and thus renders uncertainties in the base year less important (Haberl et al. 2011, 2016a; Erb et al. 2016). Data from the European HANPP dataset is available for EU27 (without Croatia, Cyprus and Malta) at 1-km spatial resolution (Plutzar et al. 2016).

3.2.2 Land use

Data for biomass flows and land use in the baseline are parametrized around the year 2012 and are derived from various primary and secondary sources (CAPRI, Eurostat, Faostat, Corinne Land Cover - CLC, Plutzar et al. 2016) and from data provided by the decision support tools used in the case studies. We additionally received a positive decision upon our request for FADN farm level data (October 2019) and look forward to receiving the data.

Data on cropland as well as grazing area and yields were provided by the CAPRI (Common agricultural Policy Regional Impact, Data Source: CAPREG – 21.03.2018) model, which is a widely used tool for impact assessment of agricultural policies with a focus on the EU (Leip et al., 2008), on national and subnational (NUTS-2) level.

The economic core of CAPRI links sequentially non-linear regional programming models with a global agricultural trade model (Britz et al. 2007; Britz and Witzke 2012, 2008; Leip et al. 2007; Kempen and Witzke 2018; Britz and Witzke 2015). CAPRI's general layout is to generate a consistent and complete data set across regional scales (Britz et al. 2011). The modelling system is fed as far as possible with data from the Eurostat database which is regularly updated and mostly centralized (area statistics, farm and market balances, yields, agricultural prices). If not available, other well-documented, official and harmonised data are used from FAOSTAT, OECD or from the Farm Accounting Data Network (FADN) (Britz and Witzke, 2008). Due to a lack of data in the EUROSTAT database some NUTS-2 regions, in all cases cities, were missing (Vienna, Hamburg, Berlin, London, Bremen, Brussels).

Cropland data (area, production, yields) was provided by the JRC from the CAPRI modelling framework (Data Source: CAPREG – 21.03.2018) and data for 36 field crops were aggregated into 8 main crop categories, which are consistent with the Eurostat database for the year 2012 (Britz and Witzke 2015; Kempen and Witzke 2018). Values were reported in fresh weight and were converted into dry matter. To estimate harvest residues or other by-products not included in statistics (e.g. straw), as well as belowground productivity, we used crop-specific factors derived from earlier studies (Krausmann et al. 2008a).

Data on **grazing land** was derived from Plutzar et al. 2016 and updated by using Eurostat land cover data (lan_lcv_ovw, downloaded in September 2019). Plutzar et al. utilized CAPRI and CLC land cover

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data to derive three distinct grazing classes – (permanent meadows and permanent pastures, other land may be grazed). They firstly delineated the class "meadows & pastures" from CAPRI with the extent of the CLC class 2.3.1 (pastures), but excluded the class 'Sparsely vegetated areas'. CAPRI reports significantly larger pasture areas in all NUTS2 regions than these CLC classes would contain. Thus, the remaining grassland areas were assigned to the class 'other grazing land'. 'Urban grassland areas' from CAPRI were allocated to the CLC class 1.4. ('artificial, non-agricultural vegetated areas'). The amount of grazed biomass was derived from the CAPRI database. In order to update the grazing areas to the year 2012, and to overcome the 50/50 split of intensive and extensive permanent meadows and pastures from CAPRI, we used the shares from Plutzar et al. (2016) from the year 2006 to calculate the shares of intensively used, highly productive permanent grasslands (grazing class 1) and extensive, mosaic permanent grasslands (grazing class 2). We then used a closed budget approach (Erb et al. 2007; Haberl et al. 2007) to calculate the category other land maybe grazed, similar to the calculation of the other grazing land category in Plutzar et al. 2016. We thus subtracted the following areas from the total land area per NUTS2 region, data derived from Eurostat lan_lcv_ovw dataset for the year 2012:

- Infrastructure. We here used twice the change rate between 2009 and 2012 from Eurostat lan_lcv_ovw dataset to update infrastructure areas from Plutzar et al. (2015).
- Woodland (excluding shrubland) for 2012 – as reported by Eurostat
- Cropland (incl. Fallows) derived from CAPRI
- Permanent meadows and pastures derived from CAPRI
- other land: Plutzar et al. 2016

3.2.3 Harvested Biomass and Residues

The amount of harvested biomass on cropland as well as on grazing land were taken from the CAPRI modelling environment (Britz et al. 2008; Weiss and Leip 2012) as well as new CAPRI data extracts for 2012 (Leip August 2018, Data Source: CAPREG – 21.03.2018) and have been available for the year 2012. The CAPRI database provides information on area and harvested biomass in fresh weight / year for the 40 cropland cultivars that have been grouped into 9 crop groups, 5 animal product groups, 3 vegetable and animal fibers and energy crops, as well as livestock feed categories (

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Table ***1***). Data in fresh weight have been converted into dry matter (DM) using the data conversion factors provided by Krausmann et al. (2013b). Fallow areas were reported by CAPRI and included in the input dataset for BioBaM.

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Table 1. Cropland cultivar groups (primary harvest) discerned in the database (referred to as CaBaM)

Cereals	1000		Ruminant meat	2000	
maize		1001	Bovine Meat		2001
rice, paddy		1002	Mutton & Goat Meat		2002
wheat		1003	Milk, butter, dairy	2100	
other cereals		1099	Milk, butter, dairy - cow		2101
Roots and Tubers	1100		Milk, butter, dairy - sheep+goat		2102
cassava		1101	Monogastric products	2200	
potatoes		1102	Pigs		2201
other roots		1199	Poultry		2202
Sugarcrops	1200		Eggs		2203
sugar cane		1201	Fish	2300	
sugar beet		1202	other fish		2399
other sugarcrops		1299	animal by products	2400	
Pulses	1300		other animal by products		2499
other pulses		1399	veg fibres + tobacco	3000	
Oilcrops	1400		other veg fibres + tobacco		3099
soybeans		1401	animal fibres	3100	
oil, palm fruit		1402	other animal fibres		3199
rape seed		1403	dedicated energy crops	3200	
Sunflower Seed		1404	other dedicated energy crops		3299
Olive oil		1405	Fodder and Roughage	4000	
Table olives		1406	Fodder Crops		4100
other oilcrops		1499	Straw		4200
Fruits	1500		Gras		4300
Apples		1501	odder fodder and roughage		4900
Citrus fruits		1502			
Table wine		1503			
Other fruits		1599			
Vegetables	1600				
Tomatoes		1601			
Other Vegetables		1699			
Other crops	1700				
Coffee and Cocoa		1702			
Other other crops		1799			
Nuts	1800	1801			

CAPRI reports biomass reported in fresh weight, but does not report the amount of crop residues (i.e. leaves, stems) which is growing each year on cropland. Additionally, there is no statistical data is available, and we

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thus extrapolated the amount of used and un-used crop residues based on harvest indices, provided by Krausmann et al. (2013b). They report factors that contain information on the ratio between primary product (e.g. corn) and the mass of the entire plant. Residues not harvested according to CAPRI (e.g. in the form of straw harvest) were assumed to be left on field.

3.2.4 Characterization of Livestock Systems

Livestock is of central importance for overall biomass flows and agricultural land use in Europe. At the global scale, livestock occupies 30% of the world's ice-free surface, consumes app. one third of global biomass harvest, and contributes 40% of global agricultural gross domestic product (Foley et al. 2011; Herrero et al. 2013; Erb et al. 2016). We thus describe the livestock related data in more detail in the following section. Besides information for agricultural primary production, the CAPRI database was also used to characterize livestock systems at the NUTS-2 level by their biophysical input-output flows. CAPRI contains data on feed demand per livestock type. It discerns 20 livestock groups at the NUTS-2 level and 11 feed categories for each of these groups (Table 2). For the further analysis with BioBaM, the 11 feed categories from CAPRI were aggregated to 4 feed categories. On the one hand, this was necessary for the comparison with other data sources, on the other hand, we were not able to discern specific crops that are broadly used in the agriculture today, such as soy beans or rape seed meal.

Table 2. Livestock groups and feed categories discerned in the database

#	Livestock group	#	Feed category	BioBaM aggregation of feed categories
1	Dairy Cows high yield	a	Feed cereals	Grains
2	Dairy Cows low yield	b	Feed rich protein	Industrial by-products
3	Other Cows	c	Feed rich energy - (kg/head)	Industrial by-products
4	Heifers breeding	d	Feed from milk product	Industrial by-products
5	Heifers fattening high weight	e	Feed other	Industrial by-products
6	Heifers fattening low weight	f	Grass	Grass
7	Male adult cattle high weight	g	Fodder maize	Roughage
8	Male adult cattle low weight	h	Fodder other on arable land	Roughage
9	Raising male calves	i	Fodder root crops	Roughage
10	Raising female Calves	j	Straw	Roughage
11	Fattening male calves	k	Milk for feeding (cow and sheep/goat)	Not used for the aggregation
12	Fattening female calves			
13	Other animals			
14	Pig fattening			
15	Pig Breeding			
16	Milk Ewes and Goat			
17	Sheep and Goat fattening			
18	Laying hens			
19	Poultry fattening			

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20 Other animals

Additionally, CAPRI contains data on animal production, discerning the following categories: a) Milk from cows, b) beef meat, c) pork meat, d) sheep and goat meat, e) sheep and goat milk, f) poultry meat, g) other marketable animal products. These categories have also been converted to dry matter. Figures 2a-d show the fit of the CAPRI animal output data to data reported by Eurostat and confirms that both sources fit very well together at the NUTS2 and at the country level. The latter comparison is used for meat, which is only reported at the country-scale by Eurostat. Table 3 provides an overview of datasets, scale, and calculation procedures used in the biomass flow modelling framework.

Table 3. Documentation of data sources and calculation procedures for establishing a dataset to calculate the baseline for the European biomass flows model BioBaM related to agricultural production – consumption system at a subnational level

Perspective	Issue	Year	Source	Explanation of accounting details
Demand	Population	2011-2013	Eurostat	NUTS-2 information
Demand	Human consumption of food	Average values 2011-2013	FAO national demand downscaled	Human consumption in primary production equivalents according to FAOSTAT Commodity Balances for Crops, Livestock and Fish Primary Equivalents. National values downscaled to NUTS 2 regions by population. Exclusion of used by-products and derived commodities, which through processing, change their nature and become part of different commodity groups.
Demand	Seed, waste, industrial uses	Average values 2011-2013	FAO national demand downscaled	Downscaled from FAO Commodity balances
Supply	Cropland production (primary)	2012	CAPRI marketbalance	Correlates to Primary production from cropland. Primary production refers to gross production from the CAPRI model at NUTS-2, items where aggregated to BioBaM categories. Including animal fodder (fodder maize, fodder root crops, fodder other on cropland).
Supply (HANPP)	Crop residues (ubp)	2012	calculated	Correlates to used by-products from cropland. Factors for the maximum shares for cereals are taken from Krausmann et al. 2008, NUTS-2
Supply (HANPP)	Crop residues unused (uubp)	2012	calculated	Unused by-products from cropland. Calculated with global HANPP factors, see Krausmann et al. 2008., NUTS-2
HANPP	Harvested HANPP	2012	calculated	Aboveground $HANPP_{harv}$ + belowground NPP_{act} on cropland, NUTS-2
HANPP	NPPpot	2011	calculated	NPP_{pot} and NPP_{act} are calculated with cropland areas from CAPRI 2012 (UAA), NUTS-2
HANPP		2012	calculated	Calculated as $HANPP_{harv}$ + pre-harvest losses on Cropland, NUTS-2
Supply	Grazing land	2006	Plutzar et al. 2016, calculated	Intensive grazing land: grazing land, permanent meadows and pastures; Extensive grazing land: other land maybe grazed, other grazing land, urban grazing, area other land (unproductive, wetlands, wilderness), 1km resolution

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Supply	Cropland area	2012	CAPRI	Cropland areas related to the specific crops at NUTS-2.
Supply	Feed output	2012	CAPRI	Feed production (on farm) on grassland and on cropland (fodder maize, roots, straw)
Demand	Livestock feed consumption	2012	CAPRI	Total feed intake from livestock (different composition) at NUTS-2; Feed intake for rabbits and horses calculated from Krausmann et al. 2013, detailed CAPRI and aggregated multiplied with herdsize numbers from CAPRI for 18 animal activities.
Demand	FCR	2012	calculated	Feed conversion ratios. These are total animal output / total feed consumption for 11 feed intake categories, which have been aggregated to 4 different categories.
Supply	animal output	2012	CAPRI; FAO	Products of animal origin at NUTS-2; FAO was used to estimate wool and leather production at national level downscaled to NUTS-2 with animal number from Hercule et al. 2017. Focus: milk, meat and eggs, NUTS-2
Stock	Herdsize	2012	CAPRI; Hercule et al. 2017	Total livestock, for 18 animal categories at NUTS-2; animal numbers for horses taken from Hercule et al. 2017. Numbers and LSU, NUTS-2

3.2.5 Consumption data

To fill the biophysical database on the consumption side, data from FAOSTAT (FAOSTAT 2018) were used. FAOSTAT establishes Commodity Balances for Crops as well as for Livestock and Fish Primary Equivalents. They provide standardized data of food and agricultural products and their respective utilization in a given country. Commodity use is specified by the elements Feed, Seed, Processing, Waste, Other Uses and Food. All elements were considered except of "Feed", since feed use respectively feed requirement of the regions is available in more detail from CAPRI (see above).

Because no reliable or comprehensive data are available for NUTS-2 regions, national data for the average consumption in 2011 to 2013 were downscaled to NUTS-2 regions on basis of population numbers. Commodities not indicated by FAO in primary equivalents, like sugar and oils, were converted into primary crop equivalents. To avoid double counting, the element "processing" of the respective primary product (e.g. Rapeseed) was excluded. We obtained consumption data of agricultural products on the Supply Level for 227 NUTS 2- regions in Europe. Data in fresh weight have been converted into dry matter by factors compiled by Krausmann et al. (2008b, 2013b) and consistently assigned to former defined cultivar groups (see

Table ***1***).

4 DATA CONSISTENCY CHECKS IN BIOBAM

This database was compiled and has accomplished a very high level of completeness and consistency. Establishing a biophysical flow model not only for European countries but also on a sub-national level (NUTS-2) requires consistent datasets for biomass flows as well as for the extent of agricultural area.

Consistency checks yield insights into the uncertainty structure behind the datasets we used, relevant information for modelling and interpretation. While data density is not sufficient to perform assessments based on modelling itself (e.g. Monte Carlo techniques), comparisons with subnational, national and global databases related to biomass flows induced through livestock allow gaining insights into the reliability of this dataset.

4.1 Data consistency checks with other datasets

So far, CAPRI provides the most coherent and comprehensive dataset at the NUTS-2 level in Europe. Therefore, CAPRI is used as main data source in WP4, complemented with additional data from various other sources such as FAOSTAT or EUROSTAT. Although, CAPRI data partially relies on Eurostat data, the integration of various data from different sources into a consistent and comprehensive biomass flow model, requires a good understanding of the baseline data. Here, we performed consistency checks on a national and on sub-regional level. The aim of the comparisons is to better understand CAPRI model assumptions as well as to check its liability and consistency with the other data sources.

Figure 2 shows the comparison of a set of items in form of scatter plots from CAPRI (x-axis) and Eurostat (y-axis). This is a) utilized agricultural area (UAA) b) wheat production c) milk production and d) animal numbers of dairy cattle. Overall, CAPRI and Eurostat data are within a range of +/- 10% for most NUTS-2 regions and datasets, because Eurostat serves as one of the underlying data sources for CAPRI.

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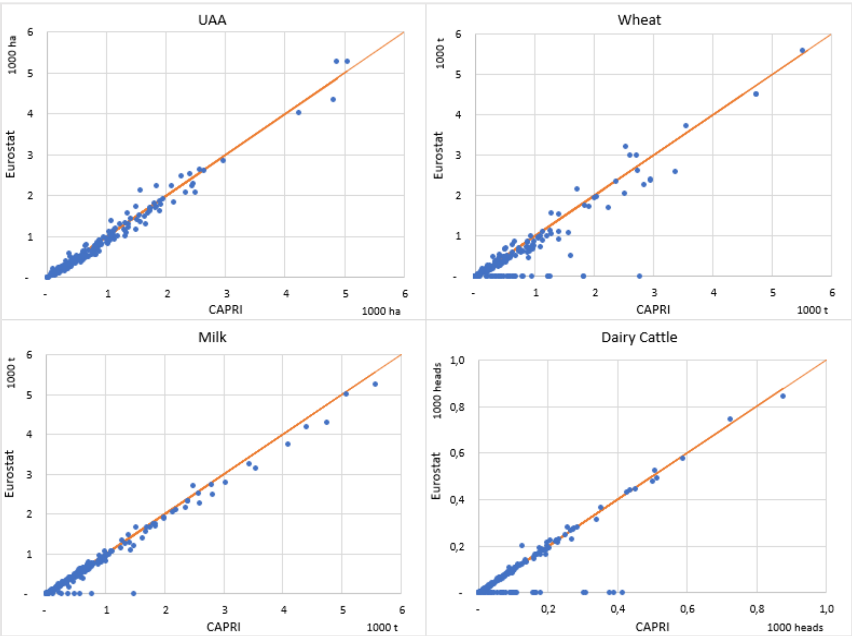

Figure 2a-2d. Data comparison CAPRI and Eurostat at NUTS-2 level: Utilized agricultural area (UAA), wheat and milk production, animal numbers of dairy cattle. n= 227, year: 2012. Some regions are only reported by CAPRI and thus show zeros.

Despite livestock's feed demand pivotal role for overall agricultural biomass flows and land use, census data on livestock feed consumption is not available. Thus, we paid particular attention on plausibility and uncertainties of different calculations of livestock feed consumption. In a first step we compared results of national livestock feed consumption calculated by different models i.e. CAPRI and GLEAM (Global Livestock Environmental Assessment Model), which was developed by the FAO (2017a). Both models provide information of about a herd's feed demand in a given nation, but are based on different model assumptions such as herd dynamics or feed composition. Figure 3 depicts results of feed consumption in 26 EU-nations by CAPRI resp. GLEAM[1]. As assumed, biomass flows for livestock feed consumption show higher variabilities than simple CAPRI vs. EUROSTAT comparisons due to their different underlying model assumptions. This first rough comparison of different models indicates high uncertainties for the calculation of total livestock feed consumption, which is however, a crucial factor in the assessment of biomass flows of regions.

[1] Within GLEAM, the term „feed intake" refers to a herd's overall feed demand, which is coined as "feed consumption" in this report. Thus, "feed intake" as used above indicates the feed demand of an animal.

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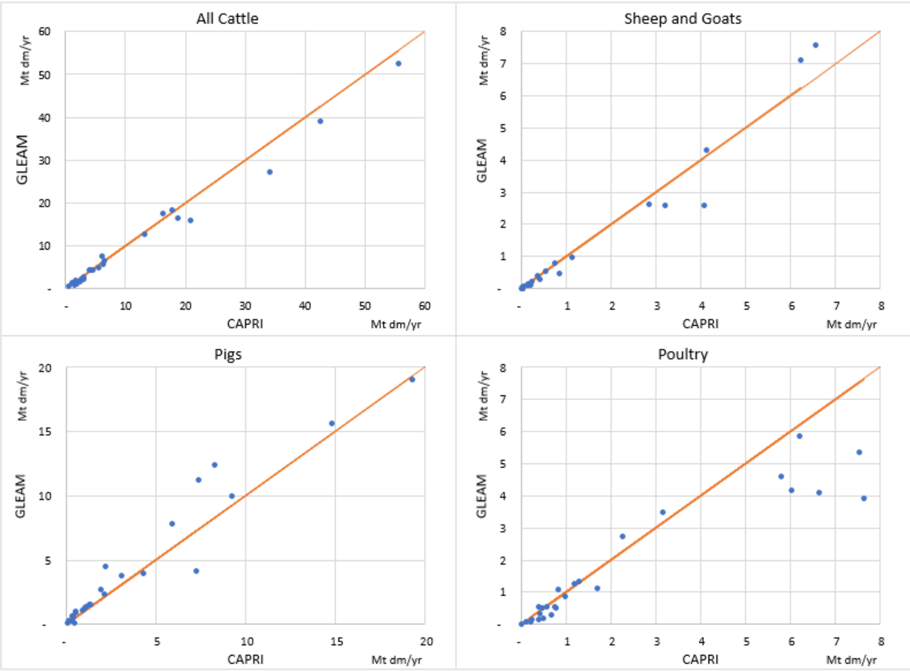

Figure 3a-3d. Comparison of total feed consumption calculated by CAPRI and GLEAM – national level, n=26, year: 2012.

Since we are interested to assess feed consumption on a NUTS-2 sub-national, we identified two further approaches to gain reliable feed consumption data based on available datasets and previous scientific research (feed availability approach and a feed efficiency approach). Figure 4 shows the procedure to compare two possible feed demand calculations approaches (both at the national and sub-national level). Both approaches rely on at least two different data sets of which one gives a national and the other a sub-national livestock information. This allows for downscaling a third component, which is the feed information. While the so-called "feed availability approach" is based on feed intake data from GLEAM and uses herd structure data from CAPRI/Eurostat to downscale, the "feed efficiency approach" distributes national Eurostat production data on the basis of sub-national CAPRI production data. Required feed information are obtained by feed conversion ratios by Herrero et el. (Herrero et al. 2013) and by Bouwman et al. (2005a). The results of both approaches can be compared with CAPRI feed demand on NUTS 2-level. We thus established a range of uncertainty assessments based on several available datasets and downscaling methods.

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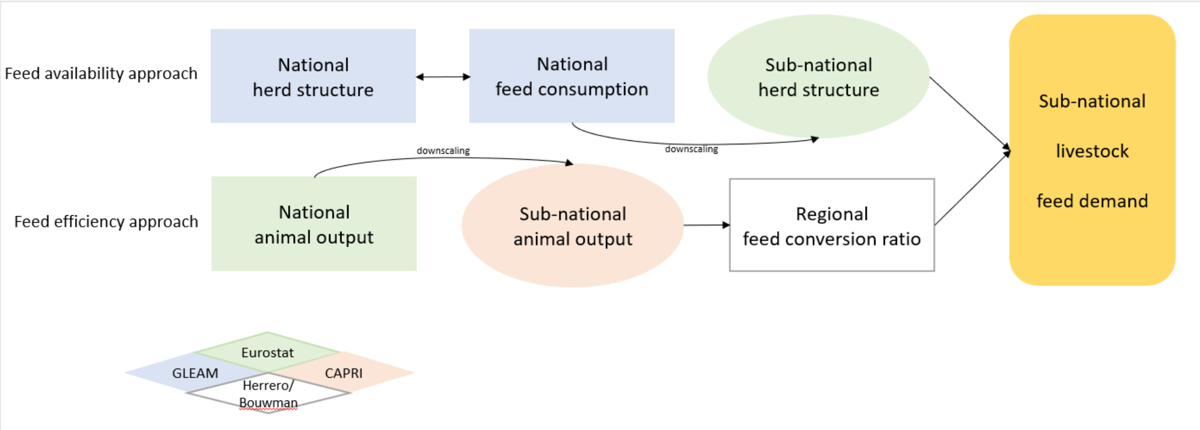

Figure 4. Drafted modelling approaches to calculate feed demand on a sub-national level.

Figure 5 shows a comparison between CAPRI and the feed efficiency approach for dairy cattle. We multiplied milk production data available at NUTS-2-level from EUROSTAT with feed conversion ratios of dairy cattle once by Herrero et el. (2013) and once by Bouwman et al. (2005).

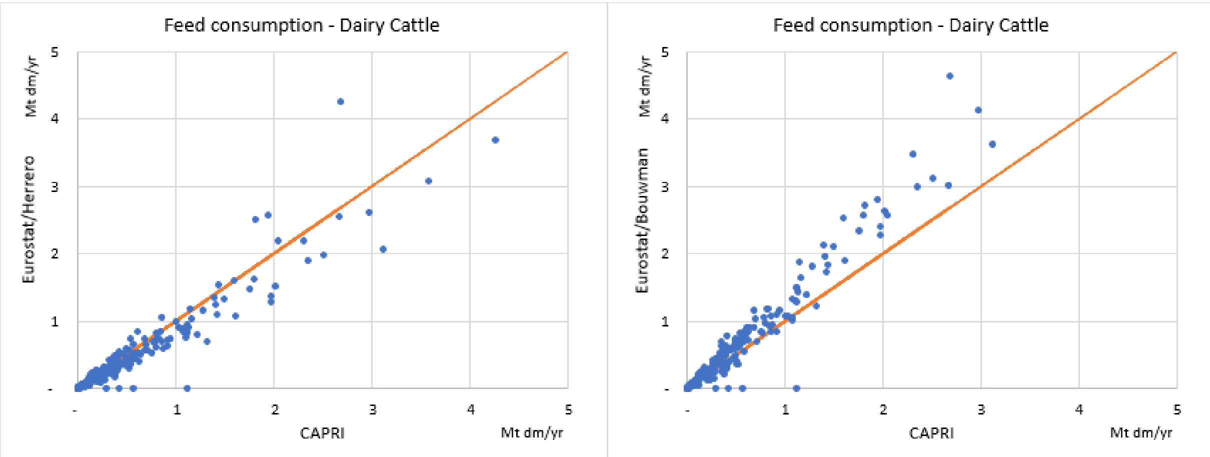

Figure 5. Comparison of total feed consumption for milk cattle by CAPRI and a combination of Eurostat multiplied with FCRs from Herrero et al. (2013, left) and Bouwman et al. (2003, right) at NUTS-2 level; FCR = feed conversion ratio. n = 227

While the combination Eurostat/Herrero shows slightly lower feed consumption than CAPRI for the 227 NUTS-2 regions in *Figure* ***5***, the combination Eurostat/Bouwman results in values which are considerably higher than the model outputs from CAPRI. Therefore, CAPRI feed demand values are within the range of the two other feed consumption calculations. We thus concluded to use the feed consumption data provided by the CAPRI modelling framework for the European livestock feed demand, and FCRs from Herrero et al. (2013), which is also the most recent global assessment of livestock feed consumption that is available, to calculate the global feed consumption. This approach warrants comparability between European and non-European biomass flows. Figure 6 shows

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scatterplots for a comparison of total feed intake as reported from the CAPRI database (y-axis) with total feed consumption, calculated by using feed conversion rations (FCRs) from Herrero et al. (2013). Feed conversion rations are used to calculated feed intake as a ratio of animal output, i.e. the primary product that livestock produces (e.g. milk, meat). The fit of livestock feed intake and consumption from both sources yielded satisfactory results with high correlation between both sources (r2 > 0,9). Feed consumption of dairy cows hat a slightly better fit than data for beef cattle, albeit with individual countries or regions showing deviations of >20. As data on grazed biomass, crop residues fed to livestock and livestock feed intake in general are not well covered by official statistics, we rely to CAPRI feed intake factors, as they firstly show a reasonably well fit with Herrero et al. (2013) and secondly to maintain data consistency with other data derived from CAPRI.

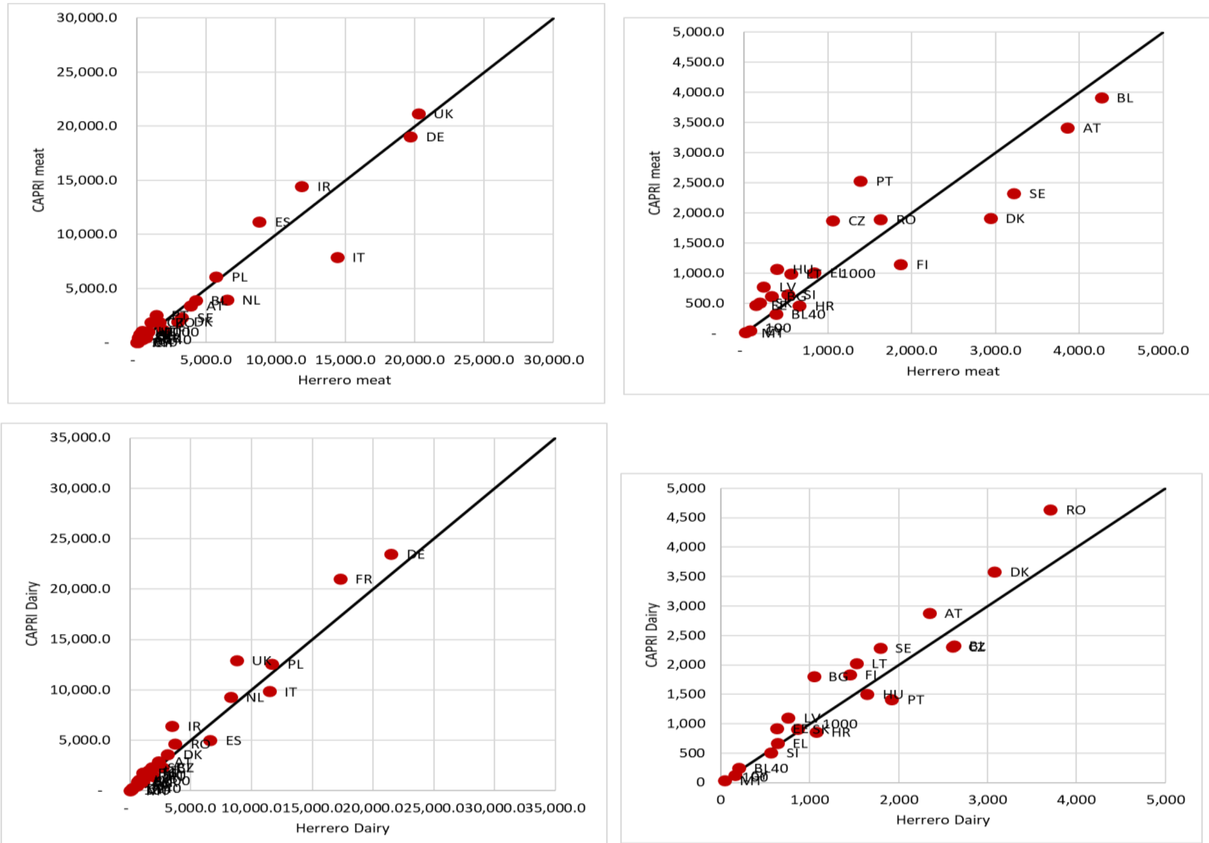

Figure 6a-6d. Scatterplots for total feed consumption in 1000t dm/yr as reported by CAPRI (Data Source: CAPREG – 21.03.2018) and as calculated with FCRs from Herrero et al. (2013). First two panels for meat cattle (Boxplot 1a for all regions, boxplot 1b for small regions with a total feed intake < 5000t dm/yr), second panels for dairy cows (Boxplot 1c for all regions, boxplot 1d for small regions with a total feed intake < 5000t dm/yr). Black lines show r2 =1.

5 BIOBAM MODELLING FRAMEWORK AND SCENARIO INPUT FOR 2050

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773901.

The data described above provides the basis to calculate a large range of scenarios to assess the feasibility of a range of demand and supply scenarios in the global model BioBaM (Erb et al. 2016). BioBaM represents a diagnostic, biophysical model that combines variations of a range of food systems demand and supply side parameters in a scenario approach (Erb et al. 2016). BioBaM is thus a global biomass balance model which allows a calculation of scenarios for the supply and demand of biomass in 2030 and 2050, based on a range of assumptions discussed in the next section. While the BioBaM model as used in Erb et al. (2016) was carried out on the level of 11 world regions, i.e. based on the classification of the macro-geographical (continental) regions and geographical sub-regions as defined by the United Nations Statistical Division (UNSD, 2006), the current implementation of BioBaM goes much more into detail. Firstly, Europe is now downscaled to 227 NUTS2 regions, while non-European regions are downscaled to 121 countries and country aggregates, as reported by (FAO 2017b). An application of the current version of BioBaM to assess future bioenergy potentials in 2050 is described in(Kalt et al. 2020).

BioBaM is based on consistent data on ecological and socioeconomic biomass flows and land use, and respects thermodynamic principles (the law of conservation of mass and energy). It uses extensive databases for the year 2012, containing consistent data on socio-ecological biomass flows in ecosystems and socioeconomic systems (including, for example, NPP, used and unused harvests for 40 cultivars for Europe derived from CAPRI, and 58 cultivars for non-Europe derived from FAO (2017b), the consumption of final products such as food and fibre, the differentiation of 19 final commodity groups), and it is consistent with spatially explicit information on land use (Erb et al. 2007a; Plutzar et al. 2016b). Integrating these data sets into a model that allows consistent integration of biomass demand and supply flows, biophysical scenarios of the global agro-food system for 2030 and 2050 were constructed, systematically combining a range of yield variants, cropland expansion variants, variants of the feedstuff composition of livestock diets, and human diet variants. The main novelties in the current model variant are that we firstly add a range of trade scenarios/allowances, and that we implement agro-ecological innovations.

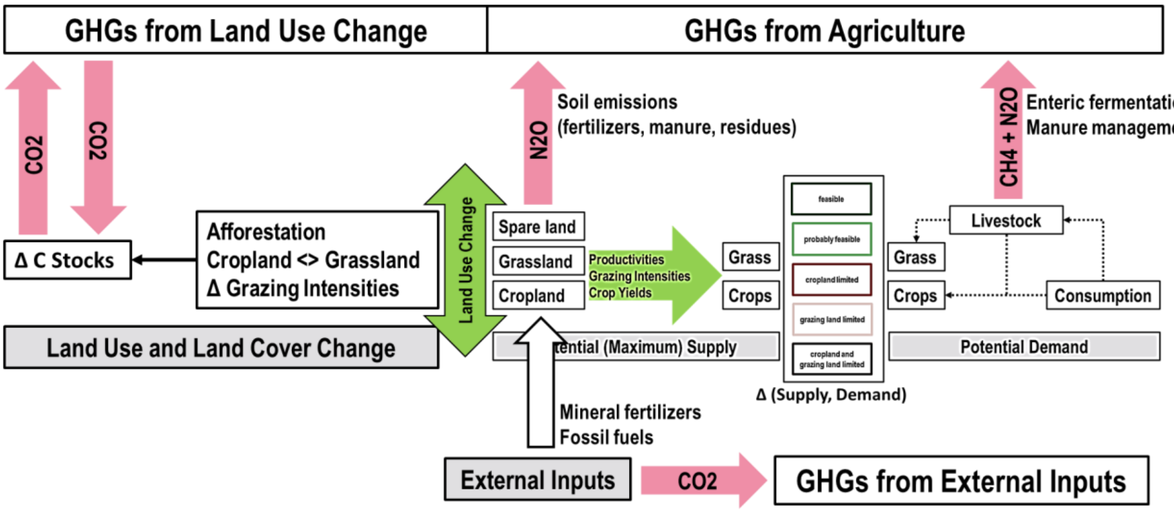

Figure 7. Schematic representation of the BioBaM modelling framework

Figure 7 presents a

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schematic representation of the BioBaM modelling framework. The basic approach of BioBaM is calculate the land use feasibility of a range of demand/supply variants and the associated GHG emissions. The potential demand in the year 2050 is based on the following parameters: The United Nations medium population forecast for the year 2050 (Source), human diets (4 variants, see below), and demand for seeds and industrial uses. We furthermore apply specific household waste rates derived from (Gustavsson et al. 2011) at the global scale, and use a number of country-wide case studies for Europe (see below). Demand for seeds and industrial uses are calculated based on the relations between food use and seed and industrial uses from the FAO commodity balances in the year 2012. Human diets consist of crops that are directly consumed and of livestock products such as milk, meat and eggs. Livestock products are converted into primary feed demand through utilizing feed conversion ratios derived from CAPRI.

The potential supply of crops and grass for the year 2050 are calculated as follows. On the supply side, the model calculates (a) the potential supply of food and feed from cropland as a function of cropland availability and yield levels and (b) the potential roughage supply from grassland, calculated by combining estimates on available grazing land (remaining after cropland expansion) with estimates on actual NPP per unit area (Haberl et al. 2007b; Plutzar et al. 2016) and the maximum achievable grazing intensities for four different grazing land classes, characterized by varying, region-specific maximum grazing suitability. Areas for cropland and grazing land are taken from CAPRI and Plutzar et al. (2016) and updated to the baseline year 2012. Data on **grazing land** was derived from CAPRI (Data Source: CAPREG – 21.03.2018) and Eurostat (2019), data on grazed biomass was derived from the CAPRI database. CAPRI provides data for intensive and extensive permanent grassland applying a 50/50 share in each region. Eurostat provides data for permanent grassland for the year 2012. Nonetheless, both data sources do not represent grazing land adequately, since both do not report temporary grazing lands. We thus utilize data from Plutzar et al. (2016) to refine available grassland areas. By applying the distribution of the following 3 grassland classes from Plutzar et al. (2016) to the land are in 2012: permanent grassland highly productive, other grazing land, other land maybe grazed. (Plutzar et al. 2016b) utilized CAPRI and data from the Corinne land cover (CLC) data to derive these three classes by firstly delineating the class “permanent meadows & pastures” from CAPRI with the extent of the CLC class 2.3.1 (pastures), but excluding the class ‘Sparsely vegetated areas’, which is also partly grazed. The class “other land maybe grazed” was derived by applying a “closed budget” approach (Erb et al. 2007a; Haberl et al. 2007a), defined as the remaining land area after subtracting the following areas from the total land area per region as provided by CAPRI (croplands, grazing lands) and Eurostat (Eurostat 2019): Infrastructure and built up land, unproductive areas, forests, waterbodies.

We then calculate a) the emissions from soil management through the application of fertilizers, manure application and shares of residues that are left on fields and b) the upstream emissions for the external inputs, i.e. mineral fertilizers, fossil fuels required for land management and transport of final goods (see below).

In BioBaM, no further deforestation is allowed in the year 2050 to avoid additional GHG emissions. However, we allow croplands to expand into grasslands of the highest quality (i.e. grazing class 1, see Erb et al. 2007), and grasslands to expand into cropland. These land use changes are associated with a loss (GL to CL) or gain (CL to GL) in soil organic carbon stocks. A detailed description of these calculations is provided below.

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For all of the resulting scenarios, which define the “biophysical option space”. a global biomass supply-demand balance is calculated. The option space is defined as the sum of feasible scenarios—that is, when global demand for cropland products is matched by supply by at least by 95% (considering a 5% uncertainty range; cropland constraints) and livestock products’ grazing intensity—that is, the ratio of grazed or mowed biomass to actually prevailing NPP (Petz et al. 2014; Erb et al. 2016) stays below ecological thresholds (grazing constraints). In the absence of more reliable data, we assumed that no more than 70% of NPP could be grazed or mowed in highly productive grazing lands and that this ratio decreased with productivity, down to 25% in low-productive ecosystems such as steppes or semi-deserts. These maximum grazing intensities are far above the current levels in most regions, albeit in Europe regions with highly intensive grassland use (e.g. in the Netherlands), and at the global scale countries that are mostly covered with low productivity grasslands (e.g. Bangladesh, central Asia) actual grazing intensities are close to, or even surpass maximum grazing thresholds. In regions where the current grazing intensity in the reference year 2012 surpasses the maximum grazing intensity, we increase the maximum threshold to the current grazing intensity. We thus reflect in BioBaM that in these regions, current grassland production is increased through intensive management regimes.

5.1 Input Data to BioBaM

5.1.1 Diets

On the demand side, the model calculates for each specific human diet (a) the demand of primary crops for food and feed from cropland and (b) roughage demand for the production of meat and milk from grassland (see below) for the reference year 2012. It discerns 19 product groups, for example, cereals, pulses, ruminant meat and eggs. The per capita food demand was multiplied by total population numbers, plus an added fraction for household food waste from Gustavsson et al. (2011). We converted household crop demand to primary crop demand by applying region- and crop-specific (a) seed factors and b) factors for processing losses, wastes and byproducts (for example, brans in flour production, based on commodity balances) based on FAO commodity balances.

The following table summarizes the per-person demand of food crops and animal products (meat, dairy products, eggs etc.) in the assumed diets derived from FAO (2018) (2012, BAU, SSS, TSS) and Willett et al (2019) (“healthy reference diet”). Values refer to household consumption; due to losses, there is a difference between actual food intake and household consumption. For converting intake recommendations according to Willett et al (2019) to household level, we used loss factors according to Gustavsson et al. (2011). Differences between world regions in cereal consumption in the “healthy reference diet” are due to different shares of rice and conversion from paddy to milled rice. The category “other crops”, containing crops like coffee or tea, is not represented in the reference diet according to Willett et al (2019). Although these crops might not be required for a healthy diet, we assumed the corresponding per-person demand of the TSS scenario.

In order to calculate specific diet scenarios at the NUTS2 level, we applied change factors between the reference year 2012 and 2050 for Western and Eastern & Southeastern Europe from the three FAO scenarios (BAU, SSS, TSS) described above to the respective diets. We thus warrant consistency between the European (NUTS2) and Rest of the world diet scenarios. We additionally use the most recent global diet recommendation from (Willett et al. 2019) as another diet scenario for 2050. Table 4 provides an

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overview of diet scenarios for selected NUTS2 regions for the year 2050.

Table 4 Selected diet scenarios for 2050 for BAU, SSS, and TSS scenario according to FAO (2018) for selected NUTS2 regions. Data in kg dm/cap/yr. BAU = business as usual, SSS = stratified societies scenario, TSS = towards sustainability scenario.

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World region	Western Europe	Western Europe	Western Europe	Western Europe	Eastern & South-Eastern Europe	Eastern & South-Eastern Europe
Region	Burgenland	Prov. Namur	Bretagne	Bremen	Koezép-Dunántúl	Západné Slovensko
		BAU				
Cereals	114	124	117	115	101	119
Roots and Tubers	12	18	11	14	12	12
Sugarcrops	51	59	44	46	25	49
Pulses	1	2	2	1	3	1
Oilcrops	24	23	22	21	26	18
Fruits	25	12	19	16	16	13
Vegetables	5	6	4	5	6	5
Other crops	9	6	8	7	4	8
Nuts	5	5	3	5	0	3
Bovine Meat	8	7	11	6	2	2
Mutton & Goat Meat	1	1	2	0	0	0
Milk butter dairy - cow	31	30	30	33	20	17
Milk butter dairy - sheep+goat	0	0	1	0	0	0
Pigs	33	24	21	35	35	30
Poultry	12	8	15	12	22	13
Eggs	5	4	4	4	6	7
Fish	3	5	7	3	1	2
animal by products	12	13	5	8	14	13
veg fibres + tobacco	0	0	0	0	0	0
animal fibres	0	0	0	0	0	0
Total	**350**	**348**	**325**	**331**	**295**	**313**
		SSS				
Cereals	118	128	121	119	104	123
Roots and Tubers	12	19	11	14	12	13
Sugarcrops	49	56	42	44	26	50
Pulses	1	2	2	1	3	1
Oilcrops	25	24	23	22	28	19
Fruits	25	12	19	16	17	13
Vegetables	5	6	4	5	6	5
Other crops	9	6	8	8	5	9
Nuts	5	5	3	5	0	3
Bovine Meat	9	8	12	7	2	2
Mutton & Goat Meat	1	1	2	0	0	0
Milk butter dairy - cow	33	32	31	34	20	18
Milk butter dairy - sheep+goat	0	0	1	0	0	0
Pigs	35	26	23	37	37	32
Poultry	13	9	16	13	24	14
Eggs	5	5	5	5	7	7
Fish	3	5	7	3	1	2
animal by products	12	13	5	8	14	13
veg fibres + tobacco	0	0	0	0	0	0
animal fibres	0	0	0	0	0	0
Total	**360**	**356**	**335**	**340**	**307**	**325**
		TSS				
Cereals	110	119	113	111	98	116
Roots and Tubers	11	18	11	13	12	12
Sugarcrops	42	48	36	38	23	45
Pulses	1	2	1	1	3	1
Oilcrops	23	22	21	20	24	17
Fruits	22	11	17	14	16	13
Vegetables	5	5	4	4	6	5
Other crops	8	5	7	7	4	8
Nuts	5	5	3	5	0	3
Bovine Meat	6	5	8	5	2	2
Mutton & Goat Meat	0	1	1	0	0	0
Milk butter dairy - cow	30	29	29	32	17	15
Milk butter dairy - sheep+goat	0	0	1	0	0	0
Pigs	24	18	15	26	27	23
Poultry	9	6	11	9	17	10
Eggs	4	3	3	3	5	5
Fish	2	4	6	2	1	1
animal by products	12	13	5	8	14	13
veg fibres + tobacco	0	0	0	0	0	0
animal fibres	0	0	0	0	0	0
Total	**314**	**314**	**292**	**297**	**270**	**290**

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5.1.2 Waste

We derive the amounts of household (i.e. consumer) food wastes from a global study (Gustavsson et al. 2011) for the global scale, and use a number of country-wide case studies for Europe. Amounts for consumer food wastes refer to the final stages of food utilization, i.e. the stage between household consumption and food intake. Several methods exist to estimate these amounts, e.g. through municipal waste statistics (Reynolds et al. 2014), assessments of the differences between household food supply and intake (Hiç et al. 2016), or through consumer surveys, albeit these are not undebated due to limitations in comparison and generalization (Xue et al. 2017; Reutter et al. 2017).

We use the following case studies to estimate food wastes in Europe

- UK: (Quested et al. 2013; Quested and Murphy 2014)
- Finnland: (Silvennoinen et al. 2015, 2014)
- Danmark: (Edjabou et al. 2016)
- Other regional studies for Europe (Vanham et al. 2015; Stenmarck 2015; Schanes et al. 2018)

5.1.3 Cropland areas and yields

For the model BioBaM, we utilize data from CAPRI for cropland areas and cropland yields for the EU-25 (except Cyprus, Croatia, Malta). For the remaining Western and Eastern Europe countries and the rest of the World we utilize data from the FAO assessment "The future of food and agriculture" (FAO 2018). FAO provides data for the reference year 2012 and three scenario for 2050: The business as usual (BAU), stratified societies scenario (SSS) and towards sustainability scenario (TSS).

As CAPRI does not provide scenario data for the year 2050, we apply the percentage changes of cropland yields from FAO (2018) to the current data for the 2012 to derive scenario data for the NUTS2 regions in 2050 (Table 5). However, the modelling environment allows for an easy and straight-forward implementation of additional/adapted yield scenarios for 2050.

Table 5. Selected crop yield scenarios for 2050 for BAU, SSS, and TSS scenario according to FAO (2018) for selected NUTS2 regions. Data in t dm/ha/yr. BAU = business as usual, SSS = stratified societies scenario, TSS = towards sustainability scenario.

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World region	Western Europe	Western Europe	Western Europe	Western Europe	Eastern & South-Eastern Europe	Eastern & South-Eastern Europe
Region	Burgenland	Prov. Namur	Bretagne	Schwaben	Koezép-Dunántúl	Západné Slovensko
			BAU			
maize	8.6	10.2	8.6	11.0	4.9	7.0
rice paddy					1.3	
wheat	4.0	8.1	7.7	7.0	3.9	5.1
other cereals	3.8	7.2	7.1	5.4	3.4	4.2
cassava						
potatoes	9.2	13.6	8.9	11.1	6.2	6.6
other roots						
sugar cane						
sugar beet	17.5	22.5	22.0	20.3	16.6	19.3
other sugarcrops						
other pulses	2.1	3.6	5.3	3.5	2.2	2.2
soybeans	2.4		3.0	0.8	1.6	2.2
oil palm fruit						
rape seed	2.8	4.5	4.0	3.5	2.5	3.4
Sunflower Seed	2.5		2.7	3.7	2.5	3.1
Olive oil			0.5			
Table olives						
other oilcrops	0.6	1.9	4.1	1.0	0.6	5.3
Apples	4.9	8.2	7.2	5.6	2.3	2.7
Citrus fruits			2.8			
Table wine	1.2	2.1	1.3	2.3	0.8	0.8
Other fruits	2.7	3.7	2.7	1.9	0.9	1.4
Tomatoes	13.1	29.2	10.0	15.1	4.7	4.0
Other Vegetables	2.6	2.8	1.9	1.8	1.0	0.5
Nuts	1.5	2.6	2.0	3.8	1.6	1.6
Coffee and Cocoa						
Other other crops	1.0	7.6	16.2	12.7	0.3	0.3
Other veg fibres + tobacco	5.7	2.9	4.9	1.1	3.3	0.1
grass						
Fodder crops	5.2	9.3	7.1	15.8	3.4	3.8
			SSS			
maize	8.5	10.1	8.6	10.9	4.6	6.5
rice paddy					1.3	
wheat	4.0	8.1	7.7	6.9	3.7	4.8
other cereals	3.7	7.2	7.0	5.4	3.2	3.9
cassava						
potatoes	9.1	13.6	8.8	11.0	5.8	6.1
other roots						
sugar cane						
sugar beet	19.3	24.9	24.3	22.4	18.9	21.9
other sugarcrops						
other pulses	2.0	3.4	4.9	3.3	2.1	2.0
soybeans	2.3		2.9	0.8	1.4	1.9
oil palm fruit						
rape seed	2.7	4.4	4.0	3.5	2.2	3.0
Sunflower Seed	2.5		2.7	3.6	2.2	2.8
Olive oil			0.5			
Table olives						
other oilcrops	0.6	1.8	4.1	1.0	0.5	4.7
Apples	4.8	8.1	7.1	5.5	2.3	2.7
Citrus fruits			2.7			
Table wine	1.2	2.1	1.3	2.2	0.8	0.8
Other fruits	2.7	3.7	2.6	1.8	0.9	1.4
Tomatoes	12.9	28.7	9.9	14.8	4.7	4.0
Other Vegetables	2.5	2.7	1.8	1.8	1.0	0.5
Nuts	1.5	2.6	2.0	3.7	1.6	1.6
Coffee and Cocoa						
Other other crops	1.0	7.6	16.2	12.7	0.3	0.3
Other veg fibres + tobacco	5.7	2.9	4.9	1.1	3.3	0.1
grass						
Fodder crops	5.2	9.3	7.1	15.8	3.4	3.8
			TSS			
maize	6.7	8.0	6.8	8.6	3.9	5.5
rice paddy					1.1	
wheat	3.1	6.4	6.1	5.5	3.1	4.0
other cereals	3.0	5.7	5.6	4.2	2.7	3.3
cassava						
potatoes	7.4	11.0	7.1	8.9	5.0	5.4
other roots						
sugar cane						
sugar beet	15.5	19.9	19.4	17.9	14.9	17.4
other sugarcrops						
other pulses	1.6	2.8	4.0	2.7	1.7	1.7
soybeans	1.9		2.3	0.6	1.2	1.6
oil palm fruit						
rape seed	2.2	3.5	3.2	2.8	1.9	2.6
Sunflower Seed	2.0		2.1	2.9	1.9	2.4
Olive oil			0.4			
Table olives						
other oilcrops	0.5	1.4	3.2	0.8	0.5	4.0
Apples	3.8	6.5	5.7	4.4	1.9	2.2
Citrus fruits			2.2			
Table wine	0.9	1.7	1.1	1.8	0.7	0.6
Other fruits	2.1	2.9	2.1	1.5	0.7	1.2
Tomatoes	10.3	22.9	7.9	11.8	3.9	3.3
Other Vegetables	2.0	2.2	1.5	1.4	0.8	0.4
Nuts	1.2	2.0	1.6	2.9	1.3	1.3
Coffee and Cocoa						
Other other crops	1.0	7.6	16.2	12.7	0.3	0.3
Other veg fibres + tobacco	5.7	2.9	4.9	1.1	3.3	0.1
grass						
Fodder crops	5.2	9.3	7.1	15.8	3.4	3.8

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5.1.4 Livestock diets

Data in relation to livestock feed consumption are not well covered by official statistics and we thus have to resume to modelled data (see above). We converted feed consumption data, which is reported by animal type in CAPRI, to a ratio of feed conversion per animal output, i.e. feed conversion ratios in dm intake per dm animal output. To derive the total feed consumption of each region's specific livestock sector in Europe, we apply data from the CAPRI model (see above), which features 18 livestock categories and 12 feed types, including grazed biomass from grasslands on a NUTS2 level. We aggregate these data as follows, in order to warrant comparability to other regional and global assessments of livestock feed consumption (Herrero et al. 2013; Bouwman et al. 2005b; Krausmann et al. 2013a; Wirsenius 2003; FAO 2017c). First, we assign the reported livestock categories to seven livestock product categories, namely milk, beef, pork, sheep & goat milk, sheep & goat meat, eggs and poultry. In order to be able to trace sectoral biomass flows, we only associate feed of dairy cows with milk production, an approach that is consistent to (Herrero et al. 2013). Consequently, feed for all other cattle categories (e.g. calves, heifers) are attributed to beef. Ruminant livestock production is associated with CH4 emissions from enteric fermentation and manure management, the calculation procedure is described below in Section 5.4.2.

We aggregated the detailed 12 feed types to the following 4 feed categories: Concentrate feed, Fodder Crops, Straw, Grass. For the year 2050, we developed a set of alternative feed conversion ratios, i.e. feed intake per animal output. The modelling framework allows a fully flexible implementation of FCR datasets. *Table **6*** summarizes the set of alternative FCR datasets utilized for the BioBaM framework.

Table 6. Set of alternative FCRs for Europe in the year 2050

Code	Total FCRs	Criteria	Efficiency	Replacement of concentrates by
1a	As Baseline	-	As Baseline	Fodder Crops and Grass
1b	As Baseline	-	As Baseline	Grass only
2a	One FCR for all regions	Highest grass share	Efficient	
2b	One FCR for all regions	Highest grass share	Inefficient	
2c	One FCR for all regions	Highest grass share	Efficient	Grass only
2d	One FCR for all regions	Highest grass share	Efficient	Fodder Crops and Grass
2e	One FCR for all regions	Highest grass share	Inefficient	Grass only
2f	One FCR for all regions	Highest grass share	Inefficient	Fodder Crops and Grass

Explanation of the code

1a: total FCR remains the same, but FCRs of Cereals, Sugarcrops and Oilcrops are moved to Grass for RUMINANTS - roughage only approach

1b: total FCR remains the same, but FCRs of Cereals, Sugarcrops, Oilcrops and Fodder Crops are moved to Grass for RUMINANTS - grass only approach

2a: all regions' FCRs are changed to be like the FCRs of the most efficient regions within the top 5% regions with biggest grass share

2b: all regions' FCRs are changed to be like the FCRs of the most inefficient regions within the top 5% regions with biggest grass share

2c: all regions' FCRs are changed to be like the FCRs of the most efficient regions within the top 5% regions with biggest grass share; then a grass

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only approach is applied

2d: all regions' FCRs are changed to be like the FCRs of the most efficient regions within the top 5% regions with biggest grass share; then a roughage only approach is applied

2e: all regions' FCRs are changed to be like the FCRs of the most inefficient regions within the top 5% regions with biggest grass share; then a grass only approach is applied

2f: all regions' FCRs are changed to be like the FCRs of the most inefficient regions within the top 5% regions with biggest grass share; then a roughage only approach is applied

5.1.5 Crop residues

Assessments of crop residue potentials are based crop production, crop-specific residue-to-product ratios and maximum sustainable removal rates. In order to estimate **harvest residues** or other harvest by-products not included in statistics (e.g. stems, leaves), as well as belowground productivity (roots), we use crop-specific factors derived from earlier studies (Krausmann et al. 2013a), see *Table **7***. Data was available for Western and for Eastern & Southeastern Europe.

The assumed sustainable removal rates for using harvest residues as livestock feed, for bioenergy production, or for other purposes (e.g. rooftops), vary widely: Literature reviews (Scarlat et al. 2010; Bentsen et al. 2014) show values ranging from 15 to 82 % (most values being in the range of 30 to 60 %, which is also in the range of Bentsen et al., 2014), depending on crop type and tillage practices. Additionally, data for harvest residues used for feed is extremely scarce, and if, only straw is reported. We thus use assumptions on the amount of crop residues fed to livestock in CAPRI (i.e. straw) and Herrero et al. (2013) as basis for the calculation of crop residues which are removed from fields and further utilized.

Table 7. Factors for crop to residue shares and shares of belowground/aboveground biomass in agricultural biomass. Source: Krausmann et al. (2013)

	E. Asia	E. Europe	Latin America	N. Africa W. Asia	N. America Oceania	S. and C. Asia	Subsahara n Africa	W. Europe
Harvest factors. Crop residue [g dry matter (DM) per year] = primary crop harvest [g DM/yr] * harvest factor.								
Wheat, other cereals	1.5	1.5	1.5	1.5	1.2	1.7	2.3	1.0
Rice, Paddy	1.0	1.2	1.2	1.2	1.2	1.5	1.5	1.2
Maize	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Millet	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Sorghum	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Roots and Tubers	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Cassava	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sugar Cane	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Sugar Beets	0.7	0.5	0.7	0.7	0.5	0.7	0.7	0.5
Pulses	0.4	1.0	0.4	0.4	1.0	0.4	0.4	1.0
Soybeans	1.2	1.5	1.5	1.5	1.2	1.5	1.5	1.2
Groundnuts in Shell	1.2	1.2	1.5	1.5	1.2	1.5	1.5	1.2
Oil Palm Fruit	1.5	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Castor Beans	0.4	1.0	0.4	0.4	1.0	0.4	0.4	1.0
Rapeseed, oil crops	2.3	1.9	2.3	2.3	1.9	2.3	2.3	1.9
Fodder crops	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Permanent crops	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Belowground/aboveground NPP ratios and loss factors for the calculation of NPP_{act} on cropland from $HANPP_{harv}$

	Least developed countries	Developing countries	Transition markets	Industrialized countries
Belowground NPP/aboveground NPP	0.15	0.15	0.15	0.15

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We use (IPCC 2019) Tier 1 default methods and parameters to determine the loss of SOC resulting from residue removal for livestock feed. GHG emissions from additional fertilizer demand required for a balanced nitrogen cycle (i.e. through the removal of crop residues) are also taken into account (i.e. upstream emissions of synthetic fertilizer production, as N_2O emissions from fertilizer application are offset by reduced N_2O emissions from residues left on the field).

5.2 Trade

Regional deficits in crop (both food and feed) or roughage supply is assumed to be compensated for by intraregional and interregional trade. In order to be able to implement different trade scenarios (see Röös et al. 2019), we defined a set of trade clusters where we can set priorities for trade, limit the amounts of allowed trade or exclude regions.

- no trade barriers – global trade: This means, that deficits in each region are compensated for with surpluses from other regions, with no spatial constraints (e.g. deficits in the NUTS2 region *FR10 Île de France* are compensated with cropland products from Australia, where there is surplus production. Feasibility is global.
- Intra-regional trade first: deficits are compensated within the same world region (e.g. Western Europe), and if domestic surplus is not sufficient, global surplus is used to balance domestic deficits. Feasibility shows whether world-regions are self-sufficient or not. Levels of self-sufficiency can be adapted.
- Trade within countries: NUTS2 regions firstly compensate deficits within the same country. Feasibility shows whether countries are self-sufficient or not. Levels of self-sufficiency can be adapted.

Overall, the levels of self-sufficiency can be different between regions, to account for e.g. urban regions (where high self-sufficiency levels nor are desirable neither feasible) and rural regions.

The volume of regional net trade will be assessed the following way: the deficit of crop products (both food and feed) or roughage in a region was assumed to be compensated for by a surplus production of crop products and roughage in those regions with highest remaining production potentials after subtracting domestic consumption. Thus, our trade results correspond to net trade quantities and are not based on economic considerations, nor do they reflect historic trade patterns or barriers whatsoever. To yield meaningful results, we express trade flows of animal products in feed equivalents, that is, the amount of roughage that would be required to close the regional supply deficit of meat and milk product demand. Hence, trade quantities with animal products are not only available as product quantities but also as feed quantities embodied in the traded products.

5.3 Emissions from the land sector: changes of C-stocks

5.3.1 Calculation of emissions from carbon stock changes

The calculation procedures of emissions from carbon stock changes are based on the approach developed in Kalt et al. (2020). We calculate carbon emissions from land-use change (LUC) using a 'stock difference approach' largely based on IPCC default data (IPCC 2019): The basic approach is to determine net CO_2 emissions to or removals from the atmosphere (i.e. CO2 sinks) by calculating the difference in natural carbon stocks on each unit area undergoing LUC:

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$$EMI_{Cstock} = -\frac{44}{12} \cdot \Delta C = -\frac{44}{12} \cdot \frac{C_{t2} - C_{t1}}{t_2 - t_1}, \quad (1)$$

EMI_{Cstock} denotes net CO_2 emissions in tons per year, ΔC annual carbon stock change per unit area in tons C per year, and C_{t1} and C_{t2} the carbon stocks at time t_1 and t_2, respectively. 44/12 is the ratio of molecular weights of CO_2 and C and the change in sign is due to the convention that negative emissions represent decreases in C stocks, i.e. emissions to the atmosphere.

