PLANET Food System Explorer Documentation

V 1.3

17 Feb 2023

https://goalsciences.org/planet-food-system-explorer

The PLANET Team welcomes suggestions for improvement or remarks about errors in either the interactive Sankey presentation or the documentation. If you find errors, want to make suggestions or if something does not make sense, then please contact us.

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0. Quick View – What Can Be Learned from the PLANET Food System Explorer Version 1.3

With just a few interactive and intuitive mouse clicks, users can:

- Track the flow of biomaterials from agricultural production via processing and animals to final goods for consumers and industry, and in this way find out, for instance, how much harvested biomass can be eaten directly as food (global average around 8%), or how much biomass