We consider a range of types of land-use changes, which represent the dynamic between cropland and grassland, and also model different options in regard to freed up agricultural land in 2050 due to lower demand for agricultural products, e.g. through lower shares of animal proteins in human diets.

The considered types of land-use change are:

- Conversion of grassland to cropland and vice versa
- Conversion of cropland and highly productive grassland to energy plantations
- Vegetation regrowth on grassland and cropland without any management (natural succession)
- Utilization of free land to decrease the overall land use intensity
- Utilization of free land for additional production of agro-ecological products for export

Since deforestation is disregarded in BioBaM, LUC from forest to agricultural land is not taken into account. Loss of agricultural land to infrastructure and settlement areas is basically considered in BioBaM; corresponding carbon stock changes are disregarded due to vast uncertainties in data.

*Figure **8*** illustrates the relevant types of LUC, underlying mechanisms and the respective C stock changes. Following IPCC (2019) accounting principles, we consider the C pools soil, above- and below-ground biomass and dead organic matter (litter; deadwood is disregarded). $\Delta C_{soil/biomass/litter}$ denotes stock changes in the respective C pool associated with the respective type of LUC. Since litter is assumed to be zero on cropland as well as grassland under Tier 1 (IPCC 2019), ΔC_{litter} is zero in case of LUC between these two land categories. For energy crops, we assume regionally specific litter stocks according to Kalt et al. (2019).

On grassland, soil C stocks are influenced by the level of degradation (IPCC Tier 1 approach). We here assume that the level of degradation is correlated to the grazing intensity, measured as grazing harvest in per cent of actual net primary production (Erb et al., 2016; see below).

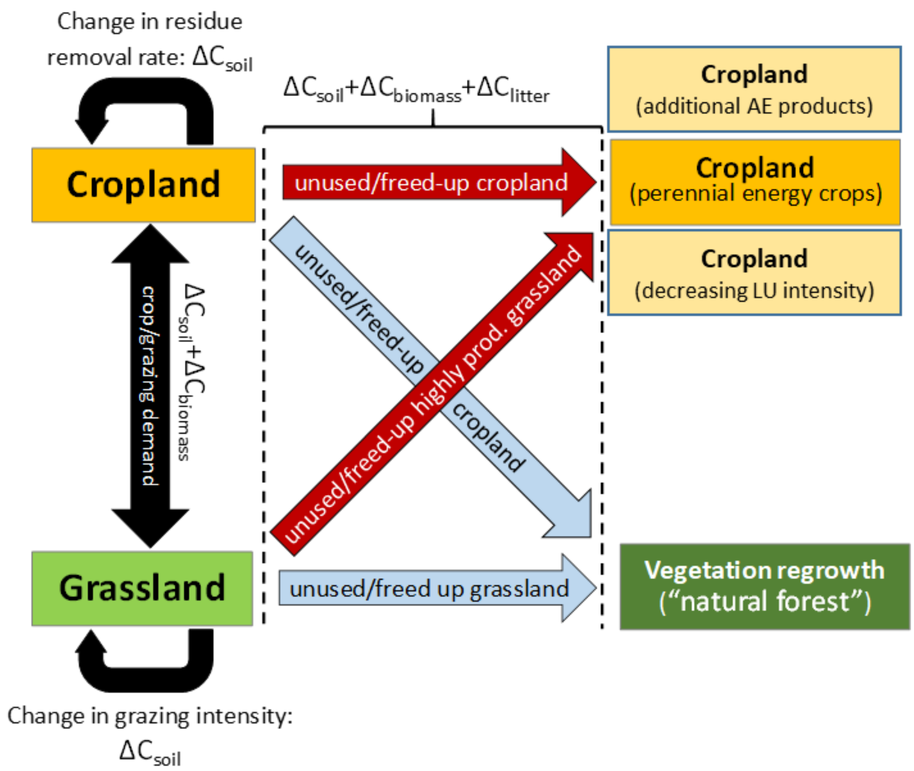

Figure 8. Relevant types of land-use change and associated C stock changes. Figure based on Kalt et al. (2020).

Following IPCC default methods, natural carbon stocks in different land-use types, and therefore also the values of ΔC_{soil}, $\Delta C_{biomass}$, ΔC_{litter} in case of LUC depend on various site-specific parameters. Based on the distribution of agricultural land and site conditions, we calculate average C stocks for every land-use type and world region. The distributions of agricultural land types among climate zones, soil types and ecological zones are provided below.

*Table **8*** gives an overview of the IPCC data tables used for deriving average C stock values. Further assumptions (due to insufficient data on global scale) are also summarized here.

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Table 8. Data basis for calculating world regional-specific C stocks for different land-use types and C pools in accordance with IPCC guidelines 2006, with according tables referring to IPCC (2006). The relevant site conditions (climate, soil and/or ecological conditions) are specified in brackets. Source: Kalt et al. (2020).

	Land-use types			
C pool	**Cropland**	**Grassland**	**Natural forest / natural vegetation**	**Further assumptions**
Soil	Table 2.3 (soil types[1], climate zones[1])			Cropland: Medium input level (see Table 5.5) is assumed as global default
	Table 5.5 (climate zones[1], tillage level[2])	Table 6.2 (climate zones[1], degradation level[3])	– (no further influencing factors than soil type and climate zone)	
Biomass	5 t C/ha (Table 5.9 IPCC Guidelines 2006)	Table 6.4 (climate zones[1])	Table 4.12 (ecological zones[4])	Belowground biomass in forests is assumed to be 30 % of aboveground biomass
Litter	– (no litter)	– (no litter)	Table 2.2 (climate zones[1], forest types)	Deadwood in natural forest is neglected (no default values available), therefore litter is the only relevant fraction of dead organic matter

Notes:
1) Raster data on soil types and climate zones: JRC (2018)
2) Assumed tillage levels are based on Prestele et al. (2018) (see below; Table 9)
3) Degradation levels are assumed to be correlated with grazing intensities (see below)
4) Raster data on ecological zones: FAO (2012)

Transition times from initial carbon stocks to a new equilibrium state extend over decades or even more than a century (in case of forest). For soil and litter carbon stocks, we assume the default 20 years according to IPCC Tier 1 methods. This implies that the emissions in 2050 depend on the timing of land-use changes during the timeframe from 2012 to 2050, and that the snapshot of land-use change emissions in 2050 is of limited significance. Therefore, we consider the total cumulative carbon stock changes during 2012 to 2050 and assume constant annual rates of land-use change during this timeframe, which we also provide as one output indicator from BioBaM (see below).

5.3.2 Calculation of soil carbon stocks

5.3.2.1 General approach

Under IPCC Tier 1, SOC stocks depend on the type of land use, site-specific ecological parameters (soil types, climate) and – in case of agricultural land – further influencing parameters like tillage practices and inputs of residues or livestock manure. Using Tier 1 default parameters, SOC stocks are calculated from

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climate- and soil-specific reference values SOCREF given in tons of C per ha and dimensionless "stock change factors" that depend on the land-use system (FLU), the management regime (FMG) and input levels (FI). For a homogenous patch of 1 hectare, the SOC stock is calculated using the following equation (based on equation 2.25 in (IPCC 2006)),

$$SOC = SOC_{REF} \bullet F_{LU} \bullet F_{MG} \bullet F_I \qquad (2)$$

The IPCC Tier 1 default values for SOCREF are provided in Table 2.3, the stock change factors for cropland in Table 5.5 and for grassland in Table 6.2 in IPCC (2006). For forest, all stock change factors under Tier 1 are equal to 1, hence SOC generally corresponds to SOCREF.

In our model, this calculation is relevant for determining ΔCsoil for changes in broad land-use classes, changes in residue removal rates on cropland and changes in grazing intensities on grazing land. The latter two are explained in detail in the following sub-sections.

5.3.2.2 Relationship between grazing intensity and soil carbon stocks

For modelling the impact of grazing on SOC stocks on grassland, we assume a linear relation between grazing intensity (measured as ratio of grazed or mowed biomass to actually prevailing net primary production; Erb et al., 2016a; Haberl et al., 2007) and degradation levels (modelled as management factor FMG). For non-degraded grassland FMG is 1. Since FLU and FI are also equal to 1 for grazing land (see Table 6.2 in IPCC, 2006), SOC stocks correspond to the soil- and climate-specific reference values SOCREF. For moderately degraded grassland, the management factor ($F_{MG}^{mod.degr.}$) ranges from 95 % to 97 %, depending on the climate zone.

We assume that grassland with zero grazing/mowing (grazing intensity = 0) is non-degraded, and that the maximum sustainable grazing intensity (GImax; see Erb et al., 2016a) corresponds to the degradation level "moderate". Between zero grazing and maximum sustainable grazing a linear decrease of SOC is assumed (*Figure **9***).

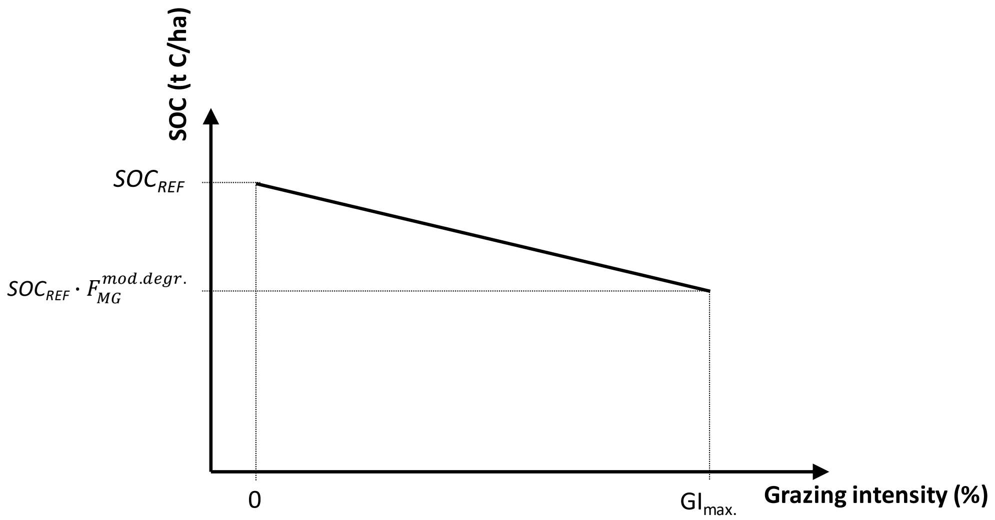

Figure 9. Assumed relationship between grazing intensity and soil organic carbon on grazing land (Source: Kalt et al. 2020).

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5.3.2.3 Relationship between residue removal and soil carbon stocks

Our approach for modelling the impact of crop residue removal on SOC is based on the "Input factor" F_I. Four levels of input are distinguished for cropland: "Low", "Medium", "High without manure" and "High with manure" (Table 5.5 in IPCC, 2006). We assume that crop residues removal up to 20 % corresponds to the level "High without manure". For removal rates between 20 and 60 %, we assume a linear relation between the residue removal rate and the input factor, with 60 % corresponding to the input level "Low". Figure 10 illustrates this assumption. The management factor F_{MG} is also relevant for cropland because it varies for different tillage levels (see next sub-section), and is therefore also included in the y-axis markings in Figure 10. The land use factor F_{LU} is omitted here because for "long-term cultivated cropland" it is equal to 1.

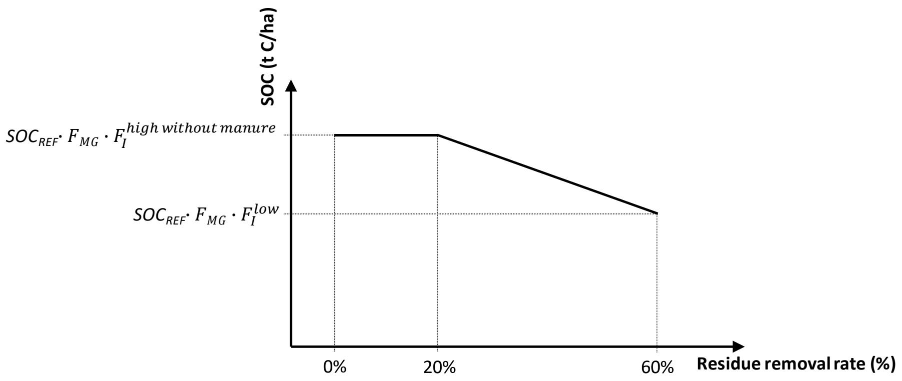

Figure 10. Assumed relationship between residue removal rate and soil organic carbon on cropland (Source: Kalt et al. 2020).

5.3.2.4 Tillage practices in world regions and Europe

According to IPCC methods (IPCC 2006), SOC stocks on cropland are influenced by tillage practices through the management factor FMG. To estimate global SOC stocks on cropland, we use literature data on tillage (shares of "conservation agriculture") per country and derive shares for the three tillage levels for each world region. Table 9, based on Prestele et al. (2018), summarizes the assumed tillage shares.

Table 9. Assumed shares of full, reduced and zero tillage for estimating SOC stocks

Region	Zero tillage	Reduced tillage	Full tillage
Northern Africa and Western Asia	0.2%	0.0%	99.8%
Sub-Saharan Africa	0.7%	0.2%	99.1%
Central Asia and Russian Federation	4.0%	1.0%	95.0%
Eastern Asia	5.9%	1.5%	92.7%
Southern Asia	0.8%	0.2%	99.0%
South-Eastern Asia	0.0%	0.0%	100.0%
Northern America	27.3%	9.2%	63.5%
Latin America & the Caribbean	33.9%	5.5%	60.6%

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Western Europe	3.4%	19.8%	76.8%
Eastern & South-Eastern Europe	2.3%	5.9%	91.8%
Oceania and Australia	37.1%	9.3%	53.6%

Source: Kalt et al. (2019), based on Prestele et al. (2018)

5.3.2.5 Regional factors: Distribution of agricultural land

All factors need to be region specific. The following *Table **10*** and *Table **11*** show the calculated distribution of cropland and highly productive (class 1) grazing land in selected European countries across ecological zones, as derived from the respective GIS data (ecological zones: (FAO 2012), soil types and climate zones: (JRC 2018), agricultural land: (Erb et al. 2007b)). These distributions, together with annual biomass growth data (Table 4.12 in IPCC, 2006), determine biomass accumulation and maximum carbon stocks in each world region.

Table 10. Distribution of cropland across ecological zones for selected countries (Source: Kalt et al. (2020))

	Austria	Bulgaria	Denmark	Finland	France	Germany	Italy	Poland	Portugal	Spain	Switzerland
Tropical.rainforest	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.moist.forest	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.dry.forest	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.shrubland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.desert	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.mountain.system	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subtropical.humid.forest	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subtropical.dry.forest	0%	4%	0%	0%	10%	0%	54%	0%	73%	76%	0%
Subtropical.steppe	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subtropical.desert	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subtropical.mountain.system	0%	0%	0%	0%	1%	0%	9%	0%	18%	20%	0%
Temperate.oceanic.forest	11%	0%	100%	0%	84%	81%	26%	10%	7%	1%	30%
Temperate.continental.forest	53%	86%	0%	7%	0%	12%	0%	88%	0%	0%	0%
Temperate.steppe	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Temperate.desert	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Temperate.mountain.system	36%	10%	0%	0%	5%	7%	11%	2%	1%	3%	70%
Boreal.coniferous.forest	0%	0%	0%	93%	0%	0%	0%	0%	0%	0%	0%
Boreal.tundra.woodland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Boreal.mountain.system	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 11. Distribution of grassland 1 (i.e. grassland with the highest quality, i.e. NPPpot) across ecological zones for selected countries (Source: Kalt et al. (2020))

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	Austria	Bulgaria	Denmark	Finland	France	Germany	Italy	Poland	Portugal	Spain	Switzerland
Tropical.rainforest	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.moist.forest	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.dry.forest	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.shrubland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.desert	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tropical.mountain.system	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subtropical.humid.forest	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subtropical.dry.forest	0%	3%	0%	0%	3%	0%	76%	0%	89%	89%	0%
Subtropical.steppe	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subtropical.desert	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subtropical.mountain.system	0%	0%	0%	0%	0%	0%	2%	0%	5%	7%	0%
Temperate.oceanic.forest	38%	0%	100%	0%	93%	85%	20%	8%	6%	2%	59%
Temperate.continental.forest	25%	93%	0%	4%	0%	12%	0%	91%	0%	0%	0%
Temperate.steppe	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Temperate.desert	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Temperate.mountain.system	37%	4%	0%	0%	4%	3%	2%	1%	0%	2%	41%
Boreal.coniferous.forest	0%	0%	0%	96%	0%	0%	0%	0%	0%	0%	0%
Boreal.tundra.woodland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Boreal.mountain.system	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

5.3.2.6 European NUTS2 regions, soil types and climate zones

The following *Table **12*** presents the climate-soil matrices for cropland for selected European countries; that is, the shares of the respective agricultural land type located in each combination of climate- and soil-type. We applied these shares to countries' respective NUTS2 regions.

Table 12. Distribution of cropland across climate zones and soil types for selected European countries (Source: Kalt et al. (2020))

Austria	organic	sandy	wetland	volcanic	spodic	high.activity.clay	low.activity.clay
warm.tempe	0%	0%	0%	0%	0%	0%	0%
warm.tempe	1%	0%	0%	0%	0%	2%	0%
cool.temper	0%	0%	0%	0%	4%	54%	8%
cool.temper	0%	0%	0%	0%	0%	29%	2%
boreal.moist	0%	0%	0%	0%	0%	0%	0%
boreal.dry	0%	0%	0%	0%	0%	0%	0%
tropical.mon	0%	0%	0%	0%	0%	0%	0%
tropical.wet	0%	0%	0%	0%	0%	0%	0%
tropical.mois	0%	0%	0%	0%	0%	0%	0%
tropical.dry	0%	0%	0%	0%	0%	0%	0%

Finland	organic	sandy	wetland	volcanic	spodic	high.activity.cla	low.activity.clay
warm.tempe	0%	0%	0%	0%	0%	10%	0%
warm.tempe	0%	0%	0%	0%	0%	77%	0%
cool.temper	0%	0%	0%	0%	0%	9%	0%
cool.temper	0%	0%	0%	0%	0%	2%	0%
boreal.moist	0%	0%	0%	0%	0%	0%	0%
boreal.dry	0%	0%	0%	0%	0%	0%	0%
tropical.mon	0%	0%	0%	0%	0%	0%	0%
tropical.wet	0%	0%	0%	0%	0%	0%	0%
tropical.mois	0%	0%	0%	0%	0%	0%	0%
tropical.dry	0%	0%	0%	0%	0%	2%	0%

Greece	organic	sandy	wetland	volcanic	spodic	high.activity.clay	low.activity.clay
warm.tempe	0%	0%	0%	0%	0%	10%	0%
warm.tempe	0%	0%	0%	0%	0%	77%	0%
cool.temper	0%	0%	0%	0%	0%	9%	0%
cool.temper	0%	0%	0%	0%	0%	2%	0%
boreal.moist	0%	0%	0%	0%	0%	0%	0%
boreal.dry	0%	0%	0%	0%	0%	0%	0%
tropical.mon	0%	0%	0%	0%	0%	0%	0%
tropical.wet	0%	0%	0%	0%	0%	0%	0%
tropical.mois	0%	0%	0%	0%	0%	0%	0%
tropical.dry	0%	0%	0%	0%	0%	2%	0%

France	organic	sandy	wetland	volcanic	spodic	high.activity.cla	low.activity.clay
warm.tempe	0%	1%	0%	0%	0%	44%	0%
warm.tempe	0%	1%	0%	0%	0%	28%	0%
cool.temper	0%	0%	0%	0%	2%	21%	0%
cool.temper	0%	0%	0%	0%	0%	1%	0%
boreal.moist	0%	0%	0%	0%	0%	0%	0%
boreal.dry	0%	0%	0%	0%	0%	0%	0%
tropical.mon	0%	0%	0%	0%	0%	0%	0%
tropical.wet	0%	0%	0%	0%	0%	0%	0%
tropical.mois	0%	0%	0%	0%	0%	0%	0%
tropical.dry	0%	0%	0%	0%	0%	0%	0%

5.4 Activity-based GHG emissions

Agricultural activity is associated with a range of GHG emissions. We calculate emissions from the following sources: CO_2 emissions from land use change (See above), CH_4 emissions from

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monogastric and ruminant livestock, whereas ruminant livestock is a source of CH4 through enteric fermentation and manure management, and monogastric livestock through manure management. Nitrogen emissions are linked to soil management and also to livestock. All activities are linked to upstream emissions from the use of chemical fertilizer, fossil energy to fuel agricultural machinery, and transport.

5.4.1 Regional factors: Distribution of livestock

BioBaM does not explicitly model the spatial distribution of livestock. Instead, we distribute the feed demand that is necessary for the production of the required animal products along the following distributional rules:

- Fixed animal product distribution: Here we assume the relative distribution of animal production in the reference year 2012, calculated from FAOSTAT data and CAPRI, to remain constant. We therefore calculate the % share of each NUTS2 region or country in the global production for each animal product and assume that this share remains constant, regardless of scenario-specific changes in consumption patterns.
- Potential based animal product distribution: BioBaM calculates the production potential of animal product for each NUTS2 region and country, based on the region's cropland and grazing area and yields (derived from CAPRI and FAO 2018) without any restriction, i.e. a global re-distribution of production potentials. The global demand for each animal product is then distributed according to the production potentials (for monogastric livestock we use the potential on cropland, for ruminant livestock the potential on grassland). For instance: a region with 3% global potential is then producing 3% of the global demand.
- Restricted potential animal product distribution: BioBaM calculates the production potential within each country grouping defined, i.e. either within one country or world-region (e.g. Western Europe), similar to the potential based distribution. The restriction to certain regions thus avoids that large production potentials are moved towards regions with large and under-utilized grasslands such as in e.g. Russia.

5.4.2 CH4 emissions from enteric fermentation

We apply the IPCC tier2 approach, which calculates emissions based on feed input, and not on animal type (IPCC tier1 approach, see IPCC 2019). All feed consumption which is reported in dry matter is converted into Gross Energy values, with 18.45 MJ/kg DM of feed.

5.4.2.1 Cattle, buffaloes, sheep, goats

We apply the following equation to calculate the CH4 emissions from Cattle, buffaloes, sheep, goats.

$$CH_{4\text{-enteric, lsc, fc}} = DMI_{lsc,\, fc} * 18.45 \text{ MJ/kg DM} * (MCF_{Max,\, lsc} - 0.05 * Digest\%_{lsc,\, fc}) / 55.65 \text{ MJ/kg } CH_4$$

Whereas $CH_{4\text{-enteric}}$ = CH_4 from enteric fermentation for livestock category *lsc* and feed category *fc.*

$DMI_{lsc,\, fc}$ is the dry Matter Intake for livestock category *lsc* and feed category *fc*, which is calculated based on output data on livestock feed consumption per region in BioBaM.

$MCF_{Max,\, lsc}$ is the maximum methane conversion factor for livestock category *lsc.* We use maximum methane conversion factors provided by the Global Livestock Environmental Assessment Model (GLEAM), see (FAO 2017c, 2017a). We draw a distinction between the share of cattle products (beef,

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milk) that is kept in feedlot and in other systems, based on shares provided by IPCC (2019) guidelines. Sheep and goats were split into "adult reproductive" and „young replacement and fattening animals". We apply the following $MCF_{Max,\ lsc}$: 9,75% of feed intake for ruminant livestock. 8.75% for sheep and goats by assuming a 50/50 rate between adult reproductive and young replacement and fattening animals.

Digest%*lsc*, *fc* are digestibilities for livestock category *lsc* and feed category *fc*. We here use standard factors on digestibilities derived from different sources, see Table 13.

18.45 MJ/kg DM: Standard energy content of feed according to IPCC AFOLU guidelines (source)

55.65 MJ/kg CH4 : Energy content of methane (IPCC 2019).

5.4.2.2 Pigs

$$CH_{4\text{-enteric}} = DMI * 18.45\ MJ/kg\ DM * MCF / 55.65\ MJ/kg\ CH_4$$

$CH_{4\text{-enteric}}$ is CH_4 from enteric fermentation for pigs.

$DMI_{lsc,\ fc}$ is the dry Matter Intake for pigs, which is calculated based on output data on livestock feed consumption per region in BioBaM.

MCF: Methane conversion factor for pigs. We use maximum methane conversion factors provided by the Global Livestock Environmental Assessment Model (GLEAM), see (FAO 2017c, 2017a). We draw a distinction between the share of „adult reproductive animals" and „replacement and fattening animals". CAPRI and FAO provides data for different cohorts of pigs, and we use this information to split the total feed intake into the two categories from above. We use a factor of 0,7% to calculate the MCF of pigs, if no data was available on the shares of adult reproductive animals and replacement and fattening animals.

18.45 MJ/kg DM : Standard energy content of feed according to (IPCC 2019)

55.65 MJ/kg CH_4 : Energy content of methane

Table 13. Energy digestibilities (Digest%$_{lsc,\ fc}$) of different livestock feed sources for ruminant and monogastric livestock.

	Ruminants	Monogastrics	Source
Grass	70.0%	42.0%	Sauvant et al. 2002, p.260, dehydrated grass; for monogastrics: mean for growing pigs and sows
Fodder crops	68.7%	54.5%	For ruminants: Feedipedia, maize silage, mean for silage with different water contents; for pigs: Sauvant et al. 2002, p.258, alfalfa dehyrated 22-25% dm, mean for growing pigs and sows (no values for maize silage for pigs)
Straw	41%	15.5%	Sauvant et al. 2002, p.262, wheat straw; for monogastrics: mean for growing pigs and sows
Cereals	86.1%	88.0%	Feedipedia, maize grain, Europe (small differences among regions)
Oil Crops	92.8%	86.5%	Feedipedia, soybean meal, average of different types (hulled, de-hulled,
Sugar Crops: Sugar cane	42.3%	17.3%	Feedipedia, sugarcane bagasse, dehydrated
Sugar crops: Sugar beet	81.0%	71.0%	Feedipedia, beet pulp, dehydrated

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5.4.3 CH4 emissions from manure management

5.4.3.1 Volatile and solid excretion

We apply the following equation to separate the amount of volatile and solid excretion from livestock

$$VS_{lsc,\,fc} = (DMI_{lsc,\,fc} * 18.45\ MJ/kg\ DM * (1 - Digest\%_{lsc,\,fc}) + (UE * DMI_{lsc,\,fc} * 18.45\ MJ/kg\ DM)) * ((1 - ASH_{fc})/ 18.45\ MJ/kg\ DM)$$

$VS_{lsc,\,fc}$: Volatile Solid Excretion for livestock category *lsc* and feed category *fc* → this is the core input into the equation to calculate CH4 emissions from manure management.

$DMI_{lsc,\,fc}$: Dry Matter Intake for livestock category *lsc* and feed category *fc* which is calculated based on output data on livestock feed consumption per region in BioBaM.

18.45 MJ/kg DM : Standard energy content of feed according to IPCC (2019)

$Digest\%_{lsc,\,fc}$: Detailed digestibilities for livestock category *lsc* and feed category *fc* are derived from Table 13.

UE : Urinary Energy share → We here apply standard factors from 0,2 - 0,4, depending on animal species.

ASH_{fc}: Ash content of feed as fraction of dry matter input. See Table 14.

Table 14. ASH_{fc} contents for different livestock feed categories

	ASH_{fc}	Source
Grass	7.8%	Sauvant et al. 2002, p.260, dehydrated grass
Fodder crops	4.0%	For ruminants: Feedipedia, maize silage, mean for silage with different water contents
Straw	5.9%	Sauvant et al. 2002, p.262, wheat straw
Cereals	1.4%	Feedipedia, maize grain, Europe (small differences among regions)
Oil Crops	7.1%	Feedipedia, soybean meal, average of different types (hulled, de-hulled,
Sugar Crops: Sugar cane	5.9%	Feedipedia, sugarcane bagasse, dehydrated
Sugar crops: Sugar beet	7.1%	Feedipedia, sugar beet pulp, dehydrated

5.4.3.2 CH4 emissions from manure management

We apply the following equation to estimate the CH4 emissions from livestock manure management

$$CH_{4\text{-manure-mgmt},\,lsc,\,fc} = (DMI_{lsc,\,fc} * (1 - Digest\%_{lsc,\,fc} + UE)\ ) * (1 - ASH_{fc}) *0.67* B_{0,\,lsc} * MCF_{lsc}$$

$VS_{lsc,\,fc}$: Volatile Solid Excretion for livestock category *lsc* and feed category *fc*, based on equation above.

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$B_{0,\,lsc}$: Maximum methane producing capacity. Standard factors per world region. Table 15 presents a summary for world regions.

MCF_{lsc}: Methane conversion factor for livestock category *lsc* → We use standard factors based on manure management systems from IPCC 2019 (Table 16).

Table 15. Default values for maximum methane producing capacity B0, Source: IPCC 2019

TABLE 10.16
DEFAULT VALUES FOR MAXIMUM METHANE PRODUCING CAPACITY (B_0) (M^3 CH_4 KG^{-1} VS) (UPDATED)

Category of animal [2]	Region					
	North America	Western Europe	Eastern Europe	Oceania	Other Regions[1]	
					High productivity systems	Low productivity systems
Dairy cattle	0.24				0.24	0.13
Non dairy cattle	0.19	0.18	0.17	0.17	0.18	0.13
Buffalo	0.10				0.10	0.10
Swine	0.48	0.45	0.45	0.45	0.45	0.29
Chicken-Layer	0.39				0.39	0.24
Chicken-Broilers	0.36				0.36	0.24
Sheep	0.19				0.19	0.13
Goats	0.18				0.18	0.13
Horses	0.30				0.30	0.26
Mules/ Asses	0.33				0.33	0.26
Camels	0.26				0.26	0.21
All Animals PRP	0.19					

Sources: All values are consistent with IPCC 2006 values from Annex 10A.2 with the exception of PRP, taken from the analysis described in Annex 10B.6.
[1] For other regions, low productivity is considered the default value for Tier 1 if not using the Tier 1a.
[2] Only presenting values for manure, compilers are recommended to consult scientific literature or develop country-specific B_0 values for the different codigestates that may be used in anaerobic digesters.
Uncertainty values are ±15%

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Table 16. Default values for methane conversion factors, Source: IPCC (2019)

TABLE 10A.6 ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR CATTLE AND BUFFALO (NEW TABLE)										
Animal Category	**Climate and System Based Category**	**AWMS (%)**								
		Lagoon	**Liquid /Slurry**	**Solid storage**	**Drylot**	**Pasture/ Range/ Paddock**	**Daily spread**	**Digester**	**Burned for fuel**	**Other**
Dairy Cattle	North America	26	24	24	0	15	11	0	0	0
	Western Europe	0	43	29	0	26	2	0	0	0
	Eastern Europe	0	5	74	0	20	1	0	0	0
	Oceania	5	0	0	0	94	1	0	0	0
	East Asia and South-East Asia (Asia)	0	1	21	29	38	0	0	11	0
	South Asia (Indian subcontinent)	0	0	1	49	30	0	0	20	0
	Latin America and the Caribbean	0	0	5	38	57	0	0	0	0
	Near East (Middle East) and North Africa	0	0	14	35	46	0	0	5	0
	Sub-Saharan Africa	0	0	20	29	45	0	0	6	0

5.4.4 N_2O emissions from agricultural activities

BioBaM quantifies different nitrogen (N) flows, which are used to derive inputs of synthetic nitrogen and N_2O emissions for different scenarios. N flows considered in the model include above- and belowground residues, crops, legumes, livestock manure and synthetic fertilizers. Crop residues are differentiated by above- and belowground biomass and N in biomass harvested (e.g. as bedding material), N in biomass left on fields and N in residues burned. N flows in livestock manure is specified for monogastrics and ruminants and are allocated to indoor/outdoor and different manure management systems. Due to the large uncertainties involved, a hybrid approach combining several data sources will be pursued in Uniseco. Prominent data sources include: (FAO 2017a; IPCC 2019; Winiwarter et al. 2018).

Biomass (crops, crop residues and legumes) will be calculated by combining biomass flows calculated in BioBaM with crop and residue specific nitrogen contents (IPCC 2019). N in livestock manure is derived from feed intake, as provided by the biomass module of BioBaM, feed digestibilities for ruminants and monogastrics (INRA et al. 2019; Sauvant et al. 2004) and outputs of N in livestock bodies, milk and eggs. Thus, N outputs in excreta is calculated as digested feed, minus N outputs in livestock products, corresponding to the IPCC tier 2 method for calculating manure outputs.

Based on these N flows and N inputs in synthetic fertilizers according to GAINS data, it is possible to derive a partial N use efficiency on cropland for 2000 and 2050 for the FAO scenario. This partial N use efficiency is defined as the sum of N inputs from biomass left on or returned to fields (crops, crop residues and legumes), livestock manure and synthetic fertilizers applied on cropland, divided by the sum of N in crops and residues fed to humans and livestock. For all other scenarios, the input of N from synthetic fertilizers (for scenarios with conventional agriculture) or N from legumes (for scenarios with organic agriculture) is derived as “nitrogen gap”, by assuming equal N use efficiencies as in the FAO reference scenario.

All N_2O emissions are calculated by combining relevant N flows with according N_2O emission factors from GAINS, which are based on standard IPCC N2O emission factors (IPCC 2019). This includes N2O from the application of synthetic fertilizers, residues (application to soils and burning), and manure management and

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application (arable land and pastures). Areas of flooded rice, to which a specific N_2O emission factor has to be applied, is derived by assuming a constant share of flooded rice to total cropland as in 2000.

5.4.5 Upstream emissions from agricultural activities

Upstream emissions include 1) manufacturing of artificial fertilizer (NPK) and legume cultivation at pre-farm level (Table 17 and

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Table **18**); 2) energy demand for field operations (Table 19). We apply a life cycle approach to calculate upstream emissions associated with agricultural activity. For all this, we distinguish values per world region.

Table 17. Upstream emissions from fertilizer production (pre-farm)

	Fertilizer production (pre-farm)				
	All	All	All	All	All
	All	All	All	All	All
	ureaproduction	non-ureaproduction	P-fertilizerproduction	K-fertilizerproduction	LegumesCultivation
	AllAllureaproduction	AllAllnon-ureaproduction	AllAllP-fertilizerproduction	AllAllK-fertilizerproduction	AllAllLegumesCultivation
	[tCO2eq/tN produced]	[tCO2eq/tN produced]	[tCO2eq/tP2O5 produced]	[tCO2eq/tK2O produced]	[tCO2eq/t N produced]
Northern Africa and Western Asia	2.99	5.24	1.51	1.29	15.91
Sub-Saharan Africa	2.99	5.24	1.51	1.29	15.91
Central Asia and Russian Federation	2.99	5.24	1.51	1.29	15.91
Eastern Asia	6.00	4.71	1.51	1.29	15.91
Southern Asia	2.99	5.24	1.51	1.29	15.91
South-Eastern Asia	2.99	5.24	1.51	1.29	15.91
Northern America	2.99	2.37	0.17	1.29	15.91
Latin America & the Carribean	2.99	5.24	1.51	1.29	15.91
Western Europe	3.47	3.52	1.51	0.89	20.16
Eastern & South-Eastern Europe	3.47	2.34	1.51	0.89	15.91
Oceania and Australia	2.99	1.86	1.51	1.29	15.91
Source	see details below				

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Table 18. Sources for emissions (tCO2eq/tN produced) of fertilizer production.

Fertilizer Name	Unit	EF	Region	Source
Urea	[tCO2eq/tN produced]	2.99	RoW	Ecoinvent3 default nach IPCC 2013
Urea	[tCO2eq/tN produced]	6.00	China	Wood&Cowie 2004
Urea	[tCO2eq/tN produced]	4.02	W-Europe	Wood&Cowie 2004
Urea	[tCO2eq/tN produced]	2.92	Europe	Ecoinvent3 default nach IPCC 2013
Urea	[tCO2eq/tN produced]	3.79	France	1 kg Urea, as N/FR U (of project AGRIBALYSE)
Urea	[tCO2eq/tN produced]	3.47	Europe	average hier
non urea production	[tCO2eq/tN produced]	5.24	RoW	Ecoinvent3 default nach IPCC 2013
non urea production	[tCO2eq/tN produced]	2.37	North America	Ecoinvent3 default nach IPCC 2013
non urea production	[tCO2eq/tN produced]	4.71	China	Ecoinvent3 default nach IPCC 2013
non urea production	[tCO2eq/tN produced]	1.86	O/Australia	Wood&Cowie 2004
non urea production	[tCO2eq/tN produced]	2.34	E-SE Europe	Wood&Cowie 2004
non urea production	[tCO2eq/tN produced]	5.33	Europe	Ecoinvent 2
non urea production	[tCO2eq/tN produced]	2.77	Europe	Ecoinvent3 default nach IPCC 2013
non urea production	[tCO2eq/tN produced]	3.52	W-Europe	Wood&Cowie 2004
non urea production	[tCO2eq/tN produced]	0.55	Niederlande	Agri-footprint - mass allocation, IPCC 2007
P-Fertilizer	[tCO2eq/tP2O5 produced]	0.82	Germany	Wood&Cowie 2004
P-Fertilizer	[tCO2eq/tP2O5 produced]	1.07	Europe	Wood&Cowie 2004
P-Fertilizer	[tCO2eq/tP2O5 produced]	1.51	Europe	Ecoinvent 2.2 nach IPCC2007
P-Fertilizer	[tCO2eq/tP2O5 produced]	0.17	N-Amerika	Wood&Cowie 2004
K-Fertilizer	[tCO2eq/tK2O produced]	0.54	Europe	Ecoinvent 2 nach IPCC 2007
K-Fertilizer	[tCO2eq/tK2O produced]	0.89	Europe	Ecoinvent3 default nach IPCC 2013
K-Fertilizer	[tCO2eq/tK2O produced]	1.29	Row	Ecoinvent3 default nach IPCC 2013
Favabean Org	[tCO2eq/t N produced]	15.91	Row	Ecoinvent3, for organic, RoW favabean production
Favabean Konv	[tCO2eq/t N produced]	20.16	Swiss	Ecoinvent2.2, konv. Swiss production

Table 19. Energy demand for field operation crop management (on farm)

	Energy demand: field operation crop management (on-farm)						
	All	All	All	All	All	All	All
	All	All	All	All	All	All	All
	cereals	roots	sugarcrops	pulses	oilcrops	vegetables and fruits	other crops
	AllAllcereals	AllAllroots	AllAllsugarcrops	AllAllpulses	AllAlloilcrops	AllAllvegetables and fruits	AllAllother crops
	[tCO2eq/ha]	[tCO2eq/ha]	[tCO2eq/ha]	[tCO2eq/ha]	[tCO2eq/ha]	[tCO2eq/ha]	[tCO2eq/ha]
Northern Africa and Western Asia	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Sub-Saharan Africa	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Central Asia and Russian Federation	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Eastern Asia	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Southern Asia	0.26	0.28	0.48	0.28	0.19	0.24	0.21
South-Eastern Asia	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Northern America	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Latin America & the Carribean	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Western Europe	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Eastern & South-Eastern Europe	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Oceania and Australia	0.26	0.28	0.48	0.28	0.19	0.24	0.21
Source	based on Lauk et al in prep.						

5.5 Biodiversity pressures

The integration of global impacts on biodiversity will be developed exploiting various approaches and datasets on the interlinkage of land use and biodiversity.

A key approach in UNISECO will be based on the species-energy relationship. This hypothesis holds that reductions in ecological energy flows (such as measured by the HANPP framework) correlate with biodiversity loss (Gaston 2000; Haberl et al. 2007a; Kehoe et al. 2015, 2017; Mouchet et al.

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2015). The HANPP (Human Appropriation of Net Primary Production) framework allows to construct socio-ecological indicators that integrate socioeconomic and ecological perspectives on land use. It traces biomass flows from its origin in ecosystems, i.e. the net primary production (NPP), to its consumption in socioeconomic processes. NPP denotes the balance between gross biomass production during photosynthesis and plant respiration, and represents a fundamental ecological process. It is intimately linked to the global biogeochemical cycles of carbon, water, nitrogen, and phosphorous. NPP is a key process for ecosystem functioning and the provision of ecosystem services and it is the starting point of all heterotrophic life on Earth (Vitousek et al. 1986).

Due to these characteristics, the HANPP framework allows to quantify trade-offs between provisioning ecosystem services, i.e. the harvest of used biomass, and regulating ecosystem functions, i.e. the amount of energy flux remaining in ecosystems after land use (see Mayer et al.; under review). The amount of biomass that is removed from agro-ecosystem through harvest can be defined as the main provisioning ecosystem service, a definition which is agreed in ecosystem service research and policy (Diaz 2019; Maes et al. 2016). In contrast, it is intricate to define unambiguous indicators for regulating ecosystem services. But, based on the HANPP framework, the energy flux remaining in ecosystem after harvest (NPPeco) and the biomass that is killed during harvested but left on field (e.g. roots, some crop residues, dentoted as unused harvest or HANPPharv_uue) can be calculated. This can be used to derived a proxy indicator for regulating ecosystem functions, as many ecosystem functions like carbon sequestration or water purification rely on these fluxes. Consequently, the measurement of provisioning versus regulating ecosystem services through the HANPP framework allows for a robust and explicit quantitative assessment of a central trade-off in ecosystem service provision through agriculture, where future land use is decisive how these trade-offs are mitigated or even increased, a strand that will be explored in Uniseco as well.

Based on the HANPP framework, we will calculate the indicator “Total Biomass Harvest Rate”, defined as the ratio of HANPPharv to potential NPP, in line with the dashboard indicator developed by Pelletier and Tyedmers (Pelletier and Tyedmers 2010). This indicator ranges between 0 and 100% in most cases, with some exceptions where carbon stocks are depleted or NPP is boosted in intensive culativation systems. The species energy hypothesis holds that species richness is larger the more energy is available in the system. In converse conclusion, the higher the ratio, the higher the pressure on ecosystems, whereat the reference level NPPpot allows to take differences in basic environmental conditions into account (Haberl et al. 2005, 2004b). This approach is thus suitable to derive indicators for pressures on biodiversity (Plutzar et al. 2016a; Haberl et al. 2007c).

Second, data on the impacts land use types, including land-use intensity, from the Predict database (Newbold et al. 2015) can also be used with the model results by BioBaM. And lastly, species-area factors from LCA literature (e.g. (de Baan et al. 2013; Chaudhary and Brooks 2018) (de Baan et al. 2013) can potentially be used to show impacts of changes in land-use patterns on biodiversity. The aim of this indicator package is to show in average terms, altered pressures on biodiversity from land use and its change. It is beyond the scope of the Uniseco developments to develop own datasets on land-use- biodiversity interrelationships. Thus, the choice of approaches in the biodiversity dimension will strictly depend on the time availability and priority setting by the stakeholders.

6 BIOBAM MODELL OUTPUTS AND INDICATORS

We calculate the following list of indicators in BioBaM. Each indicator is provided for each NUTS2

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region, country and world region.

- Land use (Mha)
  Total land use in 2050 in million hectares for cropland and grassland.
- Cropland area by crop groups (Mha)
  Total land use in 2050 for croplands by crop group in million hectares. Crop groups are cereals, roots and tubers, sugarcrops, pulses, oilcrops, fruits, vegetables, nuts, other crops, fodder crops, roughage.
- Grazing land by classes (Mha)
  Total land use in 2050 for grasslands by grassland group (3 groups for Europe, 4 groups for the Rest of the world) in million hectares.
- Net imports by crop groups (Mt dm)
  We calculate net imports by relating the domestic production to the domestic consumption for food, feed, industrial use, seeds and wastes for each crop grop in million tonnes.
  Net imports = Domestic consumption – Domestic production
- Crop production (Mt dm)
  Total production of agricultural crops from cropland in million tonnes.
- Crop consumption for food (Mt dm)
  Total consumption of crops for direct human consumption, including wastes, n million tonnes.
- Crop consumption for feed (Mt dm)
  Total consumption of crops used as livestock feed, in million tonnes. Total feed consumption from cropland is calculated through the multiplication of feed conversion ratios (FCRs) for cropland feed with animal products.
- Crop consumption for other uses (Mt dm)
  Total consumption of crops for other uses, i.e. industrial use, in million tonnes.
- Production of animal and other agricultural products (Mt dm). Agricultural products are all final products that are produced from primary biomass, also including non-food products such as fibers or biofuels.
- Agricultural products consumption for food (animal products like meat and milk) (Mt dm)
- Agricultural products consumption for other uses (e.g. biofuels produced from oilseeds) (Mt dm)
- Grazing supply (Mt dm)
  Total potential supply of grassland feed for (ruminant) livestock in million tonnes. Total supply is calculated via the maximum share of NPPact, i.e. the actual net primary production, that can be harvested without impairing the productivity of grasslands.
- Grazing demand (Mt dm)
  Total demand for grassland feed from (ruminant) livestock in million tonnes. Total grazing demand is calculated through the multiplication of feed conversion ratios (FCRs) for grassland feed with animal products.
- Grazing intensities (%)
  Calculated as share of Grazing demand in total grassland supply as %.
- Self-sufficiency (all crops) (%)
  Total self-sufficiency with crops, disregarding the different crop types (i.e. total crop demand divided by total crop production, both measured in tonnes dry matter)
- Self-sufficiency by crops (%)
  Crop-specific self-sufficiencies, i.e. calculated for each crop individually as ratio of supply and

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demand
- Self-sufficiency by agri.products (%)
  Self-sufficiencies with agricultural products, calculated for each agricultural product individually as ratio of supply and demand
- Potential self-sufficiency (%)
  Calculated as the ratio of agricultural land actually available and the agricultural land required to supply the total demand for crops and agricultural products in the respective region.
- GHG emissions from land use change (annual) (Mt dm CO2e)
  Annual total GHG emissions from land use change in Mt dm CO2 equivalents. Currently, we generally assume that agricultural land does not encroach into forests ("zero deforestation assumption"), thus only land use change between different types of agricultural land (as well as conversion to infrastructure or settlement areas) are possible.
- GHG emissions from land use change (cumulative) (Mt dm CO2e)
  Total cumulative GHG emissions from land use change during the considered timeframe (i.e. base year to final year) in million tonnes CO2 equivalents.
- GHG emissions from manure management (Mt dm CO2e)
  Total emissions from manure management in million tonnes CO2 equivalents in the year 2050.
- GHG emissions from enteric fermentation (Mt dm CO2e)
  Total emissions from enteric fermentation in million tonnes CO2 equivalents in the year 2050.
- GHG emissions: upstream emissions by crop group (Mt dm CO2e)
  Total upstream emissions in million tonnes CO2 equivalents in the year 2050.
- HANPP: Harvested biomass as share of total NPPpot (1)
  Total HANPP as share of the potential ecosystem capacity (i.e. NPPpot). This indicator provides information on changes in Human pressures upon the total ecosystem capacity per region.
- Regional grazing feasibility (1)
  Grazing demand as share of total grassland supply per region. No trade of grassland feed is assumed.
- Provisioning ecosystem services
  Share of used biomass output per NPPpot
- Regulating ecosystem services
  Share of NPPeco and HANPPharv_uue per NPPpot
- Biodiversity pressures
  see above

PART III: SOLM

This part describes SOLm, the second food systems model used in UNISECO.

7 INTRODUCTION SOLM

SOLm is a mass- and nutrient-flow model capturing the global food system on the level of geographic units (default: countries), linking production, consumption and trade, with the aim to derive and analyse the food system's input use, outputs and sustainability impacts for a wide range of future or

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counterfactual current food system scenarios. This section describes SOLm in general terms. Further details are given in the subsequent sections 8 and 9.

7.1 History

SOLm has originally been developed in the context of a project on sustainable and organic livestock production for the FAO, running from 2011-2013. This coined the name of the model, i.e. "**S**ustainability and **O**rganic **L**ivestock **m**odel – **SOLm**"[2]. It has subsequently been applied and developed further in a number of projects with a focus on food waste (still with the FAO), the alpine region ("Projekt Alpenraum", using refined data for Switzerland and Austria) and Switzerland (a Swiss National Science Foundation project on "Sustainable and Healthy Diets", focusing on refined Swiss consumption data and adding health aspects to the model), and now in the UNISECO project, with a focus on sub-country level analysis of agro-ecological production systems for the EU. It is currently available in the thoroughly reworked sixth version from autumn 2019. From now on, the acronym "SOLm" or the term "the SOL model" is used and others, such as SOL-m, Sol-m, SOL-M, Sol-M, "the SOL-model" or such are to be avoided. If the version of the model is important to be made explicit, the indication "V#" is added to "SOLm", resulting in names such as "SOLmV6" (the current version) or "SOLmV2" (the version used for the publications (Schader, Muller et al. 2015, Muller, Schader et al. 2017), for example).

7.2 General Structure

SOLm is a mass- and nutrient-flow model of the food system. It thus traces all mass and nutrient flows through the food system, from the inputs to agricultural production to the emissions from food waste disposal. Generally, the system analysed is understood as being in an equilibrium/static situation for several consecutive years. Thus, crop rotations, for example, are captured by allocating corresponding shares of the crops per hectare (cf. section 9.8) and animal herds are understood to be in a steady state of animals leaving the system and being replaced constantly. The data on animal numbers, hectares cropped, production quantities, etc. can thus be seen as the annual values observed on average over the period of several years. Thus, living animals is the numbers of animals that can be observed to be living at any point of time, while producing animals are those that produce within a year (thus, if there is a 2.5-3 turnover rate in pig production per year, producing animals count all of those, i.e. the number of producing animals can be much higher than the number of living animals – e.g. for meat production, and for chicken in particular).

The basic structure of SOLm is captured in the following two figures Figure **11** and Figure 12. Starting from a certain area for agricultural production cropped with a number of crops or managed as grasslands, the corresponding outputs are derived, comprising main outputs such as grains but also by-products such as residues. These outputs are then exported from agricultural production to be used as food, as feed for animal production, otherwise (e.g. for fiber or bioenergy), or they are recycled to the agricultural areas (e.g. as residues left on the field). Together with other inputs (e.g.

[2] In 2019, it has unofficially been renamed to "**S**ooner **O**r **L**ater **m**odel – **SOLm**"

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mineral fertilizers, pesticides) and all emissions and impacts from the production activities, all this captures the land use/plant production part of the model. Animal production is captured similarly, tracing the flows from feed from croplands and grasslands to outputs from animal production systems. Part of the outputs are recycled to animal production (e.g. whey from cheese production fed to pigs), part is used in crop production (e.g. manure), and part is exported from agricultural production to be used as food or otherwise (e.g. wool). Together with other inputs (e.g. antibiotics, drinking water for animals) and all emissions and impacts from the animal production activities, all this captures the animal production part of the model. The nutrient flows in feed and manure link animal and crop production and all these parts together describe the production part of SOLm.

This combined land use/plant-animal production system is located within geographic boundaries – the default is country level, but provided adequate data is available, it can be refined to arbitrary sub-country levels. The results from the calculations can then be aggregated to country groups, world regions or a global picture.

Forest areas and forestry can be captured in the same structure as land use/plant production, i.e. as specific activities on land areas; fish and seafood production are captured in the same structure as animal production, i.e. as animal production activities utilizing feed and other inputs to produce some outputs. It is also possible to add new activities, such as production of artificial meat or vegetables in soil-less vertical farms, as such can also be captured by tracing the inputs required, the outputs produced and the emissions and impacts incurred.

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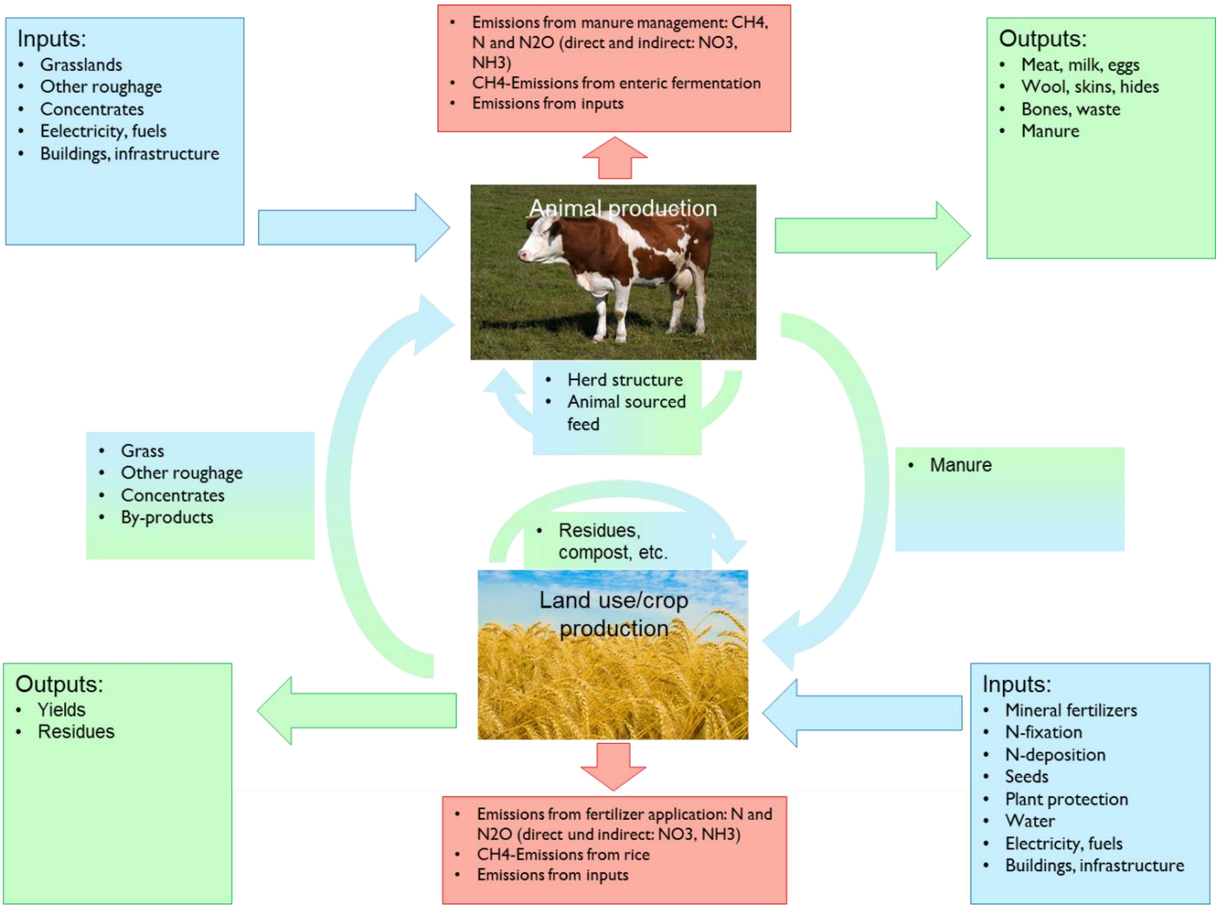

Figure 11: Structure of the agricultural production in SOLm

The calculations thus capture the agricultural areas and the numbers of animals and the related inputs, emissions, impacts and outputs in each geographic region of interest. Inputs can thereby also be imported from outside the systems, and impacts can also become relevant outside the system. This is then better captured by adopting the food-system view on the SOLm, model, schematically displayed in Figure 12, which is complementary to the production-focus discussed above. In the food-system view, the mass and nutrients flows are traced starting from the "domestically available quantity" of commodities. This quantity stems from domestic plant or animal production (depending on the commodity) and from imports and stock changes, while exports or allocation to building up stocks reduce the domestically available quantity. This domestically available quantity is then used for various utilizations such as "food", "feed" or also "waste" or "bioenergy" (here in Figure 12 captured via "other"). The share used for food determines the food availability (which food, as said, stems not only from domestic production within this region but also from imports or stock changes), captured by physical quantities but also by macro- and micro-nutrient supply, such as calories, proteins, vitamins, etc. The share used for feed determines how much feed is available for animal production within each geographic region (which feed, again, stems not only from domestic production within this region but also from imports or stock changes). Finally, as already indicated in the production view above, both plant and animal production result in a number of emissions and impacts, which – in the

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food systems view – are seen as emissions and impacts from the food system.

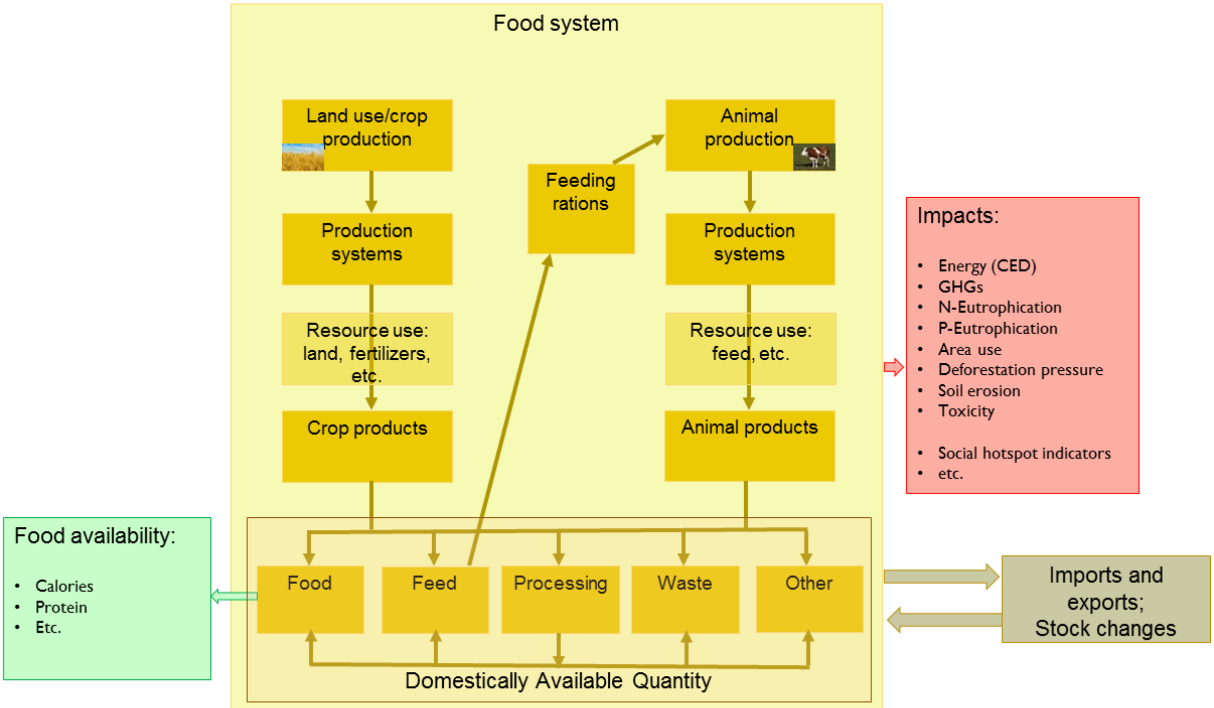

Figure 12: Structure of the food system in SOLm ("CED" is Cumulative Energy Demand, an energy use indicator from Life Cycle Analysis (LCA); "GHG" is Greenhouse Gas; "N" is Nitrogen; "P" is Phosphorus)

There is a number of entities used in the code in SOLm. The core entities used and shortly presented here are **activities**, **commodities** and **regions** (formally, these are "sets" in the programming language GAMS, cf. section 8.1). **"Activities"** are as all actions, technologies, transformations that produce a number of outputs with a number of inputs, thereby also causing emissions and other sustainability impacts. In SOLm we differentiate further between **"plant activities"** and **"animal activities"**. "Plant activities" cover crop and grassland production, where one key input is land area and where the basic metric to measure the size of an activity is the land area covered by the activity. Relative values, such as input factors, emission factors, etc. are then also primarily given on a per area base, but can easily linked to outputs via yields. "Animal activities" cover all livestock operations, i.e. all production settings where by means of some animals some feed and other inputs are transformed into a number of outputs. The basic metric for the size of an activity is the number of animal heads and many indicators are then also reported on a per animal head basis. Animal activities usually show the additional complexity of a "herd structure", which captures the number of different types of animals (different age groups, male/female animals, replacement animals, etc.) that have to be present to support a given number of producing animals. These animals do not produce anything but also need feed and cause emissions and impacts which need to be accounted for. Thus, a second view on animal activities is by building "animal production units", which combine one producing animal (e.g. a dairy cow) with a consistent proportion from all the other types of animals such as to allow for a stable population of producing animals over time (thus, per dairy cow, there is a certain share of replacement animals needed, a certain amount of calves are present, a certain share of sires for reproduction, etc.). Thus, a second view on animal activities is given by

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these animal production units (APU), where the basic metric for the size of an activity is then given by the number of APUs and key parameters are reported on a per-APU basis.

SOLm allows for a number of other activities besides plant and animal activities. In SOLmV6, these are Fish and Seafood activities, forest activities and other activities, each able to account for the specific aspects of these production activities. “Other activities” are coded very generally and not yet provided with data, but they would allow to cover activities such as insects, algae or cultured meat as soon as they would become the focus of interest in some model runs.

“Commodities” are the physical primary outputs or products from activities, including main and by-products (e.g. “Wheat grains” and “Straw” from the activity “Wheat”), as well as products derived from the primary products by one or several processing steps (e.g. “Wheat flour”, “Wheat bran”, “Starch from wheat”, etc.). The relation to primary products that are the direct outputs from activities is governed via extraction rates (e.g. 0.75 for wheat flour, when 0.750 tons of wheat flour may be derived from 1 ton of wheat grains, etc.) and the commodity trees linking the various commodities among each other by indicating which commodities are derived from which ones (e.g. “maize grains” are the primary product of the activity “maize”, “maize germs” are derived from “maize grains”, “maize germ oil” is derived from “maize germs” on a further level, etc.).

“Regions” refer to the geographical boundaries for which the data is provided. The default regions are countries (as used in FAOSTAT, for example), but they also cover sub-country level geographic areas, such as NUTS-2 regions, or counties, etc. For displaying results and certain analyses, aggregate regions are used, such as sub-continents, world regions or also a global picture aggregating all regions.

7.3 What does SOLm deliver and what not

Generally, SOLm delivers a number of indicators on areas and animal numbers, production levels, input use, emissions and other impacts of a wide range of agricultural production and food-system situations.

7.3.1 Option space, viability and scenarios

Examples of such situations are the conversion of a significant share or 100% of production to organic agriculture, the shift towards zero food-competing feed use (i.e. abandoning concentrate and forage feed specifically cropped on cropland, where food crops could be grown directly), a shift towards increased shares of fish and seafood in animal protein supply or a shift towards a healthier composition of food baskets. Often such situations involve quite drastic changes in production and consumption and are thus understood as investigations into food systems in the farther future, say in 2050 or 2100, then also using reference scenarios for the same time-scales, such as FAO or IPCC projections for 2050 (e.g. regarding population numbers, economic development, etc.). However, counterfactual analysis of the current food systems are also possible, e.g. by investigating a situation of 100% conversion to organic agriculture of the current Swiss or other national food systems, thus using the current situation as a baseline for comparison. In fact, due to historical data from FAO being available in the model (cf. section 9.1), it is in principle also possible to investigate counterfactual situations for past time periods. Generally, the term “baseline” is used to refer to one year or to a several-year time-period representing the “current” agriculture and food system. Due to data availability, this

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lies often some years in the past. The term "reference scenario" is used for a hypothetical, often future, situation which can be considerably different from the situation today, e.g. a projection for the food system in 2050 as provided by the FAO. In the model runs, further hypothetical situations of the food system are then calculated and compared to the baseline or the reference scenario, depending on the context the calculations refer to (e.g. a counterfactual to a current situation or an alternative for the 2050 business as usual food system).

The results from the model runs can be framed by the notion of the "***option space***". Let's assume that we investigate, for example, the consequences of a conversion to increasing shares of organic agriculture, combined with different levels of food-competing feed reduction and different levels of food waste reduction, all assessed in a context of increasingly strong climate change impacts on yields. The reference scenario for this example is the FAO business as usual projection for 2050 from 2012, as described in (Alexandratos and Bruinsma 2012). The results of all these changes can be framed by the various combinations of different parameter values along these four dimensions (each one combination providing one "option" for the future food system) as displayed in Figure 13, employing the example of "percentage change in cropland use with respect to the reference situation" as an impact indicator (dimension 1: shares of organic production of 0,20,40,60,80,100%; dimension 2: food-competing feed reduction by 0,50,100%; dimension 3: food waste reduction by 0,25,50%; dimension 4: climate change impact on yields resulting in yield increases till 2050 being reduced by 0,50,100% with respect to the reference forecasts). Figure 13 thus displays the "option space" for global cropland use of the combinations of changes along these four dimensions which can then be assessed to identify promising options (with strongly reduced land use) and rather negative options (with strongly increased land use).

In short, ***the option space is the totality of all options that emerge from combining different levels along a number of different key dimensions that are varied to explore the potential future or counterfactual*** (in the example above: share of organic production, food-competing feed reduction, wastage reduction and climate change impact on yields).

It has to be emphasized that the aggregation to global levels as done in this example potentially hides important regional patterns, as situations could arise, where additional local land use would be prohibitively high albeit total land use would decrease globally. SOLm however provides the data needed to also assess this, as it basically works on country (or – depending on data availability – even finer) level.

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		Climate change impact on yields																	
		Zero						Medium						High					
		% Organic						% Organic						% Organic					
% Wastage reduction	% Reduction in food-competing feed	0	20	40	60	80	100	0	20	40	60	80	100	0	20	40	60	80	100
0	0	0	5	10	17	25	33	21	26	33	40	47	57	46	50	54	58	64	71
	50	−16	−12	−8	−4	2	8	2	7	10	16	22	27	25	26	29	32	35	40
	100	−26	−24	−20	−16	−12	−8	−9	−6	−3	1	5	9	12	13	14	15	17	20
25	0	−6	−1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
	50	−22	−18	−13	−8	−4	−2	−4	0	5	9	14	21	18	20	22	25	27	32
	100	−30	−27	−25	−21	−17	−13	−14	−11	−8	−5	−1	4	6	7	8	8	10	13
50	0	−11	−7	−1	5	11	20	8	13	18	25	32	40	30	34	38	42	47	53
	50	−25	−23	−19	−14	−9	−4	−9	−6	−2	3	8	14	10	12	15	17	21	25
	100	−35	−32	−29	−25	−22	−18	−19	−17	−13	−10	−7	−3	−1	0	1	3	4	7

Figure 13: Example of an option space as the result from SOLm model runs (Source: (Muller, Schader et al. 2017) Original Figure Caption: Cropland area change. Percentage change in cropland areas with respect to the reference scenario. Scenarios differ in: organic shares (0–100%), impacts of climate change on yields (low, medium, high), food-competing feed reductions (0, 50, 100% reduced from the levels in the reference scenario), and wastage reduction (0, 25, 50% compared to the reference scenario). Colour code for comparison to the reference scenario value (i.e. 0% organic agriculture, no changes in livestock feed and food waste, dotted grey): > +5%: red, < −5% blue, between −5% and +5% yellow; in the reference scenario, cropland areas are 6% higher than in the baseline today.).

The option space can be provided for any indicator of interest, such as, besides "cropland use", greenhouse gas emissions, nitrogen surplus, deforestation pressure, aggregate eco-toxicity, erosion risk, etc. When displaying an option space for a number of parameter combinations for one indicator, the notion of "viability" of an option (i.e. of a combination of certain parameter values) is also helpful in analysis and communication. ***Viability of an option*** refers to the performance of an option, i.e. the corresponding indicator value, in relation to some general external restrictions, that can be biophysically mandatory (e.g. global potential cropland area is physically constrained and any option resulting in a larger global land use than this upper limit is biophysically impossible, i.e. unviable) or (politically highly) desirable (e.g. related to planetary boundaries on greenhouse gas emissions, deforestation or nitrogen surplus for a safe operation space of humankind, and any option that would e.g. conflict with some deforestation reduction targets or with limiting global warming to 1.5 degrees would thus also have to be termed "unviable" – but not on biophysical terms but in relation

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to the goal to not transgress these boundaries for a safe operation space for humankind).

Finally, a third term is often used in the context of option spaces and viability of options, namely "***scenarios***". In this context, we use scenarios to describe certain options or groups of closely similar options which we amend by a detailed description of which socio-economic dynamic may drive them, e.g. regarding policies, peoples' preferences and values, economic development etc. without explicitly including this additional information in the model. ***Scenarios are thus telling the rich societal, economic, psychological and value-related (i.e. ethical) stories or narratives behind a special option or behind an area of similar options in the option space.***

7.3.2 Decision structure and principle of "ceteris paribus – keeping everything else equal"

SOLm does not have an internal decision structure for decision making units (such as e.g. country-wise or global utility maximization in economic models or greenhouse gas minimization as an environmental goal, etc.). It is thus driven by the explicit exogenous assumptions set by the researchers running the model. As the scenario specification in the model is organized in its current version (for details, see section 9.4), these assumptions have to be quantified by the amount of area cropped by each crop and grassland type of relevance in each geographic region. Given this input, and a number of other assumptions that are provided as defaults or are also to be chosen by the researchers in the scenario definitions, the model runs to derive plant production, feed use and related animal production, total food availability, waste and other utilization (e.g. bioenergy) and all related emissions and other impacts.

Given the absence of an internal decision structure for decision making units, the general philosophy in SOLm is to adopt a "ceteris paribus" approach, i.e. an approach that "keeps all else equal" (to some baseline or reference situation) besides some core changes of central interest for a specific scenario. That is, besides the "core changes of central interest for a specific scenario" the approach is to keep this "number of other assumptions that are provided as defaults or are also to be chosen by the researchers in the scenario definitions" mentioned above as close as possible to some baseline or reference situation, unless the research question to be addressed in a specific scenario forces to do otherwise. Thus, the relative shares between areas for different fruits or vegetables or between chicken and pig production, for example, are assumed to be identical to the reference situation when investigating a shift towards full organic production or reduced concentrate feed use, unless some explicit assumption on those crops or animals is made that requires different assumptions (e.g. when combining reduced concentrate feed use with the goal to use most efficient animals only – thus using pigs rather than chickens for valorizing food waste as feed and in consequence changing the share of pigs to chickens in favor of pigs).

Often, models with an endogenous decision structure are deemed to be more realistic than such exogenously driven models such as SOLm, as the former consistently cover this decision making part of the system based on some underlying societal or psychological theory. However, these models with decision structure also depend on strong assumptions, such as, for economic models, on price elasticities determining how much demand changes with changing prices, or cross-price elasticities determining how much substitution occurs between commodities when their relative prices change. These assumptions are however rather hidden in the model details and not as explicit as the assumptions made exogenously in models such as SOLm. This data (e.g. on elasticities) is by far not

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always available and often assumptions on the values of these elasticities have to be made on a thin or missing empirical basis. Furthermore, the type of questions addressed with SOLm (primarily large changes, cf. next section 7.3.3) often cannot be addressed well with such models with endogenous decision structure, as the decision structure is calibrated with observed situations and how such decision structure may change with drastic deviations from these calibration points is most often unknown. Economic food system models, for example, are calibrated at the point of general market equilibrium and are most valid in a range around this point, losing validity the further off one may move from this equilibrium in a scenario, as no information is available on how preferences and elasticities may change with such large deviations. Thus, such economic models can well capture effects of an increase of organic production from an observed 15% share to 17% or 20%, or also a decrease to 12%, - but they have not a better empirical basis to answer changes towards 50, 80 or 100% organic production than the models with exogenously given assumptions such as SOLm. Hence, the absence of an endogenous decision structure is not a general disadvantage for the types of questions addressed with these models (see next section 7.3.3).

7.3.3 Which questions can be addressed with SOLm?

SOLm is most adequate to address large changes in the food system and in agriculture with respect to some baseline or reference situation. This is due to its global scope and the default country level resolution of the data used. Further differentiation is always possible, given due data is available, but generally, even with some sub-country regionalization and some differentiation between crop varieties, for example (e.g. winter vs. summer wheat), the results remain on a comparably aggregate and gross level. Thus, given the generally large uncertainties or gross averages and aggregations in the data used, results from SOLm are most helpful when comparing large changes such as a conversion to 30, 50 or 100% organic production rather than smaller changes going from 15 to 17%. Results from such small changes generally will be overshadowed by data uncertainties and error bars. Given all the uncertainties in the data, it is also often more illustrative to assess relative changes between different options than absolute values.

Regarding results, a particular focus of SOLm is to analyse trade-offs and synergies between different indicators for various options or scenarios, or between different strategies or changes with respect to certain indicators, and thus to identify potential options where particular challenges for implementation may arise, or to identify options that are particularly promising. Thus, SOLm results on a large-scale conversion to organic agriculture, for example, illustrate potential trade-offs with sufficient nitrogen supply, and the results on food-competing feed reductions illustrate how drastic the changes in animal source food supply may become and how large changes in animal source food consumption thus may need to be to make such a change in feeding practices and the corresponding implementation of more circular food-systems a widespread option (Schader, Muller et al. 2015, Muller, Schader et al. 2017).

It is important to note that any baseline or reference situation with adequate data availability can be chosen as point of comparison for the options calculated with SOLm. Thus, SOLm results can provide insights on counterfactual situations to the current (or also past) food system, or insights on different options in comparison to, for example, the FAO projections for 2050 from 2012 (Alexandratos and Bruinsma 2012) or in comparison to each of the three updated FAO scenarios for 2050 from 2018 (FAO 2018), or in comparison to the scenarios used in the IPCC report on the 1.5 degree goal (IPCC 2018), etc. If not yet

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available in SOLm, data for such reference scenarios can be added relatively easily (cf. section 8.4).

Given the absence of any societally or psychologically motivated endogenous decision structure, the results generated by SOLm primarily provide information on the biophysical and agronomic viability of food system options and scenarios with respect to certain biophysical, agronomic or political (or other) restrictions that can be translated in limit or target values for the performance indicators provided by SOLm. The results do not address the socio-economic viability of these options or scenarios in the context of some socioeconomic, psychological or other societal theory. This additional context then provides further restrictions to the viability of options which are outside the scope of the topics that can be addressed with SOLm. SOLm thus provides a basis for such further assessments and discussions, the main contributions being information on trade-offs and synergies related to different options and indicators and on the options' biophysical and agronomic viability. If the latter is not given or very challenging, for example, it can be derived that any further analysis of the respective options may not be needed as these options would anyway be unrealistic due to biophysical or agronomic reasons.

SOLm does not work with spatially explicit data and thus cannot address questions that directly rely on processing such data. However, it can clearly make use of information derived from spatially explicit data if the processing of the spatially explicit data is done outside SOLm and the relevant values are then aggregated and fed into SOLm on the level of the geographic regions chosen to run the model (i.e. e.g. on country level). SOLm does neither work on plot or farm level, but as with spatially explicit data, if plot or farm level data is processed outside SOLm and aggregated adequately to be fed into it, SOLm can work with it. See section 8.4 for a description of how to add such and other new data to SOLm.

7.4 Main opportunities and challenges

SOLm uses FAOSTAT (FAO 2019) as its main default data source for cropping areas, animal numbers, yields and production quantities, as well as for trade volumes and domestically available quantities of the commodities and for their utilization shares. IPCC coefficients and data (IPCC 2006) is used as a second main body of data for calculating emissions and impacts. This default data allows for easy linkages of SOLm to a wide range of other analyses using the same data sources, and also allows for simple updates as the data is updated repeatedly and publicly available.

An advantageous flexibility of SOLm is the ease with which new data can be added to refine or overwrite default values (cf. section 8.4). It is easy to read better data for single countries, also with a regional resolution on sub-country level. It is also easy to add new land use or livestock activities (e.g. Miscanthus, which is not covered in FAOSTAT) or to refine existing ones (e.g. separating wheat as from FAOSTAT into summer and winter wheat). Furthermore, data from other studies can be added easily to replicate their results and to use them for consistency checks of SOLm. This applies to the National Greenhouse Gas Inventories submitted by the countries under the UNFCCC (UNFCCC 2019) or to OECD nitrogen and phosphorus balances (OECD 2019), for example. Replicating those is an important consistency check for SOLm baseline calculations (cf. section 8.6).

A disadvantage of the strong reliance on FAOSTAT data as a main default data source is the inconsistency in part of this data. Besides minor misreporting that can be corrected easily when detected (e.g. wrong units by factors of 1000 for certain entries in certain countries, etc.), there is a general problem in a mismatch between animal numbers and the feed quantities reported, where

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concentrate feed tends to be significantly underreported. This clearly also depends on assumptions on feeding rations, grassland yields and feed supply, animal nutrient requirements, etc., which are described in detail in section 9. With common assumptions on these parameters, these inconsistencies cannot be resolved and are thus related to the original data.

The default procedure to deal with this in SOLm is to explicitly calculate a feed supply/demand ratio in the baseline or reference scenario and to then apply this in all options calculated to assure comparability with the baseline or reference scenario. Thus, if in a certain country FAOSTAT reports only 80% of the feed needed to feed the reported animal numbers, we assume a similar ration in all options/scenarios calculated, i.e. a given quantity of feed can always support 25% more animal feed requirement than its nutrient contents would suggest. This problem arises with the default FAOSTAT data and is also owed to the assumption that data on animal numbers is of better quality than data on feed supply. It is however often resolved when e.g. replacing the default data with specific refined national data. It is also not a problem for all countries. For some countries, this problem is larger, for others, it is nearly absent and feed supply and demand are in balance within a few percent.

An important consequence of this type of inconsistency and its treatment in SOLm is that nutrient flows are not fully closed. A detailed assessment of this is still pending, but somewhere in the system is a gap, e.g. either by reporting exaggerated animal numbers, assuming wrong feeding rations for the animals, reporting too low areas for feed production, or too low feed utilization of the domestically available quantities. Without having tested this further, we hypothesize that data is worst for feeding rations, for feed utilization of domestically available quantities, for the utilization of biomass streams not covered in the data (waste, residues, by-products, etc.) and also for biomass streams from grasslands (where data on areas, yields and production, and also on its nutritional quality as feed are highly uncertain). This mismatch between feed supply and demand is a key issue to be investigated in detail and improved soon, cf. section 8.9.

It is also important to note that for environmental impacts related to feed use in animals, the feed supply/demand ratio corrected for. Thus, each animal is assigned with its required amount of food for calculating enteric fermentation emissions, nitrogen excretion or environmental impacts of feed production, irrespective of the aggregate feed supply being less than aggregate feed requirements. This thus again reflects the assumption that animal numbers are largely correct and that the mismatch may rather stem from the feed data.

8 CURRENT CODE STRUCTURE SOLMV6

This section describes the structure of SOLmV6 in more detail and explains various aspects related to the use of this model. A detailed description of all data and each code file is then provided in the subsequent section 9.

8.1 Software, platform

SOLmV6 is coded in the Global Algebraic Modelling System GAMS language (as all previous versions) and runs on a separate password-protected server, which is accessible from outside FiBL. Data is either read from excel-, csv-, gdx-files or directly entered in the GAMS-code. Output is provided in gdx- or excel-files. GAMS can add additional output to existing excel-files without losing the data already stored there. Thus, single model runs can be added to such output files without the need to rerun all previous model

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runs again. The core code of SOLm does not use features for which GAMS is most adequate, such as optimization routines, but being coded in GAMS it directly links to such optimization modelling, as e.g. undertaken in other projects where such additional modules are executed on output from SOLm. It is also planned to include the code for optimizations as an additional core part of SOLm.

8.2 Current structure

Currently, SOLm has a general structure in two main steering files, the first – "___V6_SteeringFile1_ModelInitialisation.gms" - governing the filing in and organization of the data for the baseline, as well as of additional data to refine default values, to add new regions or activities, or to add sub-regional or sub-activity level data, as well as to add data for reference scenarios. This file produces several output files which are then used by the second steering file – "___V6_SteeringFile2_CoreModelScenariosAndEquations.gms" – where the scenario definitions and model calculations are done and output files with the results from the model runs are defined and generated.

8.2.1 "___V6_SteeringFile1_ModelInitialisation.gms"

The structure of this file is as follows (the following is the table of contents as used at the beginning of this file):

```
*DETAILED TABLE OF CONTENTS
$ontext;
- 1) General settings
         1.1) Operating systems settings, etc.
         1.2) specify some global variables to choose for global scenario
assumptions (yield gap, etc.)
                 1.2.1) specify which yield coefficients to use for organic
                 yields (Badgley, Ponisio, DePonti or Seufert)
                 1.2.2) specify which baseline years to use for the model
                 1.2.3) specify the GWP/GTP to be used
- 2) Specify whether external data needs to be loaded ("YES") (e.g. from
updated data files) or not ("NO")
         2.1) General baseline data
         2.2) Some 2050 scenario data and some 2010 Bioenergy baseline data
         2.3) New regional data
- 3) Load the baseline values for all variables and parameters
         3.1) Define some general sets needed for reading in data
         3.2) Define the general model sets, parameters and variables
         3.3) Read in the data
         3.4) Read refined baseline data
- 4) Initialise the parameters and variables for the model runs
- 5) Add data from FAO and other future scenarios
- 6) Define some output files
$offtext;
```

In more detail:

```
- 1) General settings
```

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This code section defines general operational and key settings to indicate which keys to be used when writing paths to indicate where data is located, etc. (as delimiters in folder structures, for example).

It also allows to choose the values to be used for the organic yield gaps, for the baseline years to be used and for the global warming potential (cf. section 8.3).

`- 2) Specify whether external data needs to be loaded ("YES") (e.g. from updated data files) or not ("NO")`

This part allows to specify whether the data read and reorganized for use in SOLm further down in the code has to be read anew or not. If not read anew, the existing gdx-files of the data are used for reorganizing and making available for use in SOLm. New data has to be read, for example, if FAOSTAT is updated to a new year and this should be used in a new baseline, or if new nutrient contents data is made available, etc. This is then read from excel- or csv-files and stored in gdx-files for further use in the code.

Furthermore, this code part governs the filing in of certain reference scenario data and of other additional data (e.g. for sub-regions) in a similar way as for the baseline data as just described above, i.e. filing it in anew in case the original csv- or excel-files have been changed ("YES"), or using the already available gdx-files if not ("NO").

`- 3) Load the baseline values for all variables and parameters`

This is the largest part in this code-file, governing the filing-in of all baseline values and making them available to SOLm in the SOLm-internal parameter and variable formats. It starts with defining all needed sets (such as sets of activities, regions, inputs, outputs, etc.), parameters (the values for the inputs, etc.) and variables (areas cropped under certain activities, etc.) and then reads the data and translates it to these SOLm parameters and variables.

In this part, code modules for adding new or refined baseline data can be added.

`- 4) Initialise the parameters and variables for the model runs`

This code part already defines and initializes the parameters and variables as used in the model – they are named identical to the respective sets, parameters and variables used for filing in the baseline data, besides a suffix "_MR" that is added to the names (for "model run"). They have an additional last scenario dimension to allow for values to be different for the different scenarios (the baseline values are captured by the scenario "Baseline").

This is needed to read scenario data referring to different future scenarios, such as the reference scenarios from the FAO 2050 projections (FAO 2018), as for these values, we already need a scenario-dimension in the parameters and variables to differentiate them from the baseline.

`- 5) Add data from FAO and other future scenarios`

This part then reads the new scenario data mentioned above; structurally, this works similarly to filing in the baseline data as described above.

`- 6) Define some output files`

This part defines a

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number of gdx-files containing all the baseline data read, defined and processed in the preceding code. It is organized in a number of specific gdx-files for model sets, parameters and variables.

8.2.2 "___V6_SteeringFile2_ CoreModelScenariosAndEquations.gms"

The structure of this file is as follows (the following is the table of contents as used at the beginning of this file):

```
*DETAILED TABLE OF CONTENTS
$ontext;
- 1) General settings
         1.1) Operating systems settings, etc.
         1.2) specify some global variables to choose for global scenario
assumptions (how to allocate mineral fertilizer, etc.)
- 2) Define sets, parameters and variables and load gdx files from the
baseline assignment
- 3) Run core model equations
- 4) Choice of scenarios
- 5) Further calculations after finishing the scenario runs
- 6) Define some output files
- 7) Do some further specific calculations needed for certain aspects
$offtext;
```

In more detail:

`- 1) General settings`

This code section defines general operational and key settings to indicate which keys to be used when writing paths to indicate where data is located, etc. (as delimiters in folder structures, for example).

It also allows to choose the way how to allocate mineral fertilizers and with which feed basis to start for the calculation of animal numbers (cf. section 8.3).

And it allows to indicate whether commodity import/export data shall be recalculated for the scenarios or not. This can be switched off in case a scenario has already been calculated, because running it is quite time consuming.

Finally, it allows to choose whether only one scenario is run or whether the code is executed as a loop over a number of scenarios, as defined towards the end of the steering file 2 (governed by $setglobal RunAllChosenScenarios "NO" or $setglobal RunAllChosenScenarios "YES")

`- 2) Define sets, parameters and variables and load gdx files from the baseline assignment`

This part defines all the sets, parameters and variables needed in the model in general and for filing in the data compiled in "___V6_SteeringFile1_ModelInitialisation.gms" in particular and loads all the data compiled there. It also initializes the model run parameters and variables with the baseline

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values.

`- 3) Run core model equations`

This is the largest part in this code-file, governing the core model calculations.

It starts with a module setting the scenario assumptions and initializing the scenario data with baseline or reference scenario values, where no specific scenario-related values are available. These assumptions in particular provide data on the areas for each crop and grassland type etc. in the scenario.

It then derives the total crop production and domestically available quantities (DAQ) for crops and grass. For the DAQ values, default import/export relations as in the baseline or reference scenario are assumed and the trade flows are scaled proportionally to changes in production (i.e. exports scale with domestic production, imports scale with production in the country of origin). Thereby, trade flows are traced back to the original country of production (cf. section 9.12). This allows to deal e.g. with the case that Germany imports large amounts of Soybeans from The Netherlands – which are themselves imported from Brazil – thus, this data-reorganization allows to show that Germany in fact imports from Brazil.

Then some data on crop residue management are calculated, as well as on crop and grassland nutrient requirements, animal nutrient requirements and feed supply.

Based on this, animal numbers and animal production, DAQ for animal source commodities, manure excretion and enteric fermentation are derived and aspects related to manure management are modelled.

Finally, fertilizer application (mineral fertilizers, crop residues and manure) and related emissions are calculated.

`- 4) Choice of scenarios`

Here, it is defined which scenarios shall be run in which order. The first run is for the "BaselineDerived", set at the beginning of the model code section "3) Run core model equations", by means of the code line "$setglobal Scenario "BaselineDerived". This replicates the baseline scenario and produces a number of additional output. This is also a test for the code, as it should be identical to the scenario "Baseline" on all indicators, where values for this and for "BaselineDerived" are available. After running all code files in section "3) Run core model equations", the scenario name is set to the next scenario of interest and the code jumps at the beginning of "3) Run core model equations" and executes this again. This loop is repeated until the last scenario name triggers "EndOfScenarioRuns", with which the execution continues in section "5) Further calculations after finishing the scenario runs".

An example of such a scenario choice set is displayed here:

```
$setglobal Scenario "BaselineDerived"
$label Restart
```

Then comes all code in section "`3) Run core model equations`"
Then comes the choice in section "`4) Choice of scenarios`", for example:

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```
$if %Scenario% == "Baseline_NoFCF" $goto EndOfScenarioRuns
$if %Scenario% == "Baseline_100Organic" $setglobal Scenario "Baseline_NoFCF"
$if %Scenario% == "BaselineDerived" $setglobal Scenario "Baseline_100Organic"

$if %RunAllChosenScenarios% == YES $goto Restart

$label EndOfScenarioRuns
```

`- 5) Further calculations after finishing the scenario runs`

After the scenario runs, a number of impact indicators are derived, on a per unit basis (per hectare, per ton commodity, per head, per animal production unit) and on aggregate. Aggregations of various variables over regions and activities are calculated.

`- 4) Define some output files`

This part defines a number of gdx-files containing all the results produced in the preceding code. It is organized in a number of gdx-files for model sets, parameters and variables (generated in "_V6_OutputFiles_SteeringFile2.gms"), as well as some specific result file providing data as a basis for further processing, depending on which analysis the model runs aim at. This processing thus can include graphics, tables, deriving further aggregate values, etc. and is done outside SOLm. This compilation of specific results is produced in the code file "_V6_ResultsFiles.gms".

`- 5) Do some further specific calculations needed for certain aspects`

Currently, no code is included here, but this would be the location to easily add some code for some further calculations, such as e.g. to run certain comparisons, test certain values, compile special output formats, etc.

8.3 Possible parameter choices of general model validity

This section shortly describes the parameter choices that are done with general model validity and normally do not change for single scenarios, albeit it is possible to also overwrite these choices in the scenario definitions, if needed.

For "___V6_SteeringFile1_ModelInitialisation.gms", in section "- 1) General Settings" the following choices can be made: baseline years; organic yield gaps; global warming/temperature potential; some assumptions for bioenergy: sections 8.3.1 to 8.3.4.

For "___V6_SteeringFile2_ CoreModelScenariosAndEquations.gms" the following choices can be made: allocation of mineral fertilizers, feed basis to derive animal numbers: sections 8.3.5 and 8.3.6.

8.3.1 Baseline years

The baseline is usually an average over a number of years and refers to these average values taken from FAOSTAT. Here in the code, it is indicated over which years this average shall be taken. Flexibility in this is large, any time-period previous or including the last year where data is available is possible. The code for calculating the baseline values is – where applicable – executed each time right after filing in new data in the respective code modules. It thereby accounts for missing values when deriving the

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averages by correspondingly correcting the numbers of years to be divided by.

8.3.2 Organic yield gaps

Organic yield gaps can be chosen from three sources, namely (Badgley, Moghtader et al. 2007, de Ponti, Rijk et al. 2012, Seufert, Ramankutty et al. 2012). (Ponisio, Gonigle et al. 2014) can be chosen as well, but data for this has yet to be included in the code. The default is (Seufert, Ramankutty et al. 2012). Furthermore, for the Seufert2012-data it is possible to indicate, whether organic yield gaps in developing countries are identical to those in developed countries or whether yield gaps in developing countries should be zero. This choice is available due to lack of information on yield gaps in developing countries and the hypothesis supported by some that yield gaps in developing countries are lower than in developed countries. Generally, we tend to conservatively assume that yield gaps are similar and set this choice of similar yield gaps as the default. For Badgley2007-data, it is possible to choose organic yields in developing countries to be higher than conventional yields, as suggested by their data. This is however highly contested and the default in SOLm is to not do so. In any case, (Badgley, Moghtader et al. 2007) is a highly contested publication and we suggest to not use their yield gap data.

Currently, besides the choice of Ponisio2014-data which is not yet fully implemented, an update to the most recent most encompassing review on organic yield gaps provided in (Seufert 2018) has to be done.

8.3.3 GWP and GTP

It is also possible to choose a number of values for the global warming potential (GWP) of different greenhouse gases, or to choose to use global temperature potential (GTP) rather than GWP. Currently, only data for different GWP-values are available in the code, but other values and GTP values can be added easily. The current choices differ by source ((Ramaswamy, Boucher et al. 2001) as used in the IPCC 2006 Guidelines on GHG Inventories or from IPCC AR5 (Myhre, Shindell et al. 2013)) and, for methane, by accounting or not for the fact that most methane in agriculture is biogenic, which results in slightly lower values, as the final decay product of methane – CO_2 – is renewable in this case.

8.3.4 Some assumptions for bioenergy

Some assumptions on bioenergy are currently also governed in this part of the code. They refer to assumptions on the nitrogen fertilization level of Miscanthus, i.e. on whether this is low, medium or high, and on the nitrogen contents of the bioenergy residues after bioenergy production, which are assumed to be low or high. These are very specific assumptions and may rather be moved to scenario assumptions in a further revision of the model code.

8.3.5 Allocation of mineral fertilizers

This assumption governs globally, whether mineral fertilizers are applied to crops on croplands only or to temporary

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grasslands as well.

8.3.6 Feed basis to derive animal numbers

This assumption governs whether the animal numbers are derived from the domestically available concentrate feed supply and its DM share in the feeding rations, or rather starting from the domestically available grassland feed supply and its DM share in feeding rations. Due to the challenges in feed supply data (cf. section 7.4), this can lead to certain differences in results. When starting with concentrate feed, all concentrate feed is allocated to the various animal types, then other feed is allocated according to the feeding rations. When starting from grassland feed, this is allocated to ruminants, then concentrate and forage feed, etc. is allocated to ruminants according to the feeding rations, then the remaining concentrate feed is used to derive how much non-ruminants can be fed with this in addition. In all this, the feed supply/demand ratio is accounted for by a correction factor as described in section 7.4).

8.4 Adding new data

In SOLmV6, the baseline data is read in "___V6_SteeringFile1_ModelInitialisation.gms". Towards the end of this file, also some reference scenario data for the most recent FAO projections towards 2050 (FAO 2018) and for some scenarios from the IPCC 1.5-degree goal report (IPCC 2018) are read.

In this version, new data for both baseline values or also new reference scenarios is then added via additional code files to be run from "___V6_SteeringFile1_ModelInitialisation.gms", just after having read the original data. Thus, for baseline data it is currently to be added and executed after the module "_V6_ReadData_VariousSources_CED" and before "_V6_DataDerivedBaseline_SomeHerdStructureParameters"; for the reference scenario data it would be again in "___V6_SteeringFile1_ModelInitialisation.gms" but after "_V6_ReadData_VariousSources_BioenergySR15.gms" and before "_V6_StreamlineInitialData.gms".

It is planned to reorganize this slightly and to collect the adding of new data into an additional separate steering file to be executed with the outputs from "___V6_SteeringFile1_ModelInitialisation.gms" and delivering as outputs all inputs to "___V6_SteeringFile2_ CoreModelScenariosAndEquations.gms" (cf. section 8.7).

New data can also be added in the scenario definitions. This is the approach followed for data which need not enter the general model data base of SOLm but rather be used in specific scenario runs only, as it can be done then without running "___V6_SteeringFile1_ModelInitialisation.gms". However, in principle, all new data, be it also very specific and restricted in application, should at some point of time be added to the general model data base for later availability.

Basically, for the baseline, new data just overwrites the existing data. If data on sub-regions or sub-activities is added, these sub-regions and sub-activities are first initialized with the data from the corresponding regions and activities as far as relative values (per hectare, per animal head, per ton output, etc.) are concerned. If better data on these values is available, this overwrites this default assignment. Absolute values (e.g. areas per crop, etc.) are assigned with new better data, if available,

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or with data derived from the corresponding regional or activity-specific total values, by means of some proportionality rules. There is, for example, rarely data on import and export values to sub-regions available. Thus, regional trade data is per default assigned to sub-regions proportional to production (exports) or population (imports), for example.

New data can also be added in closer relation to some complementary modelling, such as grid-based spatially explicit assessments or plot- or farm-models, in detail tracing nutrient- and mass-flows on smaller scales than captured by the spatial or activity-related resolution of SOLm. Linkage to SOLm is then established by taking averages and by aggregating the results from these finder models to a level that can be used as input to SOLm (e.g. country or activity level).

Further details on adding new data are given in section 9.5.

8.5 Model output

Output from the baseline data processing is produced at the end of file "_V6_OutputFiles_SteeringFile1.gms". This output is used as an input to "___V6_SteeringFile2_ CoreModelScenariosAndEquations.gms". This latter file then generates the general model output. It has two parts. First, it is in the form of several files containing all sets, parameter and variables that are used in the model. These result files are generated in "_V6_OutputFiles_SteeringFile2.gms". Second, there is a compilation of results for further processing, depending on which analysis the model runs aim at, including graphics, tables, aggregate values, etc. This compilation of specific results is produced in the code file "_V6_ResultsFiles.gms".

8.6 Consistency checks

Consistency checks in SOLmV6 are mainly done by comparing results to results on the same variables or parameters from other sources. Basically, such comparisons can be done on a relative basis (e.g. comparing emission factors per kg commodity) or on an aggregate basis (e.g. comparing total GHG emissions from the livestock sector in a country). There is a wealth of data available that should in principle be replicable by SOLm – or where it should be possible to understand any deviations very well – and that can thus serve as a basis for such checks. Examples are LCA databases for footprints of various commodities regarding a large number of indicators, or the national UNFCCC GHG inventories or the national OECD nutrient balances for aggregate values.

A second type of consistency check relate to internal consistency of different nutrient flows, e.g. checking whether the total nitrogen applied per hectare corresponds to the total extraction from it (inclusive losses), duly accounting for the possibility to add or extract nitrogen to or from the soil pool. This latter is currently not covered in the model, but doing this balancing of nutrient flows from inputs and outputs and losses allows to derive an approximate size of such soil-pool related flows and the consistency check then consists in assessing whether they have a reasonable size or not, for

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example. Similarly, such balancing can be done for animals with their feed uptake and manure extraction, etc. or for manure management, with incoming nutrient quantities from manure, outgoing nutrient quantities after management for application on fields, and management losses.

Currently, consistency checks are done by manually comparing some key indicators for a number of regions and activities or aggregates thereof to established literature values, and by doing some specific balances and comparing with expected literature values (e.g. for soil-pool storage of N). It is planned to make this process more encompassing and automatized. For further details see section 9.14.

8.7 Known code issues to be improved next

In the following, for completeness, some next steps for improvement of the code are listed.

First, it is planned to reorganize slightly how new data is read and to collect the corresponding code into an additional separate steering file to be executed with the outputs from the current code file "___V6_SteeringFile1_ModelInitialisation.gms" and delivering as outputs all inputs needed to execute the current code file "___V6_SteeringFile2_ CoreModelScenariosAndEquations.gms".

Thus, "___V6_SteeringFile1_ModelInitialisation.gms" would be shortened to execute all code modules as now besides "_V6_ReadAdditionalData_SwitzerlandAustria.gms". (see section 9 for details).

A new second steering file would then be coded exclusively for adding new data, e.g. "___V6_SteeringFile2_AddingNewData.gms". This would start with the code needed to read all output from "___V6_SteeringFile1_ModelInitialisation.gms", as coded now at the beginning of "___V6_SteeringFile2_CoreModelScenariosAndEquations.gms". Then new baseline or scenario data would be added (i.e. e.g. the current file "_V6_ReadAdditionalData_SwitzerlandAustria.gms"). Then the modules "_V6_DataDerivedBaseline_SomeHerdStructureParameters.gms" (doing some herd-structure parameters that can only be done after having read new data) and "_V6_StreamlineInitialData.gms" (doing some streamlining of the new data, if needed) – for details on these code files, see section 9 – and the code producing the output files (analogue to the current file "_V6_OutputFiles_SteeringFile1.gms") to be fed into the now third steering file "___V6_SteeringFile3_ CoreModelScenariosAndEquations.gms" would be executed.

In principle, the reference scenario data currently read in the first steering file in the code files "_V6_ReadData_FAOSTAT_FOFA2050.gms" and "_V6_ReadData_VariousSources_BioenergySR15.gms" could also be moved to the second steering file on filing in new data.

Then, the new third steering file ("___V6_SteeringFile3_ CoreModelScenariosAndEquations.gms") would be run as is currently the second one.

Second, the general parameter choices on "organic yield gaps"; "global warming/temperature potential"; "some assumptions for bioenergy"; "allocation of mineral fertilizers"; "feed basis to derive animal numbers"

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currently executed at the beginning of the two steering files could be decoupled from those and rather added to the scenario definitions than to the basic data. Thus, no changes in the basic data would be needed in case one would like to change these parameter choices. To do this, some reorganization of the code would however be necessary, e.g. to keep the yield gaps from the different sources separate in the basic data in SOLm parameters – currently, there is only one parameter for yield gap which is assigned the respective value conditional to this general parameter choice at the beginning of the steering file. Similar adjustments would be needed for "global warming/temperature potential"; "some assumptions for bioenergy". For "allocation of mineral fertilizers"; "feed basis to derive animal numbers" from the second steering file this is different and they could be moved to the scenario definitions without further adjustments needed, as those are governed by the choice of one or another part in the calculations, not by assignments of data. As the code is structured now, the settings on the baseline choice could not be moved to the scenarios without fundamental recoding – but this is neither a big problem, as all scenario runs usually refer to the same baseline. And in the context of one project, the baseline usually does not change.

Third, the herd structure model should be updated, expanded to chickens and re-run and linked to SOLmV6, as well as made consistent with more recent developments at FAOSTAT, such as the GLEAM model. Currently, the values from the calculations done for (Schader, Muller et al. 2015) are used (cf. section 9.1.43).

Fourth, the animal production unit (APU) – view on the animal production (cf. the description towards the end of section 7.2) should be coded systematically (i.e. by providing the needed sets, parameters and variables to implement this approach consistently). If this makes sense in the baseline, it would mean to do the hitherto empty code module "_V6_ReadData_VariousSources_AnimalProductionUnits.gms", see section 9.1.44. But it could also be added on the level of Steering File 2. Currently, APUs play a role only towards the end of Steering File 2 for the impact calculations for animal source commodities, as their impacts are based on the impacts of the whole herd and not of the producing animals only (cf. section 9.2.22).

Fifth, the consistency checks should be made automatized, such as to have a default set of values to run comparisons for, e.g. after introducing new and refined data.

Sixth, the currently independent optimization code used in some projects and building on output from SOLm should be added as an integral part to SOLm.

Seventh, the potential and possibility to make SOLm accessible via GitHub and to allow for consistent version control, etc. are currently explored.

8.8 Next things to be added

First, there is a number of smaller things to be added in the baseline data in "___V6_SteeringFile1_ModelInitialisation.gms". They are directly highlighted in the code. They are planned to be addressed in the coming 3-4 months. In particular, the yield gap data from (Ponisio, Gonigle et al. 2014) should be added for completeness. More importantly however, regarding organic yield gaps, the

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most recent data from (Seufert 2018) should be added and made the default to be used in SOLm.

Bigger topics that are partly currently addressed by master theses are

- bioenergy
- fish, seafood and aquaculture
- alternative protein sources
- vegan food systems

For each of those, encompassing databases should be compiled, allowing for scenarios to be run with a focus on various aspects of these respective topics.

8.9 Open questions and inconsistencies to be addressed next

The most pressing open question currently in SOLm is the mismatch between feed supply/demand mentioned above. It is necessary to dig into this deeper to better understand which data in FAOSTAT (e.g. from the feed utilization shares, domestically available quantities for feed, feed streams not covered such as residues, by-products or waste for feed, or other data) or elsewhere (e.g. from the feeding rations data) causes these inconsistencies.

Furthermore, the grassland data has to be cross-checked again, besides areas and yields, which has been updated recently, in particular the feed quality of grasslands, legume shares, protein and nitrogen contents, etc.

9 SOLMV6: CODE AND DATA IN DETAIL

This section presents the code in detail, going through all code modules that are executed in the course of running the two steering files as described in section 8.2 on the general model structure (sections 9.1.1 to 9.2.28). After this some specific aspects of the model code are addressed in further detail, such as how to specify scenarios, how to add new data, how to produce results files, how to treat crop rotations and herd structures, how to organize feed supply, how to capture bioenergy or fish and seafood, etc. (sections 9.3 to 9.14). Finally, some details on some of the data used are presented (sections 9.15 to 9.20).

9.1 SteeringFile 1

The following describes the content of the code files executed in "___V6_SteeringFile1_ModelInitialisation.gms" in some detail. The general structure of this file is described in section 8.2.1. In the following, we shortly list all code modules that are executed and subsequently describe those in detail (the headings displayed are the same as in the structure described in section 8.2.1):

Code modules executed in Steering File 1:

```
3) Load the baseline values for all variables and parameters
	3.1) Define some general sets needed for reading in data
```


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_V6_Sets_FAOSTAT_Regions
_V6_Sets_FAOSTAT_Items
_V6_Sets_FAOSTAT_ItemGroups
_V6_Sets_NonFAOSTAT_Items
_V6_Sets_FAOSTAT_Elements
_V6_Sets_FAOSTAT_Units
_V6_Sets_FAOSTAT_LandUse
_V6_Sets_FAOSTAT_Deforestation
_V6_Sets_FAOSTAT_OrganicSoils
_V6_Sets_ErbEtAl_Grasslands
_V6_Sets_FAOSTAT_Fertilizers
_V6_Sets_FAOSTAT_Population_HumanNutrReq
_V6_Sets_VariousSources_HerdStructures
_V6_Sets_GeneralModelSets_ForReadingData
3.2) Define the general model sets, parameters and variables
_V6_Sets_GeneralModelSets
_V6_VariablesAndParameters
3.3) Read in the data
_V6_ReadData_FAOSTAT_CropProduction
_V6_ReadData_FAOSTAT_ForageCropProduction
_V6_ReadData_FAOSTAT_LivestockProduction
_V6_ReadData_FAOSTAT_Trade
_V6_ReadData_FAOSTAT_CommodityBalances
_V6_ReadData_FAOSTAT_LandUse
_V6_ReadData_FAOSTAT_Deforestation
_V6_ReadData_FAOSTAT_OrganicSoils
_V6_ReadData_ErbEtAl_Grasslands
_V6_ReadData_FAOSTAT_Fertilizers
_V6_ReadData_FAOSTAT_WOSY_DetailedFBS
_V6_ReadData_FAOSTAT_Population
_V6_ReadData_VariousSources_HumanNutrientRequirements
_V6_ReadData_VariousSources_CropGrassNutrientRequirementsData
_V6_ReadData_VariousSources_MainOutputNutrientContentsData
_V6_ReadData_VariousSources_ResidueSharesAndNutrientContentsData
_V6_ReadData_VariousSources_SeedCharacteristicsData
_V6_ReadData_FAOSTAT_ProducerPrices
_V6_ReadData_IPCC_GWP_GTPData
_V6_ReadData_LuEtAl_NDepositionData
_V6_ReadData_VariousSources_NFixationData
_V6_ReadData_VariousSources_SoilErosionData
_V6_ReadData_VariousSources_PesticidesData
_V6_ReadData_IPCC2006_RiceCroppingEmissionsData
_V6_ReadData_VariousSources_HerdStructures
_V6_ReadData_VariousSources_AnimalProductionSystems
_V6_ReadData_VariousSources_AnimalLiveweightData
_V6_ReadData_VariousSources_AnimalDrinkingWaterRequirementData
_V6_ReadData_VariousSources_FeedingRationsData
_V6_ReadData_VariousSources_AnimalNutrientRequirementsData
_V6_ReadData_VariousSources_EntericFermentationEmissionsData
_V6_ReadData_VariousSources_CropResidueManagementData
_V6_ReadData_VariousSources_ManureExcretionData
_V6_ReadData_VariousSources_ManureManagementData

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_V6_ReadData_VariousSources_MineralFertilizerProductionEmissionsData
_V6_ReadData_VariousSources_FertilizerApplicationData
_V6_ReadData_VariousSources_NH3Emissions
_V6_ReadData_VariousSources_OrganicYieldGapsData
__SOLmV5_DataDerivedBaseline_DetailedFeedingRations
_V6_ReadData_VariousSources_CED
3.4) Read refined baseline data
_V6_ReadAdditionalData_SwitzerlandAustria
_V6_ReadAdditionalData_NUTS2_EU
_V6_DataDerivedBaseline_SomeHerdStructureParameters
_V6_ReadData_CommodityTrees_LinkActivitiesAndCommodities

4) Initialise the parameters and variables for the model runs
_V6_VariablesAndParameters_ModelRun

5) Add data from FAO and other future scenarios
_V6_ReadData_FAOSTAT_FOFA2050
_V6_ReadData_VariousSources_BioenergySR15
_V6_StreamlineInitialData

6) Define some output files
_V6_OutputFiles_SteeringFile1

The following subsections provide detailed descriptions of these code modules.

9.1.1 _V6_Sets_FAOSTAT_Regions

This file declares the sets where all countries, geographic regions and aggregates thereof as used in FAOSTAT are collected and it defines the hierarchical structure of those. The sources where these sets come from and partly some further information are given at the beginning of each set definition in the code.

In this code file, the following sets are defined:
FAOSTAT_GeographicRegionsCode
Country and region codes that may be used in FAOSTAT
FAOSTAT_CountriesAndRegions
Country and region names that may be used in FAOSTAT
FAOSTAT_CountriesAndRegionsWithCode(FAOSTAT_GeographicRegionsCode,FAOSTAT_CountriesAndRegions)
Two dimensional set containing all country and region codes and names matched that may be used in FAOSTAT
FAOSTAT_Countries(FAOSTAT_CountriesAndRegions)
Sub-set containing all country names that may be used in FAOSTAT
FAOSTAT_Regions(FAOSTAT_CountriesAndRegions)
Sub-set containing all region names that may be used in FAOSTAT
FAOSTAT_Continents(FAOSTAT_Regions)
Sub-set containing all continent names that may be used in FAOSTAT
FAOSTAT_Subcontinents(FAOSTAT_Regions)
Sub-set containing all sub-continent names that may be used in FAOSTAT
FAOSTAT_DevelopedDevelopingGroups(FAOSTAT_Regions)

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Sub-set containing developed-developing country groups that may be used in FAOSTAT
FAOSTAT_ContinentsSubcontinents(FAOSTAT_Regions,FAOSTAT_CountriesAndRegions)
Two dimensional set containing all sub-continents matched to continents
FAOSTAT_CountriesInRegions(FAOSTAT_Regions,FAOSTAT_CountriesAndRegions)
Two dimensional set containing all regions matched to countries

9.1.2 _V6_Sets_FAOSTAT_Items

This file declares the sets in which ALL activity and commodity items as used for reading in the original data from FAOSTAT are contained. The sources where these sets come from and partly some further information are given at the beginning of each set definition in the code.

In this code file, the following sets are defined:
FAOSTAT_ItemCode
All crop item codes that may be used in FAOSTAT
FAOSTAT_CropProductionItems
All crop item names that may be used in FAOSTAT
FAOSTAT_CropProductionItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_CropProductionItems)
Two dimensional set containing all crop item codes and names matched that may be used in FAOSTAT
FAOSTAT_CropsProcessedItems
All processed crop item names that may be used in FAOSTAT
FAOSTAT_CropsProcessedItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_CropsProcessedItems)
Two dimensional set containing all processed crop item codes and names matched that may be used in FAOSTAT
FAOSTAT_LivestockPrimaryItems
All livestock primary item names that may be used in FAOSTAT
FAOSTAT_LivestockPrimaryItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_LivestockPrimaryItems)
Two dimensional set containing all livestock primary item codes and names matched that may be used in FAOSTAT
FAOSTAT_LiveAnimalsItems
All live animal item names that may be used in FAOSTAT
FAOSTAT_LiveAnimalsItems_Poultry(FAOSTAT_LiveAnimalsItems)
Sub-set containing all live poultry animal item names that may be used in FAOSTAT
FAOSTAT_LiveAnimalsItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_LiveAnimalsItems)
Two dimensional set containing all live animal item codes and names matched that may be used in FAOSTAT
FAOSTAT_LivestockProcessedItems
All processed livestock item names that may be used in FAOSTAT
FAOSTAT_LivestockProcessedItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_LivestockProcessedItems)
Two dimensional set containing all processed livestock item codes and names matched that may be used in FAOSTAT
FAOSTAT_DetailedTradeMatrixItems
Commodity item names as used in the detailed trade matrix of FAOSTAT
FAOSTAT_DetailedTradeMatrixItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_DetailedTradeMatrixItems)

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Two dimensional set containing all detailed trade commodity item codes and names matched that may be used in FAOSTAT

FAOSTAT_TradeLiveAnimalsItems

Live animal item names as used in the live animal trade matrix of FAOSTAT

FAOSTAT_TradeLiveAnimalsItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_TradeLiveAnimalsItems)

Two dimensional set containing all live animal trade item codes and names matched that may be used in FAOSTAT

FAOSTAT_TradeCropsAndLivestockProductsItems

Crop and livestock product item names as used in the general trade matrix of FAOSTAT

EighteenItemsInDetTradeItems_NotInTradeProdItems

18 items (mainly live animals) covered in the set FAOSTAT_DetailedTradeMatrixItems but not in FAOSTAT_TradeCropsAndLivestockProductsItems

FAOSTAT_TradeCropsAndLivestProdItems_NODoubles

Set with items in FAOSTAT_TradeCropsAndLivestockProductsItems that are NOT included in FAOSTAT_LivestockFishCommodityBalancesItems and FAOSTAT_CropCommodityBalancesItems and NON_FAOSTAT_CropProductionItems

FAOSTAT_TradeCropsAndLivestockProductsItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_TradeCropsAndLivestockProductsItems)

Two dimensional set containing all trade crop and livestock item codes and names matched that may be used in FAOSTAT

FAOSTAT_CropCommodityBalancesItems

Set containing the commodity balances crop items

FAOSTAT_CropCommodityBalancesItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_CropCommodityBalancesItems)

Two dimensional set containing all commodity balances crop item codes and names matched that may be used in FAOSTAT

FAOSTAT_LivestockFishCommodityBalancesItems

Commodity balances livestock and fish items

FAOSTAT_LivestockFishCommodityBalancesItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_LivestockFishCommodityBalancesItems)

Two dimensional set containing all commodity balances livestock and fish item codes and names matched that may be used in FAOSTAT

FAOSTAT_ProducerPriceItems

Crop and livestock items for producer price data

FAOSTAT_ProducerPriceItemCodeAndItems(FAOSTAT_ItemCode,FAOSTAT_ProducerPriceItems)

Two dimensional set containing all producer price data crop and livestock item codes and names matched that may be used in FAOSTAT

9.1.3 _V6_Sets_FAOSTAT_ItemGroups

This file declares the sets for groups of activity and commodity items as defined in FAOSTAT.

In this code file, the following sets are defined:

FAOSTAT_CropProductionItemGroups

Crop item groups as included in FAOSTAT

FAOSTAT_CropProductionItemGroups_CompleteExclusive(FAOSTAT_CropProductionItemGroups)

Sub-set containing mutually exclusive crop item groups as included in FAOSTAT

FAOSTAT_CropProductionItemsInItemGroups(FAOSTAT_CropProductionItemGroups,FAOSTAT_CropProductionItems)

Two dimensional set containing all crop groups matched to single crop items

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FAOSTAT_LivestockPrimaryItems_Meat(FAOSTAT_LivestockPrimaryItems)
Sub-set containing MEAT items only in livestock primary items
FAOSTAT_LivestockPrimaryItems_PoultryMeat(FAOSTAT_LivestockPrimaryItems)
Sub-set containing POULTRY MEAT items only in livestock primary items
FAOSTAT_LivestockPrimaryItems_Milk(FAOSTAT_LivestockPrimaryItems)
Sub-set containing MILK items only in livestock primary items
FAOSTAT_LivestockPrimaryItems_Eggs(FAOSTAT_LivestockPrimaryItems)
Sub-set containing EGG items only in livestock primary items
FAOSTAT_LivestockPrimaryItems_HidesSkinsHair(FAOSTAT_LivestockPrimaryItems)
Sub-set containing Hides-Skins-Hair items only in livestock primary items

The following files refer to item groups used in earlier versions of SOLm (up to V4 and for reading in some data in V5):

SOLmOld_CropProductionItemGroups
OLD crop item groups as used in earlier versions of SOLm (up to V4 and for reading in some data in V5)
SOLmOld_Fruits(FAOSTAT_CropProductionItems)
FRUIT crop items building the OLD SOLm fruit group
SOLmOld_Treenuts(FAOSTAT_CropProductionItems)
TREENUT crop items building the OLD SOLm treenut group
SOLmOld_Grains(FAOSTAT_CropProductionItems)
GRAINS crop items building the OLD SOLm grains group
SOLmOld_Pulses(FAOSTAT_CropProductionItems)
PULSES crop items building the OLD SOLm pulses group
SOLmOld_Oil_Crops(FAOSTAT_CropProductionItems)
OIL CROP crop items building the OLD SOLm oil crop group
SOLmOld_Starchy_Roots(FAOSTAT_CropProductionItems)
STARCHY ROOTS crop items building the OLD SOLm starchy roots group
SOLmOld_Sugars_And_Sweeteners(FAOSTAT_CropProductionItems)
SUGARS AND SWEETENERS crop items building the OLD SOLm sugars and sweeteners group
SOLmOld_Vegetables(FAOSTAT_CropProductionItems)
VEGETABLES crop items building the OLD SOLm vegetables group
SOLmOld_Stimulants_Spices(FAOSTAT_CropProductionItems)
STIMULANTS AND SPICES crop items building the OLD SOLm stimulants and spices group
SOLmOld_Fibres_Rubber(FAOSTAT_CropProductionItems)
FIBRES AND RUBBER crop items building the OLD SOLm fibres and rubber group
SOLmOld_ForReadingDataBerries(FAOSTAT_CropProductionItems)
BERRIES crop items building the OLD SOLm berries group
SOLmOld_ForReadingDataNonLeguminousVegetables(FAOSTAT_CropProductionItems)
NON-LEGUMINOUS VEGETABLES crop items building the OLD SOLm non-leguminous vegetables group
SOLmOld_ForReadingDataLeguminousVegetables(FAOSTAT_CropProductionItems)
LEGUMINOUS VEGETABLES crop items building the OLD SOLm leguminous vegetables group

9.1.4 _V6_Sets_NonFAOSTAT_Items

This file declares additional sets for activity and commodity items that are currently not covered under FAOSTAT, but have once been (fodder crops) or are other most basic amendments to FAOSTAT items (algae, etc).

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In this code file, the following NON-FAOSTAT sets are defined:
NON_FAOSTAT_CropProductionItems
Additional crop item names that may be used and are NOT part of FAOSTAT
NON_FAOSTAT_GrassActivities(NON_FAOSTAT_CropProductionItems)
Sub-set containing all grass item names that may be used and are NOT part of FAOSTAT
NON_FAOSTAT_LivestockPrimaryItems
Additional livestock primary item names that may be used and are NOT part of FAOSTAT
NON_FAOSTAT_LiveAnimalsItems
Additional live animal item names that may be used and are NOT part of FAOSTAT
NON_FAOSTAT_TradeLiveAnimalsItems
Additional live animal item names that may be used in the live animal trade matrix but are NOT part of FAOSTAT
NON_FAOSTAT_LivestockFishCommodityBalancesItems
Additional commodity balances livestock and fish items that are NOT part of FAOSTAT

9.1.5 _V6_Sets_FAOSTAT_Elements

This file declares all the sets with elements needed in the model for reading FAOSTAT production, trade food balance and land use data. “Elements” are, grossly speaking” parameter and variables of interest, such as “yield” or “import quantity” (for further examples see below).

In this code file, the following sets are defined:
FAOSTAT_ElementCode
All element codes that may be used in FAOSTAT
FAOSTAT_CropProductionElements
All crop production elements (such as "area harvested" or "yield") that are used in FAOSTAT
FAOSTAT_LivestockProductionElements
All livestock production elements (such as "Stocks" or "yield") that are used in FAOSTAT
FAOSTAT_TradeElements All trade elements (such as "Import Quantity") that are used in FAOSTAT
FAOSTAT_CommodityBalancesElements
All commodity balances elements (such as "Domestic supply quantity" or "Waste") that are used in FAOSTAT
FAOSTAT_ProducerPriceElements
All producer price elements (such as "Producer Price") that are used in FAOSTAT

9.1.6 _V6_Sets_FAOSTAT_Units

This file declares all the sets with units needed in the model for reading FAOSTAT production, trade, food balance and land use data.

In this code file, the following sets are defined:
FAOSTAT_CropProductionUnits
All units (such as "ha" or "tonnes") that may be used in crop production in FAOSTAT
FAOSTAT_LivestockProductionUnits
All units (such as "Head" or "hg") that may be used in livestock production in FAOSTAT
FAOSTAT_TradeUnits
All units (such as "Head" or "tonnes") that may be used in trade data in FAOSTAT
FAOSTAT_CommodityBalancesUnits
All units (such as "kg" or "tonnes") that may be used in commodity balances in FAOSTAT
FAOSTAT_ProducerPriceUnits
All units (such as "USD") that may be used in producer price data in FAOSTAT

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9.1.7 _V6_Sets_FAOSTAT_LandUse

This file declares the sets where the FAOSTAT Land Use items are collected

In this code file, the following sets are defined:
FAOSTAT_LandUSeItemCode
All element codes that may be used in FAOSTAT
FAOSTAT_LandUseItems
All land use item names that may be used in FAOSTAT
FAOSTAT_LandUseItemCodeAndItems(FAOSTAT_LandUSeItemCode,FAOSTAT_LandUseItems)
Two dimensional set containing all land use item codes and names matched that may be used in FAOSTAT
FAOSTAT_LandUseElements
All land use elements (such as "Area") that are used in FAOSTAT
FAOSTAT_LandUseUnits
All land use units (such as "ha" or "million tonnes") that may be used in land use in FAOSTAT

9.1.8 _V6_Sets_FAOSTAT_Deforestation

This file declares the sets where the FAOSTAT Deforestation items are collected. See also section 9.15.

In this code file, the following sets are defined:
FAOSTAT_DeforestationItems
All deforestation item names ("Forest" and "Net Forest Conversion") that may be used in FAOSTAT
FAOSTAT_DeforestationElements
All deforestation elements (such as "Area") that are used in FAOSTAT
FAOSTAT_DeforestationUnits
All deforestation units (such as "ha" or "gigagrams") that may be used in FAOSTAT

9.1.9 _V6_Sets_FAOSTAT_OrganicSoils

This file declares the sets where the FAOSTAT Organic Soils items are collected. See also section 9.16.

In this code file, the following sets are defined:
FAOSTAT_OrganicSoilsItems
All organic soils item names (such as "cropland organic soils") that may be used in FAOSTAT
FAOSTAT_OrganicSoilsElements
All organic soils elements (such as "Area") that are used in FAOSTAT
FAOSTAT_OrganicSoilsUnits
All organic soils units (such as "ha" or "gigagrams") that may be used in FAOSTAT

9.1.10 _V6_Sets_ErbEtAl_Grasslands

This file declares the sets needed to read grassland data from (Erb, Gaube et al. 2007). For UNISECO, the grassland data is updated with the updated values from BioBaM.

In this code file, the following sets are defined:
ErbEtAl_GrasslandYieldClasses
Different grass yield classes

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ErbEtAl_AverageYieldElement
Average grass yield elements such as tDM per ha
ErbEtAl_GrasslandNutrientElements
Grass nutrient elements such as tDM per ton or MJ per tDM
ErbEtAl_GrasslandDataCountriesAndRegions
Countries and regions as used in Erb et al. 2007 grassland data
ErbEtAl_GrasslandDataCountryList(ErbEtAl_GrasslandDataCountriesAndRegions)
Sub-set with countries as used in Erb et al. 2007 grassland data
ErbEtAl_GrasslandDataRegions(ErbEtAl_GrasslandDataCountriesAndRegions)
Sub-set with regions as used in Erb et al. 2007 grassland data
ErbEtAl_GrasslandDataCountriesInRegions(ErbEtAl_GrasslandDataRegions,ErbEtAl_GrasslandDataCountryList)
Two dimensional set containing all Erb et al. 2007 grassland regions matched to countries

9.1.11 _V6_Sets_FAOSTAT_Fertilizers

This file declares the sets that are needed to read FAOSTAT fertilizer data (items, elements and units)

In this code file, the following sets are defined:
FAOSTAT_FertilizerItems
Fertilizer items (such as "ammonium nitrate (AN)" etc.) used in FAOSTAT
FAOSTAT_FertilizerElements
Fertilizer elements (such as "Export quantity" etc.) used in FAOSTAT
FAOSTAT_FertilizerUnits
Fertilizer units (e.g. "tons") used in FAOSTAT

9.1.12 _V6_Sets_FAOSTAT_Population_HumanNutrReq

This file declares the sets where the FAOSTAT population data is collected and that are needed for human nutrient requirements.

In this code file, the following sets are defined:
FAOSTAT_PopulationItems
Population items (such as population number) used in FAOSTAT
FAOSTAT_PopulationElements
Population elements (such as "urban population") used in FAOSTAT
FAOSTAT_PopulationUnits
Population units ("1000 persons") used in FAOSTAT

9.1.13 _V6_Sets_VariousSources_HerdStructures

This file assigns the sets used to work with herd structures.

In this code file, the following sets are defined:
AnimalCategoriesInHerd_VariousSources
All animal categories according to age and reproductive and production status that may be used in the model - covers also some management aspects - not mutually exclusive
AnimalCategoriesInHerd_SOLmOLD(AnimalCategoriesInHerd_VariousSources)
All animal categories as used in older versions of SOLm (up to version V4)
CattleHerdCategories_SOLmOLD(AnimalCategoriesInHerd_VariousSources)
Subset with cattle herd categories as used in older versions of SOLm
DairyCattleHerdCategories_SOLmOLD(AnimalCategoriesInHerd_VariousSources)

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Subset with DAIRY cattle herd categories as used in older versions of SOLm
BeefCattleHerdCategories_SOLmOLD(AnimalCategoriesInHerd_VariousSources)
Subset with BEEF cattle herd categories as used in older versions of SOLm
PigHerdCategories_SOLmOLD(AnimalCategoriesInHerd_VariousSources)
Subset with PIG herd categories as used in older versions of SOLm
AnimalCategoriesInHerd_FAOSTAT(AnimalCategoriesInHerd_VariousSources)
Subset with animal categories as used in FAOSTAT
AnimalCategoriesInHerd_IPCC2006(AnimalCategoriesInHerd_VariousSources)
Subset with animal categories as used in (IPCC 2006)
AnimalCategoriesInHerd_IPCC2006_Ruminants(AnimalCategoriesInHerd_VariousSources)
Subset with RUMINANT categories as used in (IPCC 2006)

9.1.14 _V6_Sets_GeneralModelSets_ForReadingData

This file declares some further sets that are needed to read in the data.

In this code file, the following sets are defined:
ProductionType
Captures the different types of production, such as organic or conventional, rain-fed or irrigated, etc. and also animal production systems - CURRENTLY only org/conv needed!
MatchFaostatLiveAnimalItems_Activities(FAOSTAT_LiveAnimalsItems,Activities)
Matches the FAOSTAT live animal items with the SOLm activities

9.1.15 _V6_Sets_GeneralModelSets

This file declares all the sets needed in the model BESIDES the sets needed for filing in the data. All these sets are displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “GeneralModelSets”.

In this code file, the following sets are defined:

9.1.15.1 Inputs
InputsCropsGrass
Captures the different inputs to the crop and grass activities, i.e. all mass and nutrient flows that are used by the activity; examples are seeds, fertilizer, land, etc.
InputsAnimals
Captures the different inputs to the animal activities, i.e. all mass and nutrient flows that are used by the activity; examples are feed, drinking water, etc.
InputsFishSeafood
Captures the different inputs to the fish and seafood activities, i.e. all mass and nutrient flows that are used by the activity; examples are feed, mangrove area, etc.
InputsForest
Captures the different inputs to the forest activities, i.e. all mass and nutrient flows that are used by the activity; examples are energy for logging, etc.
InputsOther
Captures the different inputs to the other activities, i.e. all mass and nutrient flows that are used by the activity

9.1.15.2 Outputs
OutputsCropsGrass
Captures the different outputs from the crop and grass activities, i.e. all mass and nutrient flows that result

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from an activity; thus, this covers e.g. MainOutput1 from Wheat (i.e. grains), Straw, Roots, etc., but also emissions, losses, etc.

YieldsCropsGrass(utputsCropsGrass)

Captures the yields from the crop and grass activities - unit: biomass per ha

OutputsAnimals

Captures the different outputs from the animal activities, i.e. all mass and nutrient flows that result from an activity; thus, this covers e.g. meat, milk, manure, etc., but also emissions, losses, etc.

YieldsAnimals(OutputsAnimals)

Captures the different yields from the animal activities - units: biomass per head or APU

OutputsFishSeafood

Captures the different outputs from the fish and seafood activities, i.e. all mass and nutrient flows that result from an activity; thus, this covers e.g. Meat, but also emissions, losses, etc.

OutputsForest

Captures the different outputs from the forest activities, i.e. all mass and nutrient flows that result from an activity; thus, this covers e.g. wood, etc., but also emissions, losses, etc.

OutputsOther

Captures the different outputs from the other activities, i.e. all mass and nutrient flows that result from an activity

9.1.15.3 Other Characteristics of Activities

OtherCharCropsGrass

Characteristics of the crop or grass activity being undertaken that cannot be captured well by mass/nutrient flows; this can be the biodiversity loss or deforestation, but also monetary flows, etc.

OtherCharAnimals

Characteristics of the animal activity being undertaken that cannot be captured well by mass/nutrient flows; this can be animal welfare aspects, but also monetary flows, etc.

OtherCharFishSeafood

Characteristics of the fish and seafood activity being undertaken that cannot be captured well by mass/nutrient flows; this can be seabed destruction, but also monetary flows, etc.

OtherCharForest

Characteristics of the forest activity being undertaken that cannot be captured well by mass/nutrient flows; this can be biodiversity loss, but also monetary flows, etc.

OtherCharOther

Characteristics of the other activity being undertaken that cannot be captured well by mass/nutrient flows

9.1.15.4 Animal types in herds

AnimalTypeInHerd

captures the different types of animals that are needed to build a full animal production unit, or a herd structure (i.e. with a dairy cow, there are several calves of different age, sires, etc.)

AnimalTypeInHerd_NoAggregates(AnimalTypeInHerd)

Subset of AnimalTypeInherd used to sum up to get the total amount of living animals - avoiding double counting by excluding AllAndAverageTypes, etc. - thus only relevant for animals with herd structure

CattleTypeInHerd(AnimalTypeInHerd)

Subset of AnimalTypeInHerd containing cattle types only

DairyCattleTypeInHerd(AnimalTypeInHerd)

Subset of AnimalTypeInHerd containing dairy cattle types only

BeefCattleTypeInHerd(AnimalTypeInHerd)

Subset of AnimalTypeInHerd containing beef cattle types only

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PigTypeInHerd(AnimalTypeInHerd)
Subset of AnimalTypeInHerd containing pig types only
ProducingAnimals(AnimalTypeInHerd)
Subset of AnimalTypeInHerd containing producing animals only
SuckledAnimals(AnimalTypeInHerd)
Subset of AnimalTypeInHerd that is suckled
alias(AnimalTypeInHerd,AnimalTypeInHerd_2)
Duplicates the set AnimalTypeInHerd into an identical set AnimalTypeInHerd_2
MatchSucklingSuckledAnimals(AnimalTypeInHerdAnimalTypeInHerd_2)
Matching suckling and suckled AnimalTypeInHerd

9.1.15.5 *Production systems*

ProductionSystems
Captures the different systems of production, such as organic or conventional, rainfed or irrigated, etc. and also animal production systems
ProdSyst_OrgConAll(ProductionSystems)
Subset with the production systems “organic”, “conventional” and “All”
ProdSyst_OrgCon(ProductionSystems)
Subset with the production systems “organic” and “conventional”
ProdSyst_NoAggregates(ProductionSystems)
Subset with the production systems that are not aggregates of others (thus e.g. “All” is not included)
ProductionSystems_UsingMinNFert(ProductionSystems)
Production systems that use mineral fertilizers - to correctly adjust min fert use in the scenarios

9.1.15.6 *Production conditions*

ProductionConditions
Captures the production conditions from soil types and soil characteristics, climatic conditions, etc.

9.1.15.7 *Commodities: nutrient contents and Other Characteristics*

Contents
Captures nutrient contents of commodities
ContentsPerFreshMatterNutrients(Contents)
Captures non-food and non-feed nutrient contents of commodities (and also seeds) - only the per fresh matter values
ContentsPerFreshMatterFood(Contents)
Captures food nutrient contents of commodities (and also seeds) - only the per fresh matter values
ContentsPerFreshMatterFeed(Contents)
Captures feed nutrient contents of commodities (and also seeds) - only the per fresh matter values
CommodOtherChar
Captures other characteristics of commodities

9.1.15.8 *Crop residues: nutrient contents, Other Characteristics and management*

CropResContents
Captures nutrient contents of crop residues
CropResOtherChar
Captures other characteristics of crop residues
CropResManagement

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Various parameters related to crop residue management - e.g. emissions, N losses, etc.
CropResManagement_NotSystemShares(CropResManagement)
Same as Set CropResManagement but without 'Quantity share in CropResMan system'
CropResManSystem
Crop residue management systems
CropResManSystemCropland(CropResManSystem)
all crop residue management systems from which crop residues can then be used on croplands (or grasslands as well) as it is centrally collected, or on croplands, as it is left there
CropResManSystemGrassland(CropResManSystem)
all crop residue management systems from which crop residues can then be used on grasslands

9.1.15.9 Manure: nutrient contents, Other Characteristics and management

ManureContents
Captures nutrient contents of manure
ManureOtherChar
Captures other characteristics of manure
ManureManagement
Various parameters related to manure management - e.g. emissions, N losses, etc., UNITS - per t manure TS DM, if not indicated otherwise
ManureManSystem
Manure management systems
ManureManSystemCropland(ManureManSystem)
all manure management systems from which manure can then be used on croplands (or grasslands as well) as it is centrally collected
ManureManSystemGrassland(ManureManSystem)
all manure management systems from which manure can be used on grasslands only as it is left there

9.1.15.10 Fertilizer application characteristics

FertApplicCharact
Contains various characteristics of fertilizer application, such as N lost per ton N applied, etc.

9.1.15.11 Regions

Regions
Set containing all regions, countries, subregions (e.g. NUTS2 in the EU), etc. used in the model
alias(Regions,Regions_2)
Duplicates the set Regions into an identical set Regions_2
Countries(Regions)
Sub-set containing all countries (thus excludes more aggregate regions and sub-country level regions)
FAO_Africa(Regions)
FAO_Eastern_Africa(Regions)
FAO_Middle_Africa(Regions)
FAO_Northern_Africa(Regions)
FAO_Southern_Africa(Regions)
FAO_Western_Africa(Regions)
FAO_Americas(Regions)
FAO_Northern_America(Regions)
FAO_Central_America(Regions)
FAO_Caribbean(Regions)
FAO_South_America(Regions)

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FAO_Asia(Regions)
FAO_Central_Asia(Regions)
FAO_Eastern_Asia(Regions)
FAO_Southern_Asia(Regions)
FAO_SouthEastern_Asia(Regions)
FAO_Western_Asia(Regions)
FAO_Europe(Regions)
FAO_Eastern_Europe(Regions)
FAO_Northern_Europe(Regions)
FAO_Southern_Europe(Regions)
FAO_Western_Europe(Regions)
FAO_Oceania(Regions)
FAO_Australia_NewZealand(Regions)
FAO_Melanesia(Regions)
FAO_Micronesia(Regions)
FAO_Polynesia(Regions)
FAO_EuropeanUnion(Regions)
SubSaharanAfrica(Regions)

The preceding sets define various sub-sets covering regions as used in FAOSTAT

FOFA2050_Rest_of_EAP(Regions)
FOFA2050_Rest_of_HIC(Regions)
FOFA2050_Rest_of_LAC(Regions)
FOFA2050_Rest_of_MNA(Regions)
FOFA2050_Rest_of_SAS(Regions)
FOFA2050_Rest_of_SSA(Regions)
FOFA2050_Rest_of_EU(Regions)
FOFA2050_Rest_of_ECA(Regions)

The preceding sets define various sub-sets covering regions as used in the data for the FAO 2050 projections from 2018, (FAO 2018)

Set Regions_Switzerland(Regions)
Set Regions_Austria(Regions)
Set Regions_Austria_Tal(Regions)
Set Regions_Austria_Huegel(Regions)
Set Regions_Austria_Berg(Regions)

The preceding sets define various sub-sets covering regions as used in the refined data for CH and AT used in the “Alpenprojekt”

9.1.15.12 Activities, sub-activities, aggregate activities

Activities

Set containing all activities used in the model - inclusive aggregates and sub-activities

alias(Activities,Activities_2)

Duplicates the set Activities into an identical set Activities _2

Livestock(Activities)

Subset containing all livestock activities

Ruminants(Activities)

Subset containing all ruminant activities

Poultry(Activities)
MonogastricsNonPoultry(Activities)
FishAndSeafood(Activities)
NonRuminants(Activities)
Crops(Activities)

Subset containing all crop activities

Cereals(Activities)

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Subset containing all cereal activities
Fruits(Activities)
Treenuts(Activities)
Pulses(Activities)
Legumes_NFixing(Activities)
Crops_NoNFixingLegumes(Activities)
OilCrops(Activities)
StarchyRoots(Activities)
SugarCrops(Activities)
Vegetables(Activities)
StimulantsSpices(Activities)
FibresRubber(Activities)
OtherCereals(Activities)
CitrusFruits(Activities)
Spices(Activities)
The preceding sets define sub-sets containing activity groups as indicated in their names
OtherVegetables(Activities)
Subset of all vegetables BESIDES Tomatoes
OtherOilcrops(Activities)
FibresNotCotton(Activities)
Fallows(Activities)
EnergyCrops(Activities)
The preceding sets define sub-sets containing activity groups as indicated in their names
ForageCrops(Activities)
Subset containing all forage crops
OtherFodderCrops(Activities)
Subset containing other fodder crops
GrassActivities(Activities)
Subset containing all grass activities
CoreGrassActivities(Activities)
Subset containing the key grass activities - no auxiliary ones for filing in data, etc.
CoreGrassActivitiesNoTEMPGrass(Activities)
Subset containing the key PERMANENT grass activities - no auxiliary ones for filing in data, etc.
TempMeadAndPastures(Activities)
Subset containing temporary meadows and pastures
TempAndPermMeadAndPastures(Activities)
Subset containing temporary and permanent meadows and pastures - thus covering all grasslands based on two categories from FAOSTAT
CropsAndCoreGrassActivities(Activities)
Subset of all agricultural area based activities, i.e. containing all Crops and GrassActivities
CropsAndTempGrassActivities(Activities)
Subset of all crop plus temporary grass activities
SingleCropGrassAndLivestockActivities(Activities)
Subset of single activities without aggregates - both crops and livestock

FOFA2050_SweetPotato_And_Yams(Activities)
FOFA2050_Rapeseed_And_Mustardseed(Activities)
FOFA2050_OtherCrops(Activities)
FOFA2050_OtherFibreCrops(Activities)
FOFA2050_OtherFruits(Activities)
FOFA2050_OtherOilseeds(Activities)
FOFA2050_OtherRootsAndTubers(Activities)

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FOFA2050_OtherVegetables(Activities)
FOFA2050_CitrusFruits(Activities)
FOFA2050_DriedPulses(Activities)
FOFA2050_OtherCereals(Activities)
The preceding sets define various sub-sets covering activity groups as used in the data for the FAO 2050 projections from 2018, (FAO 2018)

OtherCrops(Activities)

9.1.15.13 Commodities

Commodities
Set containing all commodities used in the model - inclusive aggregates and sub-commodities
alias(Commodities,Commodities_2)
Duplicates the set Commodities into an identical set Commodities _2
ForageCommodities(Commodities)
Subset containing all forage commodities
Grasscommodities(Commodities)
Subset containing all grass commodities
ConcentrateCommodities(Commodities)
Subset containing all concentrate commodities
Commodities_SingleCommodities(Commodities)
Subset containing single commodities only - no additional aggregates; but some commodities may be listed twice, e.g. Pork and Pigmeat, etc., some may be aggregates from the original data (e.g. vegetables) - but usually only one of them then has an entry, I think.
Commodities_FeedGroups(Commodities)
Subset containing the aggregate feed groups (such as grass, concentrate, forage,…)

9.1.15.14 Some auxiliary sets

The following sets are also needed to read in data; in the code, they are structured as follows, here we do not add this structure between the files but display it at the beginning for a better overview:

14.1) Years
14.2) Temperatures
14.3) Greenhouse gases

the sets 14.1-14.3 are also needed to read in data, not only in the model runs

14.4) Sets related to mineral fertilizers
14.5) Sets related to population and human nutrition
14.6) Sets related to feeding rations
14.7) Some auxiliary matching sets for reading data (to be defined here and not further up, as they refer to the set Activities and Commodities)
14.8) Sets related to energy production

Years
Set that contains all the different years used in the model
BasisyearsOLD(Years)
these are the years /2005*2009/ used as basis years in older versions of SOLm, up to V4
Basisyears(Years)
these are the current default basis years /2009*2013/
BasisyearsSeed(Years)
these are the current default basis years to be used for averages of seed variables (shifted by one year, as they are used in the subsequent year only) /2008*2012/

Temperatures

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Set of temperature values in degree Celsius - to be used for manure management emissions calculations, for example, etc.
Temperatures0to100Celsius(Temperatures)
generally used temperatures - range of 0 to 100 degree Celsius
TemperaturesBelow10(Temperatures)
TemperaturesAbove28(Temperatures)

GreenhouseGases
relevant greenhouse gases for agriculture, used to define the GWP and GTP, etc. in a flexible way as a parameter

MineralFertilizerType
Types of mineral fertilizers
MineralFertilizerProdTech
Mineral fertilizer production technologies
MinFertChar
Mineral fertilizer characteristics
PopulationGroups
population groups - all, male, female, children
Humans_InputsOutputsOtherCharacteristics
inputs to, outputs from and other characteristics of humans
FeedingRationOtherChar
Characteristics of feeding rations that is not captured in the set contents or so - e.g. quantity share in DM for all commodities, etc.

MatchFaostatLiveAnimalItems_Activities(FAOSTAT_LiveAnimalsItems,Activities)
Match_ActivityOutputsToCommodities_Crops(Activities,OutputsCropsGrass,Commodities)
Set to link the main outputs from the crop activities to commodities, that can then be further worked with on commodity level
Match_ActivityOutputsToCommodities_Animals(Activities,OutputsAnimals,Commodities)
Set to link the main outputs from the animal activities to commodities, that can then be further worked with on commodity level
Match_FeedCommoditiesToFeedCommodGroups(Commodities,Commodities_2)
Matches the commodities used as feed to the four main feed groups (Conc, Forage, Grass, Residues)
Match_FeedCommoditiesToFeedCommodGroups_MainByprodConc(Commodities,Commodities_2)
Matches the commodities used as feed to the main feed groups, separating main and byprod for concentrates (ConcMainProd, ConcByProd, Forage, Grass, Residues)

ConversionLevel
Primary or secondary energy
EnergyType
Type of energy (electricity heat etc.)
EnergySource
Energy source (biomass fossil etc.)
EnergyChar
Characteristics of the energy production (quantity or emissions etc.)

9.1.16 _V6_VariablesAndParameters

This file declares the key parameters and variables needed in SOLmV6

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We first provide a detailed explanation of the structure:
the first basis of the model version V6 are activity units, i.e.

- the activities undertaken on a unit of agricultural land (hectare), with all the related inputs (e.g. seed), outputs (e.g. wheat grain) and other characteristics (e.g. risk to lead to deforestation)
- the activities undertaken to produce animal source food, framed in relation to one animal production unit, with all the related inputs (e.g. feed), outputs (e.g. milk) and other characteristics (e.g. risk to lead to antibiotic resistances)
- the activities undertaken to produce animal source food, framed in relation to SINGLE ANIMALS as constituents of an animal production unit, with all the related inputs, outputs and other characteristics
- the activities undertaken to produce fish and seafood, with "ton unprocessed fish/seafood biomass output" as the basic unit, , with all the related inputs (e.g. fuel energy), outputs (e.g. fish quantity) and other characteristics (e.g. seabed destruction)
- the activities undertaken on a unit of forest land (hectare), with all the related inputs (e.g. seedlings), outputs (e.g. wood) and other characteristics (e.g. biodiversity loss)
- any other activities - to be specified (could be used to capture insects, algae, vertical farming, cultured meat, etc.)

thereby,

- activities are any action that produces outputs from inputs, characterised by the above options: crops, animals, fish/seafood, forests, and other
- inputs are all mass/nutrient flows that are used when undertaking the activity
- outputs are all mass/nutrient flows that result from the activity
- other characteristics are all characteristics of the activity being undertaken that cannot be captured well by mass/nutrient flows; this can be the biodiversity loss or seabed destruction mentioned above, but also monetary flows, etc.

All these inputs, outputs and characteristics are displayed as parameters per unit activity, or, for animals, also per head.
Multiplication by the variable "quantity of activity units" then results in variables of input, output and characteristics quantities.

In this, we differentiate the sets inputs, outputs and other characteristics according to these fundamentally different activities as well (crops, animals, fish/seafood, forests, other).
But we keep one set activities, as we may later want to have agroforestry activities with crops AND animals included, etc.

The variables corresponding to totals values for per unit parameters (derived by multiplying the activity level times the per unit values) have the same names as the parameter, just with the letter "V" added at the beginning. Thus, the parameter is e.g. ActCropsGrass_Inputs, i.e. per hectare inputs, and the variable for the total is then VActCropsGrass_Inputs. All parameters and variables come with a number of dimensions, the first usually being Regions, the next Activities, then the specific aspects such as input indicators (e.g. ton nitrogen from mineral fertilizers per hectare), etc., then a dimension for ProductionSystems (such as organic or conventional) and ProductionConditions (currently not further differentiated, thus using the entry "All", but could capture aspects such as soil quality or climatic conditions).

Part of the outputs are then commodities (e.g. MainOutput1 from wheat is "Wheat grains" (or "Wheat") as commodities.
This is captured in the second basis of the model version V6, the commodity units:

These capture the specific

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outputs from the activities that are termed "commodities" and their nutrient contents and, where relevant, other characteristics (such as energy use for production, e.g. for Wheat flour from wheat grains), on a per ton basis.
Here, the differentiation between crops, animals, etc. is not used anymore.
All these contents and characteristics are displayed as parameters per ton commodity.
Multiplication by the variable "quantity of commodity" then results in variables of content and characteristics quantities.

Various commodities are related between each other via the commodity trees. This results in two further parameters:

- the Production shares - i.e. how much of wheat grain goes into wheat flour, how much into wheat beer, etc.; and
- the extraction rate, - i.e. how much wheat flour can be produced from one ton of wheat grain

The DETAILED TABLE OF CONTENTS for the parameter and variable definitions looks as follows:
- 1) Main parameters
    - 1.1) Activities: input parameters
    - 1.2) Activities: output parameters
    - 1.3) Activities: other characteristics
    - 1.4) Commodities: nutrient contents and other characteristics
    - 1.5) Commodity tree parameters
    - 1.6) Crop residues: nutrient contents, other characteristics and management
    - 1.7) Feeding rations
    - 1.8) Manure: nutrient contents, other characteristics and management
    - 1.9) Fertilizer application: nutrients and other characteristics
- 2) Main variables
    - 2.1) Amount of activity units
    - 2.2) Inputs to activities
    - 2.3) Outputs from activities
    - 2.4) Other characteristics of activities
    - 2.5) Commodity quantities, nutrient contained and other characteristics
    - 2.6) Commodity utilizations
    - 2.7) Crop residue quantities, nutrient contained, other characteristics and management
    - 2.8) Feeding rations quantities
    - 2.9) Manure quantities, nutrients contained, other characteristics and management
    - 2.10) Fertilizer application: nutrients and other characteristics
    - 2.11) Import and export quantities
    - 2.12) Commodities expressed in primary product equivalents
- 3) Auxiliary parameters
- 4) Auxiliary variables

Thus, in this code file, the following parameters and variables are defined:

9.1.16.1 Parameters

9.1.16.1.1 Activities: input parameters

ActCropsGrass_Inputs(Regions,Activities,InputsCropsGrass,ProductionSystems,ProductionConditions)
    inputs to the crop and grass activities undertaken on a unit of agricultural land - UNIT: input per hectare
ActAnimalsAPU_Inputs(Regions,Activities,AnimalTypeInHerd,InputsAnimals,ProductionSystems,ProductionConditions)
    inputs to the animal activities undertaken to produce animal source food - UNIT: input per

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Animal Production Unit
ActAnimalsHead_Inputs(Regions,Activities,AnimalTypeInHerd,InputsAnimals,ProductionSystems,ProductionConditions)
inputs to the animal activities undertaken to produce animal source food - UNIT: input per Animal Head
ActFishSeafood_Inputs(Regions,Activities,InputsFishSeafood,ProductionSystems,ProductionConditions)
inputs to the fish and seafood activities - UNIT: input per ton unprocessed fish or seafood biomass output
ActForest_Inputs(Regions,Activities,InputsForest,ProductionSystems,ProductionConditions)
inputs to the forest activities undertaken on a unit of forest land - UNIT: input per hectare
ActOthers_Inputs(Regions,Activities,InputsOther,ProductionSystems,ProductionConditions)
inputs to any other activities undertaken - UNIT: to be specified - default: input per ton unprocessed main biomass output

9.1.16.1.2 Activities: output parameters

ActCropsGrass_Outputs(Regions,Activities,OutputsCropsGrass,ProductionSystems,ProductionConditions)
outputs from the crop and grass activities undertaken on a unit of agricultural land - UNIT: output per hectare
ActAnimalsAPU_Outputs(Regions,Activities,AnimalTypeInHerd,OutputsAnimals,ProductionSystems,ProductionConditions)
outputs from the animal activities undertaken to produce animal source food - UNIT: output per Animal Production Unit
ActAnimalsHead_Outputs(Regions,Activities,AnimalTypeInHerd,OutputsAnimals,ProductionSystems,ProductionConditions)
outputs from the animal activities undertaken to produce animal source food - UNIT: output per Animal Head
ActFishSeafood_Outputs(Regions,Activities,OutputsFishSeafood,ProductionSystems,ProductionConditions)
outputs from the fish and seafood activities - UNIT: output per ton unprocessed fish or seafood biomass output
ActForest_Outputs(Regions,Activities,OutputsForest,ProductionSystems,ProductionConditions)
outputs from the forest activities undertaken on a unit of forest land - UNIT: output per hectare
ActOthers_Outputs(Regions,Activities,OutputsOther,ProductionSystems,ProductionConditions)
outputs from any other activities undertaken - UNIT: to be specified - default: output per ton unprocessed main biomass output

9.1.16.1.3 Activities: other characteristics

ActCropsGrass_OtherChar(Regions,Activities,OtherCharCropsGrass,ProductionSystems,ProductionConditions)
other characteristics of the crop and grass activities undertaken on a unit of agricultural land - UNIT: OtherChar per hectare or ton etc.
ActAnimalsAPU_OtherChar(Regions,Activities,AnimalTypeInHerd,OtherCharAnimals,ProductionSystems,ProductionConditions)
other characteristics of the animal activities undertaken to produce animal source food - UNIT: OtherChar per Animal Production Unit
ActAnimalsHead_OtherChar(Regions,Activities,AnimalTypeInHerd,OtherCharAnimals,ProductionSystems,ProductionConditions
)
other characteristics of the animal activities undertaken to produce animal source food - UNIT: OtherChar per Animal Head
ActFishSeafood_OtherChar(Regions,Activities,OtherCharFishSeafood,ProductionSystems,ProductionConditions)
other characteristics of the fish and seafood activities - UNIT: OtherChar per ton unprocessed fish or seafood biomass output
ActForest_OtherChar(Regions,Activities,OtherCharForest,ProductionSystems,ProductionConditions)
other characteristics of the forest activities undertaken on a unit of forest land - UNIT: OtherChar per hectare or ton etc.
ActOthers_OtherChar(Regions,Activities,OtherCharOther,ProductionSystems,ProductionConditions)
other characteristics of any other activities undertaken - UNIT: to be specified - default: OtherChar per ton unprocessed main biomass output

9.1.16.1.4 Commodities: nutrient contents and other characteristics

Commod_Contents(Regions,Commodities,Contents,ProductionSystems,ProductionConditions)
nutrient contents of commodities - UNIT: units nutrient per ton commodity

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Commod_OtherChar(Regions,Commodities,CommodOtherChar,ProductionSystems,ProductionConditions)

other characteristics of commodities - UNIT: OtherChar per ton commodity

9.1.16.1.5 Commodity tree parameters

Commod_ProductionShare(Regions,Commodities,Commodities_2,ProductionSystems)

production share of different commodities from the same higher level commodity in the commodity tree - UNIT: share (i.e. percentage divided by 100)

Commod_ExtractionRate(Regions,Commodities,Commodities_2,ProductionSystems)

extraction rate of a commodity from its higher level source commodity - UNIT: share (i.e. percentage divided by 100)

The following defines a parameter that captures how aggregate commodities are disaggregated into primary activities (e.g. "Bread" comes from "All Cereals" and those have to be disaggregated to "Wheat", "Rye", etc.). Assumptions on this are often very shaky and for now, much is determined by expert guess from Adrian Muller from August 2019 - or where sensible, it is allocated according to the relative shares of single commodities in the aggregate, if this information is available.

Commod_SingleInAggregateCommodShares(Regions,Commodities,Commodities_2,ProductionSystems)

Share of single commodities in aggregate commodities - UNIT: share (i.e. percentage divided by 100)

9.1.16.1.6 Crop residues: nutrient contents, other characteristics and management

CropResidues_Contents(Regions,Activities,OutputsCropsGrass,CropResContents,ProductionSystems,ProductionConditions)

nutrient contents of crop residues - UNIT: units nutrient per ton crop residues

CropResidues_OtherChar(Regions,Activities,OutputsCropsGrass,CropResOtherChar,ProductionSystems,ProductionConditions)

other characteristics of crop residues - UNIT: OtherChar per ton crop residues

CropResidues_Management(Regions,Activities,OutputsCropsGrass,CropResManagement,CropResManSystem,ProductionSystems,ProductionConditions)

values related to crop residues management - UNIT: units management values per ton crop residues

9.1.16.1.7 Feeding rations

FeedingRations_Contents(Regions,Activities,AnimalTypeInHerd,Commodities,Contents,ProductionSystems,ProductionConditions)

"nutrient contents of feed/Feeding rations - UNIT: units nutrient per ton feed"

FeedingRations_OtherChar(Regions,Activities,AnimalTypeInHerd,Commodities,FeedingRationOtherChar,ProductionSystems,ProductionConditions)

"other characteristics of feed/Feeding rations - UNIT: other characteristics per ton feed"

FeedingRationsHeads_Contents(Regions,Activities,AnimalTypeInHerd,Commodities,Contents,ProductionSystems,ProductionConditions)

"nutrient contents of feed/Feeding rations - UNIT: units nutrient per animal head"

FeedingRationsHeads_OtherChar(Regions,Activities,AnimalTypeInHerd,Commodities,FeedingRationOtherChar,ProductionSystems,ProductionConditions)

"other characteristics of feed/Feeding rations - UNIT: other characteristics per animal head"

FeedingRationsAPU_Contents(Regions,Activities,AnimalTypeInHerd,Commodities,Contents,ProductionSystems,ProductionConditions)

"nutrient contents of feed/Feeding rations - UNIT: units nutrient per APU"

9.1.16.1.8 Manure: nutrient contents, other characteristics and management

Manure_Contents(Regions,Activities,AnimalTypeInHerd,ManureContents,ProductionSystems,ProductionConditions)

nutrient contents of manure - UNIT: units nutrient per ton manure

Manure_OtherChar(Regions,Activities,AnimalTypeInHerd,ManureOtherChar,ProductionSystems,ProductionConditions)

other characteristics of manure - UNIT: OtherChar per ton manure

Manure_Management(Regions,Activities,AnimalTypeInHerd,ManureManagement,ManureManSystem,Temperatures,ProductionSystems,ProductionConditions)

values related to manure management - UNIT: units management values per t manure TS DM if not indicated otherwise

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9.1.16.1.9 Fertilizer application: nutrients and other characteristics

below: Activities_2 is Livestock plus also aggregates thereof, therefore the set Livestock is not enough and it needs to be activities

ManureApplication(Regions,Activities,Activities_2,AnimalTypeInHerd,FertApplicCharact,ProductionSystems,ProductionConditions)

Characteristics of manure application to activities; Livestock/AnimalTypeInHerd captures the source of manure - UNIT: Char per ton manure/nutrient

CropResAndBiomassApplication(Regions,Activities,Commodities,FertApplicCharact,ProductionSystems,ProductionConditions)

Characteristics of crop residue and other crop biomass application to activities; commodities captures the source of crop residue (other biomass - UNIT: Characteristics per ton crop res/nutrient

MinFertApplication(Regions,Activities,MineralFertilizerType,FertApplicCharact,ProductionSystems,ProductionConditions)

Characteristics of min fert application to activities; MineralFertilizerType captures the source of min fert - UNIT: Char per ton min fert/nutrient

9.1.16.1.10 Extraction rates

ExtractionRate_CommodityTree(Regions,Commodities)

Extraction rates of commodities from their source products (e.g. 0.75 for “wheat flour” from “wheat grains”) – UNIT: ratio (i.e. percentage/100)

9.1.16.2 Main variables

9.1.16.2.1 Amount of activity units

VActCropsGrass_QuantityActUnits(Regions,Activities,ProductionSystems,ProductionConditions)

total amount of activity units - UNIT: Number of hectares

VActAnimalsAPU_QuantityActUnits(Regions,Activities,AnimalTypeInHerd,ProductionSystems,ProductionConditions)

total amount of activity units - UNIT: Number of Animal Production Units (APUs)

VActAnimalsHead_QuantityActUnits(Regions,Activities,AnimalTypeInHerd,ProductionSystems,ProductionConditions)

total amount of activity units - UNIT: Number of animal heads

VActFishSeafood_QuantityActUnits(Regions,Activities,ProductionSystems,ProductionConditions)

total amount of activity units - UNIT: Tons of unprocessed fish or seafood

VActForest_QuantityActUnits(Regions,Activities,ProductionSystems,ProductionConditions)

total amount of activity units - UNIT: Number of hectares

VActOthers_QuantityActUnits(Regions,Activities,ProductionSystems,ProductionConditions)

total amount of activity units - UNIT: to be specified - default: tons of unprocessed main biomass output

9.1.16.2.2 Inputs to activities

VActCropsGrass_Inputs(Regions,Activities,InputsCropsGrass,ProductionSystems,ProductionConditions)

total inputs to the crop and grass activities undertaken on agricultural land - UNIT: total input

VActAnimalsAPU_Inputs(Regions,Activities,AnimalTypeInHerd,InputsAnimals,ProductionSystems,ProductionConditions)

total inputs to the animal activities undertaken to produce animal source food - UNIT: total input

VActAnimalsHead_Inputs(Regions,Activities,AnimalTypeInHerd,InputsAnimals,ProductionSystems,ProductionConditions)

total inputs to the animal activities undertaken to produce animal source food - UNIT: total input

VActFishSeafood_Inputs(Regions,Activities,InputsFishSeafood,ProductionSystems,ProductionConditions)

total inputs to the fish and seafood activities - UNIT: total input

VActForest_Inputs(Regions,Activities,InputsForest,ProductionSystems,ProductionConditions)

total inputs to the forest activities undertaken on a unit of forest land - UNIT: total input

VActOthers_Inputs(Regions,Activities,InputsOther,ProductionSystems,ProductionConditions)

total inputs to any other activities undertaken - UNIT: total input

9.1.16.2.3 Outputs from activities

VActCropsGrass_Outputs(Regions,Activities,OutputsCropsGrass,ProductionSystems,ProductionConditions)

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total outputs from the crop and grass activities undertaken on agricultural land - UNIT: total output

VActAnimalsAPU_Outputs(Regions,Activities,AnimalTypeInHerd,OutputsAnimals,ProductionSystems,ProductionConditions)
total outputs from the animal activities undertaken to produce animal source food - UNIT: total output

VActAnimalsHead_Outputs(Regions,Activities,AnimalTypeInHerd,OutputsAnimals,ProductionSystems,ProductionConditions)
total outputs from the animal activities undertaken to produce animal source food - UNIT: total output

VActFishSeafood_Outputs(Regions,Activities,OutputsFishSeafood,ProductionSystems,ProductionConditions)
total outputs from the fish and seafood activities - UNIT: total output

VActForest_Outputs(Regions,Activities,OutputsForest,ProductionSystems,ProductionConditions)
total outputs from the forest activities undertaken on a unit of forest land - UNIT: total output

VActOthers_Outputs(Regions,Activities,OutputsOther,ProductionSystems,ProductionConditions)
total outputs from any other activities undertaken - UNIT: total output

9.1.16.2.4 Other characteristics of activities

VActCropsGrass_OtherChar(Regions,Activities,OtherCharCropsGrass,ProductionSystems,ProductionConditions)
total other characteristics of the crop and grass activities undertaken on agricultural land - UNIT: total OtherChar

VActAnimalsAPU_OtherChar(Regions,Activities,AnimalTypeInHerd,OtherCharAnimals,ProductionSystems,ProductionConditions)
total other characteristics of the animal activities undertaken to produce animal source food - UNIT: total OtherChar

VActAnimalsHead_OtherChar(Regions,Activities,AnimalTypeInHerd,OtherCharAnimals,ProductionSystems,ProductionConditions)
total other characteristics of the animal activities undertaken to produce animal source food - UNIT: total OtherChar

VActFishSeafood_OtherChar(Regions,Activities,OtherCharFishSeafood,ProductionSystems,ProductionConditions)
total other characteristics of the fish and seafood activities - UNIT: total OtherChar

VActForest_OtherChar(Regions,Activities,OtherCharForest,ProductionSystems,ProductionConditions)
total other characteristics of the forest activities undertaken on a unit of forest land - UNIT: total OtherChar

VActOthers_OtherChar(Regions,Activities,OtherCharOther,ProductionSystems,ProductionConditions)
total other characteristics of any other activities undertaken - UNIT: total OtherChar

9.1.16.2.5 Commodity quantities, nutrient contained and other characteristics

VCommod_Quantity(Regions,Commodities,ProductionSystems,ProductionConditions)
total (domestically available) commodity quantity (DAQ) - UNIT: tons

VCommod_Contents(Regions,Commodities,Contents,ProductionSystems,ProductionConditions)
total nutrient contents of commodities - UNIT: total units nutrient

VCommod_OtherChar(Regions,Commodities,CommodOtherChar,ProductionSystems,ProductionConditions)
total other characteristics of commodities - UNIT: total units OtherChar

9.1.16.2.6 Commodity utilizations

VCommod_Production(Regions,Commodities,ProductionSystems,ProductionConditions)
total quantity of commodity production - UNIT: tons

VCommod_StockChanges(Regions,Commodities,ProductionSystems,ProductionConditions)
total quantity of commodity stock changes - UNIT: tons

VCommod_Food(Regions,Commodities,ProductionSystems,ProductionConditions)
total quantity of commodity used for food - UNIT: tons

VCommod_Feed(Regions,Commodities,ProductionSystems,ProductionConditions)
total quantity of commodity used for feed - UNIT: tons

VCommod_Seed(Regions,Commodities,ProductionSystems,ProductionConditions)
total quantity of commodity used for seed - UNIT: tons

VCommod_Processing(Regions,Commodities,ProductionSystems,ProductionConditions)
total quantity of commodity used for processing - UNIT: tons

VCommod_Waste(Regions,Commodities,ProductionSystems,ProductionConditions)

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total quantity of commodity lost or wasted - UNIT: tons

VCommod_Other(Regions,Commodities,ProductionSystems,ProductionConditions)

total quantity of commodity used for other uses - UNIT: tons

*for some, we also are interested in contents and other characteristics of these commodity utilizations:

VCommod_Food_Contents(Regions,Commodities,Contents,ProductionSystems,ProductionConditions)

total nutrient contents of commodity used for food - UNIT: total units nutrient

VCommod_Feed_Contents(Regions,Commodities,Contents,ProductionSystems,ProductionConditions)

total nutrient contents of commodity used for feed - UNIT: total units nutrient

VCommod_Waste_Contents(Regions,Commodities,Contents,ProductionSystems,ProductionConditions)

total nutrient contents of commodity lost or wasted - UNIT: total units nutrient

VCommod_Food_OtherChar(Regions,Commodities,CommodOtherChar,ProductionSystems,ProductionConditions)

total other characteristics of commodity used for food - UNIT: total units OtherChar

VCommod_Feed_OtherChar(Regions,Commodities,CommodOtherChar,ProductionSystems,ProductionConditions)

total other characteristics of commodity used for feed - UNIT: total units OtherChar

VCommod_Waste_OtherChar(Regions,Commodities,CommodOtherChar,ProductionSystems,ProductionConditions)

total other characteristics of commodity lost or wasted - UNIT: total units OtherChar

9.1.16.2.7 Crop residue quantities, nutrient contained, other characteristics and management

VCropResidues_Quantity(Regions,Activities,OutputsCropsGrass,ProductionSystems,ProductionConditions)

total crop residue quantity - UNIT: tons

VCropResidues_Contents(Regions,Activities,OutputsCropsGrass,CropResContents,ProductionSystems,ProductionConditions)

total nutrient contents of crop residues - UNIT: total units nutrient

VCropResidues_OtherChar(Regions,Activities,OutputsCropsGrass,CropResOtherChar,ProductionSystems,ProductionConditions)

total other characteristics of crop residues - UNIT: total units OtherChar

VCropResidues_Management(Regions,Activities,OutputsCropsGrass,CropResManagement,CropResManSystem,ProductionSystems,ProductionConditions)

total values related to crop residues management - UNIT: total units management values

9.1.16.2.8 Feeding rations quantities

VFeedingRations_Quantity(Regions,Activities,AnimalTypeInHerd,Commodities,ProductionSystems,ProductionConditions)

total quantity of feed - UNIT: tons

VFeedingRations_Contents(Regions,Activities,AnimalTypeInHerd,Commodities,Contents,ProductionSystems,ProductionConditions)

total nutrient contents of feed - UNIT: total units nutrient

VFeedingRations_OtherChar(Regions,Activities,AnimalTypeInHerd,Commodities,FeedingRationOtherChar,ProductionSystems,ProductionConditions)

total other characteristics of feed/Feeding rations - UNIT: total other characteristics

9.1.16.2.9 Manure quantities, nutrients contained, other characteristics and management

VManure_Quantity(Regions,Activities,AnimalTypeInHerd,ProductionSystems,ProductionConditions)

total manure quantity - UNIT: tons

VManure_Contents(Regions,Activities,AnimalTypeInHerd,ManureContents,ProductionSystems,ProductionConditions)

total nutrient contents of manure - UNIT: total units nutrient

VManure_OtherChar(Regions,Activities,AnimalTypeInHerd,ManureOtherChar,ProductionSystems,ProductionConditions)

total other characteristics of manure - UNIT: total units OtherChar

VManure_Management(Regions,Activities,AnimalTypeInHerd,ManureManagement,ManureManSystem,Temperatures,ProductionSystems,ProductionConditions)

total values related to manure management - UNIT: total units management values

9.1.16.2.10 Fertilizer application: nutrients and other characteristics

below: Activities_2 is Livestock plus also aggregates thereof, therefore the set Livestock is not enough and it needs to be activities

VManureApplication(Regions,Activities,Activities_2,AnimalTypeInHerd,FertApplicCharact,ProductionSystems,ProductionConditions)

Total characteristics of manure application to activities; Livestock/AnimalTypeInHerd captures the source of manure - UNIT: total Char

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VCropResAndBiomassApplication(Regions,Activities,Commodities,FertApplicCharact,ProductionSystems,ProductionConditions)

Total characteristics of crop residue and other crop biomass application to activities; commodities captures the source of crop residue/other biomass - UNIT: total Characteristic

VMinFertApplication(Regions,Activities,MineralFertilizerType,FertApplicCharact,ProductionSystems,ProductionConditions)

Total characteristics of min fert application to activities; MineralFertilizerType captures the source of min fert - UNIT: total Char

9.1.16.2.11 Import and export quantities

VImportQuantity(Regions,Regions_2,Commodities,ProductionSystems,ProductionConditions)

total commodity quantity IMPORTED into Regions FROM Regions_2 - UNIT: tons

VExportQuantity(Regions,Regions_2,Commodities,ProductionSystems,ProductionConditions)

total commodity quantity EXPORTED from Regions INTO Regions_2 - UNIT: tons

VImportLivingAnimalsHead(Regions,Regions_2,Activities,AnimalTypeInHerd,ProductionSystems,ProductionConditions)

total number of live animals IMPORTED into Regions FROM Regions_2 - UNIT: Number of animal heads

VExportLivingAnimalsHead(Regions,Regions_2,Activities,AnimalTypeInHerd,ProductionSystems,ProductionConditions)

total number of live animals EXPORTED from Regions INTO Regions_2 - UNIT: Number of animal heads

The following is for trade in beehives and other animal activities measured in APUs only:

VImportLivingAnimalsAPU(Regions,Regions_2,Activities,ProductionSystems,ProductionConditions)

total number of live animals IMPORTED into Regions FROM Regions_2 - UNIT: Number of Animal Production Units (APUs)

VExportLivingAnimalsAPU(Regions,Regions_2,Activities,ProductionSystems,ProductionConditions)

total number of live animals EXPORTED from Regions INTO Regions_2 - UNIT: Number of Animal Production Units (APUs)

9.1.16.2.12 Commodities expressed in primary product equivalents

The following variables are expressed in prim prod equivalents, derived from the corresponding variables that are reported in commodity quantities (cf. definitions above), by means of extraction rates, etc. There is no need to add activity and output dimensions, as this information is captured in the relevant matching sets as defined in "_V6_ReadData_CommodityTrees_LinkActivitiesAndCommodities.gms"

VPrimProd_Commod_Quantity(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT commodity quantity - UNIT: tons

VPrimProd_Commod_Production(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT quantity of commodity production - UNIT: tons

VPrimProd_Commod_StockChanges(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT quantity of commodity stock changes - UNIT: tons

VPrimProd_Commod_Food(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT quantity of commodity used for food - UNIT: tons

VPrimProd_Commod_Feed(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT quantity of commodity used for feed - UNIT: tons

VPrimProd_Commod_Seed(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT quantity of commodity used for seed - UNIT: tons

VPrimProd_Commod_Processing(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT quantity of commodity used for processing - UNIT: tons

VPrimProd_Commod_Waste(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT quantity of commodity lost or wasted - UNIT: tons

VPrimProd_Commod_Other(Regions,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT quantity of commodity used for other uses - UNIT: tons

VPrimProd_ImportQuantity(Regions,Regions_2,Commodities,ProductionSystems,ProductionConditions)

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total PRIMARY PRODUCT EQUIVALENT commodity quantity IMPORTED into Regions FROM Regions_2 - UNIT: tons

VPrimProd_ExportQuantity(Regions,Regions_2,Commodities,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT commodity quantity EXPORTED from Regions INTO Regions_2 - UNIT: tons

VPrimProd_Commod_Quantity_CropActivities(Regions,Commodities,Activities,OutputsCropsGrass,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT commodity quantity - linked to activities - UNIT: tons

VPrimProd_Commod_Quantity_AnimalActivities(Regions,Commodities,Activities,OutputsAnimals,ProductionSystems,ProductionConditions)

total PRIMARY PRODUCT EQUIVALENT commodity quantity - linked to activities - UNIT: tons

9.1.16.3 Auxiliary parameters

HumanCharacteristics(Regions,PopulationGroups,Humans_InputsOutputsOtherCharacteristics,Commodities)

any characteristics of humans - such as nutrient requirements, nutrient excretions and others - UNITS: characteristics/inputs/outputs per CAPITA. Thereby, commodities refer to the source of food, e.g. plant or animal based, but also cereals, oil crops, etc. or even finer on commodity level

SeedContents(Regions,Activities,Contents,ProductionSystems,ProductionConditions)

any characteristics of seeds - such as nutrient and DM contents, etc. - UNITS: per ton seed

MineralFertilizerCharacteristics(Regions,MineralFertilizerType,MineralFertilizerProdTech,MinFertChar,ProductionSystems)

any characteristics of mineral fertilizers - such as production emissions, etc. - UNITS: per ton min. fert. nutrient

GWP_GTP_SOLm(GreenhouseGases)

values for the radiative forcing of GHGs - GWP or GTP - to be set at the beginning and then to be used for all calculations

9.1.16.4 Auxiliary variables

VMineralFertilizerQuantity(Regions,MineralFertilizerType,MineralFertilizerProdTech,ProductionSystems)

total amount of mineral fertilizers from 'min. fert. production technology', applied on 'production systems' in 'region' - UNIT: tons N, P2O5, K2O

VPopulationNumbers(Regions,PopulationGroups)

total population numbers per region - differentiated by population groups, such as male, female, children, etc. - UNIT: number of people

VEnergyProduction(Regions,ConversionLevel,EnergyType,EnergySource,EnergyChar)

total energy related variables - total production and supply, emissions, related CCS, etc. - UNIT: units total

9.1.17 _V6_ReadData_FAOSTAT_CropProduction

This code reads the following data from FAOSTAT:

VActCropsGrass_QuantityActUnits.l(Regions,Activities,"AllProdSyst","AllProdCond")

area harvested in hectares

VActCropsGrass_Outputs.l(Regions,Activities,"MainOutput1 (t)","AllProdSyst","AllProdCond")

main production in tonnes

VActCropsGrass_Inputs.l(Regions,Activities,"Seeds (t)","AllProdSyst","AllProdCond")

total seed inputs in tonnes

ActCropsGrass_Outputs(Regions,Activities,"MainOutput1 (t)","AllProdSyst","AllProdCond")

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yield in tonnes per hectare

Then derive seed input per ha from seed quantity and areas harvested (better would be: area cropped, instead of harvested!). This is a very gross measure of seed use per ha to be improved, e.g. by standard seed application rates for crops, etc.
ActCropsGrass_Inputs(Regions,Activities,"Seeds (t)","AllProdSyst","AllProdCond")
seed input in tonnes per ha

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_CropProductionItems of the set Activities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_CropProductionItems".

9.1.18 _V6_ReadData_FAOSTAT_ForageCropProduction

This code reads the following data from FAOSTAT:
VActCropsGrass_QuantityActUnits.l(Regions,Activities,"AllProdSyst","AllProdCond")
area harvested in hectares
VActCropsGrass_Outputs.l(Regions,Activities,"MainOutput1 (t)","AllProdSyst","AllProdCond")
main production in tonnes
ActCropsGrass_Outputs(Regions,Activities,"MainOutput1 (t)","AllProdSyst","AllProdCond")
yield in tonnes per hectare

Seed data is not available, but is assigned from similar crops by a specific matching filed defined in the code (e.g. sees for forage maize is taken to be the same as for maize, etc.) and from some specific data for certain crops as indicated in the code.
ActCropsGrass_Inputs(Regions,Activities,"Seeds (t)","AllProdSyst","AllProdCond")
seed input in tonnes per ha

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_ForageCropProductionItems of the set Activities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_ForageCropProdItems".

IMPORTANT: This data has not been officially validated by FAOSTAT. FAOSTAT indicates that the data is not as reliable as the data made publicly available. This data is thus not anymore publicly available on the web, but it is provided on request. The data currently used in SOLm is from the original file "Production_Fodder crops 1990_2017_export SWS official 25.09.2018.xlsx" as sent to us per mail from FAO on 25.9.2018.

9.1.19 _V6_ReadData_FAOSTAT_LivestockProduction

This code reads the following data from FAOSTAT:
VActAnimalsHead_Outputs.l(Regions,Activities,AnimalTypeInHerd,OutputsAnimals,"AllProdSyst","AllProdCond")
Production from animals in tonnes (derived from "number producing heads"*"yield per producing animal")
VActAnimalsHead_QuantityActUnits.l(Regions,Activities,"Living","AllProdSyst","AllProdCond")
Number of animals (heads)
VActAnimalsAPU_Outputs.l(Regions,"Beehives",AnimalTypeInHerd,OutputsAnimals,"AllProdSyst","AllProdCond")
APU is animal production unit; Production from animals in tonnes (derived from "number of APUs"*"yield per APU")
VActAnimalsAPU_QuantityActUnits.l(Regions,"Beehives",AnimalTypeInHerd,"AllProdSyst","AllProdCond")

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Number of APUs
ActAnimalsHead_Outputs(Regions,Activities,AnimalTypeInHerd,OutputsAnimals,"AllProdSyst","AllProdCond")
Yield per head producing animal in tonnes / head
ActAnimalsAPU_Outputs(Regions,"Beehives",AnimalTypeInHerd,OutputsAnimals,"AllProdSyst","AllProdCond")
Yield per APU in tonnes / APU

The APU data is used for “Beehives” only, all other animals are covered by the “head” data. Values are available for the subset FAOSTAT_Countries of the set Regions (displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “FAOSTAT_Countries”) and for the subset FAOSTAT_LiveAnimalsItems of the set Activities. The subset FAOSTAT_LiveAnimalsItems captures the set FAOSTAT_LivestockPrimaryItems in which the data is provided from FAOSTAT best on SOLmV6 Activities – in combination with output types, as described in the sets displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “FAOSTAT_LiveAnimalsItems”.

9.1.20 _V6_ReadData_FAOSTAT_Trade

This code reads the following data from FAOSTAT:
VImportQuantity(Regions,Regions_2,Commodities,"AllProdSyst","AllProdCond")
Import quantity of Commodities (from Regions_2 into Regions) in tonnes
VExportQuantity(Regions,Regions_2,Commodities,"AllProdSyst","AllProdCond")
Export quantity of Commodities (from Regions to Regions_2) in tonnes
VImportLivingAnimalsHead(Regions,"World",Activities,"Living","AllProdSyst","AllProdCond")
Import of living animals in heads, from “World” to Regions
VExportLivingAnimalsHead(Regions,"World",Activities,"Living","AllProdSyst","AllProdCond")
Export of living animals in heads, from Regions to “World”
VImportLivingAnimalsAPU(Regions,"World","Beehives","AllProdSyst","AllProdCond")
Import of living animals in APU, from “World” to Regions
VExportLivingAnimalsAPU(Regions,"World","Beehives","AllProdSyst","AllProdCond")
Export of living animals in APU, from Regions to “World”

The APU data is used for “Beehives” only, all other animals are covered by the “head” data. Values are available for the subset FAOSTAT_Countries of the set Regions, for the subset FAOSTAT_DetailedTradeMatrixItems of the set Commodities and for the subset FAOSTAT_TradeLiveAnimalsItems of the set Activities. These subsets are displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheets “FAOSTAT_Countries” and “ActCommod_FAOSTATTrade”.

Importantly, the trade data for "China, Hong Kong SAR", "China, Macao SAR", "China, mainland" and "China, Taiwan Province of" has been summed to values for “China” and then these four parts have been dropped. Thus, the data is more consistent with the production data, etc., where only “China” is reported.

To assign correct sustainability impacts to the commodities available in a region, they have to be traced back to their countries of production (thus, e.g. Germany may report to import considerable quantities of soy from The Netherlands. This soy, however, is not grown in The Netherlands, but imported from other countries, say Brazil and the US. Thus, it is assumed that the soy imported into Germany from The Netherlands in fact originates from Brazil and the US. This information is not available in the FAO trade-data and additional calculations and assumptions are needed to derive such systematically for all trade flows to assign the direct linkage between country of production and final importing country. (Kastner, Kastner et al. 2011) provides procedures on how to do this, which are also implemented in SOLm..

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9.1.21 _V6_ReadData_FAOSTAT_CommodityBalances

This code reads the following data from FAOSTAT:

VCommod_Quantity.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Domestically available quantity (DAQ) of Commodities in a Region in tonnes
VImportQuantity.l(Regions,"World",Commodities,"AllProdSyst","AllProdCond")
Imported quantity of Commodities from "World" into a Region in tonnes
VExportQuantity.l(Regions,"World",Commodities,"AllProdSyst","AllProdCond")
Exported quantity of Commodities to "World" from a Region in tonnes
VCommod_StockChanges.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Stock changes of Commodities in a Region in tonnes
VCommod_Production.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Production of Commodities in a Region in tonnes
VCommod_Feed.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Quantity of Commodities in a Region used as FEED in tonnes
VCommod_Seed.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Quantity of Commodities in a Region used as SEED in tonnes
VCommod_Food.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Quantity of Commodities in a Region used as FOOD in tonnes
VCommod_Waste.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Quantity of Commodities in a Region WASTED/LOST in tonnes
VCommod_Processing.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Quantity of Commodities in a Region used as PROCESSED FURTHER in tonnes
VCommod_Other.l(Regions,Commodities,"AllProdSyst","AllProdCond")
Quantity of Commodities in a Region used OTHERWISE (e.g. bioenergy) in tonnes
Commod_OtherChar(Regions,Commodities,"Util food (share)","AllProdSyst","AllProdCond")
Commod_OtherChar(Regions,Commodities,"Util feed (share)","AllProdSyst","AllProdCond")
Commod_OtherChar(Regions,Commodities,"Util seed (share)","AllProdSyst","AllProdCond")
Commod_OtherChar(Regions,Commodities,"Util waste (share)","AllProdSyst","AllProdCond")
Commod_OtherChar(Regions,Commodities,"Util other (share)","AllProdSyst","AllProdCond")
Commod_OtherChar(Regions,Commodities,"Util processing (share)","AllProdSyst","AllProdCond")
The parameters above capture the various utilization shares of commodities as described in their names; unit: share (derived by division of the respective utilization quantity by the total DAQ).

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subsets FAOSTAT_LivestockFishCommodityBalancesItems, FAOSTAT_CropCommodityBalancesItems, ForageCommodities of the set Commodities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "Commod_FAOCommodBalances".

9.1.22 _V6_ReadData_FAOSTAT_LandUse

This code reads the following data from FAOSTAT:

VActCropsGrass_QuantityActUnits.l(Regions,Activities,"AllProdSyst","AllProdCond")
Areas under various land use as captured in the corresponding Activities, in hectares
VActForest_QuantityActUnits.l(Regions,Activities,"AllProdSyst","AllProdCond")
Areas under various forest use as captured in the corresponding Activities, in hectares
Values are available for the subset FAOSTAT_Countries of the set Regions and for some elements of the subset FAOSTAT_LandUse of the set Activities as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_LandUse".

9.1.23 _V6_ReadData_FAOSTAT_Deforestation

This code reads the

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following data from FAOSTAT:
ActCropsGrass_OtherChar(Regions,Crops,"Deforestation (ha)","AllProdSyst","AllProdCond")
ActCropsGrass_OtherChar(Regions,GrassActivities,"Deforestation (ha)","AllProdSyst","AllProdCond")
unit: ha deforestation per ha agricultural area, positive - if no deforestation occurs, this value is zero, as this is already coded like this in the FAO data

ActCropsGrass_OtherChar(Regions,Crops,"Deforest GHG emissions (tCO2e)","AllProdSyst","AllProdCond")
ActCropsGrass_OtherChar(Regions,GrassActivities,"Deforest GHG emissions (tCO2e)","AllProdSyst","AllProdCond")
unit: t CO_2eq emissions from deforestation per ha agricultural area, positive - if no deforestation occurs, this value is zero, as this is already coded like this in the FAO data

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subsets Crops and GrassActivities of the set Activities as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "SOLmV6_CropsGrassAct". For further details, see section 9.15.

9.1.24 _V6_ReadData_FAOSTAT_OrganicSoils

This code reads the following data from FAOSTAT:
ActCropsGrass_OtherChar(Regions,Crops,"CultOrgSoils (ha)","AllProdSyst","AllProdCond")
ActCropsGrass_OtherChar(Regions,GrassActivities,"CultOrgSoils (ha)","AllProdSyst","AllProdCond")
unit: ha managed organic soils per ha agricultural area, positive - if no organic soils are used, this value is zero, as this is already coded like this in the FAO data
ActCropsGrass_OtherChar(Regions,Crops,"CultOrgSoils GHG emissions (tCO2e)","AllProdSyst","AllProdCond")
ActCropsGrass_OtherChar(Regions,GrassActivities,"CultOrgSoils GHG emissions (tCO2e)","AllProdSyst","AllProdCond")
unit: t CO2eq emissions from managed organic soils per ha agricultural area, positive - if no organic soils are managed, this value is zero, as this is already coded like this in the FAO data
ActCropsGrass_OtherChar(Regions,Crops,"CultOrgSoils C emissions (tCO2e)","AllProdSyst","AllProdCond")
ActCropsGrass_OtherChar(Regions,GrassActivities,"CultOrgSoils C emissions (tCO2e)","AllProdSyst","AllProdCond")
unit: t C emissions in tCO2eq from managed organic soils per ha agricultural area, positive - if no organic soils are managed, this value is zero, as this is already coded like this in the FAO data
ActCropsGrass_OtherChar(Regions,Crops,"CultOrgSoils N2O emissions (tCO2e)","AllProdSyst","AllProdCond")
ActCropsGrass_OtherChar(Regions,GrassActivities,"CultOrgSoils N2O emissions (tCO2e)","AllProdSyst","AllProdCond")
unit: t N2O emissions in tCO2eq from managed organic soils per ha agricultural area, positive - if no organic soils are managed, this value is zero, as this is already coded like this in the FAO data

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subsets Crops and GrassActivities of the set Activities as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "SOLmV6_CropsGrassAct". For further details, see section 9.16.

9.1.25 _V6_ReadData_ErbEtAl_Grasslands

This code reads the following data from (Erb, Gaube et al. 2007):
ActCropsGrass_Outputs(Regions,Activities,"MainOutput1 (t DM)","AllProdSyst","AllProdCond")
Grassland DM yield, tDM/ha
ActCropsGrass_Outputs(Regions,Activities,"MainOutput1 (t)","AllProdSyst","AllProdCond")
Grassland yield, t/ha
Commod_Contents(Regions,Activities,"FeedME in DM (MJ)","AllProdSyst","AllProdCond")
Grass FeedME contents in DM (MJ/tDM)
Commod_Contents(Regions,Activities,"FeedXP in DM (t)","AllProdSyst","AllProdCond")
Grass FeedXP contents in DM (tXP/tDM)

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Commod_Contents(Regions,Activities,"DM (t)","AllProdSyst","AllProdCond")
Grass DM contents (tDM/t)
Commod_Contents(Regions,Activities,"FeedME (MJ)","AllProdSyst","AllProdCond")
Grass FeedME contents (MJ/t)
Commod_Contents(Regions,Activities,"FeedXP (t)","AllProdSyst","AllProdCond")
Grass FeedXP contents (tXP/t)
Commod_Contents(Regions,Activities,"N (t)","AllProdSyst","AllProdCond")
Grass N contents (tN/t)
Commod_Contents(Regions,Activities,"FeedGE (MJ)","AllProdSyst","AllProdCond")
Grass FeedGE contents (MJ/t)
Commod_Contents(Countries,Activities,"P2O5 (t)","AllProdSyst","AllProdCond")
Grass P contents (tP2O5/t)
VActCropsGrass_Outputs.l(Regions,Activities,"MainOutput1 (t)","AllProdSyst","AllProdCond")
Total grass production quantity in tonnes
VCommod_Quantity.l(Regions,Activities,"AllProdSyst","AllProdCond")
Total grass domestically available quantity in tonnes (usually equals production – at least in the baseline FAO data, there is no trade in grass)
VCommod_Production.l(Regions,Activities,"AllProdSyst","AllProdCond")
Total grass commodity production quantity in tonnes (equals VActCropsGrass_Outputs.l)
VCommod_Feed.l(Regions,Activities,"AllProdSyst","AllProdCond")
Total grass domestically available quantity used as feed in tonnes (usually equals DAQ, i.e. 100% is used as feed)

Values are available for the subset ErbEtAl_GrasslandDataCountryList of the subset FAOSTAT_Countries of the set Regions as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheets “FAOSTAT_Countries” (ErbEtAl_GrasslandDataCountryList is not displayed there but can be found in the code; it differs by absence of some small countries only), and for the elements "Permanent meadows and pastures" and "Temporary meadows and pastures" of the set Activities, displayed in the set GrassActivities in “SOLmV6_CropsGrassAct”.

9.1.26 _V6_ReadData_FAOSTAT_Fertilizers

This code reads the following data from FAOSTAT:
VMineralFertilizerQuantity.l(Regions,"mineral N fert (N)","AllMinFertProdTech","AllProdSyst")
VMineralFertilizerQuantity.l(Regions,"mineral P fert (P2O5)","AllMinFertProdTech","AllProdSyst")
VMineralFertilizerQuantity.l(Regions,"mineral K fert (K2O)","AllMinFertProdTech","AllProdSyst")
This is mineral fertilizer quantities used in Regions, units are tons nutrients: N, P2O5, K2O.

Values are available for the subset FAOSTAT_Countries of the set Regions as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “FAOSTAT_Countries”.

9.1.27 _V6_ReadData_FAOSTAT_WOSY_DetailedFBS

*This is an old code module using FAOSTAT data on detailed food balance sheets that is not publicly available. It played a role in in SOLmV2; currently not in use and not updated to SOLmV6 as the publicly available data is good enough as a default for what is needed here; will likely be deleted soon.

9.1.28 _V6_ReadData_FAOSTAT_Population

This code reads the following data from FAOSTAT:
VPopulationNumbers.l(Regions,PopulationGroups)
Number of people in the respective population groups (“PopulationAll”, “Male”, “Female”)

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Values are available for the subset FAOSTAT_Countries of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries".

9.1.29 _V6_ReadData_VariousSources_HumanNutrientRequirements

This code reads the following data:
HumanCharacteristics(Regions,"PopulationAll",Humans_InputsOutputsOtherCharacteristics,"All commodities")

> This contains the average human nutrient requirements (kcal ADER (average daily energy requirements), kcal MDER (minimum daily energy requirements), gram protein and gram fat, all on a per capita and per day basis. Could be differentiated per commodity groups, but currently, it is the total. Sources: (Walpole, Prieto-Merino et al. 2012) or (FAO WFP and IFAD 2012) – this latter data was provided by FAOSTAT, it does not seem to be publicly available – to be checked again).

Values are available for the subset FAOSTAT_Countries of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries".

9.1.30 _V6_ReadData_VariousSources_CropGrassNutrientRequirementsData

Currently, this code does not read any data; in earlier versions of SOLm, up to V4, it has been used to read some data, but the quality of it was low. In the code, the nutrient requirement has then be changed to exclusively be a parameter that is derived rather than taken from some data base. Thus, the nutrient requirement is currently derived from nutrient output in produced biomass, etc. – if better data is available, this can be read and used in the scenario definitions to overwrite the default derived from output nutrient quantities.

9.1.31 _V6_ReadData_VariousSources_MainOutputNutrientContentsData

This code reads the following data from a number of sources – for details, see the code file:
Commod_Contents(Countries,Commodities,Contents,"AllProdSyst","AllProdCond")

> Contents is N, P2O5, DM, partly ME, GE, XP contents in fresh and partly also in dry matter, i.e. values per ton commodity or per ton DM commodity

Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries". Commodities covers the primary output commodities only, i.e. it is FAOSTAT_CropProductionItems, forage crops in NON_FAOSTAT_CropProductionItems, and livestock primary products - a selection from livestock commodities that most closely capture the main outputs from livestock activities, all as described in in the sheet "CommodNutrientContents" in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx".

9.1.32 _V6_ReadData_VariousSources_ResidueSharesAndNutrientContentsData

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This code reads the following data from a number of sources – for details, see the code file:
CropResidues_Contents(Regions,Activities,"Average residues (t)",CropResContents,"AllProdSyst","AllProdCond")
Residues N-, P2O5-, DM-contents, before management, unit: tN, tP2O5, tDM/t
CropResidues_OtherChar(Regions,Activities,"Average residues (t)",CropResOtherChar,"AllProdSyst","AllProdCond")
Residue shares, i.e. residues in DM per DM main output: "Residue share t DM / t DM MainOutput1"

Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “FAOSTAT_Countries” and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet “FAOSTAT_CropProductionItems” and the elements "Temporary meadows and pastures" and "Permanent meadows and pastures" of the set Activities, displayed in the set GrassActivities in the sheet “SOLmV6_CropsGrassAct”.

9.1.33 _V6_ReadData_VariousSources_SeedCharacteristicsData

This code reads the following data from a number of sources – for details, see the code file:
ActCropsGrass_Inputs(Regions,Activities,"Seeds (t)","AllProdSyst","AllProdCond")
Seed inputs in ton seeds per ha
SeedContents(Regions,Activities,Contents,"AllProdSyst","AllProdCond")
Seed N, P2O5 and DM contents in tons per ton seed

The sets Regions (basically: all countries) contains the elements as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “Regions_FAOCropProd” and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet “FAOSTAT_CropProductionItems”.

9.1.34 _V6_ReadData_FAOSTAT_ProducerPrices

This code reads the following data from FAOSTAT:
Commod_OtherChar(Regions,Commodities,"Producer price ($)","AllProdSyst","AllProdCond")
Producer prices in $ per ton commodity

Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “FAOSTAT_Countries” and Commodities contains the elements from the set FAOSTAT_ProducerPriceItems as displayed in the sheet “Commod_FAOProducerPrices”.

9.1.35 _V6_ReadData_IPCC_GWP_GTPData

This code reads the following data from IPCC:
GWP_GTP_SOLm(GreenhouseGases)
Global warming/temperature potential for the three key greenhouse gases in agriculture, CO2, CH4, N2O

9.1.36 _V6_ReadData_LuEtAl_NDepositionData

This code reads the following data from (Lu, Jiang et al. 2013):
ActCropsGrass_Inputs(Regions,Activities,"N deposition (tN)","AllProdSyst","AllProdCond")
ActForest_Inputs(Regions,"Forest","N deposition (tN)","AllProdSyst","AllProdCond")

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Atmospheric N deposition in tN per hectare

The data is world-sub-region average values from the reference named above. Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries" and Activities are the elements from the subset Crops as displayed in the sheet "Activities_NDeposition_LuEtAl", as well as the elements "Forest" and "Temporary meadows and pastures" and "Permanent meadows and pastures" from the set Activities.

9.1.37 _V6_ReadData_VariousSources_NFixationData

This code reads the following data from various sources (mainly from (Herridge, Peoples et al. 2008)), for details see the code file:

ActCropsGrass_OtherChar(Regions,Activities,"N fixation per ton MainOutput1 (tN)","AllProdSyst","AllProdCond")

N fixation per ton main output, tons N fixed per ton main output.

Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries" and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet "FAOSTAT_CropProductionItems" and the set NON_FAOSTAT_CropProductionItems as displayed in sheet "CommodNutrientContents".

9.1.38 _V6_ReadData_VariousSources_SoilErosionData

This code reads the following data from various sources (for details, see the code file and section 9.20 or (Schader, Muller et al. 2015)):

ActCropsGrass_OtherChar(Regions,Activities,"Soil water erosion (t soil lost)","AllProdSyst","AllProdCond")

Water erosion of soil, tons soil lost per hectare.

Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries" and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet "FAOSTAT_CropProductionItems" and the elements "Temporary meadows and pastures" and "Permanent meadows and pastures" of the set Activities, displayed in the set GrassActivities in the sheet "SOLmV6_CropsGrassAct", and forage and other forage crops in NON_FAOSTAT_CropProductionItems in the sheet "CommodNutrientContents".

9.1.39 _V6_ReadData_VariousSources_IrrigationWaterData

This code reads the following data from various sources, mainly AQUASTAT and Water Footprint Network (for details, see the code file and section 9.17):

ActCropsGrass_Inputs(Regions,Activities,"Irrigation water – irrigated areas (m3)","AllProdSyst","AllProdCond")

Irrigation water use per hectare irrigated crop.

ActCropsGrass_Inputs(Regions,Activities,"Irrigation water – averaged over all areas (m3)","AllProdSyst","AllProdCond")

Irrigation water use per hectare average crop: Irrigation water use averaged over all cropping areas, i.e. each hectare cropped needs on average this amount of irrigation water (which reflects the share of areas irrigated and the irrigation water use per irrigated area).

ActCropsGrass_OtherChar(Regions,Activities,"Share irrigated areas (share)","AllProdSyst","AllProdCond")

Share of area per crop that is irrigated, unit: share.

ActCropsGrass_OtherChar(Regions,Activities,"Water scarcity indicator (index)","AllProdSyst","AllProdCond")

A region-specific index for water scarcity; captures the pressure on water sources from irrigation.

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Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries" and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet "FAOSTAT_CropProductionItems" and the elements "Temporary meadows and pastures" and "Permanent meadows and pastures" of the set Activities, displayed in the set GrassActivities in the sheet "SOLmV6_CropsGrassAct", and forage and other forage crops in NON_FAOSTAT_CropProductionItems in the sheet "CommodNutrientContents".

9.1.40 _V6_ReadData_VariousSources_AnimalWelfareData

This code reads the following data from various sources (for details, see the code file and section 9.18):

ActAnimalsHead_OtherChar(Regions,Activities,"AllAndAverageTypes","General animal welfare index", "AllProdSyst","AllProdCond")
ActAnimalsHead_Inputs(Regions,"Cattle",CattleTypeInHerd, "General animal welfare index","AllProdSyst","AllProdCond")
ActAnimalsHead_Inputs(Regions,"Pigs",PigTypeInHerd, "General animal welfare index","AllProdSyst","AllProdCond")

General animal welfare index per animal head and year.

ActAnimalsHead_OtherChar(Regions,Activities,"AllAndAverageTypes","General parasite infestation index", "AllProdSyst","AllProdCond")
ActAnimalsHead_Inputs(Regions,"Cattle",CattleTypeInHerd, "Genera parasite infestation index","AllProdSyst","AllProdCond")
ActAnimalsHead_Inputs(Regions,"Pigs",PigTypeInHerd, "General parasite infestation index","AllProdSyst","AllProdCond")

General parasite infestation index per animal head and year.

ActAnimalsHead_Inputs(Regions,"Cattle","Producing_Dairy_Cattle", "Mastitis incidence index","AllProdSyst","AllProdCond")

Mastitis incidence index per producing dairy cattle head and year.

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_LiveAnimalsItems plus the element "Game" of the set Activities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_LiveAnimalsItems". The cattle/PigTypeInHerd values are identical to the averages for all cattle/pig.

9.1.41 _V6_ReadData_VariousSources_PesticidesData

This code reads the following data from various sources (for details, see the code file and section 9.19 or (Schader, Muller et al. 2015)):

ActCropsGrass_OtherChar(Regions,Activities,"Aggreg. Pest. use level (index)","AllProdSyst","AllProdCond")

This is an aggregate pest use level index (dimensionless) – given on a per hectare basis; it is derived from indices on ease of access to pesticides per country, level of legislation on pesticides per country and pesticide use intensity of crops.

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_CropProductionItems of the set Activities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_CropProductionItems".

9.1.42 _V6_ReadData_IPCC2006_RiceCroppingEmissionsData

This code reads the following data from (IPCC 2006) (for details, see the code file):

ActCropsGrass_Outputs(Countries,"Rice, paddy","CH4 flooded rice (t CH4)","AllProdSyst","AllProdCond")

CH_4 emissions of rice, t CH_4 per hectare

Values are available for the subset FAOSTAT_Countries of the set Regions. This subset is displayed

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in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheets “FAOSTAT_Countries”

9.1.43 _V6_ReadData_VariousSources_HerdStructures

This code reads the following data on the herd structures as derived in (Schader, Muller et al. 2015), see also section 9.6:
VActAnimalsHead_QuantityActUnits(Regions,"Cattle",AnimalTypeInHerd,"AllProdSyst","AllProdCond")
VActAnimalsHead_QuantityActUnits(Regions,"Pigs",AnimalTypeInHerd,"AllProdSyst","AllProdCond")
Number of animals in each of the herd structure types (such as “Sows”, “Boars”, “Producing_Dairy_Cattle”, etc.) .

Values are available for the subset FAOSTAT_Countries of the set Regions and for the elements “Cattle” and “Pigs” of the set Activities. This subset is displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “FAOSTAT_Countries”. The set AnimalTypeInHerd covers the core herd animal types as used in SOLm. For all other livestock activities than “Cattle” and “Pigs”, there is no herd structure and the element used there is thus “AllAndAverageTypes”. For “Cattle” and “Pigs”, the elements are part of the set AnimalTypeInHerd as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “SOLm_HerdStructure”.

This data on the herd structures is calculated separately based on the values for the FAOSTAT living and producing animals by means of a maximum entropy model. For details see section 9.6 and (Schader, Muller et al. 2015). The numbers for each herd type category are then set in relation to these two values (living/Producing), and those shares are then applied to scenario values of living/producing animals to get herd structures in the scenarios, thus assuming that the herd structure does not change. Currently, these herd structures are derived for cattle and pigs only.

9.1.44 _V6_ReadData_VariousSources_AnimalProductionUnits

This file does not yet contain any code or data – to be designed yet. The aim would be to more systematically capture the animal production unit (APU) view on animal production, cf. the description towards the end of section 7.2.

9.1.45 _V6_ReadData_VariousSources_AnimalLiveweightData

This code reads the following data from various sources, mainly (IPCC 2006):
ActAnimalsHead_OtherChar(Regions,Activities,AnimalTypeInHerd,"Liveweight (t)","AllProdSyst","AllProdCond")
Live weight per animal head, in tons.

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_LiveAnimalsItems of the set Activities. These subsets are displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheets “FAOSTAT_Countries” and “FAOSTAT_LiveAnimalsItems”. The set AnimalTypeInHerd covers the core herd animal types as used in SOLm as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “SOLm_HerdStructure”.

9.1.46 _V6_ReadData_VariousSources_AnimalDrinkingWaterRequirementData

This code reads the

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following data from various sources, for details see the code file:
ActAnimalsHead_OtherChar(Regions,Activities,"AllAndAverageTypes","Drinking water (m3)","AllProdSyst","AllProdCond")
ActAnimalsHead_Inputs(Regions,"Cattle",CattleTypeInHerd,"Drinking water (m3)","AllProdSyst","AllProdCond")
ActAnimalsHead_Inputs(Regions,"Pigs",PigTypeInHerd,"Drinking water (m3)","AllProdSyst","AllProdCond")
Drinking water requirement per animal head and year, in m^3

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_LiveAnimalsItems plus the element "Game" of the set Activities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_LiveAnimalsItems". The cattle/PigTypeInHerd values are identical to the averages for all cattle/pig.

9.1.47 _V6_ReadData_VariousSources_FeedingRationsData

This code reads the following data from (Herrero, Havlik et al. 2013):
ActAnimalsHead_OtherChar(Regions,Activities,"AllAndAverageTypes",OtherCharAnimals,"AllProdSyst","AllProdCond")
Quantity share of aggregate feed groups in total DM feed uptake

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_LiveAnimalsItems plus the element "Game" of the set Activities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_LiveAnimalsItems". OtherCharAnimals is the share in feed on the level of aggregate feed groups, i.e. it covers the elements "Concentrates in Feed DM (share)", "Forage crops in Feed DM (share)", "Grass in Feed DM (share)" and "Residues in Feed DM (share)".

The same values are also reported in another parameter, with a focus on commodities supplied as feed rather than on animals and what they take in as feed:
FeedingRations_OtherChar(Regions,Activities,AnimalTypeInHerd,Commodities,"Quantity share in DM (share)","AllProdSyst","AllProdCond")
FeedingRations_OtherChar(Regions,"Cattle",CattleTypeInHerd,Commodities,"Quantity share in DM (share)","AllProdSyst","AllProdCond")
FeedingRations_OtherChar(Regions,"Pigs",PigTypeInHerd,Commodities,"Quantity share in DM (share)","AllProdSyst","AllProdCond")
Quantity share of aggregate feed groups in total DM feed uptake

Regions and Activities are as above, Commodities cover aggregate feed groups, i.e. the elements "AggregateFeedConcentrates_Commodity","AggregateFeedForageCrops_Commodity","AggregateFeedGrass_Commodity","AggregateFeedResidues_Commodity". The set AnimalTypeInHerd covers the core herd animal types as used in SOLm as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "SOLm_HerdStructure".

9.1.48 _V6_ReadData_VariousSources_AnimalNutrientRequirementsData

This code reads the following data from various sources, for details see the code file:
ActAnimalsHead_OtherChar(Regions,Livestock,AnimalTypeInHerd,"FeedME_req_Total (MJ)","AllProdSyst","AllProdCond")
Total per animal head requirements of feed metabolisable energy ME in MJ/head/year
ActAnimalsHead_OtherChar(Regions,Livestock,AnimalTypeInHerd,"FeedXP_req_Total (t)","AllProdSyst","AllProdCond")
Total per animal head requirements of feed crude protein XP in tons/head/year
ActAnimalsHead_OtherChar(Regions,Livestock,AnimalTypeInHerd,"FeedGE_req_Total (MJ)","AllProdSyst","AllProdCond")
Total per animal head requirements of feed gross energy GE in MJ/head/year
ActAnimalsHead_OtherChar(Regions,"Cattle","Producing_Dairy_Cattle",OtherCharAnimals,"AllProdSyst","AllProdCond")
Additional parameters used to derive the ME requirements for cattle, related to energy use for

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maintenance, walking, pregnancy and milking
ActAnimalsHead_OtherChar(Regions,Livestock,AnimalTypeInHerd,"XPperME_InFeedReq (gXP/MJ)","AllProdSyst","AllProdCond")
An auxiliary parameter to derive protein contents XP values from metabolisable energy ME values, in gXP per MJ ME
ActAnimalsHead_OtherChar(Regions,Livestock,"AllAndAverageTypes","UE_per_GE (share)","AllProdSyst","AllProdCond")
Urinary energy expressed as fraction of GE
ActAnimalsHead_OtherChar(Regions,Livestock,"AllAndAverageTypes","Animal specific FeedGE cont (MJ/t)","AllProdSyst","AllProdCond")
Default value for feed GE contents in MJ/ton
ActAnimalsHead_OtherChar(Regions,Livestock,"AllAndAverageTypes","Digestibility of Feed (%)","AllProdSyst","AllProdCond")
Digestibility of feed as a percentage
Commod_Contents(Regions,"Milk, Whole","Milk solid contents (t)","AllProdSyst","AllProdCond")
Milk solid contents in tons per ton milk

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_LiveAnimalsItems plus the element "Game" of the set Activities. – which is the same as the SOLmV6-subset Livestock of the set Activities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_LiveAnimalsItems". OtherCharAnimals is specifically for Dairy cattle, specific parameters to derive ME requirements: "FeedME_Req_MilkProd (MJ/head)", "FeedME_Req_Maintenance (MJ/head)", "FeedME_Req_Walking (MJ/head)", "FeedME_Req_Pregnancy (MJ/head)". The set AnimalTypeInHerd covers the core herd animal types as used in SOLm as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "SOLm_HerdStructure".

9.1.49 _V6_ReadData_VariousSources_EntericFermentationEmissionsData

This code reads the following data from (IPCC 2006), for details see the code file:
FeedingRationsHeads_OtherChar(Countries,Livestock,AnimalTypeInHerd,Commodities,"Percentage GE in feed converted to enteric CH4","AllProdSyst","AllProdCond")
Percentage GE in feed converted to enteric CH4, used to derive the enteric fermentation emissions later in the model (in Steering 2).

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_LiveAnimalsItems plus the element "Game" of the set Activities. – which is the same as the SOLmV6-subset Livestock of the set Activities (for enteric fermentation, data is provided for Ruminants, Pigs and Chickens only) These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_LiveAnimalsItems". The set AnimalTypeInHerd covers the core herd animal types for Cattle, Pigs and "AllAndAverageTypes" for other ruminants and chickens as used in SOLm as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "SOLm_HerdStructure". Commodities cover aggregate feed groups, i.e. the elements "AggregateFeedConcentrates_Commodity","AggregateFeedForageCrops_Commodity","AggregateFeedGrass_Commodity","AggregateFeedResidues_Commodity".

9.1.50 _V6_ReadData_VariousSources_CropResidueManagementData

This code reads the following data, mainly from (IPCC 2006), for details see the code file:
CropResidues_Management(Regions,Activities,"Average Residues (t)",CropResManagement,CropResManSystem,ProductionSystems,"AllProdCond")

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Various aspects of crop residue management, such as crop residue management system shares, nutrients lost, emissions, and nutrients contained in the output from the crop residue management systems, available for field application, etc., see below.

Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “FAOSTAT_Countries” and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet “FAOSTAT_CropProductionItems” and the elements "Temporary meadows and pastures" and "Permanent meadows and pastures" of the set Activities, displayed in the set GrassActivities in the sheet “SOLmV6_CropsGrassAct”. CropResManSystem covers the crop residue management systems as displayed in the sheet “CropResManagement” in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” ProductionSystems are “AllProdSyst” and for the element "Quantity share in CropResMan system" in CropResManagement also “Convent” and “Organic”.

There are values for the following elements of the set CropResManagement (which set is also displayed in sheet CropResManagement in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx”):

- "Quantity share in CropResMan system"
- "Crop res man CH4 (tCH4)"
- "Crop res man N2O (tN2O)"
- "Crop res man N loss (tN)"
- "Crop res N for areas (tN)"
- "Crop res man share P lost (tP2O5/tP2O5 in crop res)"
- "Crop res man P loss (tP2O5)"
- "Crop res P for areas (tP2O5)"

If not indicated otherwise, the units are per ton crop residues.

9.1.51 _V6_ReadData_VariousSources_ManureExcretionData

This code reads the following data, mainly from (IPCC 2006), for details see the code file:

ActAnimalsHead_OtherChar(Regions,Livestock,AnimalTypeInHerd,"N in manure per ton liveweight (tN/t lw/y)","AllProdSyst","AllProdCond")

t N excreted in manure per ton liveweight and year

ActAnimalsHead_OtherChar(Regions,Livestock,AnimalTypeInHerd,"P in manure per ton liveweight (tP2O5/t lw/y)","AllProdSyst","AllProdCond")

t P2O5 excreted in manure per ton liveweight and year

Manure_OtherChar(Countries,Livestock,AnimalTypeInHerd,"Ash content in feed DM (share)","AllProdSyst","AllProdCond")

Share ash in feed dry matter (used to derive volatile and total solids in manure)

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_LiveAnimalsItems plus the element “Game” of the set Activities. – which is the same as the SOLmV6-subset Livestock of the set Activities. These subsets are displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheets “FAOSTAT_Countries” and “FAOSTAT_LiveAnimalsItems”. The set AnimalTypeInHerd covers the core herd animal types as used in SOLm as displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “SOLm_HerdStructure”.

9.1.52 _V6_ReadData_VariousSources_ManureManagementData

This code reads the following data, mainly from (IPCC 2006), for details see the code file:

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"Quantity share in ManureMan system" ,ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

Share of total manure quantity in the different manure management systems

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"MCF: CH4 conversion factor (%)"

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,ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

Methane conversion factor (%) – used in some IPCC calculations on CH_4 emissions from manure management.

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"Bo: max. CH4 prod. cap. (m3CH4/kgVS)",ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

Methane production capacity per quantity volatile solids (VS) in manure; another parameter used for deriving CH_4 emissions from manure management $m^3CH_4/kgVS$

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"Manure man N volat (% of N in manure)",ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

N volatized from manure during manure management (% of total N in manure)

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"Manure man N leach (% of N in manure)",ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

N leached from manure during manure management (% of total N in manure)

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"Manure man N2O dir (tN2O-N/tN)" ,ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

Direct N_2O emissions from manure management (tN_2O-N emitted per tN in manure)

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"Manure man N2O-N from N volat (tN/tN volat)",ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

N_2O from N volatized during manure management: ton N per ton N volatized

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"Manure man N2O-N from N leach (tN/tN leach)",ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

N_2O from N leached during manure management: ton N per ton N leached

Manure_Management(Regions,Livestock,AnimalTypeInHerd,"Manure man P loss as % of P in manure (%)",ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

P lost from manure during manure management (% of total P in manure)

Values are available for the subset FAOSTAT_Countries of the set Regions and for the subset FAOSTAT_LiveAnimalsItems plus the element "Game" of the set Activities – which is the same as the SOLmV6-subset Livestock of the set Activities. These subsets are displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheets "FAOSTAT_Countries" and "FAOSTAT_LiveAnimalsItems". The set AnimalTypeInHerd covers the core herd animal types as used in SOLm as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "SOLm_HerdStructure".

9.1.53 _V6_ReadData_VariousSources_MineralFertilizerProductionEmissionsData

This code reads the following data from (Wood and Cowie 2004), for details see the code file:
MineralFertilizerCharacteristics(Countries,"mineral N fert (tN)","AllMinFertProdTech","t CO2e/tN production","AllProdSyst")
MineralFertilizerCharacteristics(Countries,"mineral P fert (tP2O5)","AllMinFertProdTech","t CO2e/tP2O5 production","AllProdSyst")

Greenhouse gas emissions from mineral N and P fertilizer production: tCO_2e/ton N or P_2O_5

Values are available for the subset FAOSTAT_Countries of the set Regions. This subset is displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries".

9.1.54 _V6_ReadData_VariousSources_FertilizerApplicationData

This code reads the following data from (IPCC 2006), for details see the code file:
ManureApplication(Countries,Activities,Livestock,"AllAndAverageTypes",FertApplicCharact,"AllProdSyst","AllProdCond")

Various emission characteristics (see below) related to application of manure from source livestock to crops and grassland ("AllAndAverageTypes" is AnimalTypeInHerd)

CropResAndBiomassApplication(Countries,Activities,"All Residues",FertApplicCharact,"AllProdSyst","AllProdCond")

Various emission characteristics (see below) related to application of crop residues and

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biomass to crops and grassland

MinFertApplication(Countries,Activities,"mineral N fert (N)",FertApplicCharact,"AllProdSyst","AllProdCond")

Various emission characteristics (see below) related to application of mineral fertilizers to crops and grassland

Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries" and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet "FAOSTAT_CropProductionItems" and the subset CoreGrassActivities of the set Activities, displayed in the sheet "SOLmV6_CropsGrassAct". The SOLmV6-subset Livestock of the set Activities is displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_LiveAnimalsItems".

There are values for the following elements of FertApplicCharact:

- "N2O-N per kg fertilizer N applied (tN/tN)"
- "Volatized N as percentage of fertilizer N applied (%)"
- "Leached N as percentage of fertilizer N applied (%)"
- "N2O-N per kg N volatized from fert applic (share)"
- "N2O-N per kg N leached from fert applic (share)"

9.1.55 _V6_ReadData_VariousSources_NH3Emissions

This code reads the following data from various sources, for details see the code file:

MinFertApplication(Countries,Activities,"mineral N fert (N)","NH3-N as percentage of fertilizer N applied (%)","AllProdSyst","AllProdCond")

N lost as NH3 from mineral fertilizer N application; unit: NH3-N as percentage of fertilizer N applied (%)

ManureApplication(Countries,Activities,Livestock,"AllAndAverageTypes","NH3-N as percentage of fertilizer N applied (%)","AllProdSyst","AllProdCond")

N lost as NH3 from manure N application (source: Livestock); unit: NH3-N as percentage of manure N applied (%)

CropResAndBiomassApplication(Countries,Activities,"All Residues","NH3-N as percentage of fertilizer N applied (%)","AllProdSyst","AllProdCond")

N lost as NH3 from crop residue and other biomass N application; unit: NH3-N as percentage of crop residues and other biomass N applied (%)

Manure_Management(Countries,Livestock,AnimalTypeInHerd,"Manure man NH3-N (% of N in manure)",ManureManSystem,"AllAndAverageTemp","AllProdSyst","AllProdCond")

N lost as NH3 from manure N during manure management; unit: NH3-N as percentage of manure N in the management system (%)

The NH_3 emissions are PART OF the N-volatilization already addressed in a previous code file. They are NOT ADDITIONAL to this. Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries" and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet "FAOSTAT_CropProductionItems" and the subset CoreGrassActivities of the set Activities, displayed in the sheet "SOLmV6_CropsGrassAct". The SOLmV6-subset Livestock of the set Activities is displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_LiveAnimalsItems". The set AnimalTypeInHerd covers the core herd animal types as used in SOLm as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "SOLm_HerdStructure".

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9.1.56 _V6_ReadData_VariousSources_OrganicYieldGapsData

This code reads the following data from various sources, for details see the code file and section 8.3.2:
ActCropsGrass_OtherChar(Regions,Activities,"organic yield gap (ratio org/conv yield)","AllProdSyst","AllProdCond")
ActAnimalsHead_OtherChar(Regions,Livestock,ProducingAnimals,"organic yield gap (ratio org/conv yield)","AllProdSyst","AllProdCond")
Organic yield gap for crop, grass and livestock activities: ratio organic/conventional

Values are available for the subset FAOSTAT_Countries (which is Countries in SOLmV6) of the set Regions as displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_Countries" and Activities contains the elements from the set FAOSTAT_CropProductionItems as displayed in the sheet "FAOSTAT_CropProductionItems" and the subset NON_FAOSTAT_CropProductionItems (which also covers some GRASS activities!) as displayed in sheet "CommodNutrientContents". The SOLmV6-subset Livestock of the set Activities is displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "FAOSTAT_LiveAnimalsItems".

9.1.57 __SOLmV5_DataDerivedBaseline_DetailedFeedingRations

This module is currently not operational for the baseline in SOLmV6. It is about more detailed – commodity-specific – feeding rations and will be finalized in the coming weeks.

9.1.58 _V6_ReadData_VariousSources_CED

This code reads the following data from various sources, for details see the code file:
CED is "Cumulative Energy Demand", a Live-Cycle-Assessment (LCA)-based measure for non-renewable energy use. This data is read in considerable detail for various crop and livestock management related processes and aggregated in SOLm to the following two indicators, available for all crops, grass and livestock activities: "Total CED (MJ)" and "Total GWP from CED (tCO2e)". The CED data is taken from ecoinvent 2.0 ((Nemecek, Heil et al. 2007)) and converted to GWP values by means of process-specific conversion factors (see code file), also taken from ecoinvent 2.0.

9.1.59 _V6_ReadAdditionalData_SwitzerlandAustria

This code reads new more detailed baseline data for Switzerland and Austria, as used in a completed project on the alpine region. See section 9.5.1 for details.

9.1.60 _V6_ReadAdditionalData_NUTS2_EU

This code reads new more detailed baseline data for NUTS2 data for the EU as used in the H2020 project UNISECO. See section 9.5.2 for details.

9.1.61 _V6_DataDerivedBaseline_SomeHerdStructureParameters

This file derives the relation of the various animal types in the herd to the total living animal number for the baseline and for the animals with herd structure in the baseline: cattle and pigs. This is then the basis to derive the herd structure for the total animal numbers in scenarios, etc.
Thus, the following data is provided:

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ActAnimalsHead_OtherChar(Regions,"Cattle",AnimalTypeInHerd,"Share animal type in total living animals",ProductionSystems,ProductionConditions)
ActAnimalsHead_OtherChar(Regions,"Pigs",AnimalTypeInHerd,"Share animal type in total living animals",ProductionSystems,ProductionConditions)
Shares of animal type in herd in relation to all living animals, for cattle and pigs (as only those have herd structures in the baseline)

These parameters are thus available for the same elements for Regions etc. as the source data, i.e. the variables on animal numbers for animal types in herds, cf. section 9.1.43.

9.1.62 _V6_ReadData_CommodityTrees_LinkActivitiesAndCommodities

This file contains the code for linking the outputs from Activities to the elements of Commodities. This is done by means of the commodity trees, extraction rates and shares of processing lines from one parent commodity. The basis for the default values for this is the FAO document "Technical Conversion Factors for Agricultural Commodities" from 1996 (there is no newer encompassing information available from FAO; for specific countries and commodities, better information can be searched for and added as new data, as described at the beginning of section 9.1 and in section 9.5). It is organized in seven parts referring to different types of commodities (such that are aggregates of other, such with well-defined co-products, such that are equivalent to primary outputs from activities, etc.). It defines the corresponding sets, the parameters “ExtractionRates” and the primary product equivalent values of commodities, etc. – a detailed description is provided in section 9.13. The seven sets are also listed and described shortly in section 9.2.1.

9.1.63 _V6_VariablesAndParameters_ModelRun

This file declares the parameters and variables for the model runs. In this, it is identical to the file “`_V6_VariablesAndParameters.gms`” described in section 9.1.16 and defines exactly the same parameters and variables besides adding a scenario-dimension to each of these parameters and variables, amending their names with a suffix “_MR” for “model run” and defining the corresponding scenario set. The general procedure to define the model-run-parameters and –variables is thus as follows: add “_MR” (for model run) to the parameter/variable names and add the scenario dimension at the end of them.

The set Scenarios is displayed in the excel-file “UNISECO D4.1_SOLm_Appendix.xlsx” in the sheet “Scenarios”.

After having defined the model run parameters and variables, those for which baseline values are available are assigned so, i.e. so that the model run parameter and variables with scenario dimension “Baseline” are set equal to the baseline values as read in the previous files.

9.1.64 _V6_ReadData_FAOSTAT_FOFA2050

This code reads the data for the food system projections to 2050 as presented in (FAO 2018). See section 9.5.3 for details.

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9.1.65 _V6_ReadData_VariousSources_BioenergySR15

This code reads the data for the food system projections to 2050 and 2100 as presented in (IPCC 2018). See section 9.5.4 for details.

9.1.66 _V6_StreamlineInitialData

This file streamlines the initial data as produced by the SteeringFile1 and then collected in the following gdx-files (they are generated in the code file "`_V6_OutputFiles_SteeringFile1.gms`", see section 9.1.67):

- 'GeneralModelSets'
- 'GeneralModelParameters_Inputs'
- 'GeneralModelParameters_Outputs'
- 'GeneralModelParameters_OtherChar'
- 'GeneralModelParameters_Various'
- 'GeneralModelParameters_Auxiliary'
- 'GeneralModelVariables_ActivityQuantities'
- 'GeneralModelVariables_Inputs'
- 'GeneralModelVariables_Outputs'
- 'GeneralModelVariables_OtherChar'
- 'GeneralModelVariables_Various'
- 'GeneralModelVariables_Trade'
- 'GeneralModelVariables_CommodityTree'
- 'GeneralModelVariables_Auxiliary'
- 'FOFA2050_BioeSR15_Data_InModelRunEntities'

Going through these files, several useless, unimportant or confusing assignments have been identified. These are dropped and partly replaced further down in this code file. And several missing assignments have been identified and have been added. This file is then run before the gdx-files are read out in the code file "`_V6_OutputFiles_SteeringFile1.gms`" for further use in SteeringFile2.

In a later version of SOLm, one could incorporate all this directly in the preceding code files or change those such as to avoid the missing/useless assignments corrected here.

9.1.67 _V6_OutputFiles_SteeringFile1

This file contains the code to produce the following gdx-files. Subsequently it is displayed in detail what is contained in each of those files.

- GeneralModelSets.gdx
- GeneralModelParameters_Inputs.gdx
- GeneralModelParameters_Outputs.gdx
- GeneralModelParameters_OtherChar.gdx
- GeneralModelParameters_Various.gdx
- GeneralModelParameters_Auxiliary.gdx
- GeneralModelVariables_ActivityQuantities.gdx
- GeneralModelVariables_Inputs.gdx
- GeneralModelVariables_Outputs.gdx
- GeneralModelVariables_OtherChar.gdx
- GeneralModelVariables_Various.gdx
- GeneralModelVariables_Trade.gdx
- GeneralModelVariables_CommodityTree.gdx
- GeneralModelVariables_Auxiliary.gdx
- FOFA2050_BioeSR15_Data_InModelRunEntities.gdx

Detailed contents: below, the code directly from the GAMS-file is displayed. For each gdx-file to be generated, it has an "execute_unload" statement that defines the gdx-file to be generated: the statement is

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followed by the name of the new file and after this, all sets, parameters and variables to be included in the file are listed, ending with a semicolon ";". After this comes a comment section between "$ontext$" and "$offtext$" in detail presenting what is contained in each parameter and variable in the gdx-files.

All these sets, parameters and variables are then available to be read by subsequent code, currently the second steering file where the model runs are executed.

9.1.67.1 GeneralModelSets.gdx'

```
execute_unload 'GeneralModelSets'
InputsCropsGrass
InputsAnimals
InputsFishSeafood
InputsForest
InputsOther
OutputsCropsGrass
YieldsCropsGrass
OutputsAnimals
YieldsAnimals
OutputsFishSeafood
OutputsForest
OutputsOther
OtherCharCropsGrass
OtherCharAnimals
OtherCharFishSeafood
OtherCharForest
OtherCharOther
AnimalTypeInHerd
AnimalTypeInHerd_NoAggregates
CattleTypeInHerd
DairyCattleTypeInHerd
BeefCattleTypeInHerd
PigTypeInHerd
ProducingAnimals
SuckledAnimals
AnimalTypeInHerd_2
MatchSucklingSuckledAnimals

ProductionSystems
ProdSyst_OrgConAll
ProdSyst_OrgCon
ProdSyst_NoAggregates
ProductionSystems_UsingMinNFert
ProductionConditions
Contents
ContentsPerFreshMatterNutrients
ContentsPerFreshMatterFood
ContentsPerFreshMatterFeed
CommodOtherChar
ManureOtherChar
CropResContents
CropResOtherChar
CropResManagement
CropResManagement_NotSystemShares
CropResManSystem
CropResManSystemCropland
CropResManSystemGrassland
ManureContents
ManureManagement
ManureManSystem
ManureManSystemCropland
ManureManSystemGrassland
FertApplicCharact

Regions
Regions_2
Countries

FAO_Africa
FAO_Eastern_Africa
FAO_Middle_Africa
FAO_Northern_Africa
FAO_Southern_Africa
FAO_Western_Africa
FAO_Americas
FAO_Northern_America
FAO_Central_America
FAO_Caribbean
FAO_South_America
FAO_Asia
FAO_Central_Asia
FAO_Eastern_Asia
FAO_Southern_Asia
FAO_SouthEastern_Asia
FAO_Western_Asia
FAO_Europe
FAO_Eastern_Europe
FAO_Northern_Europe
FAO_Southern_Europe
FAO_Western_Europe
FAO_Oceania
FAO_Australia_NewZealand
FAO_Melanesia
FAO_Micronesia
FAO_Polynesia
FAO_EuropeanUnion
```

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```
SubSaharanAfrica

FOFA2050_Rest_of_EAP
FOFA2050_Rest_of_HIC
FOFA2050_Rest_of_LAC
FOFA2050_Rest_of_MNA
FOFA2050_Rest_of_SAS
FOFA2050_Rest_of_SSA
FOFA2050_Rest_of_EU
FOFA2050_Rest_of_ECA
Regions_Switzerland
Regions_Austria
Regions_austria_Tal
Regions_Austria_Huegel
Regions_austria_Berg

Activities
Activities_2
Livestock
Ruminants
Poultry
MonogastricsNonPoultry
FishAndSeafood
NonRuminants
Crops
Cereals
Fruits
Treenuts
Pulses
Legumes_NFixing
Crops_NoNFixingLegumes
OilCrops
StarchyRoots
SugarCrops
Vegetables
StimulantsSpices
FibresRubber
Fallows
EnergyCrops
OtherCereals
CitrusFruits
Spices
OtherVegetables
OtherOilcrops
FibresNotCotton
ForageCrops
OtherFodderCrops
GrassActivities
CoreGrassActivities
CoreGrassActivitiesNoTEMPGrass
TempAndPermMeadAndPastures
TempMeadAndPastures
CropsAndCoreGrassActivities
CropsAndTempGrassActivities
SingleCropGrassAndLivestockActivities
FOFA2050_SweetPotato_And_Yams
FOFA2050_Rapeseed_And_Mustardseed
FOFA2050_OtherCrops
FOFA2050_OtherFibreCrops
FOFA2050_OtherFruits
FOFA2050_OtherOilseeds
FOFA2050_OtherRootsAndTubers
FOFA2050_OtherVegetables
FOFA2050_CitrusFruits
FOFA2050_DriedPulses
FOFA2050_OtherCereals
OtherCrops

Commodities
Commodities_2
ForageCommodities
Grasscommodities
ConcentrateCommodities
Commodities_SingleCommodities
Commodities_FeedGroups

*the following sets are also needed to read in data
Years
BasisyearsOLD
Basisyears
BasisyearsSeed
Temperatures
Temperatures0to100Celsius
TemperaturesBelow10
TemperaturesAbove28
GreenhouseGases

MineralFertilizerType
MineralFertilizerProdTech
MinFertChar
PopulationGroups
Humans_InputsOutputsOtherCharacteristics
FeedingRationOtherChar
MatchFaostatLiveAnimalItems_Activities
Match_ActivityOutputsToCommodities_Crops
Match_ActivityOutputsToCommodities_Animals
Match_FeedCommoditiesToFeedCommodGroups
Match_FeedCommoditiesToFeedCommodGroups_MainByprodConc

ConversionLevel
EnergyType
EnergySource
EnergyChar
```

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```
Scenarios
FOFA2050_Scenarios
BioeSR15_Scenarios

MatchCommAct_AggregateCommodities_Crops
MatchCommAct_AggregateActivities_Crops
MatchCommAct_WellDefinedCoProducts_Crops
MatchCommAct_ComplexCases_Crops
MatchCommAct_ComplexAnimalCommodities
MatchCommAct_CommodEquivalentAct_Crops
MatchCommAct_CommodEquivalentAct_Animals
MatchCommAct_CommodAndProductsEquivalentAct_Crops

SubsetCommod_MatchWithAct_AggregateCommodities
SubsetCommod_MatchWithAct_AggregateActivities
SubsetCommod_MatchWithAct_WellDefinedCoProducts
SubsetCommod_MatchWithAct_ComplexCases
SubsetCommod_MatchWithAct_ComplexAnimalCommodities
SubsetCommod_MatchWithAct_CommodEquivalentAct
SubsetCommod_MatchWithAct_CommodAndProductsEquivalentAct

SubsetCommod_MatchWithAct_WellDefinedCoProducts_Level1_Main
SubsetCommod_MatchWithAct_WellDefinedCoProducts_Level1_Co
SubsetCommod_MatchWithAct_WellDefinedCoProducts_Level2_Main
SubsetCommod_MatchWithAct_WellDefinedCoProducts_Level2_Co
MatchMainWithCoProd_WellDefinedCoProducts_Level1
MatchMainWithCoProd_WellDefinedCoProducts_Level2
MatchMainWithCoPr_WellDefCoProd_Level1And2_TwoByprod
;
```

9.1.67.2 GeneralModelParameters_Inputs.gdx

```
execute_unload 'GeneralModelParameters_Inputs'
*1.1) Activities: input param
ActCropsGrass_Inputs
ActAnimalsAPU_Inputs
ActAnimalsHead_Inputs
ActFishSeafood_Inputs
ActForest_Inputs
ActOthers_Inputs
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-ActAnimalsHead_Inputs
         "Drinking water (m3)"     Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                              CattleTypeInHerd
                                              PigTypeInherd
                                              "AllAndAverageTypes"       "AllProdSyst"        "AllProdCond"      WITH CATTLE AND PIGS!!
         "Total GWP from CED (tCO2e)"
         "Total CED (MJ)"          Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                              CattleTypeInHerd
                                              PigTypeInherd
                                              "AllAndAverageTypes"       "AllProdSyst"
                                                                          "Convent"
                                                                          "Organic"           "AllProdCond"      WITH CATTLE AND PIGS!!
-ActCropsGrass_Inputs
         "N deposition (tN)"       Crops / temp/perm grass                "AllProdSyst"        "AllProdCond"
         "Seeds (t)"               Crops (partly only)                    "AllProdSyst"        "AllProdCond"
         "Total GWP from CED (tCO2e)"
         "Total CED (MJ)           Crops / Core grass activities          "AllProdSyst"
                                       (No MISCANTHUS)                    "Convent"
                                                                          "Organic"           +AllProdCond"
-ActForest_Inputs
         "N deposition (tN)"       "Forest"                                 "AllProdSyst"        "AllProdCond"

$offtext;
```

9.1.67.3 GeneralModelParameters_Outputs.gdx

```
execute_unload 'GeneralModelParameters_Outputs'
*1.2) Activities: output para
ActCropsGrass_Outputs
ActAnimalsAPU_Outputs
ActAnimalsHead_Outputs
ActFishSeafood_Outputs
ActForest_Outputs
ActOthers_Outputs
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-ActAnimalsAPU_Outputs
         "Honey (t)"               "Beehives       "Honey Producing"          "AllProdSyst"        "AllProdCond"
         "Wax (t)"                 "Beehives       "Wax Producing"            "AllProdSyst"        "AllProdCond"
-ActAnimalsHead_Outputs
                                 Livestock (NO dairy/beef cattle; layer/broiler chickens)
         "Milk (t"                                 "Milk Producing"           "AllProdSyst"        "AllProdCond"
         "Meat (t)"                                "Meat Producing"           "AllProdSyst"        "AllProdCond"
         "Eggs (t)"                                "Eggs Producing"           "AllProdSyst"        "AllProdCond"
         "HidesSkins (t)"                          "HidesSkins Producing"     "AllProdSyst"        "AllProdCond"
-ActCropsGrass_Outputs
         "MainOutput1 (t)"          Crops/ miscanth / temp/perm grass          "AllProdSyst"        "AllProdCond"
         "MainOutput1 (tDM)"        "Miscanthus" / temp/perm grass             "AllProdSyst"        "AllProdCond"
         "CH4 flooded rice (tCH4)"  "Rice, paddy"                              "AllProdSyst"        "AllProdCond"


$offtext;
```

9.1.67.4 GeneralModelParameters_OtherChar.gdx

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```
execute_unload 'GeneralModelParameters_OtherChar'
*1.3) Activities: other chara
ActCropsGrass_OtherChar
ActAnimalsAPU_OtherChar
ActAnimalsHead_OtherChar
ActFishSeafood_OtherChar
ActForest_OtherChar
ActOthers_OtherChar
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-ActAnimalsHead_OtherChar
         "Organic yield gap (ratio org/conv yield"
                         Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                         "Milk Producing"            "AllProdSyst         "AllProdCond"
                                         "Meat Producing"            "AllProdSyst         "AllProdCond"
                                         "Eggs Producing"            "AllProdSyst         "AllProdCond"
                                         "HidesSkins Producing"      "AllProdSyst         "AllProdCond"
                                         "Wool Producing"            "AllProdSyst         "AllProdCond"
         "Grass in feed DM (share)"
         "Forage crops in feed DM (share)"
         "Concentrates in feed DM (share)"
         "Residues in feed DM (share)"
         "UE_per_GE (share)"
         "Animal specific FeedGE cont (MJ/t)"
                         Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                         "AllAndAverageTypes"        "AllProdSyst"         "AllProdCond"
         "Digestibility of feed (%)"
                         Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                         CattleTypeInHerd
                                         PigTypeInherd
                                         "AllAndAverageTypes"        "AllProdSyst"         "AllProdCond"      WITH CATTLE AND PIGS!!
         "Liveweight (t)"
                         "Cattle"          CattleTypeInHerd
                         "Pigs"            PigTypeInherd
                         Livestock (NO dairy/beef cattle; layer/broiler chickens) - NO CATTLE NO PIGS!!
                                         "AllAndAverageTypes"        "AllProdSyst"         "AllProdCond"
         "FeedME_Req_Total (MJ)"
         "FeedXP_Req_Total (t)"
         "FeedGE_Req_Total (MJ)"
                         "Cattle"          CattleTypeInHerd
                         "Pigs"            PigTypeInherd
                         Livestock (NO dairy/beef cattle; layer/broiler chickens) - NO CATTLE NO PIGS!!
                                         "AllAndAverageTypes"        "AllProdSyst"         "AllProdCond"

         "FeedME_Req_MilkProd (MJ)"
         "FeedME_Req_Maintenance (MJ)"
         "FeedME_Req_Walking (MJ)"
         "FeedME_Req_Pregnancy (MJ)"
         "DailyWalkingDistance (km)"
         "Summergrazing (days)"
         "ME to produce 1kg milk (MJ/kg milk)"
         "ME maintenance per weight per day (MJ/kg liveweight/day)"
         "ME maintenance basis per day (MJ/day)"
         "ME walking per km (MJ/km)"
         "ME pregnancy per weight per day (MJ/kg liveweight/day)"
         "ME pregnancy basis per day (MJ/day)"
                         "Cattle"
                                         "Producing_Dairy_Cattle"  "AllProdSyst"         "AllProdCond"

         "XPperME_InFeedReq (gXP/MJ)"
                         "Cattle"          CattleTypeInHerd          "AllProdSyst"         "AllProdCond"
                         "Pigs"            PigTypeInherd             "AllProdSyst"         "AllProdCond"

         "Share organic in total animals (share heads)"
         "Share animal type in total living animals"
                         Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                         "Living"                 "AllProdSyst"        "AllProdCond"      WITH CATTLE AND PIGS!!
                                         CattleTypeInHerd         "AllProdSyst"        "AllProdCond"
                                         PigTypeInherd            "AllProdSyst"        "AllProdCond"
                                         "Milk Producing"         "AllProdSyst"        "AllProdCond"
                                         "Meat Producing"         "AllProdSyst"        "AllProdCond"
                                         "Eggs Producing"         "AllProdSyst"        "AllProdCond"
                                         "HidesSkins Producing    "AllProdSyst"        "AllProdCond"
                                         "Wool Producing"         "AllProdSyst"        "AllProdCond"


         "N in manure per ton liveweight (tN/t lw/y)"
         "P in manure per ton liveweight (tP2O5/t lw/y)"
                         "Cattle"          CattleTypeInHerd
                         "Pigs"            PigTypeInherd
                         Livestock (NO dairy/beef cattle; layer/broiler chickens) - NO CATTLE NO PIGS!!
                                         "AllAndAverageTypes"        "AllProdSyst"         "AllProdCond"
-ActCropsGrass_OtherChar
         "Share organic in total area (share ha)"
         "Organic yield gap (ratio org/conv yield)"
         "N fixation per ton MainOutput1 (tN)"
         "Deforestation (ha)"
         "CultOrgSoils (ha)"
         "CultOrgSoils GHG emissions (tCO2e)"
         "CultOrgSoils C emissions (tCO2e)"
         "CultOrgSoils N2O emissions (tCO2e)"
                         All crops (incl. miscanth.) and grass           "AllProdSyst"         "AllProdCond"
         "Soil water erosion (t soil lost)"
         "Aggreg. Pest. use level (index)"
                         Crops (incl. miscanth.) / temp/perm grass       "AllProdSyst"         "AllProdCond"
$offtext;
```

9.1.67.5 GeneralModelParameters_Various.gdx

```
execute_unload 'GeneralModelParameters_Various'
*1.4) Commodities: nutrient contents
                                                                                          Commod_Contents
```


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```
Commod_OtherChar

*1.5) Commodity tree paramete
Commod_ProductionShare
Commod_ExtractionRate
Commod_SingleInAggregateCommodShares

*1.6) Crop residues: nutrient
CropResidues_Contents
CropResidues_OtherChar
CropResidues_Management

*1.7) Feeding rations
FeedingRations_Contents
FeedingRations_OtherChar
FeedingRationsHeads_Contents
FeedingRationsHeads_OtherChar
FeedingRationsAPU_Contents

*1.8) Manure: nutrient conten
Manure_Contents
Manure_OtherChar
Manure_Management

*1.9) Fertilizer application:
ManureApplication
CropResAndBiomassApplication
MinFertApplication

*extraction rates:
ExtractionRate_CommodityTree
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-Commod_Contents
         "Calories (kcal)"
         "Protein (t)"
         "N (t)"
         "P2O5 (t)"
         "FeedME (MJ)"
         "FeedGE (MJ)"
         "FeedXP (t)"
         "DM (t)"
         "FeedME in DM (MJ)"
         "FeedGE in DM (MJ)"
         "FeedXP in DM (t)"
                              All/most/many commodities (plant, animal)   "AllProdSyst"        "AllProdCond"
         "N in DM (t)"        "Miscanthus"                                 "AllProdSyst"        "AllProdCond"
         "Milk solid contents (t)" "Milk, whole"                           "AllProdSyst"        "AllProdCond"

-Commod_OtherChar
         "Producer price ($)"      Many commodities (plant, animal; NO grass, miscanthus)
                                                                         "AllProdSyst"        "AllProdCond"
         "Util feed (share)"
         "Util food (share)"
         "Util seed (share)"
         "Util processing (share)"
         "Util waste (share)"
         "Util other (share)"
                            All/most/many commodities (plant, animal); incl. grass, miscanthus
                                                                         "AllProdSyst"        "AllProdCond"
-CropResAndBiomassApplication
         "N2O-N per kg fertilizer N applied (tN/tN)"
         "Volatized N as percentage of fertilizer N applied (%)"
         "Leached N as percentage of fertilizer N applied (%)"
         "N2O-N per kg N volatized from fert applic (share)"
         "N2O-N per kg N leached from fert applic (share)"
         "NH3-N as percentage of fertilizer N applied (%)"
                            ALL crop grass activities; incl. ALL grass types; miscanthus
                                                  "All Residues"         "AllProdSyst"        "AllProdCond"

-CropResidues_Contents
         "N (t) - before management"
         "P2O5 (t) - before management"
         "DM (t) - before management"
                            Crops / temp/perm grass / miscanth
                                                  "Average residues (t)" "AllProdSyst"        "AllProdCond"

-CropResidues_Management
         "Quantity share in CropResMan system"
                            Crops / temp/perm grass / miscanth
                                                  "Average residues (t)" CropResManSystems    "AllProdSyst/Con/org        "AllProdCond"
         "Crop res man CH4 (tCH4)"
         "Crop res man N2O (tN2O)"
                            Crops (NO grass/miscanthus - as their systems come without losses; grass e.g. the N2O is from residues as fertilizers
                           applied, not from residue management "left on the field")
                                                  "Average residues (t)" CropResManSystems    "AllProdSyst"               "AllProdCond"
         "Crop res man N loss (tN)"
         "Crop res man share P lost (tP2O5/tP2O5 in crop res)"
         "Crop res man P loss (tP2O5)"
                            Crops / miscanth (NO grass - as their systems come without losses; grass e.g. the N2O is from residues as fertilizers
                            applied, not from residue management "left on the field")
         "Crop res N for areas (tN)"
         "Crop res P for areas (tP2O5)"
                            Crops / temp/perm grass / miscanth
                                                  "Average residues (t)" CropResManSystems    "AllProdSyst"               "AllProdCond"

-CropResidues_OtherChar
         "Residue share t DM / t DM MainOutput1 (share)"
                            Crops / temp/perm grass / miscanth
                                                  "Average residues (t)" "AllProdSyst"        "AllProdCond"

-ExtractionRate_CommodityTree
                                                                                                   Crops   /   temp/perm   grass
```


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```
(partly all grass) / miscanth

-FeedingRations_OtherChar
        "Quantity share in DM (share)"
                "AggregateFeedConcentrates_Commodity"
                "AggregateFeedForageCrops_Commodity"
                "AggregateFeedGrass_Commodity"
                "AggregateFeedResidues_Commodity"
                                Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                                CattleTypeInHerd
                                                PigTypeInherd
                                                "AllAndAverageTypes"        "AllProdSyst"        "AllProdCond"      WITH CATTLE AND PIGS!!
-FeedingRationsHeads_OtherChar
        "Percentage GE in feed converted to enteric CH4"
                "AggregateFeedConcentrates_Commodity"
                "AggregateFeedForageCrops_Commodity"
                "AggregateFeedGrass_Commodity"
                "AggregateFeedResidues_Commodity"
                                Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                                CattleTypeInHerd
                                                PigTypeInherd
                                                "AllAndAverageTypes"        "AllProdSyst"        "AllProdCond"      WITH CATTLE AND PIGS!!

-Manure_Management
        "Quantity share in ManureMan system"
        "Bo: max. CH4 prod. cap. (m3CH4/kgVS)"
        "Manure man N volat (% of N in manure)"
        "Manure man N leach (% of N in manure)"
        "Manure man NH3-N (% of N in manure)"
                                "Cattle"        CattleTypeInHerd
                                "Pigs"          PigTypeInherd
                                Livestock (NO dairy/beef cattle; layer/broiler chickens) - NO CATTLE NO PIGS!!
                                                "AllAndAverageTypes"            ManureManSystem            "AllAndAverageTemp"        "AllProdSyst"
"AllProdCond"
        "MCF: CH4 conversion factor (%)"
        "Manure man N2O dir (tN2O-N/tN)"
        "Manure man N2O-N from N volat (tN/tN volat)"
        "Manure man N2O-N from N leach (tN/tN leach)"
        "Manure man P loss as % of P in manure (%)"
                                Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                                CattleTypeInHerd
                                                PigTypeInherd
                                                "AllAndAverageTypes"            ManureManSystem            "AllAndAverageTemp"        "AllProdSyst"
"AllProdCond"      WITH CATTLE AND PIGS!!

-Manure_OtherChar
        "Ash content in feed DM (share)"
                                Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                                CattleTypeInHerd
                                                PigTypeInherd
                                                "AllAndAverageTypes"            ManureManSystem            "AllAndAverageTemp"        "AllProdSyst"
"AllProdCond"      WITH CATTLE AND PIGS!!

-MinFertApplication
        "N2O-N per kg fertilizer N applied (tN/tN)"
        "Volatized N as percentage of fertilizer N applied (%)"
        "Leached N as percentage of fertilizer N applied (%)"
        "N2O-N per kg N volatized from fert applic (share)"
        "N2O-N per kg N leached from fert applic (share)"
        "NH3-N as percentage of fertilizer N applied (%)"
                                ALL crop grass activities; incl. ALL grass types; miscanthus
                                                        "Mineral N fert (N)"        "AllProdSyst"        "AllProdCond"

-ManureApplication
        "N2O-N per kg fertilizer N applied (tN/tN)"
        "Volatized N as percentage of fertilizer N applied (%)"
        "Leached N as percentage of fertilizer N applied (%)"
        "N2O-N per kg N volatized from fert applic (share)"
        "N2O-N per kg N leached from fert applic (share)"
        "NH3-N as percentage of fertilizer N applied (%)"
                                ALL crop grass activities; incl. ALL grass types; miscanthus
                                                        Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                                                "AllAndAverageTypes"        "AllProdSyst"        "AllProdCond"

   XXXX ALTERNATIVE XXXX
        ABOVE: besides the first entry, the values are NOT DIFFERENT for different animals - thus may simplify by not having separate but only "All
        Animals" there.
                Then we have the ALTERNATIVE: it would be as follows:
        "N2O-N per kg fertilizer N applied (tN/tN)"
                                ALL crop grass activities; incl. ALL grass types; miscanthus
                                                        Livestock (NO dairy/beef cattle; layer/broiler chickens)
                                                                "AllAndAverageTypes"        "AllProdSyst"        "AllProdCond"
        "Volatized N as percentage of fertilizer N applied (%)"
        "Leached N as percentage of fertilizer N applied (%)"
        "N2O-N per kg N volatized from fert applic (share)"
        "N2O-N per kg N leached from fert applic (share)"
        "NH3-N as percentage of fertilizer N applied (%)"
                                ALL crop grass activities; incl. ALL grass types; miscanthus
                                                        "All Animals"
                                                                "AllAndAverageTypes"        "AllProdSyst"        "AllProdCond"

$offtext;
```

9.1.67.6 GeneralModelParameters_Auxiliary.gdx

```
execute_unload 'GeneralModelParameters_Auxiliary'
HumanCharacteristics
SeedContents
MineralFertilizerCharacteristics
GWP_GTP_SOLm
;
$ontext;
from    this,                                                                                  you  get  the  following  -
```


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```
always on COUNTRY LEVEL (stuff not mentioned is not available!):
-HumanCharacteristics
         "kcal/cap/day (ADER) SOFI2012"
         "g protein/cap/day SOFI2012"
         "g fat/cap/day SOFI2012"
         "kcal/cap/day (ADER) Walpole2012"
         "g protein/cap/day Walpole2012"
         "g fat/cap/day Walpole2012"
                 "PopulationAll"          "AllCommodities"

-SeedContents
         "N (t)"
         "P2O5 (t)"
         "DM (t)"
                 Crops (most but not all, e.g. no miscanth.)      "AllProdSyst"        "AllProdCond"

-MineralFertilizerCharacteristics
         "t CO2e/tN production"
                 "mineral N fert (N)"
                 "mineral P fert (P2O5)"
                         "AllMinFertProdTech"        "AllProdSyst"

-GWP_GTP_SOLm               **BIG EXCEPTION!! THIS IS NOT ON COUNTRY LEVEL - just global values
         Values for CO2, CHç, N2O
$offtext;
```

9.1.67.7 GeneralModelVariables_ActivityQuantities.gdx

```
execute_unload 'GeneralModelVariables_ActivityQuantities'
*2.1) Amount of activity units
VActCropsGrass_QuantityActUnits
VActAnimalsAPU_QuantityActUnits
VActAnimalsHead_QuantityActUnits
VActFishSeafood_QuantityActUnits
VActForest_QuantityActUnits
VActOthers_QuantityActUnits
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-VActAnimalsAPU_QuantityActUnits
         "Beehives"        "AllAndAverageTypes"    "AllProdSyst"    "AllProdCond"

-VActAnimalsHead_QuantityActUnits
         Livestock (NO dairy/beef cattle; layer/broiler chickens)
                          CattleTypeInHerd
                          PigTypeInherd
                          "Living"                 "AllProdSyst"        "AllProdCond"      WITH CATTLE AND PIGS!!
                          "Milk Producing"         "AllProdSyst"        "AllProdCond"
                          "Meat Producing"         "AllProdSyst"        "AllProdCond"
                          "Eggs Producing"         "AllProdSyst"        "AllProdCond"
                          "HidesSkins Producing    "AllProdSyst"        "AllProdCond"
                          "Wool Producing"         "AllProdSyst"        "AllProdCond"

-VActCropsGrass_QuantityActUnits
         ALL crop grass activities; incl. ALL grass types; miscanthus
                          "AllProdSyst"        "AllProdCond"

-VActForest_QuantityActUnits
         "Forest"
         "Planted forest"
         "Primary forest"   (The previous two categories are SUB-CATEGORIES of the first "Forest" - but NOT EXHAUSTING it)
                          "AllProdSyst"        "AllProdCond"

$offtext;
```

9.1.67.8 GeneralModelVariables_Inputs.gdx

```
execute_unload 'GeneralModelVariables_Inputs'
*2.2) Inputs to activities
VActCropsGrass_Inputs
VActAnimalsAPU_Inputs
VActAnimalsHead_Inputs
VActFishSeafood_Inputs
VActForest_Inputs
VActOthers_Inputs
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-VActCropsGrass_Inputs
         "Seeds (t)"              Crops (partly only)                      "AllProdSyst"        "AllProdCond"
$offtext;
```

9.1.67.9 GeneralModelVariables_Outputs.gdx

```
execute_unload 'GeneralModelVariables_Outputs'
*2.3) Outputs from activities
VActCropsGrass_Outputs
VActAnimalsAPU_Outputs
VActAnimalsHead_Outputs
VActFishSeafood_Outputs
VActForest_Outputs
VActOthers_Outputs
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-VActAnimalsAPU_Outputs
         "Honey (t)"              "Beehives        "Honey Producing"           "AllProdSyst"        "AllProdCond"
         "Wax (t)"                "Beehives        "Wax Producing"             "AllProdSyst"        "AllProdCond"

-VActAnimalsHead_Outputs
                                                                                            Livestock    (NO    dairy/beef
```


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```
cattle; layer/broiler chickens)
         "Milk (t"                            "Milk Producing"            "AllProdSyst"          "AllProdCond"
         "Meat (t)"                           "Meat Producing"            "AllProdSyst"          "AllProdCond"
         "Eggs (t)"                           "Eggs Producing"            "AllProdSyst"          "AllProdCond"
         "HidesSkins (t)"                     "HidesSkins Producing"      "AllProdSyst"          "AllProdCond"
         "Wool (t)"                           "Wool Producing"            "AllProdSyst"          "AllProdCond"

-VActCropsGrass_Outputs
         "MainOutput1 (t)"       Crops / miscanth / temp/perm grass       "AllProdSyst"          "AllProdCond"
$offtext;
```

9.1.67.10 GeneralModelVariables_OtherChar.gdx

```
execute_unload 'GeneralModelVariables_OtherChar'
*2.4) Other characteristics of a
VActCropsGrass_OtherChar
VActAnimalsAPU_OtherChar
VActAnimalsHead_OtherChar
VActFishSeafood_OtherChar
VActForest_OtherChar
VActOthers_OtherChar
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):

NOT YET ANY DATA IN THIS FILE!!!

$offtext;
```

9.1.67.11 GeneralModelVariables_Various.gdx

```
execute_unload 'GeneralModelVariables_Various'
*2.5) Commodity quantities, nutr
VCommod_Quantity
VCommod_Contents
VCommod_OtherChar

*2.6) Commodity untilizationa
VCommod_Production
VCommod_StockChanges
VCommod_Food
VCommod_Feed
VCommod_Seed
VCommod_Processing
VCommod_Waste
VCommod_Other

VCommod_Food_Contents
VCommod_Feed_Contents
VCommod_Waste_Contents
VCommod_Food_OtherChar
VCommod_Feed_OtherChar
VCommod_Waste_OtherChar

*2.7) Crop residue quantities, n
VCropResidues_Quantity
VCropResidues_Contents
VCropResidues_OtherChar
VCropResidues_Management

*2.8) Feeding rations quantities
VFeedingRations_Quantity
VFeedingRations_Contents
VFeedingRations_OtherChar

*2.9) Manure quantities, nutrien
VManure_Quantity
VManure_Contents
VManure_OtherChar
VManure_Management

*2.10) Fertilizer application: n
VManureApplication
VCropResAndBiomassApplication
VMinFertApplication
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-VCommod_Feed
         Quantities fresh matter used for FEED:
                  Crop, livestock and grass commodities; incl. temp/perm grass
                                 "AllProdSyst"        "AllProdCond"
-VCommod_Food
         Quantities fresh matter used for FOOD:
                  Crop and livestock commodities:
                                 "AllProdSyst"        "AllProdCond"
-VCommod_Other
         Quantities fresh matter used for OTHER uses (e.g. bioenergy):
                  Crop, livestock commodities; incl. Miscanthus; would also be applicable to temp/perm grass - but currently not; all this is used for
                  feed
                                 "AllProdSyst"        "AllProdCond"
-VCommod_Processing
         Quantities fresh matter used for PROCESSING:
                  Crop, livestock commodities; would also be applicable to miscanthus and temp/perm grass - but currently not; all this is used for
                  other uses (energy) and feed
                                 "AllProdSyst"        "AllProdCond"
-VCommod_Production
         Quantities fresh matter stemming from DOMESTIC PRODUCTION:
                  Crop, livestock commodities; incl. Miscanthus and temp/perm grass
                                 "AllProdSyst"        "AllProdCond"
-VCommod_Quantity
                                                                                                   Domestically      available
```


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```
QUANTITIES fresh matter (sum of all utilizations, resp. prod + imp - exp):
                  Crop, livestock commodities; incl. Miscanthus; temp/perm grass
                                  "AllProdSyst"        "AllProdCond"
-VCommod_Seed
         Quantities fresh matter used for SEED:
                  Crop and livestock commodities:
                                  "AllProdSyst"        "AllProdCond"
-VCommod_StockChanges
         Quantities fresh matter stemming from STOCK CHANGES (can also be negative):
                  Crop and livestock commodities:
                                  "AllProdSyst"        "AllProdCond"
-VCommod_Waste
         Quantities fresh matter lost as WASTE:
                  Crop and livestock commodities:
                                  "AllProdSyst"        "AllProdCond"

$offtext;
```

9.1.67.12 GeneralModelVariables_Trade.gdx

```
execute_unload 'GeneralModelVariables_Trade'
*2.11) Import and export quantit
VImportQuantity
VExportQuantity
VImportLivingAnimalsHead
VExportLivingAnimalsHead
*for trade in beehives and other
VImportLivingAnimalsAPU
VExportLivingAnimalsAPU
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-VExportLivingAnimalsAPU
         "Beehives"
                 exported to "WORLD"
                                         "AllProdSyst"        "AllProdCond"
-VExportLivingAnimalsHead
         All Livestock
                 exported to "WORLD"
                         "Living"        "AllProdSyst"        "AllProdCond"
-VImportLivingAnimalsAPU
         "Beehives"
                 imported from "WORLD"
                                         "AllProdSyst"        "AllProdCond"
-VImportLivingAnimalsHead
         All Livestock
                 imported from "WORLD"
                         "Living"        "AllProdSyst"        "AllProdCond"
-VImportQuantity
         Crop and livestock commodities:
                 imported from Countries AND "WORLD"
                                         "AllProdSyst"        "AllProdCond"
-VExportQuantity
         Crop and livestock commodities:
                 exported to Countries AND "WORLD"
                                         "AllProdSyst"        "AllProdCond"
$offtext;
```

9.1.67.13 GeneralModelVariables_CommodityTree.gdx

```
*2.12) Commodities expressed in primary product equivalents
execute_unload 'GeneralModelVariables_CommodityTree'
VPrimProd_Commod_Quantity
VPrimProd_Commod_Production
VPrimProd_Commod_StockChanges
VPrimProd_Commod_Food
VPrimProd_Commod_Feed
VPrimProd_Commod_Seed
VPrimProd_Commod_Processing
VPrimProd_Commod_Waste
VPrimProd_Commod_Other
VPrimProd_ImportQuantity
VPrimProd_ExportQuantity
VPrimProd_Commod_Quantity_CropActivities
VPrimProd_Commod_Quantity_AnimalActivities
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-VPrimProd_Commod_Quantity
         Crop and livestock commodities (prim prod equivalents)
                                         "AllProdSyst"        "AllProdCond"
-VPrimProd_Commod_Quantity_CropActivities
         Crop commodities (prim prod equivalents)
                 Linked to ACTIVITIES   incl AGGREGATE CROP ACTIVITIES   (such as "All Cereals")
                                         "MainOutput1 (t)"
                                                 "AllProdSyst"        "AllProdCond"
-VPrimProd_Commod_Quantity_AnimalActivities
         Livestock commodities (prim prod equivalents)
                 Linked to ACTIVITIES   incl AGGREGATE ANIMAL ACTIVITIES   (such as "All Animals")
                                        "Meat (t)"
                                        "Milk (t)"
                                        "Eggs (t)"
                                        "Honey (t)"
                                        "Wool (t)"
                                                 "AllProdSyst"        "AllProdCond"
$offtext;
```

9.1.67.14 GeneralModelVariables_Auxiliary.gdx

```
execute_unload 'GeneralModelVariables_Auxiliary'
                                                                              VMineralFertilizerQuantity
```


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```
VPopulationNumbers
VEnergyProduction
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):
-VMineralFertilizerQuantity
         "Mineral N fert (N)"
         "Mineral P fert (P2O5)"
         "Mineral K fert (K2O)"
                 "AllMinFertProdTech"  "AllProdSyst"
                              also for some WORLD REGIONS
-VPopulationNumbers
         "PopulationAll"
         "Male"
         "Female"

$offtext;
```

9.1.67.15 FOFA2050_BioeSR15_Data_InModelRunEntities.gdx

```
*store the FOFA2050 and BioeSR15 data
*this is contained in _MR entities, thus store them:
execute_unload 'FOFA2050_BioeSR15_Data_InModelRunEntities'
ActCropsGrass_Outputs_MR
ActCropsGrass_OtherChar_MR
ActAnimalsHead_Outputs_MR
VActCropsGrass_QuantityActUnits_MR
VActCropsGrass_Outputs_MR
VActCropsGrass_Inputs_MR
VActAnimalsHead_QuantityActUnits_MR
VActForest_QuantityActUnits_MR
VPopulationNumbers_MR
HumanCharacteristics_MR
VEnergyProduction_MR
VCropResidues_Quantity_MR
CropResidues_Management_MR
ActForest_OtherChar_MR

AUX_FeedSupplyFactor_BioeSR15_MR
;
$ontext;
from this, you get the following - always on COUNTRY LEVEL (stuff not mentioned is not available!):

*AND - for doing this data, all "Baseline" values that are already available have been assigned - below, THOSE are NOT displayed to be available!!

-ActAnimalsHead_Outputs_MR
         FOFA_BAU_2050
                 Buffaloes, Cattle, Chickens, Goats, Pigs, Sheep
                         "Milk (t)"      "Milk Producing"            "AllProdSyst"
                                                                     "Convent"
                                                                     "Organic"        "AllProdCond"
                         "Meat (t)"      "Meat Producing"            "AllProdSyst"
                                                                     "Convent"
                                                                     "Organic"        "AllProdCond"
                         "Eggs (t)"     "Egg Producing"              "AllProdSyst"
                                                                     "Convent"
                                                                     "Organic"        "AllProdCond"
-ActCropsGrass_OtherChar_MR
         FOFA_BAU_2050
                 Crops (no perm/temp grass/no miscanthus; not all crops)
                          "Cropping intensity (ratio)"               "Irrigated"
                                                                     "Rainfed"        "AllProdCond"
-ActCropsGrass_Outputs_MR
         FOFA_BAU_2050
                 Crops (no perm/temp grass/no miscanthus; not all crops)
                          "MainOutput1 (t)"                          "Irrigated"
                                                                     "Rainfed"
                                                                     "AllProdSyst"
                                                                     "Convent"
                                                                     "Organic"        "AllProdCond"

         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                 "Miscanthus"
                          "MainOutput1 (t)"
                          "MainOutput1 (t DM)"                       "AllProdSyst"
                                                                     "Convent"
                                                                     "Organic"        "AllProdCond"
                 "All Cereals"
                 "All Sugar Crops"
                 "All Oilcrops"
                          "MainOutput1 (t DM)"                       "AllProdSyst"
                                                                     "Convent"
                                                                     "Organic"        "AllProdCond"
-ActForest_OtherChar_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                 "Forest"
                          "Forest res bioe N for areas (tN/t DM res)"
                                                                     "AllProdSyst"    "AllProdCond"

-AUX_FeedSupplyFactor_BioeSR15_MR        auxiliary parameter capturing the total feed demand in the BioeSR15 scenario P4
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100

-CropResidues_Management_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                                                                                                    "Miscanthus"
```


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```
                        "Average Residues (t)"
                                 "Quantity share in CropResMan system"     "Crop res N for areas (tN)"
                        "Average Residues (t DM)"
                                 "Crop res N for areas (tN/t DM res)"
                "All crops"
                        "Average Residues (t DM)"
                                 "Crop res N for areas (tN/t DM res)"
                                                        "All bioenergy" (crop res man system)
                                                                    "AllProdSyst"
                                                                    "Convent"
                                                                    "Organic"        "AllProdCond"
-HumanCharacteristics_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                 "PopulationAll"
                         "kcal/cap/day (BioeSR15 req)"
                                "All Commodities"
                                "All crop based Commodities"
                                "All animal based Commodities"
                 NO COUNTRIES, ONLY Regions:
                                        World
                                        R5ASIA
                                        R5LAM
                                        R5MAF
                                        R5OECD90+EU
                                        R5REF
-VActAnimalsHead_QuantityActUnits_MR
         FOFA_BAU_2050
                 "Buffaloes"
                 "Cattle"
                 "Chickens"
                 "Goats"
                 "Pigs"
                 "Sheep"
                 "All animals"  (in LIVESTOCK UNITS - NOT HEADS)
                                  "Living"                 "AllProdSyst"        "AllProdCond"
-VActCropsGrass_Inputs_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                 "Miscanthus"
                 "All crops and grass"
                         "N from all fertilizers (tN)"
                                                         "AllProdSyst"        "AllProdCond"
-VActCropsGrass_Outputs_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                 "Miscanthus"
                         "MainOutput1 (t DM)"
                                                         "AllProdSyst"        "AllProdCond"
-VActCropsGrass_QuantityActUnits_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                  All crop grass activities; incl. perm/temp mead. and past; miscanthus;
                          "AllProdSyst"        "AllProdCond"
         FOFA_BAU_2050
                  All crop activities; NO perm/temp mead. and past; NO miscanthus!!!
                          "Irrigated"
                          "Rainfed"
                          "AllProdSyst"        "AllProdCond"

-VActForest_QuantityActUnits_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                 "Forest"
                 "Forestry"
                 "Natural forest"   (TO BE CLARIFIED: relation of these categories!!??)
                                 "AllProdSyst"        "AllProdCond"

-VCropResidues_Quantity_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                 "Miscanthus"
                      "Average Residues (t)"
                          "AllProdSyst"        "AllProdCond"
-VEnergyProduction_MR
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                 "Miscanthus"
                 "Forest and crop residues"
                          "Primary Energy"       "AllEnTypes"    "Production (EJ)"
      NO COUNTRIES, ONLY Regions:          World
                                        AFR
                                        CHN
                                        EUR
                                        IND
                                        JPN
                                        LAM
                                        MEA
                                        OAS
                                        ROW
                                        RUS
                                        USA
                          "Secondary Energy"       "AllEnTypes"     "N from Bioe residues (tN)"
                                                                  "Bioe conversion Biomass input (tDM)"   (FOR secondary energy: we have country
values)
                 "AllEnSources"
                                                                                                             "Biomass"
```

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```
                    "Primary Energy"        "AllEnTypes"     "Production (EJ)"
                    "Secondary Energy"      "Electricity"
                                            "Gases"
                                            "Hydrogen"
                                            "Liquids"        "Production (EJ)"
           "EtOH residues"
                    "Secondary Energy"      "Electricity"    "Production (EJ)"
           "Biomass"
                    "Secondary Energy"      "Liquids"        "N from Bioe residues (tN)"
     NO COUNTRIES, ONLY Regions:        World
                                        R5ASIA
                                        R5LAM
                                        R5MAF
                                        R5OECD90+EU
                                        R5REF

-VPopulationNumbers_MR
         FOFA_BAU_2050
         BioeSR15_P4_2010
         BioeSR15_P4_2050
         BioeSR15_P4_2100
                  "PopulationAll"

$offtext;
```

9.2 SteeringFile 2

The following describes the content of the code modules executed in "___V6_SteeringFile2_ CoreModelScenariosAndEquations.gms" in detail. The general structure of this file is described in section 8.2.2. In the following, we shortly list all code modules that are executed and subsequently describe those in detail (the headings displayed are the same as in the structure described in section 8.2.2):

Code modules executed in Steering File 2:

2) Define sets, parameters and variables and load gdx files from the baseline assignment

_V6_Sets_GeneralModelSets_ForSteeringFile2
_V6_VariablesAndParameters
_V6_ReadOutputFilesFromSteeringFile1
_V6_VariablesAndParameters_ModelRun_ForSteeringFile2
_V6_BaselineValues_ForModelRuns

3) Run core model equations

_V6_InitialiseSetsForModelRuns

```
$setglobal Scenario "BaselineDerived"
$label Restart
```

_V6_ScenarioAssumptions
_V6_AssignInitialValuesToScenarios
_V6_DataDerived_CropProductionTotalsAndDAQ
_V6_DataDerived_CropResidueManagement
_V6_DataDerived_CropGrassNutrientRequirements
_V6_CoreModelEquations_NutrientRequirementsAndFeedSupply
_V6_CoreModelEquations_DeriveAnimalNumbersAndProduction
_V6_CoreModelEquations_ManureExcretionAndManagement
_V6_CoreModelEquations_EntericFermentation
_V6_CoreModelEquations_FertilizerApplication
_V6_CoreModelEquations_FertilizerApplicationEmissions

4) Choice of scenarios

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Example of a scenario choice:
```
$if %Scenario% == "Baseline_NoFCF" $goto EndOfScenarioRuns
$if %Scenario% == "Baseline_100Organic" $setglobal Scenario "Baseline_NoFCF"
$if %Scenario% == "BaselineDerived" $setglobal Scenario "Baseline_100Organic"
```

The following code is always here, governing the scenario loops:
```
$if %RunAllChosenScenarios% == YES $goto Restart
$label EndOfScenarioRuns
```

```
5) Further calculations after finishing the scenario runs
```
_V6_DeriveAggregateImpacts_PerUnit
_V6_DeriveTotalImpacts
_V6_DeriveGeographicAggregations
_V6_DeriveActivityGroupAggregations
_V6_DerivePerAPUValues
_V6_DerivePerPrimaryProductImpacts
_V6_DeriveAggregateImpacts_PrimProd
_V6_DerivePerCommodityImpacts

```
6) Define some output files
```
_V6_OutputFiles_SteeringFile2
_V6_ResultsFiles

```
7) Do some further specific calculations needed for certain aspects
```
__SOLmV5_CoreModelEquations_SomeSpecialOutputForNFP69.gms

The following subsections provide detailed descriptions of these code modules.

9.2.1 _V6_Sets_GeneralModelSets_ForSteeringFile2

The first part of this code is identical to the code described in section 9.1.15 describing the code-file "_V6_Sets_GeneralModelSets.gms", defining the same sets, besides the following, which is not needed anymore (Set MatchFaostatLiveAnimalItems_Activities(FAOSTAT_LiveAnimalsItems,Activities)). Then, it defines some further sets, that are also present in Steering File 1, but are defined in other code than "_V6_Sets_GeneralModelSets" that is executed later. These additional sets are the scenario set, and then the many sets related to the commodity trees (for details on those, see section 9.13). In this code-file, all these sets are only defined, but not yet filled with contents – this is then done when loading the data from the output from steering file 1 in section 9.2.3, "_V6_ReadOutputFilesFromSteeringFile1.gms", as all these sets are already present there from the execution of steering file 1.

Scenarios

Set containing all scenario names that may be used in the various model runs. The baseline is "Baseline", then there is always a scenario "BaselineDerived" which replicates the baseline and provides additional values needed for the other model runs. Other elements refer to the various scenarios, such as "Baseline_100Organic" which would be the baseline, converted to 100% organic, or "Baseline_NoFCF" which would be the baseline with food-competing feed reduced to zero. The set Scenarios is displayed in the excel-file "UNISECO D4.1_SOLm_Appendix.xlsx" in the sheet "Scenarios".

FOFA2050_Scenarios(Scenarios)

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BioeSR15_Scenarios(Scenarios)

Subsets containing the scenarios used in the FAO 2050 projections (FAO 2018) and in the IPCC SR15 bioenergy scenarios (IPCC 2018).

The following are the sets used for defining the commodity trees, for further details on those, see section 9.13. They divide the set Commodities in 7 subsets (for headings, etc. referred to as Set1-Set7), which have different characteristics regarding the relation of the set elements to single or aggregate commodities, to primary crop products, to co-products, etc. as described below after each set name.

The following sets link the Commodities to Activities and OutputsAnimals or OutputsCropsGrass.

Set1

SubsetCommod_MatchWithAct_AggregateCommodities(Commodities)

MatchCommAct_AggregateCommodities_Crops(Commodities,Activities,OutputsCropsGrass)

Set with the cases where commodities correspond to an aggregate of some non primary commodities. This captures the cases where commodities correspond to an aggregate of some non primary commodities - for prim prod quantities of outputs from activities, we thus need to disaggregate and to translate the commodities to the outputs from activities via commodity trees. Contains crop commodities only, hence only one file needed for crops.

Set2

SubsetCommod_MatchWithAct_AggregateActivities(Commodities)

MatchCommAct_AggregateActivities_Crops(Commodities,Activities,OutputsCropsGrass)

Set with the cases where commodities correspond to prim prod outputs of aggregate activities. This captures the cases where commodities correspond to prim prod outputs of aggregate activities and thus need to be allocated to outputs from single activities. Contains crop commodities only, hence only one file needed for crops.

Set3

SubsetCommod_MatchWithAct_WellDefinedCoProducts(Commodities)

MatchCommAct_WellDefinedCoProducts_Crops(Commodities,Activities,OutputsCropsGrass)

Set matching activities and commodities for the cases of well-defined coproducts. This captures the cases of well-defined coproducts. Contains crop commodities only, hence only one file needed for crops.

Set4

SubsetCommod_MatchWithAct_ComplexCases(Commodities)

MatchCommAct_ComplexCases_Crops(Commodities,Activities,OutputsCropsGrass)

Set matching activities and commodities for the most complex cases such as fats and alcohol". This captures the most complex cases such as fats and alcohol. Contains crop commodities only, hence only one file needed for crops.

Set5

SubsetCommod_MatchWithAct_ComplexAnimalCommodities(Commodities)

MatchCommAct_ComplexAnimalCommodities(Commodities,Activities,OutputsAnimals)

Set matching activities and commodities for the more complex animal commodities. This covers the more complex animal commodities. Contains animal commodities only, hence only one file needed for animals.

Set6

SubsetCommod_MatchWithAct_CommodEquivalentAct(Commodities)

MatchCommAct_CommodEquivalentAct_Crops(Commodities,Activities,OutputsCropsGrass)

Set covering all crop commodities that are equivalent to main outputs from activities

MatchCommAct_CommodEquivalentAct_Animals(Commodities,Activities,OutputsAnimals)

Set covering all animal commodities that are equivalent to main outputs from activities This captures all commodities that are equivalent to main outputs from activities.

Set7

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SubsetCommod_MatchWithAct_CommodAndProductsEquivalentAct(Commodities)
MatchCommAct_CommodAndProductsEquivalentAct_Crops(Commodities,Activities,OutputsCropsGrass)

Set matching activities and commodities for all commodities that are captured together with their derived products and expressed in primary product equivalents.

The following sets capture the product/coproduct relations by defining subsets of all the commodities as follows: main products on level 1, co-products on level 1, main products on level 2, co-products on level 2: via additional sets that capture the main product - co-product pairings (or, in few cases: triplets). This results in the following sets:
SubsetCommod_MatchWithAct_WellDefinedCoProducts_Level1_Main(Commodities)

subset of SubsetCommod_MatchWithAct_WellDefinedCoProducts(Commodities) with the commodities that are on level 1 and that are MAIN Commodities there (e.g. "Starch")

SubsetCommod_MatchWithAct_WellDefinedCoProducts_Level1_Co(Commodities)

subset of SubsetCommod_MatchWithAct_WellDefinedCoProducts(Commodities) with the commodities that are on level 1 and that are CO-Commodities to the main ones there (e.g. "Wheat brans")

SubsetCommod_MatchWithAct_WellDefinedCoProducts_Level2_Main(Commodities)

subset of SubsetCommod_MatchWithAct_WellDefinedCoProducts(Commodities) with the commodities that are on level 2 and that are MAIN Commodities there (e.g. "Gluten")

SubsetCommod_MatchWithAct_WellDefinedCoProducts_Level2_Co(Commodities)

subset of SubsetCommod_MatchWithAct_WellDefinedCoProducts(Commodities) with the commodities that are on level 2 and that are CO-Commodities to the main ones there (e.g. "Wheat brans")

Matching of main and co-products:
MatchMainWithCoProd_WellDefinedCoProducts_Level1(Commodities,Commodities_2)
MatchMainWithCoProd_WellDefinedCoProducts_Level2(Commodities,Commodities_2)
some products have two byproducts, collect them separately:
alias(Commodities,Commodities_3)
MatchMainWithCoPr_WellDefCoProd_Level1And2_TwoByprod(Commodities,Commodities_2,Commodities_3)

9.2.2 _V6_VariablesAndParameters

This is identical to the code described in section 9.1.16.

9.2.3 _V6_ReadOutputFilesFromSteeringFile1

This code file reads the gdx-output-files from Steering file 1. These are the following files (for details on what is containd in each file, see section 9.1.67):

- GeneralModelSets.gdx
- GeneralModelParameters_Inputs.gdx
- GeneralModelParameters_Outputs.gdx
- GeneralModelParameters_OtherChar.gdx
- GeneralModelParameters_Various.gdx
- GeneralModelParameters_Auxiliary.gdx
- GeneralModelVariables_ActivityQuantities.gdx
- GeneralModelVariables_Inputs.gdx
- GeneralModelVariables_Outputs.gdx
- GeneralModelVariables_OtherChar.gdx
- GeneralModelVariables_Various.gdx
- GeneralModelVariables_Trade.gdx
- GeneralModelVariables_CommodityTree.gdx

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- GeneralModelVariables_Auxiliary.gdx

The following file is read later only, after having introduced the "..._MR" parameters and variables, i.e. in module "_V6_VariablesAndParameters_ModelRun_ForSteeringFile2" (see section 9.2.4), section 5.0.

- FOFA2050_BioeSR15_Data_InModelRunEntities.gdx

9.2.4 _V6_VariablesAndParameters_ModelRun_ForSteeringFile2

This file declares the parameters and variables for the model runs. In this, it is largely identical to the file "`_V6_VariablesAndParameters_ModelRun.gms`" described in section 9.1.63. It then loads the yet missing data from "FOFA2050_BioeSR15_Data_InModelRunEntities.gdx".

After having defined and loaded the model run parameters and variables, those for which baseline values are available are assigned so, i.e. so that the model run parameter and variables with scenario dimension "Baseline" are set equal to the baseline values as read in the previous files.

However, before this initialization, it also adds a few additional parameters and variables as follows, mainly used to fasten code execution in certain places:

In the section of the commodity utilizations, it adds
AUX_VCommod_Feed_Contents_MR(Regions,Commodities,Contents,ProductionSystems,ProductionConditions,Scenarios)
    AUXILIARY variable - used to fasten some divisions - total nutrient contents of commodity used for feed - UNIT: total units nutrient
In the section on auxiliary parameters, it adds
AUX_FeedSupplyFactor_BioeSR15_MR(Regions,Scenarios)
    auxiliary parameter capturing the total feed demand in the BioeSR15 scenario P4
In the section on auxiliary variables, it adds
VImportStorageAUX_VImportQuantity_MR(Regions,Regions_2,Commodities,ProductionSystems,ProductionConditions,Scenarios)
    AUXILIARY variable for fastening the code: total crop commodity quantity IMPORTED into Regions FROM Regions_2 - UNIT: tons
VExportStorageAUX_VExportQuantity_MR(Regions,Regions_2,Commodities,ProductionSystems,ProductionConditions,Scenarios)
    AUXILIARY variable for fastening the code: total crop commodity quantity EXPORTED from Regions INTO Regions_2 - UNIT: tons
And for animal commodities:
VImportStorageAUX2_VImportQuantity_MR(Regions,Regions_2,Commodities,ProductionSystems,ProductionConditions,Scenarios)
    AUXILIARY variable for fastening the code: total animal commodity quantity IMPORTED into Regions FROM Regions_2 - UNIT: tons
VExportStorageAUX2_VExportQuantity_MR(Regions,Regions_2,Commodities,ProductionSystems,ProductionConditions,Scenarios)
    AUXILIARY variable for fastening the code: total animal commodity quantity EXPORTED from Regions INTO Regions_2 - UNIT: tons

9.2.5 _V6_BaselineValues_ForModelRuns

This file contains the derivations of certain baseline values needed for the model runs, as described below (structure copied from the code file):

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```
- 1) Do some Baseline calculations that are needed for the scenarios (e.g. to derive single crop shares in total crop groups, etc.)
    1.1) Total crop production
    1.2) Commodities
```

Production of primary products as commodities
Use the sets
Match_ActivityOutputsToCommodities_Crops(Activities,OutputsCropsGrass,Commodities) to link production from activities to primary commodities PRODUCTION level (not DAQ) - equal the activity outputs to these commodities by these matching sets. Derive DAQ by adding imports, subtracting exports and accounting for stock changes. These are then the quantities for the primary products, - all processed (e.g. wheat flour from wheat) can then be derived from this basis.

```
    1.3) derive some sums of activities that we need in the baseline
```

these sums are needed for deriving imp/exp values in the scenarios - they are used for scaling, not for aggregate quantities - hence the partly maybe not fully correct assignments (summing over all fruits for fruits fresh, nes, etc.

```
- 2) Nutrient requirements
```

Derive the feed requirements of dairy cows for the baseline by means of the same equations as done later for the scenarios (using energy for maintenance, walking, pregnancy, etc.); derive some other relevant feed requirement quantities.

```
- 3) Feed supply
    3.1) Feed supply from DAQ
```

Derive total quantities per utilization; on the level of domestically available quantities, and based on DAQ and utilization shares; another path of calculations is to start from these quantities and then to derive the shares rather via division by total DAQ. All this is in fresh matter. Thus, here: derive Feed from DAQ*FeedUtilization, and DAQ is Prod+Imp-Exp as also derived in the TotalProdDAQ-module (i.e. in "_V6_DataDerived_CropProductionTotalsAndDAQ.gms" and similarly for animals). Then derive some further feed related quantities, such as the sum over commodities to get the total supply per feed group.

```
    3.2) Feed supply demand ratio
```

Derive the ration of feed supplied and demanded per country and feed group for the baseline.

```
    3.3) Share of animals in requirements per feed group
```

Derive the share of animals in total feed requirements per feed group, for the baseline.

```
- 4) Suckled animals
```

Derive the ratio of suckling to suckled animals to derive the number of the latter from the former, as the latter do not report any feed requirements (being included in the requirements from the suckling animal), for the baseline

```
- 5)Values needed to adjust mineral fertilizer quantities in the scenarios
```

Derive some baseline values that are needed to adjust fertilizer quantities in the scenarios (see section 9.2.16 for how this is done in detail).

9.2.6 _V6_InitialiseSetsForModelRuns

This file contains the initialisation of the core model sets for the model runs. It thus defines which regions to use, which set of activities and commodities, etc. This is governed by using subsets in the dimensions of the parameters and variables only. E.g. when calculating on country level only, the code does not need the full set Regions, but the subset Countries is enough. Then an assignment of Regions_MR to be equal to Countries is made. Or similarly when using a NUTS2-level resolution for the EU, a subset of Regions containing all countries outside the EU and all NUTS2-regions in the EU is used. Thus, as with the parameters and variables, the sets for the model runs are defined with an suffix "_MR" and all model equations use those sets, and these sets are then allocated with the `alias`-statement, for example, or defined directly. Currently, this reads as follows:

```
alias(Activities_MR,SingleCropGrassAndLivestockActivities);
```


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```
alias(Crops_MR,Crops);
alias(CoreGrassActivities_MR,CoreGrassActivities);
alias(CropsAndCoreGrassActivities_MR,CropsAndCoreGrassActivities);
alias(CropsAndTempGrassActivities_MR,CropsAndTempGrassActivities);
alias(CoreGrassActivitiesNoTEMPGrass_MR,CoreGrassActivitiesNoTEMPGrass);
alias(Regions_MR,Countries);
alias(Regions_MR_2,Regions_MR);
alias(Commodities_MR,Commodities_SingleCommodities);

alias(ConcentrateCommodities_MR,ConcentrateCommodities);
alias(ForageCommodities_MR,ForageCommodities);
alias(GrassCommodities_MR,GrassCommodities);

alias(Livestock_MR,Livestock);
alias(AnimalTypeInHerd_MR,AnimalTypeInHerd);
```

9.2.7 _V6_ScenarioAssumptions

This file contains the set of assumptions for each of the scenarios, each one labelled with a label related to its scenario name. The execution of the respective part for the scenario chosen for a specific scenario run is governed by the global variable `%Scenario%` (cf. section 9.2 at the beginning, where it reads "4) Choice of Scenarios…"). This is organized at the beginning by the following code:

```
$if %Scenario% == "Baseline" $goto AssumptionsBaseline
$if %Scenario% == "BaselineDerived" $goto AssumptionsBaselineDerived
$if %Scenario% == "BioeSR15_P4_2050" $goto AssumptionsBioeSR15_P4_2050
$if %Scenario% == "BioeSR15_P4_2050_RefNoBioe" $goto AssumptionsBioeSR15_P4_2050_ReferenceNoBioe
$if %Scenario% == "BioeSR15_P4_2100" $goto AssumptionsBioeSR15_P4_2100
$if %Scenario% == "BioeSR15_P3_2050" $goto AssumptionsBioeSR15_P3_2050
$if %Scenario% == "BioeSR15_P4_2050_Bio" $goto AssumptionsBioeSR15_P4_2050_Bio
$if %Scenario% == "BioeSR15_P4_2050_Bio_AreaIncrease" $goto AssumptionsBioeSR15_P4_2050_Bio_AreaIncrease
$if %Scenario% == "BioeSR15_P4_2050_Bio_AreaIncr_NoFCF" $goto AssumptionsBioeSR15_P4_2050_Bio_AreaIncr_NoFCF
$if %Scenario% == "BioeSR15_P4_2050_Bio_AreaIncr_NoFCF_LessFW" $goto AssumptionsBioeSR15_P4_2050_Bio_AreaIncr_NoFCF_LessFW

$if %Scenario% == "Baseline_100Organic" $goto AssumptionsBaseline_100Organic
$if %Scenario% == "Baseline_NoFCF" $goto AssumptionsBaseline_NoFCF
```

etc.…

Some further details on how to specify scenarios are given in section 9.4.

In general, the following parameters and variables from various code files have to / most likely need to be specified in the scenario assumptions, all other parameters and variables can (if required by the scenario) but need not be specified specifically for the scenarios.

From section 9.2.9:
To run these calculations, the following inputs **need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed).

- the areas harvested of the various crops and grasslands, etc.:
`VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Activities_MR, ProductionSystems,ProductionConditions,"%Scenario%")`

From section 9.2.12:
To run these calculations, the following inputs **need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed).

- the feed supply on commodity level (for an explanation, see above)
`VCommod_Feed_MR.l(Regions_MR,Commodities_MR,ProductionSystems,`

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```
ProductionConditions,"%Scenario%")
```

Furthermore, to run these calculations, the following inputs **may/likely need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed). This is so, a changes in feeding rations and feed use is a core aspect of many scenarios.

- the feeding rations, i.e. DM shares per feed group (concentrates, forage, grass, residues):

```
FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"AggregateFeedConcentrates_Commodity","Quantity share in DM (share)",
ProductionSystems,ProductionConditions,"%Scenario%")

FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"AggregateFeedForageCrops_Commodity","Quantity share in DM (share)",
ProductionSystems,ProductionConditions,"%Scenario%")

FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"AggregateFeedGrass_Commodity","Quantity share in DM (share)",
ProductionSystems,ProductionConditions,"%Scenario%")

FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"AggregateFeedResidues_Commodity","Quantity share in DM (share)",
ProductionSystems,ProductionConditions,"%Scenario%")
```

From section 9.2.13:
To run these calculations, the following inputs **may/likely need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed). This is so, a changes in feeding rations and feed use is a core aspect of many scenarios.

- share of the single animal activities in total FeedGE requirements by all animal activities, for the different feed groups:

```
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"Share in FeedGE_Req_Total from Conc",ProductionSystems,
ProductionConditions,"%Scenario%")

ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"Share in FeedGE_Req_Total from Grass",ProductionSystems,
ProductionConditions,"%Scenario%")

ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"Share in FeedGE_Req_Total from Forage",ProductionSystems,
ProductionConditions,"%Scenario%")
```

From section 9.2.16:
To run these calculations, the following inputs **may/likely need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed). These quantities can also be derived in the code, but for some scenarios, they will be provided in the scenario assumptions.

- the mineral N and P fertilizer quantities:

```
VMineralFertilizerQuantity_MR.l(Regions_MR,"mineral N fert
```

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```
(N)","AllMinFertProdTech","AllProdSyst","%Scenario%")

VMineralFertilizerQuantity_MR.l(Regions_MR,"mineral P fert
(P2O5)","AllMinFertProdTech","AllProdSyst","%Scenario%")
```

9.2.8 _V6_AssignInitialValuesToScenarios

This file contains the code for assigning baseline values to all parameters for initialising the scenario runs. This is done conditional on values for the scenarios already being available - as e.g. provided in the scenario definition files. For all parameters, where values are missing for the scenario, these are assigned here equal to the baseline. Variables are all derived during the code execution, or provided by the scenario definitions, hence there is no initialisation of variables with baseline values needed.

For the scenarios, it is possible to choose whether organic and conventional (or for other systems, such as rainfed/irrigated, etc.) values shall be used or not. If so, these values are initialized here as well. This choice is governed by setting it accordingly in the scenario definition, cf. section 9.4).

9.2.9 _V6_DataDerived_CropProductionTotalsAndDAQ

This file contains the calculations to derive total crop production (areas*yields) and DAQs (Production + Imports - Exports). Animal products are derived later, after having calculated animal numbers. The table of contents is:

```
$ontext;
- 1) Total crop production
- 2) Commodities
         2.1) Production of primary products as commodities
         2.2) Import and export values
         2.3) DAQ
$offtext;
```

In more detail:

```
- 1) Total crop production
```

It derives `"Land use per Mainoutput1 (ha)"` as the inverse of yields as a new parameter per ton output:

```
ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,"Land use per Mainoutput1
                              (ha)",ProductionSystems,ProductionConditions,"%Scenario%")
               $ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,"MainOutput1
                       (t)",ProductionSystems,ProductionConditions,"%Scenario%")
= 1/ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,"MainOutput1
                       (t)",ProductionSystems,ProductionConditions,"%Scenario%");
```

Then it derives the total output by multiplying the total area with yields:

```
VActCropsGrass_Outputs_MR.l(Regions_MR,Activities_MR,OutputsCropsGrass,ProductionSystems,
               ProductionConditions,"%Scenario%")
= VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Activities_MR,ProductionSystems,
               ProductionConditions,"%Scenario%")
        *ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,OutputsCropsGrass,
               ProductionSystems,ProductionConditions,"%Scenario%");
```

And it derives total input values, as far as available – e.g. seed inputs, by multiplying total area with inputs per hectare:

```
VActCropsGrass_Inputs_MR.l(Regions_MR,Activities_MR,InputsCropsGrass,ProductionSystems,
               ProductionConditions,"%Scenario%")
= VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Activities_MR,ProductionSystems,
```


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```
                ProductionConditions,"%Scenario%")
        *ActCropsGrass_Inputs_MR(Regions_MR,Activities_MR,InputsCropsGrass,
                ProductionSystems,ProductionConditions,"%Scenario%");
```

```
- 2) Commodities
          2.1) Production of primary products as commodities
```

Commodity production of primary products is set equal to the domestic production from the activities, by means of the matching file between commodities and activities:

```
VCommod_Production_MR.l(Regions_MR,Commodities_MR,ProductionSystems,
                ProductionConditions,"%Scenario%")
          = sum((Activities_MR,OutputsCropsGrass)
                $Match_ActivityOutputsToCommodities_Crops(Activities_MR,
                                OutputsCropsGrass,Commodities_MR),
                VActCropsGrass_Outputs_MR.l(Regions_MR,Activities_MR,OutputsCropsGrass,
                        ProductionSystems,ProductionConditions,"%Scenario%"));
```

On commodity level, dry matter, nutrient, etc. contents in the primary commodities produced in the country are derived by multiplying the commodity quantity with the per ton contents:

```
VCommod_Contents_MR.l(Regions_MR,Commodities_MR,ContentsPerFreshMatterNutrients,
                ProductionSystems,ProductionConditions,"%Scenario%")
          = VCommod_Production_MR.l(Regions_MR,Commodities_MR,ProductionSystems,
                ProductionConditions,"%Scenario%")
             *Commod_Contents_MR(Regions_MR,Commodities_MR,ContentsPerFreshMatterNutrients,
                ProductionSystems,ProductionConditions,"%Scenario%");
          2.2) Import and export values
```

The default procedure to derive import and export values for commodities in the scenarios is to scale the baseline import export values with the change in production in the scenarios. Thus, the scenario import to country A from country B equals this baseline import, multiplied with the production in country B in the scenario, as derived above, divided by the production in country B in the baseline. For exports from country A it is similar, scaling the baseline exports from country A with the change in production in the scenario, i.e. multiplying with the production in country A in the scenario and dividing by the baseline production in country A. For new commodities not present in the baseline, import and export values have to be provided in the scenario assumptions. As baseline import and export values are available for all production systems together only (element "AllProdSyst"), the code is set up with those and organic and conventional values scale identically, unless scenario assumptions provide different values directly which are then used (governed by the condition that these calculations are only executed in case the respective values are not available: "`$(NOT…`".

These calculations are done separately for the 7 different commodity sets, as they are separately matched to activities (see section 9.2.1). Examples read as follows, for Set1:

Exports:

```
VExportQuantity_MR.l(Regions_MR,Regions_2,Commodities_MR,ProductionSystems,
                ProductionConditions,"%Scenario%")
                  $(NOT VExportQuantity_MR.l(Regions_MR,Regions_2,Commodities_MR,
                                ProductionSystems,ProductionConditions,"%Scenario%"))
= sum((Activities,OutputsCropsGrass)
        $(MatchCommAct_AggregateCommodities_Crops(Commodities_MR,Activities,OutputsCropsGrass)
                          AND
                VActCropsGrass_Outputs_MR.l(Regions_MR,Activities,OutputsCropsGrass,
                        "AllProdSyst",ProductionConditions,"Baseline")),
        VExportQuantity_MR.l(Regions_MR,Regions_2,Commodities_MR,"AllProdSyst",
                ProductionConditions,"Baseline")
        *VActCropsGrass_Outputs_MR.l(Regions_MR,Activities,OutputsCropsGrass,
                ProductionSystems,ProductionConditions,"%Scenario%")
        /VActCropsGrass_Outputs_MR.l(Regions_MR,Activities,OutputsCropsGrass,
                "AllProdSyst",ProductionConditions,"Baseline"));
```

Imports:

```
VImportQuantity_MR.l(Regions_MR,Regions_2,Commodities_MR,ProductionSystems,
                ProductionConditions,"%Scenario%")
                                                                        $(NOT
```


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```
VImportQuantity_MR.l(Regions_MR,Regions_2,Commodities_MR,
                              ProductionSystems,ProductionConditions,"%Scenario%"))
         = sum((Activities,OutputsCropsGrass)
        $(MatchCommAct_AggregateCommodities_Crops(Commodities_MR,Activities,OutputsCropsGrass)
                           AND
                VActCropsGrass_Outputs_MR.l(Regions_2,Activities,OutputsCropsGrass,
                        "AllProdSyst",ProductionConditions,"Baseline")),
        VImportQuantity_MR.l(Regions_MR,Regions_2,Commodities_MR,"AllProdSyst",
                ProductionConditions,"Baseline")
        *VActCropsGrass_Outputs_MR.l(Regions_2,Activities,OutputsCropsGrass,
                ProductionSystems,ProductionConditions,"%Scenario%")
        /VActCropsGrass_Outputs_MR.l(Regions_2,Activities,OutputsCropsGrass,
                "AllProdSyst",ProductionConditions,"Baseline"));
```

```
         2.3) DAQ
```

Domestically available quantities (DAQ) are then derived from the values calculated above: DAQ = Production + Imports – Exports, where imports are summed over all countries the commodity is imported from and exports are summed over all countries the commodity is exported to.

```
VImportQuantity_MR.l(Regions,"World",Commodities,ProductionSystems,
        ProductionConditions,"%Scenario%")
=sum(Regions_MR,VImportQuantity_MR.l(Regions,Regions_MR,Commodities,ProductionSystems,
        ProductionConditions,"%Scenario%"));

VExportQuantity_MR.l(Regions,"World",Commodities,ProductionSystems,
        ProductionConditions,"%Scenario%")
=sum(Regions_MR,VExportQuantity_MR.l(Regions,Regions_MR,Commodities,ProductionSystems,
        ProductionConditions,"%Scenario%"));

VCommod_Quantity_MR.l(Regions,Commodities,ProductionSystems,ProductionConditions,"%Scenario%")
         = VCommod_Production_MR.l(Regions,Commodities,ProductionSystems,
                ProductionConditions,"%Scenario%")
         + VImportQuantity_MR.l(Regions,"World",Commodities,ProductionSystems,
                ProductionConditions,"%Scenario%")
         - VExportQuantity_MR.l(Regions,"World",Commodities,ProductionSystems,
                ProductionConditions,"%Scenario%");
```

To run these calculations, the following inputs **need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed).

- the areas harvested of the various crops and grasslands, etc.:
VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Activities_MR, ProductionSystems,ProductionConditions,"%Scenario%")

9.2.10 _V6_DataDerived_CropResidueManagement

This file contains the code to model crop residue management and related emissions. The table of contents is:

```
$ontext;
- 1) Crop residue management
         1.1) Derive residue quantities:
         1.2) Derive other nutrient such as N and P2O5 contents of residues:
         1.3) Crop res management characteristics from total residues
$offtext;
```

In more detail:

```
- 1) Crop residue management
         1.1) Derive residue quantities:
```

This code calculates the residue production. This is derived based on the dry matter (DM) production, using the residue shares of tons DM residues per ton DM production - the latter is available on commodity level, namely as "`VCommod_Contents_MR.l(Regions,Commodities,"DM (t)", ProductionSystems,ProductionConditions,"%Scenario%")`". Thus, derive residue quantities again with the general activity-commodity-matching:

```
VCropResidues_Contents_MR.l(Regions_MR,Activities_MR,"Average residues (t)",
       "DM (t) - before management",ProductionSystems,ProductionConditions,"%Scenario%")
  = sum(Commodities_MR$Match_ActivityOutputsToCommodities_Crops(Activities_MR,
         "MainOutput1 (t)",Commodities_MR),
       VCommod_Contents_MR.l(Regions_MR,Commodities_MR,"DM (t)",ProductionSystems,
              ProductionConditions,"%Scenario%")
       *CropResidues_OtherChar_MR(Regions_MR,Activities_MR,"Average residues (t)",
              "Residue share t DM / t DM MainOutput1",ProductionSystems,ProductionConditions,
              "%Scenario%"));
```

Then derive the wet matter residue quantities by division with DM contents (the "before management" values is used to indicate that these quantities may reduce during management due to various losses and emissions and that the quantities applied to the fields are thus lower):

```
VCropResidues_Quantity_MR.l(Regions_MR,Activities_MR,"Average residues (t)",ProductionSystems,
       ProductionConditions,"%Scenario%")
        $CropResidues_Contents_MR(Regions_MR,Activities_MR,"Average residues (t)",
          "DM (t) - before management",ProductionSystems,ProductionConditions,"%Scenario%")
  = VCropResidues_Contents_MR.l(Regions_MR,Activities_MR,"Average residues (t)",
      "DM (t) - before management",ProductionSystems,ProductionConditions,"%Scenario%")
        /CropResidues_Contents_MR(Regions_MR,Activities_MR,"Average residues (t)",
          "DM (t) - before management",ProductionSystems,ProductionConditions,"%Scenario%");
```

```
          1.2) Derive other nutrient such as N and P2O5 contents of residues:
```

Multiplication of residue quantities with per ton contents delivers total nutrient quantities, etc., e.g. for nitrogen (and similarly for P_2O_5):

```
VCropResidues_Contents_MR.l(Regions_MR,Activities_MR,"Average residues (t)",
       "N (t) - before management",ProductionSystems,ProductionConditions,"%Scenario%")
  = VCropResidues_Quantity_MR.l(Regions_MR,Activities_MR,"Average residues (t)",
       ProductionSystems,ProductionConditions,"%Scenario%")
    *CropResidues_Contents_MR(Regions_MR,Activities_MR,"Average residues (t)",
       "N (t) - before management",ProductionSystems,ProductionConditions,"%Scenario%");
```

```
          1.3) Crop res management characteristics from total residues
```

Derive some further numbers based on total residue quantities, e.g. further characteristics such as management losses and emissions, etc., as covered in the set `CropResManagement_NotSystemShares`. As those characteristics may depend on the crop residue management system, this dimension is added by the share of residues managed in the different systems.

```
VCropResidues_Management_MR.l(Regions_MR,Activities_MR,"Average Residues (t)",
       CropResManagement_NotSystemShares,CropResManSystem,
              ProductionSystems,ProductionConditions,"%Scenario%")
  = VCropResidues_Quantity_MR.l(Regions_MR,Activities_MR,"Average residues (t)",
       ProductionSystems,ProductionConditions,"%Scenario%")
       *CropResidues_Management_MR(Regions_MR,Activities_MR,"Average Residues (t)",
          "Quantity share in CropResMan system",CropResManSystem,ProductionSystems,
          ProductionConditions,"%Scenario%")
             *CropResidues_Management_MR(Regions_MR,Activities_MR,"Average Residues (t)",
                 CropResManagement_NotSystemShares,CropResManSystem,ProductionSystems,
                    ProductionConditions,"%Scenario%");
```

And for forest residues (bioenergy), the N in forest bioenergy residues that can be applied as fertilizer is derived:

```
ActForest_OtherChar_MR.l(Regions_MR,"Forest","Forest res bioe N for areas (tN)",
       ProductionSystems,ProductionConditions,"%Scenario%")
  = VEnergyProduction_MR.l(Regions_MR,"Secondary energy","AllEnTypes",
          "Forest and crop residues","Bioe conversion Biomass input (tDM)","%Scenario%")
       *ActForest_OtherChar_MR(Regions_MR,"Forest",
```


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```
            "Forest res bioe N for areas (tN/t DM res)",ProductionSystems,
                ProductionConditions,"%Scenario%");
```

To run these calculations, **no inputs need to be specified** in the scenario assumptions (as all values are available via the initialization (cf. section 9.2.8); but they can be changed in the scenario assumptions, if needed).

9.2.11 _V6_DataDerived_CropGrassNutrientRequirements

This file contains the code for an alternative approach to determine crop and grass nutrient requirements (than to use the data provided in the baseline), based on the nutrient contents in the output, accounting for crop residue output and N from N fixation. This is only assigned, though, in case no other, better data is available from the baseline or scenario assumptions. Currently, however, there is no data read in in the baseline, thus all requirements are derived here (unless new data is added to improve the baseline). The table of contents is:

```
$ontext;
- 1) Crop and grass nutrient requirements derived
$offtext;
```

In more detail:

```
- 1) Crop and grass nutrient requirements derived
```

The N requirements per ton yield are derived as a proxy via total N in outputs (assuming a maximum of three outputs; for most cases, it is one only; as the reference is the first main output, the others are scaled proportionally to arrive at values per ton first output) and residues minus total N fixation with some correction factors; these correction factors still need to be backed by literature/improved. The requirements are only calculated if no value is available from the data (hence the condition "`$(NOT…`".). Thus, the N contents in the various outputs and the residues is calculated and then the total requirements are derived as follows (if a negative value results, this is set to zero in subsequent code not reported here).

These values are then later used to allocate total nutrients available in a region to the single crops. Hence it is not important whether this value exactly equals an agronomically sensible value for nutrient requirements or not. It is rather important that it correlates with such requirement as the relative values between crops govern how much of the total nutrient quantity is then applied to which crop (cf. section 9.2.16). Thus, this gross indicator for requirements is adequate in absence of better values.

```
ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,
       "N req - per ton yield based (tN)",ProductionSystems,ProductionConditions,
              "%Scenario%")
           $((NOT ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,
              "N req - per ton yield based (tN)",ProductionSystems,ProductionConditions,
                     "%Scenario%"))
              AND ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,
                "MainOutput1 (t)",ProductionSystems,ProductionConditions,"%Scenario%"))
= ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,"N in MainOutput1 (tN)",
       ProductionSystems,ProductionConditions,"%Scenario%")
   +ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,"N in MainOutput2 (tN)",
       ProductionSystems,ProductionConditions,"%Scenario%")
         *ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,"MainOutput2 (t)",
              ProductionSystems,ProductionConditions,"%Scenario%")
         /ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,"MainOutput1 (t)",
              ProductionSystems,ProductionConditions,"%Scenario%")
   +ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,"N in MainOutput3 (tN)",
       ProductionSystems,ProductionConditions,"%Scenario%")
         *ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,"MainOutput3 (t)",
              ProductionSystems,ProductionConditions,"%Scenario%")
```


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```
        /ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,"MainOutput1 (t)",
            ProductionSystems,ProductionConditions,"%Scenario%")
   + 0.5*ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,
        "N in residues - per ton MainOutput1 (tN)",ProductionSystems,ProductionConditions,
            "%Scenario%")
   -0.75*ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,
        "N fixation per ton MainOutput1 (tN)",ProductionSystems,ProductionConditions,
            "%Scenario%");
```

After these calculations for nitrogen, the same is calculated for phosphorus (in P_2O_5).

To run these calculations, **no inputs need to be specified** in the scenario assumptions (as all values are available via the initialization (cf. section 9.2.8); but they can be changed in the scenario assumptions, if needed).

9.2.12 _V6_CoreModelEquations_NutrientRequirementsAndFeedSupply

This file contains all the core model equations needed to derive animal nutrient requirements and feed supply. The table of contents is:

```
$ontext;
- 1) Nutrient requirements
- 2) Feed supply and nutrient contents
         2.1) Feed supply from DAQ
         2.2) Feed GE contents per DM
- 3) DM requirements
- 4) Detailed Feeding Rations
$offtext;
```

In more detail:

```
- 1) Nutrient requirements
```

First, the FeedME (metabolisable energy) requirements for dairy cows is derived, based on requirements for milk production (depending on the milk yield), maintenance (basic metabolism), walking and pregnancy, which are all themselves derived in specific equations (for details, see the code file), as also done for the baseline (see section 9.2.5).

```
ActAnimalsHead_OtherChar_MR(Regions_MR,"Cattle","Producing_Dairy_Cattle",
        "FeedME_Req_Total (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
     $ActAnimalsHead_OtherChar_MR(Regions_MR,"Cattle","Producing_Dairy_Cattle",
        "Liveweight (t)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_OtherChar_MR(Regions_MR,"Cattle","Producing_Dairy_Cattle",
        "FeedME_Req_MilkProd (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
+ ActAnimalsHead_OtherChar_MR(Regions_MR,"Cattle","Producing_Dairy_Cattle",
        "FeedME_Req_Maintenance (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
+ ActAnimalsHead_OtherChar_MR(Regions_MR,"Cattle","Producing_Dairy_Cattle",
        "FeedME_Req_Walking (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
+ ActAnimalsHead_OtherChar_MR(Regions_MR,"Cattle","Producing_Dairy_Cattle",
        "FeedME_Req_Pregnancy (MJ)",ProductionSystems,ProductionConditions,"%Scenario%");
```

The $-condition on the presence of liveweight values is needed to avoid that the requirement is assigned also if one of the liveweight-related terms is missing (this likely being the case, e.g. when there are no animals in a country).

Then feed crude protein (FeedXP) requirements are derived from FeedME requirements by means of a proportionality factor (quite a gross approach), in case there is no better data available (hence the condition “`$(NOT…`”.):

```
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedXP_Req_Total (t)",ProductionSystems,ProductionConditions,"%Scenario%")
    $(ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
```

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```
        "XPperME_InFeedReq (gXP/MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
     AND (NOT ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedXP_Req_Total (t)",ProductionSystems,ProductionConditions,"%Scenario%")))
= ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedME_Req_Total (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
     *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "XPperME_InFeedReq (gXP/MJ)",ProductionSystems,ProductionConditions,
        "%Scenario%")/1000000;
```

And after this, gross energy (FeedGE) requirements are derived from FeedME requirements, based on equations from (IPCC 2006):

```
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedGE_Req_Total (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
    $((ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Digestibility of Feed (%)",ProductionSystems,ProductionConditions,"%Scenario%")/100
       - ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
               "UE_per_GE (share)",ProductionSystems,ProductionConditions,"%Scenario%"))
    AND NOT ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedGE_Req_Total (MJ)",ProductionSystems,ProductionConditions,"%Scenario%"))
= ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedME_Req_Total (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
    /(ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Digestibility of Feed (%)",ProductionSystems,ProductionConditions,"%Scenario%")/100
       - ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
               "UE_per_GE (share)",ProductionSystems,ProductionConditions,"%Scenario%"));
```

IMPORTANT: if the equations to derive the dairy cow FeedME requirements are changed here, then they also need to be changed identically in section 9.2.5, where the baseline of this is derived.

Then derive the FeedGE requirements per feed group. For this, use the DM shares in the feeding rations to derive GE shares; this will be roughly ok, and it is done, because feeding rations are available in DM shares and not in GE shares:

```
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedGE_Req_Total from Conc (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedGE_Req_Total (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
   *FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "AggregateFeedConcentrates_Commodity","Quantity share in DM (share)",
               ProductionSystems,ProductionConditions,"%Scenario%");
```

And similarly for forage, grass and residues. For further use, also the totals per region and animal type are derived from per head requirements times animal numbers (again the example for concentrates, similarly for forage, grass and residues):

```
VActAnimalsHead_OtherChar_MR.l(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedGE_Req_Total from Conc (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
=VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,AnimalTypeInHerd,
        ProductionSystems,ProductionConditions,"%Scenario%")
    *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedGE_Req_Total from Conc (MJ)",ProductionSystems,ProductionConditions,
               "%Scenario%");
```

```
- 2) Feed supply and nutrient contents
        2.1) Feed supply from DAQ
```

Derive total quantities per utilization; on the level of domestically available quantities, and based on DAQ and utilization shares, all in fresh matter. Thus, derive Feed = DAQ*FeedUtilization, where DAQ = Production+Imports-Exports (cf. section 9.2.9).

IMPORTANT: currently, the DAQ-calculation is not yet fully operational, due to differences in the FAOSTAT commodity sets used for production and imports/exports, such that the calculation via DAQ = Production+Imports-Exports leads to useless values. Hence, currently, the Feed quantity is

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directly defined in the scenario assumptions. This has yet to be improved.

Then sum over commodities to get the total supply per feed group. This is first done such that the concentrates' group covers ALL concentrates (i.e. from main and by-products), after that it is done such that these are kept separately, resulting in a main-product concentrate group and a by-product-concentrate group. This is achieved by using different matching files allocating commodities to feed groups.

```
VCommod_Feed_MR.l(Regions_MR,Commodities_2,ProductionSystems,
       ProductionConditions,"%Scenario%")
              $(NOT VCommod_Feed_MR.l(Regions_MR,Commodities_2,ProductionSystems,
                     ProductionConditions,"%Scenario%"))
= sum(Commodities_MR$Match_FeedCommoditiesToFeedCommodGroups(Commodities_MR,Commodities_2),
       VCommod_Feed_MR.l(Regions_MR,Commodities_MR,ProductionSystems,
              ProductionConditions,"%Scenario%"));
```

Now the main and by-product concentrates are kept separately:

```
VCommod_Feed_MR.l(Regions_MR,Commodities_2,ProductionSystems,
       ProductionConditions,"%Scenario%")
              $(NOT VCommod_Feed_MR.l(Regions_MR,Commodities_2,ProductionSystems,
                     ProductionConditions,"%Scenario%"))
= sum(Commodities_MR$Match_FeedCommoditiesToFeedCommodGroups_MainByprodConc(Commodities_MR,
              Commodities_2),
       VCommod_Feed_MR.l(Regions_MR,Commodities_MR,ProductionSystems,
              ProductionConditions,"%Scenario%"));
```

Then derive dry matter and GE, ME and XP quantities by multiplying the feed quantities with the corresponding contents (below: the example of DM):

```
VCommod_Feed_Contents_MR.l(Regions_MR,Commodities_MR,"DM (t)",ProductionSystems,
       ProductionConditions,"%Scenario%")
= VCommod_Feed_MR.l(Regions_MR,Commodities_MR,ProductionSystems,
       ProductionConditions,"%Scenario%")
    *Commod_Contents_MR(Regions_MR,Commodities_MR,"DM (t)",ProductionSystems,
       ProductionConditions,"%Scenario%");
```

And derive the totals per feed group by summing as done above.

```
         2.2) Feed GE contents per DM
```

Derive the FeedGE per DM content values per commodity and per feed group by dividing the corresponding total FeedGE value by the total DM value, e.g.:

```
Commod_Contents_MR(Regions_MR,Commodities_MR,"FeedGE in DM (MJ)",ProductionSystems,
       ProductionConditions,"%Scenario%")
    $VCommod_Feed_Contents_MR.l(Regions_MR,Commodities_MR,"DM (t)",ProductionSystems,
       ProductionConditions,"%Scenario%")
= VCommod_Feed_Contents_MR.l(Regions_MR,Commodities_MR,"FeedGE (MJ)",ProductionSystems,
       ProductionConditions,"%Scenario%")
    /VCommod_Feed_Contents_MR.l(Regions_MR,Commodities_MR,"DM (t)",ProductionSystems,
       ProductionConditions,"%Scenario%");
```

```
- 3) DM requirements
```

Now all values are available to derive the Feed DM requirements per feed group (here the example of concentrates, similar for the others) by dividing the GE requirements by GE in DM contents:

```
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedDM_Req_Total from Conc (t DM)",ProductionSystems,ProductionConditions,
       "%Scenario%")
    $Commod_Contents_MR(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "FeedGE in DM (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedGE_Req_Total from Conc (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
    /Commod_Contents_MR(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "FeedGE in DM (MJ)",ProductionSystems,ProductionConditions,"%Scenario%");
```


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```
- 4) Detailed Feeding Rations
```

Now derive the detailed feeding rations, by multiplying the DM requirements per feed group per head by the relative shares of commodities in the total of this feed group (here the example of concentrates, similar for the others). As the division below (in grey) makes the code extremely slow, we avoid it by auxiliary variables to be calculated first:

```
AUX_VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "DM (t)",ProductionSystems,ProductionConditions,"%Scenario%")
    $VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "DM (t)",ProductionSystems,ProductionConditions,"%Scenario%")
= 1/VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "DM (t)",ProductionSystems,ProductionConditions,"%Scenario%");

FeedingRationsHeads_Contents_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       ConcentrateCommodities,"DM (t)",ProductionSystems,ProductionConditions,"%Scenario%")
*$VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "DM (t)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedDM_Req_Total from Conc (t DM)",ProductionSystems,ProductionConditions,
              "%Scenario%")
      *VCommod_Feed_Contents_MR.l(Regions_MR,ConcentrateCommodities,"DM (t)",
              ProductionSystems,ProductionConditions,"%Scenario%")
*/VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "DM (t)",ProductionSystems,ProductionConditions,"%Scenario%");
      *AUX_VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
              "DM (t)",ProductionSystems,ProductionConditions,"%Scenario%");
```

To run these calculations, the following inputs **need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed).

- the feed supply on commodity level (for an explanation, see above)

VCommod_Feed_MR.l(Regions_MR,Commodities_MR,ProductionSystems, ProductionConditions,"%Scenario%")

Furthermore, to run these calculations, the following inputs **may/likely need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed). This is so, a changes in feeding rations and feed use is a core aspect of many scenarios.

- the feeding rations, i.e. DM shares per feed group (concentrates, forage, grass, residues):

FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd, "AggregateFeedConcentrates_Commodity","Quantity share in DM (share)", ProductionSystems,ProductionConditions,"%Scenario%")

FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd, "AggregateFeedForageCrops_Commodity","Quantity share in DM (share)", ProductionSystems,ProductionConditions,"%Scenario%")

FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd, "AggregateFeedGrass_Commodity","Quantity share in DM (share)", ProductionSystems,ProductionConditions,"%Scenario%")

FeedingRations_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd, "AggregateFeedResidues_Commodity","Quantity share in DM (share)", ProductionSystems,ProductionConditions,"%Scenario%")

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9.2.13 _V6_CoreModelEquations_DeriveAnimalNumbersAndProduction

This file contains the core model equations for deriving animal numbers from feed supply and feeding rations and for deriving animal production, and imports/exports. The table of contents is:

```
$ontext;
- 1) Derive animal numbers
        1.1) First option: allocate concentrate feed to all animals according to their share
              in conc feed per animal; then do the same for grass for the animal where no
              animal numbers have yet been derived, then again the same for forage:
        1.2) Second option: allocate all grass to grass-eating animals, then allocate the
              concentrates, forage, etc. needed for these animals according to the feeding
              ration; then subtract these quantities of feed from the totals and allocate the
              remaining to the non grass-eating animals
- 2) Derive animal production
        2.1) Production of primary products from activities
        2.2) Production of primary products as commodities
- 3) Derive animal commodity imports and exports
        3.1) Import and export values
- 4) Derive feed requirements per APU
$offtext;
```

In more detail:

```
- 1) Derive animal numbers
```

First, it is determined which approach to be chosen for deriving animal numbers – based on grass or concentrate feed quantities (cf. section 8.3.6). Depending on the choice, the code for the first or second option is executed, as described in the following under “1.1)” and “1.2)”.

```
        1.1) First option: allocate concentrate feed to all animals according to their share
              in conc feed per animal; then do the same for grass for the animal where no
              animal numbers have yet been derived, then again the same for forage:
```

The formula used derives the animal number based on the concentrate feed supply, the share of each animal activity in total concentrate feed requirements in the baseline (or adapted according to scenario assumptions), the supply-demand ratio for concentrates from the baseline or reference scenario (to account for missing feed quantities thus assuring comparability of scenario runs to the baseline or reference scenario, cf. the discussion in section 7.4), and the per animal concentrate requirements: Nr of animals = Total GE supply from concentrates * share animal type in total concentrate requirements / Supply-demand ratio / GE requirement per animal head. In detail:

IMPORTANT: this option is currently not yet fully consistent, as the grass and forage supply should be corrected for the demand of the animal numbers already derived from concentrate supply – similarly to the procedure used in the second option 1.2) below – hence this second option is used currently.

Derive animal number from concentrate feed supply:

```
VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,AnimalTypeInHerd,
       ProductionSystems,ProductionConditions,"%Scenario%")
    $(Commod_OtherChar_MR(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "Feed GE supply/demand ratio Conc",ProductionSystems,ProductionConditions,
       "%Scenario%")
      *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedGE_Req_Total from Conc (MJ)",ProductionSystems,ProductionConditions,
       "%Scenario%"))
= VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "FeedGE (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
    *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
```


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```
        "Share in FeedGE_Req_Total from Conc",ProductionSystems,ProductionConditions,
        "%Scenario%")
    /(Commod_OtherChar_MR(Regions_MR,"AggregateFeedConcentrates_Commodity",
        "Feed GE supply/demand ratio Conc",ProductionSystems,ProductionConditions,
        "%Scenario%")
      *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "FeedGE_Req_Total from Conc (MJ)",ProductionSystems,ProductionConditions,
        "%Scenario%"));
```

For those animals, where no numbers have yet been derived, derive animal numbers from grass feed supply:

```
VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,AnimalTypeInHerd,
        ProductionSystems,ProductionConditions,"%Scenario%")
    $((NOT VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,AnimalTypeInHerd,
        ProductionSystems,ProductionConditions,"%Scenario%"))
     AND (Commod_OtherChar_MR(Regions_MR,"AggregateFeedGrass_Commodity",
        "Feed GE supply/demand ratio Grass",ProductionSystems,ProductionConditions,
               "%Scenario%")
          *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
               "FeedGE_Req_Total from Grass (MJ)",ProductionSystems,ProductionConditions,
               "%Scenario%")))
= VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedGrass_Commodity",
        "FeedGE (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
    *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Share in FeedGE_Req_Total from Grass",ProductionSystems,ProductionConditions,
        "%Scenario%")
    /(Commod_OtherChar_MR(Regions_MR,"AggregateFeedGrass_Commodity",
        "Feed GE supply/demand ratio Grass",ProductionSystems,ProductionConditions,
               "%Scenario%")
          *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
               "FeedGE_Req_Total from Grass (MJ)",ProductionSystems,ProductionConditions,
               "%Scenario%"));
```

And for those animals, where still no numbers have been derived, derive animal numbers from forage feed supply:

```
VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,AnimalTypeInHerd,
        ProductionSystems,ProductionConditions,"%Scenario%")
    $((NOT VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,AnimalTypeInHerd,
        ProductionSystems,ProductionConditions,"%Scenario%"))
     AND (Commod_OtherChar_MR(Regions_MR,"AggregateFeedForageCrops_Commodity",
        "Feed GE supply/demand ratio Forage",ProductionSystems,ProductionConditions,
               "%Scenario%")
          *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
               "FeedGE_Req_Total from Forage (MJ)",ProductionSystems,ProductionConditions,
               "%Scenario%")))
= VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedForageCrops_Commodity",
        "FeedGE (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
     *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Share in FeedGE_Req_Total from Forage",ProductionSystems,ProductionConditions,
        "%Scenario%")
     /(Commod_OtherChar_MR(Regions_MR,"AggregateFeedForageCrops_Commodity",
         "Feed GE supply/demand ratio Forage",ProductionSystems,ProductionConditions,
               "%Scenario%")
           *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
               "FeedGE_Req_Total from Forage (MJ)",ProductionSystems,ProductionConditions,
               "%Scenario%"));

          1.2) Second option: allocate all grass to grass-eating animals, then allocate the
               concentrates, forage, etc. needed for these animals according to the feeding
               ration; then subtract these quantities of feed from the totals and allocate the
               remaining to the non grass-eating animals
```

This is calculated similarly to above in 1.1), only that the remaining animals after accounting for grass feed are derived based on the remaining concentrate feed after having fully fed these animals that have been derived from grass supply, thus, the following quantities (example: for concentrates, similarly needed for forage) are needed:

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```
VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "FeedGE (MJ) - left after feeding ruminants",ProductionSystems,ProductionConditions,
       "%Scenario%")
= VCommod_Feed_Contents_MR.l(Regions_MR,"AggregateFeedConcentrates_Commodity",
       "FeedGE (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
    *(1-sum((Livestock,AnimalTypeInHerd)
              $VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Livestock,AnimalTypeInHerd,
                     ProductionSystems,ProductionConditions,"%Scenario%"),
       ActAnimalsHead_OtherChar_MR(Regions_MR,Livestock,AnimalTypeInHerd,
              "Share in FeedGE_Req_Total from Conc",ProductionSystems,ProductionConditions,
              "%Scenario%")));
```

The proportionality between different animals is then used as follows to derive unknown parameters in the equations to derive animal numbers:

```
$ontext;

                                               ConcSupplyLeftFromRumi * ShareOfConcDemandOfTheseAnimalsInConcLeft
NumberOfAnimals(From Conc left from Ruminants) = ------------------------------------------------------------------------
                                                 SupplyDemandRatioOfConc * (TotalperHeadConcRequirements)

In this, the second factor in the numerator is not known.But the following holds for this second factor:

                                             ShareOfConcDemandOfTheseAnimalsInALLConc
ShareOfConcDemandOfTheseAnimalsInConcLeft =  -------------------------------------------------------
                                            SUM_AnimalsLeft(ShareOfConcDemandOfTheseAnimalsInALLConc)

And inserting this above results in the following:

NumberOfAnimals(From Conc left from Ruminants) =

                              ConcSupplyLeftFromRumi * ShareOfConcDemandOfTheseAnimalsInALLConc
        ---------------------------------------------------------------------------------------------------
        SupplyDemandRatioOfConc * (TotalperHeadConcRequirements) * SUM_AnimalsLeft(ShareOfConcDemandOfTheseAnimalsInALLConc)

$offtext;
```

This is then implemented in the model code – see the code file for details.

Then derive the number of suckled animals as those do not report any feed requirements (being included in the requirements from the suckling animal). This is done on the basis of the ratio of various herd animal types in relation to total living animals. With the corresponding factor, then also derive the number of producing animals:

```
VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,SuckledAnimals,
       ProductionSystems,ProductionConditions,"%Scenario%")
   $(NOT VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,SuckledAnimals,
       ProductionSystems,ProductionConditions,"%Scenario%"))
= sum(AnimalTypeInHerd$MatchSucklingSuckledAnimals(AnimalTypeInHerd,SuckledAnimals),
       VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,AnimalTypeInHerd,
       ProductionSystems,ProductionConditions,"%Scenario%")
    *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,SuckledAnimals,
       "Share suckled to suckling",ProductionSystems,ProductionConditions,"%Scenario%"));
```

Now derive the total amount of animals and then the producing animals:

```
VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,"AllAndAverageTypes",
       ProductionSystems,ProductionConditions,"%Scenario%")
    $(NOT VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,"AllAndAVerageTypes",
       ProductionSystems,ProductionConditions,"%Scenario%"))
sum(AnimalTypeInHerd_NoAggregates,
       VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,
       AnimalTypeInHerd_NoAggregates,ProductionSystems,ProductionConditions,"%Scenario%"));

VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,ProducingAnimals,
       ProductionSystems,ProductionConditions,"%Scenario%")
= VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,"AllAndAverageTypes",
       ProductionSystems,ProductionConditions,"%Scenario%")
    *ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,ProducingAnimals,
       "Share animal type in total living animals",ProductionSystems,ProductionConditions,
       "%Scenario%");
```

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```
- 2) Derive animal production
        2.1) Production of primary products from activities
```
The production is derived as numbe of producing animals times yields:
```
VActAnimalsHead_Outputs_MR.l(Regions_MR,Activities_MR,ProducingAnimals,OutputsAnimals,
       ProductionSystems,ProductionConditions,"%Scenario%")
= VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Activities_MR,ProducingAnimals,
       ProductionSystems,ProductionConditions,"%Scenario%")
    *ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,ProducingAnimals,OutputsAnimals,
       ProductionSystems,ProductionConditions,"%Scenario%");
```

```
        2.2) Production of primary products as commodities
```
Derive this by using the set
`Match_ActivityOutputsToCommodities_Animals(Activities,OutputsAnimals,Commodities)`
to link production from activities to primary commodities production level: equal the activity outputs to these commodities by this matching set. Then derive DAQ by adding imports, subtracting exports and accounting for stock changes (see further down in -3) ff). These are then the quantities for the primary products; all processed products (e.g. whey from milk) can then be derived from this basis by means of extraction rates, etc. (see section 9.13).

```
VCommod_Production_MR.l(Regions_MR,Commodities_MR,ProductionSystems,ProductionConditions,
       "%Scenario%")
     $(NOT VCommod_Production_MR.l(Regions_MR,Commodities_MR,ProductionSystems,
       ProductionConditions,"%Scenario%"))
= sum((Activities_MR,OutputsAnimals,ProducingAnimals)
    $Match_ActivityOutputsToCommodities_Animals(Activities_MR,OutputsAnimals,Commodities_MR),
  VActAnimalsHead_Outputs_MR.l(Regions_MR,Activities_MR,ProducingAnimals,OutputsAnimals,
       ProductionSystems,ProductionConditions,"%Scenario%"));
```

Now derive total nutrient etc. quantities as contained in the primary commodities produced in the country:
```
VCommod_Contents_MR.l(Regions_MR,Commodities_MR,ContentsPerFreshMatterNutrients,
       ProductionSystems,ProductionConditions,"%Scenario%")
    $(NOT VCommod_Contents_MR.l(Regions_MR,Commodities_MR,ContentsPerFreshMatterNutrients,
       ProductionSystems,ProductionConditions,"%Scenario%"))
= VCommod_Production_MR.l(Regions_MR,Commodities_MR,ProductionSystems,ProductionConditions,
       "%Scenario%")
     *Commod_Contents_MR(Regions_MR,Commodities_MR,ContentsPerFreshMatterNutrients,
       ProductionSystems,ProductionConditions,"%Scenario%");
```

```
- 3) Derive animal commodity imports and exports
        3.1) Import and export values
```
Import and export values for animal products are derived as for crop products (cf. section 9.2.9), by scaling according to the changes in production in the exporting countries in relation to the baseline values, for details, see the code file.

IMPORTANT: still to be completed: the derivation of DAQ for animal products!

```
- 4) Derive feed requirements per APU
```
Based on the per head feed requirements and the herd structures (relative shares of the different herd animal types), feed requirements per APU are derived (for details, see the code file). First, this is done on the level of feeding rations, i.e. DM quantities per APU for the various commodities.

To run these calculations, the following inputs **may/likely need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed). This is so, a changes in feeding rations and feed use is a core aspect of many scenarios.

- share of the single animal activities in total FeedGE requirements by all animal activities, for the different feed groups:

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```
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"Share in FeedGE_Req_Total from Conc",ProductionSystems,
ProductionConditions,"%Scenario%")

ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"Share in FeedGE_Req_Total from Grass",ProductionSystems,
ProductionConditions,"%Scenario%")

ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"Share in FeedGE_Req_Total from Forage",ProductionSystems,
ProductionConditions,"%Scenario%")
```

9.2.14 _V6_CoreModelEquations_ManureExcretionAndManagement

This file contains all the equations for calculating manure excretion, manure management and related emissions, based on (IPCC 2006). The table of contents is:

```
$ontext;
- 1) Manure excretion
- 2) Manure management
         2.1) Some general calculations
         2.2) Methane emissions
         2.3) N2O emissions
                 2.3.1) Direct emissions
                 2.3.2) Indirect Emissions
                   2.3.2 A) indirect emissions from volatilisation:
                   2.3.2 B) indirect emissions from leach/runoff:
                 2.3.3) Total N and GHG emissions and losses from manure management
         2.4) P emissions
         2.5) N and P available for fertilization
$offtext;
```

In more detail:

```
- 1) Manure excretion
```

derive VS - Volatile solidesexcretion rates - are determined as follows:

VS = [GE*(1 - DE%/100) + UE*GE] * [(1 - ASH)/GE_per_DM]

unit: t VS in DM/animal/year

Where:
VS = volatile solid excretion per year on a dry-organic matter basis, kg VS year-1
GE = gross energy intake, MJ year-1
DE% = digestibility of the feed in percent (e.g. 60%)
(UE*GE) = urinary energy expressed as fraction of GE times GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.
ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.
GE_per_DM = conversion factor for dietary GE per kg of dry matter (MJ kg-1). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock. IPCC Default: 18.45 - we use the values derived from feed supply, which are largely ok, it seems.

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```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "VS DM in manure (tVS)",ProductionSystems,ProductionConditions,"%Scenario%")
     $Commod_Contents_MR(Regions_MR,"AggregateFeedTotal_Commodity",
       "FeedGE in DM (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedGE_Req_Total (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
     *(1 - ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Digestibility of Feed (%)",ProductionSystems,ProductionConditions,"%Scenario%")/100
       + ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
              "UE_per_GE (share)",ProductionSystems,ProductionConditions,"%Scenario%"))
            *(1 - Manure_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
              "Ash content in feed DM (share)",ProductionSystems,ProductionConditions,
              "%Scenario%"))
      /Commod_Contents_MR(Regions_MR,"AggregateFeedTotal_Commodity",
              "FeedGE in DM (MJ)",ProductionSystems,ProductionConditions,"%Scenario%");
```

Then derive manure total solids (TS). Assume total solids to be volatile solids plus ash, then being equal to total dry matter. Unit: t TS/animal/year:

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "VS DM in manure (tVS)",ProductionSystems,ProductionConditions,"%Scenario%")
    + ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedDM_Req_Total (t DM)",ProductionSystems,ProductionConditions,"%Scenario%")
      *Manure_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Ash content in feed DM (share)",ProductionSystems,ProductionConditions,"%Scenario%");
```

```
- 2) Manure management
         2.1) Some general calculations
```

This contains some general calculations to derive N and P excretion per head (from the values per ton liveweight), and N and P contents of manure totale and volatile solids. For details, see the code file.

```
         2.2) Methane emissions
```

Methane emissions from manure management are calculated based on (IPCC 2006), Tier 2 approach, Volume 4, chapter 10, equations 10.23 ff.
Methane emissions are calculated in the unit: m^3 CH_4 / kg manure excreted

EF(T) = (VS(T) * 365) * (Bo(T) * 0.67 kg/m3 * Sum(S,k)MCF(S,k)/100*MS(T,S,k))

where
EF(T) = annual CH_4 emission factor for livestock category T, kg CH_4 animal^{-1} yr^{-1}
VS(T) = daily volatile solid excreted for livestock category T, kg dry matter animal^{-1} day^{-1}
365 = basis for calculating annual VS production, days yr^{-1}
Bo(T) = maximum methane producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted
0.67 = conversion factor of m^3 CH_4 to kilograms CH_4
MCF(S,k) = methane conversion factors for each manure management system S by climate region k, %
MS(T,S,k) = fraction of livestock category T's manure handled using manure management system S in climate region k, dimensionless

thereby, VS - Volatile solids excretion rates - are determined as follows:

VS = [GE*(1 - DE%/100) + UE*GE] * [(1 - ASH)/GE_per_DM]

Where:
VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day^{-1}
GE = gross energy

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intake, MJ day^{-1}
DE% = digestibility of the feed in percent (e.g. 60%): thus choose 0.6
(UE*GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.
ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.
GE_per_DM = conversion factor for dietary GE per kg of dry matter (MJ kg-1). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock. IPCC Default: 18.45 - we use the values derived from feed supply, which are largely ok, it seems.

The following data is used:
Bo(T): tables 10A-4 to 10A-9
MCF(S,k): table 10.17

Most of these parameters are already defined in the modules for reading data on manure excretion and manure management, etc.

Now do the calculations:
*EF(T) = (VS(T)) * (Bo(T) * 0.67 kg/m3 * Sum(S,k)MCF(S,k)/100*MS(T,S,k))
That is the original IPCC-formula - but for per animal values, we refrain from summing over climate, as one animal is usually located in one climate only.
In the IPCC-formula, there is a factor 365, as it is per day value for VS - but we have annual values, thus no 365 needed (cf. the baseline data code on manure excretion, section 9.1.51)
VS is: `ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,"VS DM in manure (tVS)",ProductionSystems,ProductionConditions,"%Scenario%")`
unit: t CO_2eq/head/year;
division by 100 at MCF in the formula above for transforming percentages to shares/fractions
Bo*0.67kg/m^3 is kgCH_4/kg VS, thus equal to tCH_4/tVS

Now derive the CH_4-emissions (in tCH_4 per head):

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man CH4 (tCH4)" ,ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "VS DM in manure (tVS)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystem,Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Bo: max. CH4 prod. cap. (m3CH4/kgVS)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")
     *0.67*Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "MCF: CH4 conversion factor (%)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")/100
     *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Quantity share in ManureMan system",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%"));
```

and derive the CH_4-emissions in tCO_2eq per head:

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man CH4 (tCO2e)" ,ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man CH4 (tCH4)" ,ProductionSystems,ProductionConditions,"%Scenario%")
     *GWP_GTP_SOLm_MR("CH4","%Scenario%");
```

Now derive the CH_4-emissions per ton of manure TS DM in one specific manure management system:
Emissions/t manure (Manman syst) = (Emissions/head (If all manure would be managed in ONE manman syst) / (Manure/head); unit: t CO_2eq / t manure TS DM

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```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man CH4 (tCH4)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%")
     $ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "VS DM in manure (tVS)",ProductionSystems,ProductionConditions,"%Scenario%")
     *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Bo: max. CH4 prod. cap. (m3CH4/kgVS)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")
      *0.67*Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "MCF: CH4 conversion factor (%)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")/100
     /ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%");
```

And also in tCO_2eq per head:

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man CH4 (tCO2e)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%")
= Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man CH4 (tCH4)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%")
     *GWP_GTP_SOLm_MR("CH4","%Scenario%");
```

```
        2.3) N2O emissions
                2.3.1) Direct emissions
```

Direct N_2O-emissions from manure management are calculated according to (IPCC 2006), volume 10, chapter 4, equation 10.25:

N2O_direct_perHead = Nex(T) * MS(T,S) * EF3(S) * 44/28

unit: tons CO_2eq/head/year

Where:

N2O_direct_perHead = direct N2O emissions from Manure Management in the country, per head of animal, kg N_2O yr^{-1}

Nex(T) = annual average N excretion per head of species/category T in the country, kg N $animal^{-1}$ yr^{-1}

MS(T,S) = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless

EF3(S) = emission factor for direct N_2O emissions from manure management system S in the country, kgN_2O-N/kg N in manure management system S (values from Table 10.21)

S = manure management system

T = species/category of livestock

44/28 = conversion of N_2O-N emissions to N_2O emissions

Direct N_2O emissions from manure management in tN_2O/head:

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O dir (tN2O)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
    *sum(ManureManSystem,
       Manure_Management_MR(Regions_MR,Activities_MR,
         AnimalTypeInHerd,"Manure man N2O dir (tN2O-N/tN)",ManureManSystem,
         "AllAndAverageTemp",ProductionSystems,ProductionConditions,"%Scenario%")
        *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
         "Quantity share in ManureMan system",ManureManSystem,"AllAndAverageTemp",
         ProductionSystems,ProductionConditions,"%Scenario%"))
     *44/28;
```

Converted to tCO_2eq/head:

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O dir (tCO2e)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
```

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```
        "Manure man N2O dir (tN2O)",ProductionSystems,ProductionConditions,"%Scenario%")
     *GWP_GTP_SOLm_MR("N2O","%Scenario%");
```

Derive the N quantity lost through these emissions (divide the N_2O emissions by the N_2O-N to N_2O-factor 44/28:
unit: tons N/head/year

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N in N2O dir (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O dir (tN2O)",ProductionSystems,ProductionConditions,"%Scenario%")
     /44*28;
```

And derive the direct N losses via N_2O-emissions per ton manure TS DM:
*tN Losses/t manure (Manman syst) = (Losses/head (If all manure would be managed in ONE manman syst) / (Manure/head)
unit: t N / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
"Manure man N in N2O dir (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
     $ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
     *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O dir (tN2O-N/tN)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")
    /ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%");
```

Derive the corresponding N_2O emissions (in tCO_2eq) per ton manure:
unit: t CO_2eq / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O dir (tCO2e)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
= Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N in N2O dir (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
      *44/28*GWP_GTP_SOLm_MR("N2O","%Scenario%");

                  2.3.2) Indirect Emissions
                    2.3.2 A) indirect emissions from volatilisation:
```

Indirect N_2O emissions are calculated according to eq. 10.26 and 10.27 in (IPCC 2006):
N_2O_indirect_perHead_Volat = Nex(T) * MS(T,S) * (FracGasMS/100) * EF4(S) * 44/28
Where:
FracGasMS = percent of managed manure nitrogen for livestock category T that volatilises as NH_3 and NO_x in the manure management system S, unit: percentage; values are from table 22, (IPCC 2006), vol4, chapter 10.
EF4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilised)$^{-1}$; the default value is 0.01 kg N_2O-N (kg NH_3-N + NO_x-N volatilised)$^{-1}$, from (IPCC 2006) Chapter 11, Table 11.3
unit: share (i.e. percentage/100)

Now do these calculations for indirect volatilisation N_2O emissions:
*unit: t N_2O/head/year

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O volat (tN2O)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystem,
```


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```
    Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N volat (% of N in manure)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")/100
   *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O-N from N volat (tN/tN volat)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")
   *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,"Quantity share in
       ManureMan system",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%"))
     *44/28;
```

Now convert to t CO2eq/head/year

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O volat (tCO2e)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O volat (tN2O)",ProductionSystems,ProductionConditions,"%Scenario%")
      *GWP_GTP_SOLm_MR("N2O","%Scenario%");
```

Then calculate the related N quantity lost through volatilization:
unit: t N /head/year

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N volat (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystem,
     Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N volat (% of N in manure)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")/100
    *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,"Quantity share in
       ManureMan system",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%"));
```

Derive NH_3-emissions as a specific part of the volatilization:
unit: t NH_3/head/year (17/14 converts N to NH_3)

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man NH3 (tNH3)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystem,
       Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
               "Manure man NH3-N (% of N in manure)",ManureManSystem,"AllAndAverageTemp",
               ProductionSystems,ProductionConditions,"%Scenario%")/100
       *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
               "Quantity share in ManureMan system",ManureManSystem,"AllAndAverageTemp",
               ProductionSystems,ProductionConditions,"%Scenario%"))
            *17/14;
```

Now convert the per head values to per ton manure values: derive first N lost through volatilisation per ton manure TS DM:
Emissions/t manure (Manman syst) = (Emissions/head (If all manure would be managed in ONE manman syst) / (Manure/head)
unit t N / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N volat (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%")
   $ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
   *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N volat (% of N in manure)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")/100
```


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```
    /ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%");
```

and corresponding indirect N_2O emissions from volatilisation:
unit: t N_2O / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O volat (tN2O)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")
= Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N volat (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%")
    *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O-N from N volat (tN/tN volat)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")
     *44/28;
```

And corresponding GHG emissions, i.e. converted to t CO_2eq / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O volat (tCO2e)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%")
= Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O volat (tN2O)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%")
    *GWP_GTP_SOLm_MR("N2O","%Scenario%");
```

and also NH_3 emissions as specific part of the volatilization:
unit t NH_3 / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man NH3 (tNH3)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
       ProductionConditions,"%Scenario%")
     $ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
     *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man NH3-N (% of N in manure)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")/100
     /ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
     *17/14;
```

2.3.2 B) indirect emissions from leach/runoff:

This is done with equations 10.28 and 10.29 from (IPCC 2006):
N_2O_indirect_perHead_Leach = Nex(T) * MS(T,S) * (FracLeachMS/100) * EF5(S) * 44/28
with
FracleachMS = percent of managed manure nitrogen losses for livestock category T due to runoff and leaching during solid and liquid storage of manure (typical range 1-20%)
EF5 = emission factor (share - i.e. %/100) for N_2O emissions from nitrogen leaching and runoff, kg N_2O-N/kg N leached and runoff (default value 0.0075 kg N_2O-N (kg N leaching/runoff)$^{-1}$, given in Chapter 11, Table 11.3
unit: t N2O/head/year

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O leach (tN2O)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
    *sum(ManureManSystem,
       Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N leach (% of N in manure)",ManureManSystem,"AllAndAverageTemp",
       ProductionSystems,ProductionConditions,"%Scenario%")/100
     *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Manure man N2O-N from N leach (tN/tN leach)",ManureManSystem,"AllAndAverageTemp",
```

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```
        ProductionSystems,ProductionConditions,"%Scenario%")
      *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Quantity share in ManureMan system",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%"))
       *44/28;
```

Convert to t CO2eq/head/year

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O leach (tCO2e)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O leach (tN2O)",ProductionSystems,ProductionConditions,"%Scenario%")
      *GWP_GTP_SOLm_MR("N2O","%Scenario%");
```

and calculate the related N quantity:
unit: t N /head/year

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N leach (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystem,
        Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N leach (% of N in manure)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")/100
      *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Quantity share in ManureMan system",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%"));
```

Now derive N2O indirect leach per ton manure TS DM:
E/t manure (Manman syst) = (E/head (If all manure would be managed in ONE manman syst) / (Manure/head)
unit t N / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N leach (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
      $ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "N in manure (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
      *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N leach (% of N in manure)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")/100
      /ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%");
```

Derive the corresponding N_2O emissions:
unit: t N_2O / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O leach (tN2O)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
= Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N leach (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
     *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O-N from N leach (tN/tN leach)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")
       *44/28;
```

Derive he corresponding GHG emissions:
unit: t CO_2eq / t manure TS DM

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O leach (tCO2e)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
```

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```
= Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O leach (tN2O)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")
      *GWP_GTP_SOLm_MR("N2O","%Scenario%");
```

```
                  2.3.3) Total N and GHG emissions and losses from manure management
```

Now sum the N emissions and losses via direct and indirect paths to get total N losses from manure management:

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O total (tCO2e)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O dir (tCO2e)",ProductionSystems,ProductionConditions,"%Scenario%")
   + ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O volat (tCO2e)",ProductionSystems,ProductionConditions,"%Scenario%")
   + ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O leach (tCO2e)",ProductionSystems,ProductionConditions,"%Scenario%");

ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N total loss (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N in N2O dir (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
   + ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N volat (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
   + ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N leach (tN)",ProductionSystems,ProductionConditions,"%Scenario%");

Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O total (tCO2e)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
= Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O dir (tCO2e)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")
   + Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O volat (tCO2e)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")
   + Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N2O leach (tCO2e)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%");

Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N total loss (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
= Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N in N2O dir (tN)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")
   + Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N volat (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
   + Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man N leach (tN)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%");
```

***IMPORTANT: Add N_2 losses from denitrification explicitly to track N_2 losses from denitrification for the N balances and thus to get a better grasp for the N surplus!!**

```
         2.4) P emissions
```

Unit: tP_2O_5 lost/t manure TS DM per year

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man P total loss (tP2O5)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")
= Manure_Contents_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "P in TS DM (tP2O5/t TS DM)",ProductionSystems,ProductionConditions,"%Scenario%")
     *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
```

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```
        "Manure man P loss as % of P in manure (%)",ManureManSystem,"AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")/100;
```

*derive per animal head values:
*unit: t P_2O_5 /head/year

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure man P total loss (tP2O5)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "P in manure (tP2O5)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystem,
        Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Manure man P loss as % of P in manure (%)",ManureManSystem,
                "AllAndAverageTemp",ProductionSystems,ProductionConditions,"%Scenario%")/100
       *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Quantity share in ManureMan system",ManureManSystem,"AllAndAverageTemp",
                ProductionSystems,ProductionConditions,"%Scenario%"));
```

```
          2.5) N and P available for fertilization
```

Here, the reminder of N and P in manure, after subtracting losses, is calculated. This is the amount that is in principle available for fertilization.

```
Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure N for areas (tN)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
= Manure_Contents_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "N in TS DM (tN/t TS DM)",ProductionSystems,ProductionConditions,"%Scenario%")
     - Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Manure man N total loss (tN)",ManureManSystem,"AllAndAverageTemp",
                ProductionSystems,ProductionConditions,"%Scenario%");

Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure P for areas (tP2O5)",ManureManSystem,"AllAndAverageTemp",ProductionSystems,
        ProductionConditions,"%Scenario%")
= Manure_Contents_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "P in TS DM (tP2O5/t TS DM)",ProductionSystems,ProductionConditions,"%Scenario%")
     - Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Manure man P total loss (tP2O5)",ManureManSystem,"AllAndAverageTemp",
                ProductionSystems,ProductionConditions,"%Scenario%");
```

Subsequently, negative values are set equal zero (see code file for details).
Then convert to per animal head values, and differentiate between N and P for crop and grassland areas:

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure N for crop areas (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystemCropland,
        Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Manure N for areas (tN)",ManureManSystemCropland,"AllAndAverageTemp",
                ProductionSystems,ProductionConditions,"%Scenario%")
       *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Quantity share in ManureMan system",ManureManSystemCropland,
                "AllAndAverageTemp",ProductionSystems,ProductionConditions,"%Scenario%"));

ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure N for grass areas (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystemGrassland,
       Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Manure N for areas (tN)",ManureManSystemGrassland,"AllAndAverageTemp",
                ProductionSystems,ProductionConditions,"%Scenario%")
       *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
```


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```
                "Quantity share in ManureMan system",ManureManSystemGrassland,
                "AllAndAverageTemp",ProductionSystems,ProductionConditions,"%Scenario%"));

ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure P for crop areas (tP2O5)",ProductionSystems,ProductionConditions,"%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystemCropland,
        Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Manure P for areas (tP2O5)",ManureManSystemCropland,"AllAndAverageTemp",
                ProductionSystems,ProductionConditions,"%Scenario%")
         *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Quantity share in ManureMan system",ManureManSystemCropland,
                "AllAndAverageTemp",ProductionSystems,ProductionConditions,"%Scenario%"));

ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure P for grass areas (tP2O5)",ProductionSystems,ProductionConditions,
        "%Scenario%")
= ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "TS DM in manure (tTS)",ProductionSystems,ProductionConditions,"%Scenario%")
     *sum(ManureManSystemGrassland,
        Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Manure P for areas (tP2O5)",ManureManSystemGrassland,"AllAndAverageTemp",
                ProductionSystems,ProductionConditions,"%Scenario%")
    *Manure_Management_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
                "Quantity share in ManureMan system",ManureManSystemGrassland,
                "AllAndAverageTemp",ProductionSystems,ProductionConditions,"%Scenario%"));
```

To run these calculations, **no inputs need to be specified** in the scenario assumptions (as all values are available via the initialization (cf. section 9.2.8); but they can be changed in the scenario assumptions, if needed).

9.2.15 _V6_CoreModelEquations_EntericFermentation

This file contains the equations for calculating enteric fermentation emissions, based on (IPCC 2006). The table of contents is:

```
$ontext;
- 1) Enteric fermentation
$offtext;
```

In more detail:

```
- 1) Enteric fermentation
```

This calculates enteric fermentation as a function of GE uptake, (IPCC 2006), chapter 10, tier 2, equation 10.21:

EF = (GE * Ym/100 * 365) / 55.65

with

EF = emission factor, kg CH_4 head^{-1} yr^{-1}

GE = gross energy intake, MJ head^{-1} year^{-1} (in the IPCC 2006 documents it is per day, but here in the code it is already per year, as GE is per year: thus, NO factor 365 is needed, but a division by 1000 is needed, as we want tons per year, and not kg per year.

Ym = methane conversion factor, per cent of gross energy in feed converted to methane coded as `FeedingRations_OtherChar_MR(Regions,Activities,AnimalTypeInHerd,Commodities,"Percentage GE in feed converted to enteric CH4",ProductionSystems,ProductionConditions,"Baseline")`.

The factor 55.65 (MJ/kg CH_4) is the energy content of methane.

Ym is taken from tables 10.12 und 10.13; the values are basically 6.5% for all cases besides >90% concentrates-fed cattle: there it is 3%. And lambs from sheep have 4.5% (< 1 year). Thus assume a linear relation with the

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share of concentrates, and disregard the special value for lamb for now, as we do not differentiate the different roles in the herd for sheep.

```
ActAnimalsHead_Outputs_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "Enteric ferment (t CO2e)",ProductionSystems,ProductionConditions,"%Scenario%")
= (ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedGE_Req_Total from Conc (MJ)",ProductionSystems,ProductionConditions,"%Scenario%")
    *FeedingRationsHeads_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "AggregateFeedConcentrates_Commodity",
       "Percentage GE in feed converted to enteric CH4",
       ProductionSystems,ProductionConditions,"%Scenario%")
    + ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedGE_Req_Total from Forage (MJ)",ProductionSystems,
       ProductionConditions,"%Scenario%")
     *FeedingRationsHeads_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "AggregateFeedForageCrops_Commodity",
       "Percentage GE in feed converted to enteric CH4",
       ProductionSystems,ProductionConditions,"%Scenario%")
    + ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedGE_Req_Total from Grass (MJ)",ProductionSystems,
       ProductionConditions,"%Scenario%")
     *FeedingRationsHeads_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "AggregateFeedGrass_Commodity",
       "Percentage GE in feed converted to enteric CH4",
       ProductionSystems,ProductionConditions,"%Scenario%")
    + ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "FeedGE_Req_Total from Residues (MJ)",ProductionSystems,
       ProductionConditions,"%Scenario%")
     *FeedingRationsHeads_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
       "AggregateFeedResidues_Commodity",
       "Percentage GE in feed converted to enteric
       CH4",ProductionSystems,ProductionConditions,"%Scenario%"))
  *GWP_GTP_SOLm_MR("CH4","%Scenario%")/100/55.65/1000;
```

To run these calculations, **no inputs need to be specified** in the scenario assumptions (as all values are available via the initialization (cf. section 9.2.8); but they can be changed in the scenario assumptions, if needed).

9.2.16 _V6_CoreModelEquations_FertilizerApplication

This file contains the equations for fertilizer application. The table of contents is:

```
$ontext;
- 1) Total fertilizer supply
         1.1) Manure
         1.2) Crop residues
         1.3) Mineral fertilizers
- 2) Relative nutrient requirements for the different crops and grasses
- 3) Fertilizer allocation to crops and grassland
$offtext;
```

In more detail:

```
- 1) Total fertilizer supply
         1.1) Manure
```

Derive total manure N available to be put on the field (crop and grass), per geographic unit. This is based on per animal head values for manure N for areas, multiplied with animal numbers and summed over all animals:

```
VManure_Management_MR.l(Regions_MR,"All Animals","AllAndAverageTypes",
       "Manure N for crop areas (tN)","AllManManSystems","AllAndAverageTemp",
```


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```
        ProductionSystems,ProductionConditions,"%Scenario%")
= sum((Livestock_MR,AnimalTypeInHerd_MR),
        ActAnimalsHead_Outputs_MR(Regions_MR,Livestock_MR,AnimalTypeInHerd_MR,
           "Manure N for crop areas (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
    *VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Livestock_MR,AnimalTypeInHerd_MR,
               ProductionSystems,ProductionConditions,"%Scenario%"));

VManure_Management_MR.l(Regions_MR,"All Animals","AllAndAverageTypes",
        "Manure N for grass areas (tN)","AllManManSystems","AllAndAverageTemp",
        ProductionSystems,ProductionConditions,"%Scenario%")
= sum((Livestock_MR,AnimalTypeInHerd_MR),
        ActAnimalsHead_Outputs_MR(Regions_MR,Livestock_MR,AnimalTypeInHerd_MR,
          "Manure N for grass areas (tN)",ProductionSystems,ProductionConditions,"%Scenario%")
    *VActAnimalsHead_QuantityActUnits_MR.l(Regions_MR,Livestock_MR,AnimalTypeInHerd_MR,
               ProductionSystems,ProductionConditions,"%Scenario%"));
```

Similarly, derive the total manure P available to be put on the field (crop and grass), per geographic unit (for details, see the code file).

```
         1.2) Crop residues
```

Derive the total crop residue N and P available to be put on the field, per geographic unit. Sum over all crops and crop residue management systems (also including “left on field” - this is also applied to other crops due to other crops standing next season, etc. – on average, such a sum is thus ok):

```
VCropResidues_Management_MR.l(Regions_MR,"All Crops","Average Residues (t)",
        "Crop res N for areas (tN)","AllAndAverageCropResManSystem",ProductionSystems,
        ProductionConditions,"%Scenario%")
= sum((Crops_MR,CropResManSystemCropland),
        VCropResidues_Management_MR.l(Regions_MR,Crops_MR,"Average Residues (t)",
               "Crop res N for areas (tN)",CropResManSystemCropland,ProductionSystems,
               ProductionConditions,"%Scenario%"));
```

Similarly, derive the total crop residue P available to be put on the field, per geographic unit (for details, see the code file).

For grass, the residues are the difference between yield and harvest/grazing, thus they remain on the land, thus no sum over different grassland, etc. and no removal to cropland occurs, thus just use the following values:

```
VCropResidues_Management_MR.l(Regions_MR,CoreGrassActivities,"Average Residues (t)",
        "Crop res N for areas (tN)","AllAndAverageCropResManSystem",ProductionSystems,
        ProductionConditions,"%Scenario%")
= sum(CropResManSystemGrassland,
        VCropResidues_Management_MR.l(Regions_MR,CoreGrassActivities,"Average Residues (t)",
               "Crop res N for areas (tN)",CropResManSystemGrassland,ProductionSystems,
               ProductionConditions,"%Scenario%"));
```

Similarly, derive the total grass residue P available to be left on the field, per geographic unit (for details, see the code file).

```
         1.3) Mineral fertilizers
```

Total mineral N and P fertilizer requirements per geographic unit are derived by either using values as specified in the scenario assumptions, or by scaling the baseline total mineral fertilizer quantities by the changes in total N and P requirements, either for cropland only or for cropland PLUS temporary grassland (this can be chosen at the beginning of steering file 2, cf. section 8.3). Thus, the Baseline quantity is multiplied by the requirements in the scenario and divided by the baseline requirements. For details, see the code file.

```
- 2) Relative nutrient requirements for the different crops and grasses
```

Derive various types of N and P requirements per crop in relation to total N and P requirements of all crops (or all crops PLUS temporary grassland, etc.). This parameter is then used below as a proportionality factor to allocate total available nutrients to single crops. For details, see the code file.

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```
- 3) Fertilizer allocation to crops and grassland
```

The allocation of N in manure, residues and mineral fertilizers is derived by allocating the respective total quantity available per geographic region to the single crops in proportion to their relative N requirement as a share of the N requirement of all crops in this region. P from mineral fertilizers is also allocated like this. P in manure and residues is derived from the quantity of manure and residues applied due to the allocation rule for N application, because the quantity of P in manure and residues is linked to the quantity of N applied and cannot be chosen independently anymore. Thus, when applying a certain amount of N in manure and residues, this comes with a certain amount of biomass, which contains a certain amount of P. For details, see the code file.

To run these calculations, the following inputs **may/likely need to be specified** in the scenario assumptions (all other values are available via the initialization (cf. section 9.2.8); but also they can be changed in the scenario assumptions, if needed). These quantities can also be derived in the code, but for some scenarios, they will be provided in the scenario assumptions.

- the mineral N and P fertilizer quantities:

```
VMineralFertilizerQuantity_MR.l(Regions_MR,"mineral N fert (N)","AllMinFertProdTech","AllProdSyst","%Scenario%")

VMineralFertilizerQuantity_MR.l(Regions_MR,"mineral P fert (P2O5)","AllMinFertProdTech","AllProdSyst","%Scenario%")
```

9.2.17 _V6_CoreModelEquations_FertilizerApplicationEmissions

This file contains the equations for the emissions from fertilizer application. The table of contents is:

```
$ontext;
- 1) Direct N2O emissions and N losses from fertilizer application
        1.1) Direct N2O emissions from fertilizer application
        1.2) Corresponding direct N losses from fertilizer application:
- 2) Indirect N2O emissions and N losses from fertilizer application
        2.1) Indirect N2O emissions from fertilizer application
        2.2) Corresponding indirect N losses from fertilizer application:
- 3) Adapt N deposition to manure quantities and fertilizer use
$offtext;
```

In more detail:

```
- 1) Direct N2O emissions and N losses from fertilizer application
        1.1) Direct N2O emissions from fertilizer application
```

First, some preparatory calculations on manure application are executed, to simplify the data, which is quite large for this parameter. Currently, this consists in replacing the activity dimension by “AllCrops” and “Grass” only, as the values are identical for all crop activities and for all grass activities, and it is thus not efficient to retain all these identical values for all these different activities. For details, see the code file.

Then, the emissions from fertilizer application are derived: direct N_2O emissions, emissions from volatilization and leaching, NH_3 emissions (as part of the emissions from volatilization), and corresponding N losses from direct emissions, and from volatilization and leaching. All these are provided for mineral fertilizers, manure and residues. They are all derived based on the emission factors from (IPCC 2006), emissions per ton N applied, and the amount of N applied per hectare. In the following, we list the parameters derived here, using the example of mineral fertilizer (similar for manure, residues). For further details, see the code file.

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Direct N_2O emissions from fertilizer application, units: t CO_2eq / ha

```
ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,
        "Direct N2O from mineral fert N applic (tCO2e)",ProductionSystems,
        ProductionConditions,"%Scenario%")
```

```
         1.2) Corresponding direct N losses from fertilizer application:
```

Direct N losses from fertilizer application, units: t N / ha

```
ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,
        "Direct N loss from mineral fert N applic (tN)",ProductionSystems,
        ProductionConditions,"%Scenario%")
```

```
- 2) Indirect N2O emissions and N losses from fertilizer application
         2.1) Indirect N2O emissions from fertilizer application
```

Indirect N_2O emissions from volatilization from fertilizer application units: t CO_2eq/ha

```
ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,
        "N2O volat from mineral fert N applic (tCO2e)",ProductionSystems,
        ProductionConditions,"%Scenario%")
```

Do NH_3 emissions as specific part of the volatilization, units: t NH_3/ha

```
ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,
        "NH3 from mineral fert N applic (tNH3)",ProductionSystems,
        ProductionConditions,"%Scenario%")
```

Indirect N_2O emissions from leaching from fertilizer application units: t CO_2eq/ha

```
ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,
        "N2O leach from mineral fert N applic (tCO2e)",ProductionSystems,
        ProductionConditions,"%Scenario%")
```

```
         2.2) Corresponding indirect N losses from fertilizer application:
```

N losses from volatilisation and leaching from fertilizer application. As with the emissions from manure management (section 9.2.14), this is not only the N that is lost via N_2O, but ALL N that is lost via volatilization and leaching; units: t N/ha

```
ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,
        "N volat from mineral fert N applic (tN)",ProductionSystems,
        ProductionConditions,"%Scenario%")

ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,
        "N leach from mineral fert N applic (tN)",ProductionSystems,
        ProductionConditions,"%Scenario%")
```

9.2.18 _V6_DeriveAggregateImpacts_PerUnit

This code calculates various totals (on a per unit (i.e. ha, head, etc.) basis), such as the sum of all GHG emissions related to cropland use (i.e. fertilizer application, deforestation, etc.), or to animals (i.e. enteric fermentation plus manure management). On this level not yet including the embodies emissions in inputs.

The following parameters are calculated; for details, see the code file:

```
ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,
        "Total GHG em. - crops, incl. defor/orgSoils (tCO2e)",ProductionSystems,ProductionConditions,Scenarios)
ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,
        "Total GHG em. - crops, no defor/orgSoils (tCO2e)",ProductionSystems,ProductionConditions,Scenarios)
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Total N-losses from animals, i.e. manure management (tN)",ProductionSystems,ProductionConditions,Scenarios)
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Manure Man GHG emissions - animals (tCO2e)",ProductionSystems,ProductionConditions,Scenarios)
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
        "Total GHG emissions - animals (tCO2e)",ProductionSystems,ProductionConditions,Scenarios)
ActCropsGrass_Inputs_MR(Regions_MR,Activities_MR,"N inputs - crops (tN)",ProductionSystems,ProductionConditions,Scenarios)
```


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```
ActCropsGrass_Outputs_MR(Regions_MR,Activities_MR,"N outputs - crops (tN)",ProductionSystems,ProductionConditions,Scenarios)
ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,
          "N balance - plot level based (tN)",ProductionSystems,ProductionConditions,Scenarios)
ActCropsGrass_OtherChar_MR(Regions_MR,Activities_MR,"NH3 from areas (tNH3)",ProductionSystems,ProductionConditions,Scenarios)
ActAnimalsHead_OtherChar_MR(Regions_MR,Activities_MR,AnimalTypeInHerd,
          "NH3 from animals, i.e. manure management (tNH3)",ProductionSystems,ProductionConditions,Scenarios)
```

9.2.19 _V6_DeriveTotalImpacts

This file contains the code to derive the TOTAL impacts from the impacts per unit, i.e. per ha, per ton and per animal head or per APU values, by multiplication of the per unit impacts with the activity quantities, i.e. number of hectares, tons, animal heads, or APUs. For details, see the code file.

9.2.20 _V6_DeriveGeographicAggregations

This code sums the various total impacts over geographic groups (e.g. deriving values for “Southern Europe”, “Western Africa” or “World” by summing the corresponding values for all countries in these regions). For details, see the code file.

9.2.21 _V6_DeriveActivityGroupAggregations

This code sums the various total impacts over activity groups (e.g. deriving values for “Cereals”, “Treenuts” or “Ruminants” by summing the corresponding values for all activities in these activity groups. For details, see the code file.

9.2.22 _V6_DerivePerAPUValues

This code derives per animal production unit (APU) input, output and other values, based on the corresponding per animal head values and the herd structure. Thus, it is a weighted sum of the per animal head values with the relative share of the respective herd type animals in the APU. For details, see the code file.

9.2.23 _V6_DerivePerPrimaryProductImpacts

This file contains the code to derive per primary product values for inputs, outputs, other characteristics (focusing on environmental impacts) from the corresponding per activity values. Thus, for example, it derives per ton values from per hectare and yield values. For details, see the code file.

9.2.24 _V6_DeriveAggregateImpacts_PrimProd

This file contains the code to derive some aggregate impacts **per primary product** (on a per unit basis: per hectare, ton, etc.) - such as summing all parts of GHG emissions, coding the OECD-N-Balance, etc. It is organized by first defining subsets over which to be summed, and then doing the sums. The table of contents is:

```
$ontext;
- 1) Derive aggregate impacts
         1.1) Subsets for aggregations
         1.2) Code for aggregation

$offtext;
```


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In more detail:

```
- 1) Derive aggregate impacts
        1.1) Subsets for aggregations
```

Currently, this looks as follows:

"Total GHG emissions - crops, incl. deforest and org. soils (tCO2e)"

```
Set Subset_GHGEmissionsCrops_InclDeforestOrgSoils(PerCommodImpact)
/
"Deforest GHG emissions (tCO2e)"
"CultOrgSoils GHG emissions (tCO2e)"
"CultOrgSoils C emissions (tCO2e)"
"CultOrgSoils N2O emissions (tCO2e)"
"Direct N2O from mineral fert N applic (tCO2e)"
"Direct N2O from CropRes/biomass as fert N applic (tCO2e)"
"Direct N2O from manure as fert N applic (tCO2e)"
"N2O leach from mineral fert N applic (tCO2e)"
"N2O leach from CropRes/biomass as fert N applic (tCO2e)"
"N2O leach from manure as fert N applic (tCO2e)"
"N2O volat from mineral fert N applic (tCO2e)"
"N2O volat from CropRes/biomass as fert N applic (tCO2e)"
"N2O volat from manure as fert N applic (tCO2e)"
"CH4 flooded rice (tCO2e)"
/;
```

"Total GHG emissions - crops, no deforest and org. soils (tCO2e)"

```
Set Subset_GHGEmissionsCrops_NoDeforestOrgSoils(PerCommodImpact)
/
"Direct N2O from mineral fert N applic (tCO2e)"
"Direct N2O from CropRes/biomass as fert N applic (tCO2e)"
"Direct N2O from manure as fert N applic (tCO2e)"
"N2O leach from mineral fert N applic (tCO2e)"
"N2O leach from CropRes/biomass as fert N applic (tCO2e)"
"N2O leach from manure as fert N applic (tCO2e)"
"N2O volat from mineral fert N applic (tCO2e)"
"N2O volat from CropRes/biomass as fert N applic (tCO2e)"
"N2O volat from manure as fert N applic (tCO2e)"
"CH4 flooded rice (tCO2e)"
/;
```

"Total N-losses from animals, i.e. manure management (tN)"

```
Set Subset_NLossesAnimals(PerCommodImpact)
/
"Manure man N in N2O dir (tN)"
"Manure man N volat (tN)"
"Manure man N leach (tN)"
"Manure man N total loss (tN)"
/;
```

"Total GHG emissions - animals (tCO2e)"

```
Set Subset_GHGEmissionsAnimals(PerCommodImpact)
/
"Manure man GHG total (tCO2e)"
"Manure man N2O leach (tCO2e)"
"Manure man N2O volat (tCO2e)"
"Manure man N2O dir (tCO2e)"
"Manure man CH4 (tCO2e)"
"Enteric ferment (t CO2e)"
/;
```

"N inputs - crops (tN)"

```
Set Subset_N_InputsCrops(PerCommodImpact)
/
```

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```
"N fixation (tN)"
"N deposition (tN)"
"N from CropRes/biomass as fert (tN)"
"N from mineral fert (tN)"
"N from manure as fert (tN)"
/;
```

"N outputs - crops (tN)"

```
Set Subset_N_OutputsCrops(PerCommodImpact)
/
"N in MainOutput1 (tN)"
"N in residues - per ton MainOutput1 (tN)"
/;
```

"NH3 from areas (tNH3)"

```
Set Subset_NH3_from_Fields(PerCommodImpact)
/
"NH3 from soils (tNH3)"
"NH3 from mineral fert N applic (tNH3)"
"NH3 from CropRes/biomass as fert N applic (tNH3)"
"NH3 from manure as fert N applic (tNH3)"
/;
```

"NH3 from animals, i.e. manure management (tNH3)"

```
Set Subset_NH3_from_Animals(PerCommodImpact)
/
"Manure man NH3 (tNH3)"
/;
```

1.2) Code for aggregation

The code for aggregation then looks as follows, for example – for other cases and further details, see the code file (the $-condition is used to assign this only for crops where there is a non-zero area and for animals where there is a non-zero number of heads reported):

```
ActCropsGrass_PerPrimProdImpact_MR(Regions_MR,Activities_MR,
        "Total GHG em. - crops, incl. defor/orgSoils (tCO2e)",ProductionSystems,
        ProductionConditions,Scenarios)
                $VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Activities_MR,
                ProductionSystems,ProductionConditions,Scenarios)
=sum(Subset_GHGEmissionsCrops_InclDeforestOrgSoils,
        ActCropsGrass_PerPrimProdImpact_MR(Regions_MR,Activities_MR,
                Subset_GHGEmissionsCrops_InclDeforestOrgSoils,ProductionSystems,
                ProductionConditions,Scenarios));
```

9.2.25 _V6_DerivePerCommodityImpacts

This file contains the code to derive per commodity values for inputs, outputs, other characteristics (focusing on environmental impacts) from the corresponding per primary product values, by means of the extraction rates, etc. For details, see the code file.

9.2.26 _V6_OutputFiles_SteeringFile2

This file contains the code to produce the following gdx-files. See the code file for details on what is contained in each of those files.

- GeneralModelSets_MR.gdx
- GeneralModelParameters_Inputs_MR.gdx
- GeneralModelParameters_Outputs_MR.gdx

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- GeneralModelParameters_OtherChar_MR.gdx
- GeneralModelParameters_Various_MR.gdx
- GeneralModelParameters_Auxiliary_MR.gdx
- GeneralModelVariables_ActivityQuantities_MR.gdx
- GeneralModelVariables_Inputs_MR.gdx
- GeneralModelVariables_Outputs_MR.gdx
- GeneralModelVariables_OtherChar_MR.gdx
- GeneralModelVariables_Various_MR.gdx
- GeneralModelVariables_Trade_MR.gdx
- GeneralModelVariables_CommodityTree_MR.gdx
- GeneralModelVariables_Auxiliary_MR.gdx

9.2.27 _V6_ResultsFiles

This file contains all the code to produce some specifically designed results files with a selection of results of interest only, for further use, e.g. to produce graphs, etc.; for details, see the code file.

9.2.28 __SOLmV5_CoreModelEquations_SomeSpecialOutputForNFP69.gms

This file is currently not in use, it has to be transferred to SOLmV6 yet. It has been used to produce some additional specific output for a particular project. At this place in the steering file 2, other such files could be added, for some final calculations for additional specific output, as needed for single projects, etc.

9.3 Output files and graphics

SOLm provides a number of output files containing all parameters and variables used in the model (cf. section 9.2.26). It also provides specific results files, containing a restricted amount of parameter and variable values only, designed for efficient further processing, e.g. analysis of few core results, or as a basis for tables and figures for specific results (cf. section 9.2.27). The results can also be read out to excel-files, where graphics can be readily produced. If such figures are predefined in excel, GAMS can write new data to the excel-files, such as to readily generate the pre-defined graphics with this new data.

9.4 Scenario definitions

The general structure of the scenario assumption code file and the variables and parameters that have to or likely are assigned by scenario assumptions are described and listed in section 9.2.7.

Here, we display for illustration the assumptions for the scenario “BaselineDerived” which derives all baseline values from setting the cropping area numbers only and for the scenario “Baseline_100Organic” which switches the baseline situation to 100% organic production, based on a number of additional assumptions besides areas. These are relatively simple sets of scenario assumptions, and many more assumptions on parameters and variables can be added, on any aspects that may be changed in a scenario – for details see the code file “_V6_ScenarioAssumptions.gms”:

Further examples will be added later..

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Baseline derived:

```
*1) BaselineDerived
$label AssumptionsBaselineDerived

$setglobal UseProdSyst_ConvOrg "YES"

*assign areas (no organic areas)
VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,ProductionSystems,
       ProductionConditions,"%Scenario%")
= VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,ProductionSystems,
       ProductionConditions,"Baseline");

VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,"Convent",
       ProductionConditions,"%Scenario%")
= VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,"AllProdSyst",
       ProductionConditions,"Baseline");

$goto EndOfScenarioAssumptions
```

Baseline 100% organic:

```
*8) Baseline_100Organic
$label AssumptionsBaseline_100Organic

$setglobal UseProdSyst_ConvOrg "YES"

*assign areas as already assigned, but 0% convent, 100% organic:
VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,"Convent",
       ProductionConditions,"Baseline_100Organic")
         = 0;

VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,"Organic",
       ProductionConditions,"Baseline_100Organic")
  = VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,"AllProdSyst",
       ProductionConditions,"Baseline");

VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,"AllProdSyst",
       ProductionConditions,"Baseline_100Organic")
  = VActCropsGrass_QuantityActUnits_MR.l(Regions,Activities,"AllProdSyst",
       ProductionConditions,"Baseline");


*adjust legume area shares in case they are less than 20% in total:
VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Legumes (Nfixing)",
       ProductionSystems,ProductionConditions,"Baseline")
  =sum(Legumes_NFixing,VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Legumes_NFixing,
       ProductionSystems,ProductionConditions,"Baseline"));

VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Crops without Legumes (Nfixing)",
       ProductionSystems,ProductionConditions,"Baseline")
  =sum(Crops_NoNFixingLegumes,VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,
       Crops_NoNFixingLegumes,ProductionSystems,ProductionConditions,"Baseline"));

VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Crops",ProductionSystems,
       ProductionConditions,"Baseline")
  =sum(Crops_MR,VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Crops_MR,
       ProductionSystems,ProductionConditions,"Baseline"));

ActCropsGrass_OtherChar_MR(Regions_MR,"All Crops","Share legumes in cropland (share ha)",
       ProductionSystems,ProductionConditions,"Baseline")
     $VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Crops",ProductionSystems,
```


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```
= VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Legumes (Nfixing)",
        ProductionSystems,ProductionConditions,"Baseline")
     /VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Crops",ProductionSystems,
              ProductionConditions,"Baseline");

VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Legumes_NFixing,"Organic",
        ProductionConditions,"Baseline_100Organic")
     $(VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Legumes (Nfixing)",
        "AllProdSyst",ProductionConditions,"Baseline")
       AND (ActCropsGrass_OtherChar_MR(Regions_MR,"All Crops",
        "Share legumes in cropland (share ha)","AllProdSyst",
              ProductionConditions,"Baseline") < 0.2))
  = 0.2*VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Crops","AllProdSyst",
        ProductionConditions,"Baseline")
              *VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Legumes_NFixing,"AllProdSyst",
                     ProductionConditions,"Baseline")
                 /VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Legumes (Nfixing)",
                     "AllProdSyst",ProductionConditions,"Baseline");

VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Crops_NoNFixingLegumes,"Organic",
        ProductionConditions,"Baseline_100Organic")
     $(VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Crops without Legumes (Nfixing)",
        "AllProdSyst",ProductionConditions,"Baseline")
       AND (ActCropsGrass_OtherChar_MR(Regions_MR,"All Crops",
        "Share legumes in cropland (share ha)","AllProdSyst",
              ProductionConditions,"Baseline") < 0.2))
  = 0.8*VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,"All Crops","AllProdSyst",
        ProductionConditions,"Baseline")
              *VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,Crops_NoNFixingLegumes,
                     "AllProdSyst",ProductionConditions,"Baseline")
                 /VActCropsGrass_QuantityActUnits_MR.l(Regions_MR,
                     "All Crops without Legumes (Nfixing)",
                     "AllProdSyst",ProductionConditions,"Baseline");


*assign mineral N fertilizer values:
VMineralFertilizerQuantity_MR.l(Regions,"mineral N fert (N)","AllMinFertProdTech",
        "AllProdSyst","Baseline_100Organic")
  = VActCropsGrass_Inputs_MR.l(Regions,"All crops and grass","N from all fertilizers (tN)",
        "AllProdSyst","AllProdCond","Baseline")*0;
VMineralFertilizerQuantity_MR.l(Regions,"mineral N fert (N)","AllMinFertProdTech",
        "Convent","Baseline_100Organic")
  = VActCropsGrass_Inputs_MR.l(Regions,"All crops and grass","N from all fertilizers (tN)",
        "AllProdSyst","AllProdCond","Baseline")*0;

$goto EndOfScenarioAssumptions
```

9.5 Adding new data

New data is added in several steps towards the end of steering file 1 (cf. beginning of section 9.1), captured in specific files for organizing this (some examples are given further down in this section).

First, by adding better values of already existing ones, e.g. better country specific values on animal numbers and cropping areas than reported in FAOSTAT. This is done by replacing the old values with the better ones by assigning the latter to the corresponding parameters or variables.

Second, by adding new inputs, output, other characteristics, etc. to the variables and parameters, defining these new elements in the corresponding sets and then assigning the corresponding values.

Third, by defining new regions and activities and herd-structures, if needed (e.g. sub-regions of countries or sub-activities of existing activities or new activities, or new herd animal types) and then

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assigning data to these new regions and activities and herd animal types. The default for parameters values for new regions and activities is to assign existing data from the baseline or reference scenario values, as it fits (e.g. country values for parameters on sub-country levels). The default for total values for new regions and activities (variables) is to allocate them proportionally to some other variable (e.g. imports to sub-regions could be allocated proportionally to population). Where specific and better data for these total values is available, this is directly assigned, replacing these default values.

These new indicators etc. can also be derived from e.g. gridded data, process models on plot or farm level, etc. Thus, SOLm can link to such more refined models if their output is aggregated adequately.

Data for new herd structures is assigned similarly, by assigning parameter values from existing herd structure information that fits best (if no better data is directly provided from some new data set to be used), and by assigning variable values proportionally (similar to sub-regions, etc. as described above, in case the new herd structure refines the old one), or by assigning values from the best fitting category – of, if specific better data is available, by directly assigning this.

The following sections present some examples of files for reading new data.

9.5.1 _V6_ReadAdditionalData_SwitzerlandAustria

This code reads new more detailed data for Switzerland and Austria, as used in a completed project on the alpine region.

9.5.2 _V6_ReadAdditionalData_NUTS2_EU

This code reads new more detailed data for NUTS2 data for the EU as used in the H2020 project UNISECO.

9.5.3 _V6_ReadData_FAOSTAT_FOFA2050

This code reads the data for the food system projections to 2050 as presented in (FAO 2018).

9.5.4 _V6_ReadData_VariousSources_BioenergySR15

This code reads the data for the energy and food system projections to 2050 and 2100 as presented in (IPCC 2018), containing scenarios that massively rely on bioenergy with carbon capture and storage (BECCS).

9.6 Herd structures

This section describes the herd structures used in SOLm (cf. section 9.1.43). It is based on the supplementary information of (Schader, Muller et al. 2015).

Herd structures describe the composition of an animal herd in terms of different sub-classes defined according to age, sex and production purpose of the animal (Table 20). Herd structures were calculated for pigs and cattle based on assumptions relating to fertility rates, age of first calving, slaughtering rates and losses due to diseases and accidents (Table 21), calibrated using FAOSTAT data

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for producing animals, living animals (stocks), imports and exports. Herd structures were calculated for each country with a separate optimization model using a cross entropy estimator (Golan, Judge et al. 1996). These models predict the most likely average herd structure in a country, based on information that is available. Support points 1, 2 and 3 were defined based on expert opinions. While support point 2 describes a central value, support points 1 and 3 refer to the upper and lower bounds of a country-specific parameter.

$$H(p,q) = -\sum_{X} p(x) * \log q(x)$$

Where:
$H\ (p,q)$ is the entropy
$P\ (x)$ is the true distribution
$q\ (x)$ is the given probability distribution

This model has been run with baseline data averaging the years 2005-2009.

Table 20. Overview of livestock types defined in cattle, pig and chicken herd structure models

Herd	Sub-class	Description
Cattle	A_Dcow	Number of dairy cows
Cattle	A_Dsire	Number of dairy sires
Cattle	A_DFemaleCalf1	Number of female dairy calves aged 1 year
Cattle	A_DFemaleCalf2	Number of female dairy calves aged 2 years
Cattle	A_DFemaleCalf3	Number of female dairy calves aged 3 years
Cattle	A_DMaleCalf1	Number of male dairy calves aged 1 year
Cattle	A_DMaleCalf2	Number of male dairy calves aged 2 years
Cattle	B_Bcow	Number of beef cows
Cattle	B_Bsire	Number of beef sires
Cattle	B_BFemaleCalf1	Number of female beef calves aged 1 year
Cattle	B_BFemaleCalf2	Number of female beef calves aged 2 years
Cattle	B_BMaleCalf1	Number of male beef calves aged 1 year
Cattle	B_BMaleCalf2	Number of male beef calves aged 2 years
Pigs	A_Sows	Number of sows
Pigs	A_Boars	Number of boars
Pigs	A_Sucklers	Number of sucklers
Pigs	A_Weaners	Number of weaners

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Herd	Sub-class	Description
Pigs	A_Fatteners	Number of fatteners

Table 21. Overview of external variables of the cattle, pig and chicken herd structure models

Herd	Variable	Support point 1	Support point 2	Support point 3
Cattle	Share of calve losses in year 1	0.01	0.10	0.50
Cattle	Share of calve losses in year 2	0.01	0.10	0.50
Cattle	Share of calve losses in year 3	0.01	0.10	0.50
Cattle	Fertility rate of dairy cows	0.50	0.90	1.00
Cattle	Fertility rates of beef cows	0.50	0.80	1.00
Cattle	Calving rates	0.55	0.95	1.00
Cattle	Share of slaughtered male dairy calves aged 1 year	0.00	0.05	0.10
Cattle	Share of slaughtered female dairy calves aged 1 year	0.00	0.01	0.10
Cattle	Share of slaughtered female dairy calves aged 2 years	0.00	0.05	0.10
Cattle	Share of slaughtered male beef calves aged 1 year	0.00	0.05	0.10
Cattle	Share of slaughtered female beef calves aged 1 year	0.00	0.05	0.10
Cattle	Share of sires	0.0095	0.01	0.0105
Cattle	Dairy cow replacement rate	0.10	0.30	0.50
Cattle	Beef cow replacement rate	0.10	0.30	0.50
Cattle	Dairy sire replacement rate	0.10	0.30	0.50
Cattle	Beef sire replacement rate	0.10	0.30	0.50
Cattle	Age at first calving (years)	2.00	2.50	4.00
Pigs	Share of suckler losses	0.01	0.12	0.40
Pigs	Share of weaner losses	0.01	0.05	0.20
Pigs	Share of fattener losses	0.01	0.03	0.10
Pigs	Suckling period (days)	7.00	28.00	45.00
Pigs	Weaning period (days)	20.00	35.00	60.00

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Herd	Variable	Support point 1	Support point 2	Support point 3
Pigs	Fattening period (days)	80.00	120.00	250.00
Pigs	Litters per year	1.00	1.50	2.50
Pigs	Litter size	8.00	13.00	15.00
Pigs	Share of boars	0.01	0.08	0.10
Pigs	Culling rate of sows	0.20	0.40	0.50
Pigs	Culling rate of boars	0.25	0.40	0.50
Pigs	Age at first parturition (months)	12.00	15.00	18.00

All herd structures are based on a virtual starting population of each age and sex category (marked in Figure 14, Figure 15 and Figure 16 with the abbreviation ST). After one year the starting population is modified by: a) subtracting young animal losses (LO), animal slaughtering (SL), young animals entering the adult population (XC), and exports (EXP); and b) adding replacement animals (REP) and imports (IMP), to give an end of year population. The final number of animals in each category refers to the arithmetic mean of the start (ST) and end population numbers (EN). The end population of each cohort serves as the starting population for the next year (e.g. the end population of one year old animals in the first year serves as the starting population of two year old animals in the second year). For pigs of different age and sex categories, we calibrated the herds to one year. Average numbers (AV) are multiplied by the number of life cycles per year. For cattle, we defined a dairy and a beef herd structure. Each herd structure is linked through several conditions (purple boxes) which state that the total number slaughtered, living, imported and exported must equal the observed quantities in FAOSTAT.

Figure 14, Figure 15 and Figure 16 describe the herd structures and dynamics for dairy cattle, beef cattle and pigs. All herd structure figures should be read from left to right for each age and sex category. The dairy and beef herd structures are similar, except for the absence of third year female beef calves. Some support points also differ between dairy and beef cattle (Table 21).

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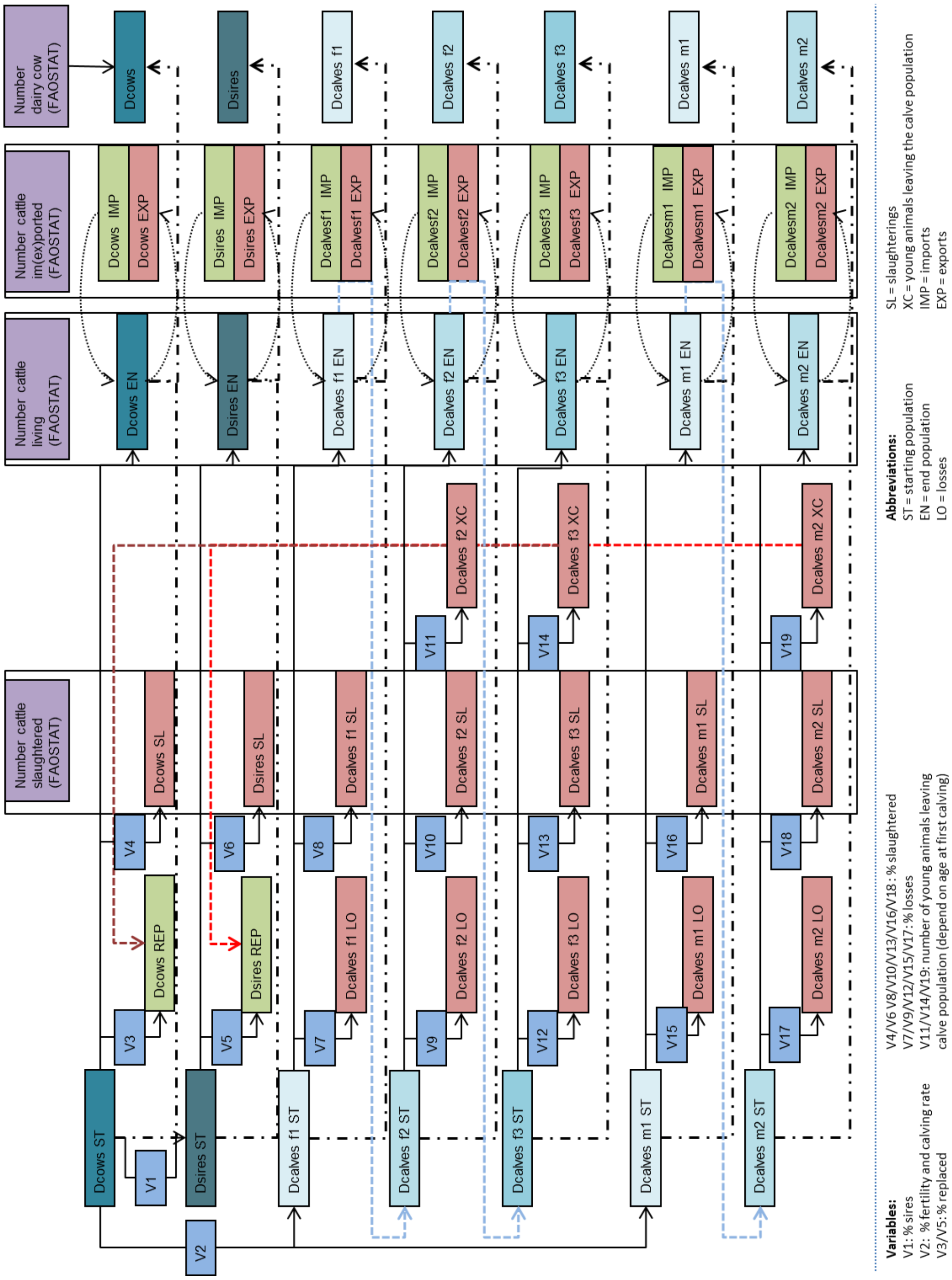

Figure 14. Illustration of dairy cow herd structure

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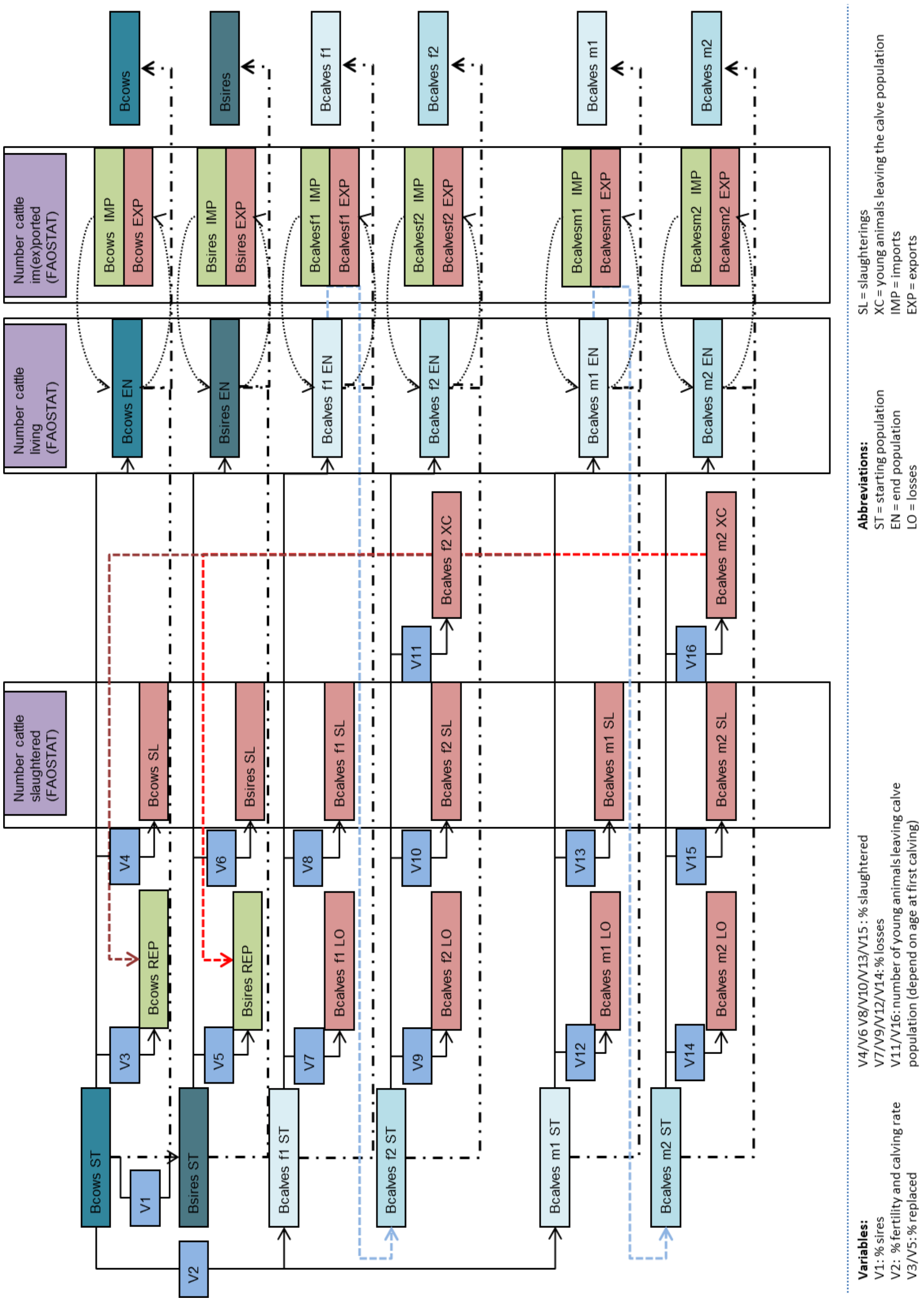

Figure 15. Illustration of beef cow herd structure

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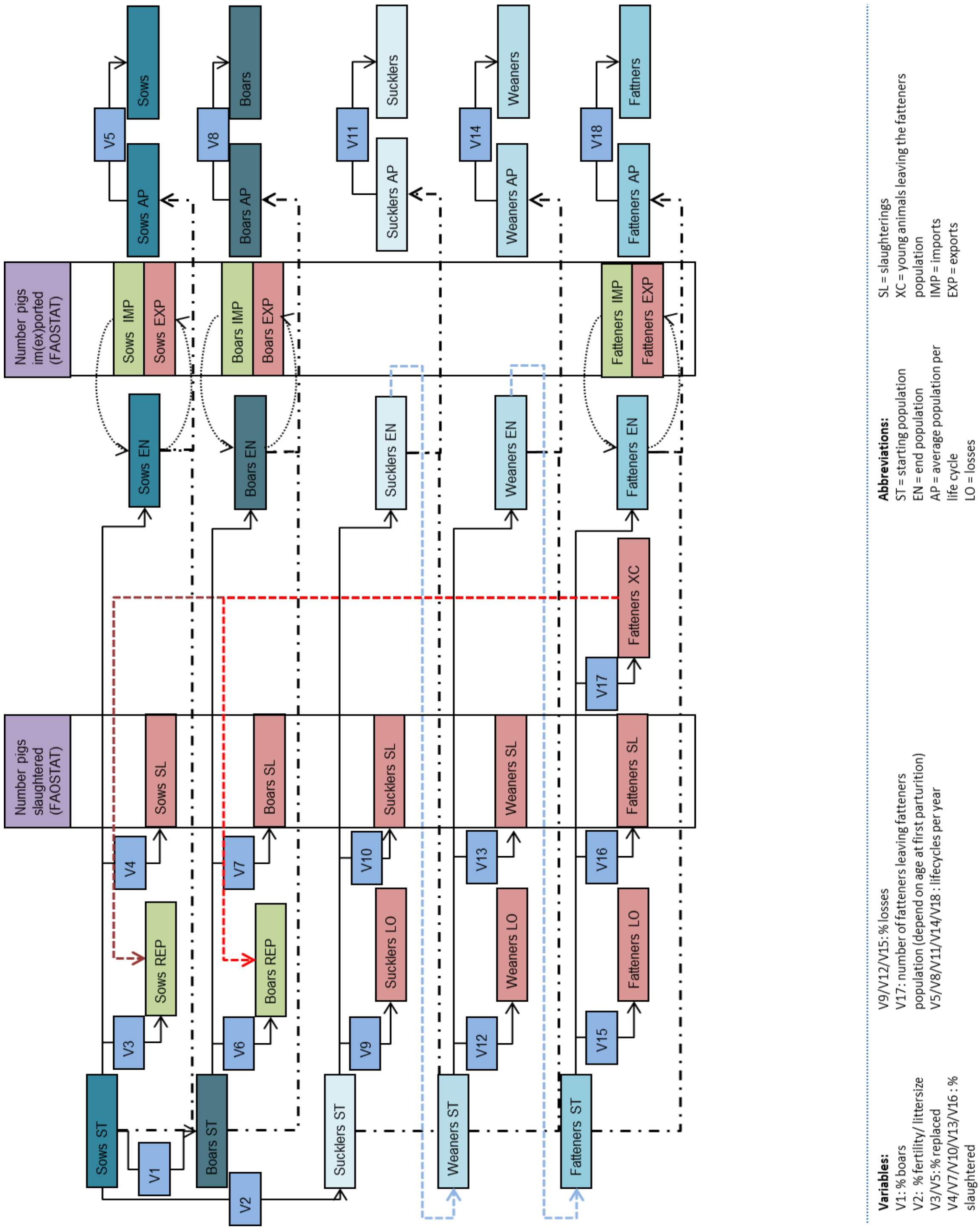

Figure 16. Illustration of pig herd structure

9.7 Feeding rations and feed supply for animals

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See also section 9.2.12. Currently, SOLm contains assumptions on feeding rations on the level of four feed groups, namely concentrates, forage crops, grass and residues. These feed groups are built from various commodities as defined in the corresponding set in section 9.1.15.14 (Match_FeedCommoditiesToFeedCommodGroups(Commodities,Commodities_2) and Match_FeedCommoditiesToFeedCommodGroups_MainByprodConc(Commodities,Commodities_2) differentiating between main products and byproducts for concentrate feed (second set) or not (first set)). Thus, currently, the feed groups are the same for all animal types (i.e. concentrates for cattle and pigs, for example, have the same composition). From the feeding rations, the requirements and the composition of the feed groups, it is then possible to derive the detailed commodity supply per animal and the related impacts of these commodity quantities and thus of the animal feed.

9.8 Crop rotations

Currently, crop rotations are dealt with by assuming fixed area shares of the different crop rotation elements. Thus, instead of cropping a number of different crops one season after the other on the same plot, it is captured by cropping the corresponding shares of the area for each crop (e.g. a rotation with five different crops on one hectare in five years is captured by allocating a fifth of a hectare to each of these crops).

Thus, there is no specific nutrient dynamics between different elements of the crop rotations captured, such as from soybeans in one year to maize in the subsequent year. Residues left on the field are currently treated as other residues (e.g. in compost) regarding application to soils (management losses are however zero for residues left on the field, and emissions from those are accounted for under application losses only; cf. section 9.2.16).

Another approach to model crop rotations in SOLmV6 is to define new activities that include all elements (e.g. “Soy-maize-rotation”) and report 50% of the annual yield only – but for each crop. The specific nutrient dynamics can then be captured by reducing the nutrient requirements from maize and the residue left on the field output from soy, for example.

9.9 Fish and Seafood

In SOLmV6, there is no default data on fish and seafood production from FAOSTAT, while FAOSTAT provides default values for commodity quantities. Fish and seafood production is thus captured in specific activities with corresponding input, output and other characteristics parameters and quantity variables and the default data for this is read in the code file “_V6_ReadData_VariousSources_FishAndSeafoodData.gms”. In this file, the commodity quantities from FAOSTAT are then also adjusted to be consistent with the production values read in. Part of the domestically available quantities for feed are allocated to fish and seafood and then not available for livestock anymore. This is organized in code file “_V6_CoreModelEquations_NutrientRequirementsAndFeedSupply.gms”.

9.10 Bioenergy

Currently, bioenergy is captured via two activities, namely miscanthus and residues from forestry. For the former, input needs regarding nitrogen demand are specified, and for both it is derived how much nitrogen may be recycled to the fields after the various processing steps for energy generation.

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The data is taken from (IPCC 2018), both for the baseline (here the year 2010) and several scenarios for 2050. For details, see section 9.1.65.

9.11 Fertilizer Application

SOlm calculates the fertilizer application levels per ha based on the nutrient requirements of the plants. These nutrient requirements are either provided by baseline or reference scenario data to be read explicitly (not included in the default data), or by the nutrients in the total outputs from the activities (i.e. in the sum of the main products and residues, cf. section 9.2.16, and in detail, section 9.2.11).

The nutrients available per region are then applied proportionally to these requirements. This applies for nitrogen in manure, residues and mineral fertilizers and for phosphorus in mineral fertilizers. Phosphorus in manure and residues is calculated from the quantities of manure and residues applied, which have been derived based on the nitrogen application in these fertilizers (i.e. choosing the quantity of manure and residues based on nitrogen determines how much phosphorus is then applied, as the phosphorus quantity applied is not independent of the nitrogen quantity, both being related to the quantity of manure and residues via their contents.

The nutrients applied are thus dependent on the yield levels. Currently, yields do however not directly react to nutrient inputs. Furthermore, the nutrient inputs derived like this may not reflect values reported in the literature. This is due to these latter often being determined in optimal systems without massive over-fertilization, for example fertilization rates suggested by advisory services' institutions, while the former account for the overall nutrient availability in a region, which can be way beyond what would be required from the crops, but which is in reality nevertheless applied to the fields (e.g. nutrients in manure in regions of massive concentrate feed imports resulting in oversupply of nutrients in manure).

Nutrient supply levels thus result in an indicator of nutrient oversupply (in case the total nutrient balance of nutrient inputs minus nutrient outputs is positive) or undersupply (in the opposite case). In a situation of oversupply, the nutrients not used are largely lost to the environment. In the case of undersupply, yield levels may be kept due to some non-reported nutrient flows, e.g. from the soil pool. But in general, undersupply rather indicates that the production as modelled in this case is not possible and that yields should be lower or additional fields need to be cropped with legumes to provide sufficient nutrients.

Currently, this is taken up by reporting the nutrient undersupply as some risk level for yield drops or the yields are adjusted downwards or the legume areas are increased in additional scenario runs, to achieve a more balanced situation where nutrient supply and demand match better. This is then implemented by corresponding scenario assumptions: The dependence of yields on nitrogen supply can in a first approximation be modelled as a linear relation between nitrogen inputs and yields (e.g. (Godard, Roger-Estrade et al. 2008)). This however may tend to underestimate yields. At lower supply levels, changes in yields in reaction to changes in nitrogen supply tend to be larger than at higher levels and the response curve is concave rather than linear. It thus can be captured in more detail by crop specific response functions of yields to nitrogen supply taken from the literature.

It is also important to emphasize that the "equilibrium view" adopted in SOLm, as described in section 7.2 also influences how fertilization application and nutrient availability is to be understood.

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Nutrient balances, etc. are calculated on the basis of the annual input and output values, but it is implicitly assumed that part of the nutrients applied are stored in the soil for one, two or more years, but that corresponding nutrient quantities are also released from the soil in the given year, one, two or more years after their earlier applications. This could be refined by adding data on nutrient storage in and release from the soils, but this is not part of SOLmV6 yet.

9.12 Trade-flow reorganization

FAOSTAT/TRADESTAT reports commodity trade between countries in considerable detail. For assessing sustainability impacts of the commodities traded, it is important to know the country of origin, which is often not directly intelligible from TRADESTAT, as trade via several trade partners may occur. SOLm implements the method suggested in (Kastner, Kastner et al. 2011) to trace commodity trade back to the countries of origin. The principle to do this is to assume that exports from country A of a commodity X originate proportionally to the production- and import-shares of the domestically available quantity (DAQ) of commodity X in country A from domestic sources or imports. Thus, the share in DAQ of production of X in country A and of the imports of X from other countries to country A, are the shares to be applied to the exports of commodity X from country A.

9.13 Linking activities and commodities

Activities and commodities are linked via the commodity trees and extraction rates. Default values for those are taken from (FAO 2000, FAO 2001). This code is organized in seven specific sets relating different types of commodities and activities. The seven sets are also listed and described shortly in section 9.2.1.

9.14 Code details for consistency checks

Here, code details for automated consistency checks will be added as soon as such are coded. Currently, the consistency checks are done manually, cf. section 8.6.

9.15 Deforestation data

The following is an updated version of the description of deforestation in (Schader, Muller et al. 2015). Because agricultural land is scarce and natural grasslands are generally not well suited for cultivation (water or temperature limited), increasing the amount of land needed for agricultural production increases pressure on grasslands and forests (Smith, Gregory et al. 2010). Conversion of grassland to cropland may also indirectly lead to increased deforestation, owing to displacement effects that result in the conversion of forests to meadows and pastures (Andrade de Sá, Palmer et al. 2013, Meyfroidt, Lambin et al. 2013). With limited data available, we have assumed that additional cropland generally increases pressure on forests and may lead to increased deforestation. Following (Kissinger, Herold et al. 2012), we have attributed 80% of deforestation to agriculture.

The deforestation potential of agricultural land expansion is estimated as follows: deforestation values are calculated using the total agricultural area as a proxy for the pressure of agriculture on forests; deforestation rates are then calculated by multiplying the total agricultural land area per region in each scenario by the ratio of deforestation areas per region from FAOSTAT (Tubiello,

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Salvatore et al. 2013) over total agricultural land area per region in the base years, scaled by the factor 0.8. In the same way, emissions from deforestation as available in FAOSTAT (Tubiello, Salvatore et al. 2013) are linked to agricultural land. The indicators for deforestation were applied only in the cases of positive deforestation rates. Deforestation was set to zero in countries where total forest area increased.

Thus, the deforestation values and related emissions currently included in SOLmV6 serve as a gross pressure indicator, to assess how big pressure of increasing land use on deforestation in a certain region may be and which potential effect this may have on GHG emissions.

9.16 Utilization of organic soils

Agricultural utilization of organic soils leads to huge emissions (Leifeld and Menichetti 2018). These are accounted for in SOLm as follows. The potential of agricultural land use and expansion to utilize organic soils and result in corresponding emissions is estimated as follows: organic soil utilization values are calculated using the total agricultural area as a proxy for the pressure of agriculture on organic soils; organic soil utilization rates are then calculated by multiplying the total agricultural land area per region in each scenario by the ratio of organic soil areas under agriculture per region from FAOSTAT (Tubiello, Salvatore et al. 2013) over total agricultural land area per region in the base years. In the same way, emissions from utilization of organic soils (CO_2, N_2O) as available in FAOSTAT (Tubiello, Salvatore et al. 2013) are linked to agricultural land.

Thus, the utilization of organic soils and related emissions currently included in SOLmV6 serve as a gross pressure indicator, to assess how big pressure of increasing land use on utilization of organic soils in a certain region may be and which potential effect this may have on GHG emissions.

9.17 Irrigation water use data

This section describes the irrigation water use data from AQUASTAT (AQUASTAT 2019) and the Water Footprint Network (Water Footprint Network 2019) and others (Pfister et al.), cf. 9.1.39. This data contains irrigation water use values in m^3/ha for various crops and countries, shares of irrigated areas per crop and country, as well as water scarcity indicators as described in in more detail.

9.18 Animal welfare data

This section describes the animal welfare data used in SOLm, cf. 9.1.40. This covers indicators for general health levels in different livestock production systems, such as related to intensity and yields (e.g. an index for mastitis incidence in different dairy production systems, or for parasites infestation in pasture-based systems). Other indices capture the possibilities for showing natural behaviours, such as an index for roaming space, livestock density or also having horns or not. In total, these indicates provide a pressure/risk indicator for decent welfare and living conditions for livestock, i.e. capturing whether a change to certain production systems may rather increase risk, that animal welfare and health deteriorate or not.

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9.19 Pesticides data

This section describes the qualitative aggregated pesticide use indicator used in SOLm (cf. section 9.1.41). It is based on the supplementary information of (Schader, Muller et al. 2015). It is built based on i) pesticide use intensity per crop and farming system, ii) pesticide legislation in a country, and iii) access to pesticides by farmers in a country, as displayed in Table 22,

Table **23** and Table 24. These values are based on expert judgments from 2012:

Table 22. Pesticide model classifications

Rating	Pesticide level per crop (PUI)
0	No harmful pesticides* used
1	Low level of pesticide application
2	Medium level of pesticide application
3	High level of pesticide application / harmful pesticides used*

* WHO classification

Rating	Pesticide legislation per country (PL)
0	All chem.-synthetic pesticides (WHO-classes 1-2) banned
1	Rigid pesticide legislation and control excludes harmful pesticides*
2	Average pesticide legislation and control
3	Legislation does not preclude the use of harmful pesticides*

*WHO classification

Rating	Access to pesticides per country (AP)
0	Farmers have no access to chem.-synthetic (WHO-classes 1-2) pesticides
1	Only few farmers have access to chem.-synthetic pesticides (max. 10% of the cultivated land is treated with pesticides)
2	Some farmers have access to chem.-synthetic pesticides (10-50% of the land that deserves treatment is treated)
3	Many farmers have access to chem.-synthetic pesticides (min. 50% of the land that deserves treatment is treated)

Table 23. Country-specific ratings of pesticide legislation (PL) and the accessibility of pesticides to farmers (AP)

Country	PL	AP

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Country	PL	AP
Afghanistan	3	1
Albania	2.5	2.5
Algeria	2	2
American Samoa	2	3
Andorra	2	3
Angola	3	1
Anguilla	2	3
Antigua and Barbuda	2	3
Argentina	2	2.5
Armenia	3	3
Aruba	2	3
Australia	1	3
Austria	1	3
Azerbaijan	3	2
Bahamas	2	3
Bahrain	2	2.5
Bangladesh	3	1
Barbados	2	3
Belarus	2.5	3
Belgium	1	3
Belize	2	3
Benin	2.5	1
Bermuda	2	3
Bhutan	3	1.5
Bolivia (Plurinational State of)	3	2
Bosnia and Herzegovina	2	3
Botswana	2	1.5
Brazil	1.5	2.5
British Virgin Islands	2	3
Brunei Darussalam	2	2
Bulgaria	2.5	3
Burkina Faso	2.5	1
Burundi	2	2
Cambodia	3	1
Cameroon	3	2
Canada	1	3

Country	PL	AP
Cape Verde	3	1.5
Cayman Islands	2	3
Central African Republic	3	1
Chad	3	1
Channel Islands	1	3
Chile	2	3
China	3	2
Colombia	2	2.5
Comoros	2	2
Congo	3	1
Cook Islands	1.5	3
Costa Rica	2	3
Côte d'Ivoire	3	1
Croatia	1.5	3
Cuba	2.5	2
Cyprus	2	3
Czech Republic	2	3
Democratic People's Republic of Korea	3	1.5
Democratic Republic of the Congo	3	1
Denmark	1	3
Djibouti	3	2
Dominica	2	2.5
Dominican Republic	2	2.5
Ecuador	2.5	2.5
Egypt	2	3
El Salvador	2	3
Equatorial Guinea	3	2
Eritrea	2.5	1
Estonia	1.5	3
Ethiopia	2	1.5
Falkland Islands (Malvinas)	2	3
Faroe Islands	1	3
Fiji	2	3
Finland	1	3

Country	PL	AP
France	1	3
French Guiana	2	2
French Polynesia	1.5	3
Gabon	3	1.5
Gambia	2.5	1
Georgia	3	2
Germany	1	3
Ghana	2	1.5
Gibraltar	2	3
Greece	2	3
Greenland	1	2.5
Grenada	2	3
Guadeloupe	2	2.5
Guam	2	3
Guatemala	2	3
Guinea	2.5	1
Guinea-Bissau	3	1
Guyana	2.5	2
Haiti	3	2
Honduras	2	3
Hungary	2	3
Iceland	1	3
India	3	1.5
Indonesia	3	1
Iran (Islamic Republic of)	3	2
Iraq	2	2
Ireland	1	3
Isle of Man	1	3
Israel	2	3
Italy	1.5	3
Jamaica	2	2.5
Japan	1	3
Jordan	2	3
Kazakhstan	3	2
Kenya	2	2
Kiribati	2	3
Kuwait	2	3
Kyrgyzstan	3	2

Country	PL	AP
Lao People's Democratic Republic	3	1
Latvia	1.5	3
Lebanon	2	2
Lesotho	2	2
Liberia	3	1
Libya	2	2
Liechtenstein	2	3
Lithuania	1.5	3
Luxembourg	1	3
Madagascar	2	2
Malawi	2	2
Malaysia	2	1.5
Maldives	2	2
Mali	2.5	1
Malta	1.5	3
Marshall Islands		
Martinique	2	3
Mauritania	2.5	1
Mauritius	2	2
Mayotte	3	1
Mexico	2	2.5
Micronesia (Federated States of)	2	3
Mongolia	3	1
Montenegro	2	3
Montserrat	2	3
Morocco	1	2
Mozambique	2	2
Myanmar	3	1
Namibia	2	2
Nauru	2	3
Nepal	3	1
Netherlands	1	3
Netherlands Antilles	2	3
New Caledonia	1.5	3
New Zealand	1	3
Nicaragua	2	2.5
Niger	2.5	1

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Country	PL	AP
Nigeria	3	1
Niue	2	2.5
Norfolk Island		
Northern Mariana Islands		
Norway	1	3
Occupied Palestinian Territory	3	1
Oman	2	3
Pakistan	3	1
Palau		
Panama	2	3
Papua New Guinea	2.5	1.5
Paraguay	2	3
Peru	2.5	2
Philippines	2.5	1.5
Pitcairn Islands		
Poland	2	3
Portugal	1	3
Puerto Rico	2	2
Qatar	2	3
Republic of Korea	1.5	3
Republic of Moldova	3	2.5
Réunion	3	2

Country	PL	AP
Romania	2	3
Russian Federation	3	2
Rwanda	2	2
Saint Helena	3	1
Saint Kitts and Nevis	2	3
Saint Lucia	2	3
Saint Pierre and Miquelon	1	3
Saint Vincent and the Grenadines	2	3
Samoa	2	3
San Marino	2	3
Sao Tome and Principe	3	2
Saudi Arabia	2	3
Senegal	2	1
Serbia	2	3
Serbia and Montenegro	2	3
Seychelles	3	2
Sierra Leone	3	1
Singapore	2.5	2.5
Slovakia	2	3
Slovenia	2	3
Solomon Islands	2	3

Country	PL	AP
Somalia	3	1
South Africa	2	2
Spain	1.5	3
Sri Lanka	2.5	1
Sudan	3	1
Suriname	2.5	2
Swaziland	3	2
Sweden	1	3
Switzerland	1	3
Syrian Arab Republic	2	2
Tajikistan	3	2
Thailand	2.5	1
The former Yugoslav Republic of Macedonia	2	3
Timor-Leste	3	1
Togo	2.5	1
Tokelau	2	2.5
Tonga	2	3
Trinidad and Tobago	2	3
Tunisia	2	2
Turkey	2	2
Turkmenistan	3	2.5
Turks and Caicos Islands	2	3

Country	PL	AP
Tuvalu	2	2.5
Uganda	2	2
Ukraine	2.5	3
United Arab Emirates	2	3
United Kingdom	1	3
United Republic of Tanzania	2	2
United States of America	1	3
United States Virgin Islands	1.5	3
Uruguay	2	3
Uzbekistan	3	2
Vanuatu	2	3
Venezuela (Bolivarian Republic of)	2	2.5
Viet Nam	3	1
Wallis and Futuna Islands	2	3
Western Sahara	2	1
Yemen	2	2
Yugoslav SFR	2	3
Zambia	3	1.5
Zimbabwe	3	1

PL = Pesticide legislation; AP = accessibility of pesticides to farmers

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Table 24. Crop-specific pesticide use intensity (PUI)

Activity	PUI
Agave Fibres Nes	1
Alfalfa For Forage+Silag	0
Alfalfa Meal And Pellets	0
Almonds, with shell	2
Anise, badian, fennel, corian.	1
Apples	3
Apricots	3
Arabic Gum	0
Arecanuts	1
Artichokes	2.5
Asparagus	2.5
Avocados	3
Bambara beans	2
Bananas	3
Barley	2
Beans, dry	3
Beans, green	2
Beets For Fodder	0
Berries Nes	2
Blueberries	2
Brazil nuts, with shell	1
Broad beans, horse beans, dry	3
Buckwheat	1
Cabbages and other brassicas	3
Canary seed	1
Carobs	2
Carrots and turnips	3
Cashew nuts, with shell	1.5
Cashewapple	2
Cassava	2.5
Castor oil seed	3
Cauliflowers and broccoli	3
Cereals, most	0
Cereals, nes	2
Cherries	3
Chestnuts	1.5
Chick peas	3
Chicory roots	2.5
Chillies and peppers, dry	2.5
Chillies and peppers, green	2.5
Cinnamon (canella)	2
Citrus fruit, nes	3
Clover For Forage+Silage	0
Cloves	3
Cocoa beans	3
Coconuts	2.5
Coffee, green	3
Coir	2
Cow peas, dry	3
Cranberries	1
Cucumbers and gherkins	3
Currants	2
Dates	3
Eggplants (aubergines)	3
Eggs Excl Hen	0
Fibre Crops Nes	3
Figs	2
Flax fibre and tow	2
Fonio	1
Forage Products Nes	0
Fruit Fresh Nes	3
Fruit, tropical fresh nes	3
Fruits, most	0
Garlic	1.5
Ginger	2
Gooseberries	3
Grapefruit (inc. pomelos)	3
Grapes	3
Grass	0
Grasses Nes,Forage+Silag	0
Groundnuts, with shell	2
Gums Natural	3
Hay (Clover,Lucerne,Etc)	0
Hay (Unspecified)	0
Hay Non-Leguminous	0
Hazelnuts, with shell	1
Hemp Tow Waste	2
Hempseed	1
Hops	2
Jojoba	0
Jute	2
Kapok Fruit	2
Karite Nuts (Sheanuts)	1
Kiwi fruit	3
Kolanuts	1
Leguminous Nes,For+Sil	0
Leguminous vegetables, nes	2.5
Lemons and limes	3
Lentils	1
Lettuce and chicory	2.5
Linseed	1
Lupins	1
Maize	3
Maize For Forage+Silage	0
Maize, green	3
Mangoes, mangosteens, guavas	3
Manila Fibre (Abaca)	2
Maple	0
Maté	2
Melonseed	1
Millet	2.5
Mixed grain	2
Mules	0
Mushrooms and truffles	0
Mustard seed	1
Natural rubber	3
Nutmeg, mace and cardamoms	2
Nuts, nes	1.5
Oats	1
Oil Of Citronella	0
Oil palm fruit	3
Oils Marine Animals	0
Oilseeds, Nes	2.5

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Activity	PUI
Okra	2
Olives	2
Onions (inc. shallots), green	2
Onions, dry	2
Oranges	3
Other Bastfibres	2
Other melons (inc.cantaloupes)	2.5
Papayas	3
Peaches and nectarines	3
Pears	3
Peas, dry	3
Peas, green	3
Pepper (Piper spp.)	2
Peppermint	1
Persimmons	2
Pigeon peas	2
Pineapples	2.5
Pistachios	1
Plantains	3
Plums and sloes	3
Pome Fruit Nes	3
Popcorn	2.5
Poppy seed	1
Potatoes	3
Pulses, nes	2
Pumpkins, squash and gourds	3

Activity	PUI
Pyrethrum,Dried	0
Quinces	3
Quinoa	1
Ramie	1
Rapeseed	3
Raspberries	3
Rice, paddy	3
Roots and Tubers, most	0
Roots and Tubers, nes	2.5
Rye	1
Safflower seed	2
Seed cotton	3
Sesame seed	2
Sisal	2
Sorghum	2.5
Sour cherries	3
Soybeans	3
Spices, nes	2
Spinach	3
Starch and Sugar crops for Alc	0
Stone fruit, nes	3
Straw, Husks	0
Strawberries	3
String beans	3
Sugar beet	2.5
Sugar cane	3

Activity	PUI
Sugar crops, nes	2.5
Sunflower seed	1
Swedes For Fodder	0
Sweet potatoes	2.5
Tallow tree	0
Tangerines, mandarins, clem.	3
Taro (cocoyam)	2.5
Tea	3
Tea Nes	0
Tobacco, unmanufactured	3
Tomatoes	3
Triticale	2
Tung Nuts	1
Turkeys	0
Turnips For Fodder	0
Vanilla	2
Vegetables fresh nes	2.5
Vegetables, most	0
Vegetables+Roots,Fodder	0
Vetches	1
Walnuts, with shell	1.5
Watermelons	3
Wheat	2
Yams	2.5
Yautia (cocoyam)	2.5

PUI = Pesticide use intensity; nes = other, not elsewhere specified

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9.20 Soil erosion data

This section describes the soil erosion indicator used in SOLm (cf. section 9.1.38). It is based on the supplementary information of (Schader, Muller et al. 2015), i.e. the following *Table **25***, compiled in 2013:

*Table 25. Soil erosion (from water) values in tonnes soil lost/ha*yr*

Country	min	Agricultural Land/Cropland mean	max	min	Grassland/ Pasture mean	max	Forest	Orchard	Shrubs	Vineyard	Reference
Albania	0.78		1.86								Grazhdani (2006)
Argentina	0.20	18.80	38.00		0.00						Pimentel (1993) and Lal, Hall et al. (1989) (averages)
Austria	0.50	8.93	39.00								Darmendrail, Cerdan et al. (2004) (average) and Strauss and Klaghofer (2006) (range)
Belgium	2.80	8.50	17.60								Darmendrail, Cerdan et al. (2004) (average) and Verstraeten, Poesen et al. (2006) (range)
Benin	17.00		28.00								Lal, Hall et al. (1989)
Brazil		18.80									Lal, Hall et al. (1989)
Bulgaria	0.27	4.76	5.15	0.03	2.69	6.00		12.65		12.65	Rousseva, Lazarov et al. (2006)
Burkina Faso	5.00		35.00								Pimentel (1993)
China	10.00		251.00								Lal, Hall et al. (1989)
Colombia		22.00									Lal, Hall et al. (1989)
Côte d'Ivoire	60.00		570.00								Lal, Hall et al. (1989)
Czech Republic	0.00	2.27	13.89								Dostal, Janecek et al. (2006)
Denmark	0.26	0.64	12.79		0.03						Darmendrail, Cerdan et al. (2004), Veihe and Hasholt (2006)
Ecuador	210.00		564.00								Lal, Hall et al. (1989)
Ethiopia	8.00		117.70	2.00		29.40					Taddese (2001)
Finland	0.10		2.35								Tattari and Rekolainen (2006)
France		2.03			0.01					11.09	Darmendrail, Cerdan et al. (2004)
Germany		1.32			0.14		0.00		0.13	33.23	Darmendrail, Cerdan et al. (2004). Auerswald (2006) (Grassland)
Ghana	5.00		10.00								Lal (1993)

Country	min	Agricultural Land/Cropland mean	max	min	Grassland/ Pasture mean	max	Forest	Orchard	Shrubs	Vineyard	Reference
Greece		0.58						0.05	1.17	0.41	Darmendrail, Cerdan et al. (2004)
Guatemala	5.00		35.00								Lal, Hall et al. (1989)
Guinea	17.90		24.50								Lal, Hall et al. (1989)
India		25.00									Ismail and Ravichandran (2008)
Indonesia (Java)	50.80		144.30								Magrath and Arens (1989)
Italy		1.33			0.28		0.20		0.06	54.86	Darmendrail, Cerdan et al. (2004)
Jamaica		90.00									Lal, Hall et al. (1989)
Kenya	25.00		45.00		5.00		1.00		7.50		Cohen, Brown et al. (2006)
Lesotho		20.00									Bojö (1996)
Lithuania	2.50	19.38	32.20		0.01						Darmendrail, Cerdan et al. (2004) (average), Jankausas and Fullen (2006) (range)
Malawi		20.00									Bojö (1996)
Mali		6.50									Bojö (1996)
Mexico	10.00		15.00								Margulis (1992)
Nepal		40.00									Lal, Hall et al. (1989)
Netherlands		6.76									Darmendrail, Cerdan et al. (2004)
Nicaragua		11.00									Alfsen, De Franco et al. (1996)
Niger	35.00		70.00								Lal, Hall et al. (1989)
Nigeria		14.40									Lal, Hall et al. (1989)
Norway	0.20		3.50	0.10		2.60					Oygarden, Lundekvam et al. (2006)
Papua New Guinea	6.00		320.00								Lal, Hall et al. (1989)
Paraguay		18.80									Lal, Hall et al. (1989)
Peru		15.00									Lal, Hall et al. (1989)
Portugal		0.59			0.04				0.40		Darmendrail, Cerdan et al. (2004)
Romania	0.70		44.80								Ionita, Radoane et al. (2006)
Russian Federation	0.50	4.80	20.00								Sidochuk, Litvin et al. (2006)
Rwanda	35.00		246.00								Berry, Olson et al. (2003)
Senegal	5.00		30.00								Pimentel (1993)
Slovakia		20.00									Stankoviansky, Fulajtar et al. (2006)
Slovenia	2.39		10.94	0.04		1.89		4.77		22.12	Hrvatin, Komac et al. (2006)
South Africa		5.00									Bojö (1996)

Country	min	Agricultural Land/Cropland mean	max	min	Grassland/ Pasture mean	max	Forest	Orchard	Shrubs	Vineyard	Reference
Spain		0.30			0.84		0.00		0.52		Darmendrail, Cerdan et al. (2004)
Switzerland		0.67									Prasuhn (2004)
The former Yugoslav Republic of Macedonia	0.04		4.77								Blinkov and Trendafilov (2006)
Turkey		2.42									Demirci and Karaburun (2012)
Uganda		5.10					0.10				Isabirye (2005)
United Kingdom	0.59	2.09	5.60		0.01						Darmendrail, Cerdan et al. (2004) Boardman and Evans (2006)
United Republic of Tanzania	10.10		92.80								Lal, Hall et al. (1989)
United States of America		6.68									Ismail and Ravichandran (2008)
Zimbabwe		43.00									Bojö [78]

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First, the references for sections 3 to 6 (BioBam) are given, subsequently, the references for the other sections (general sections and SOLm) are listed.

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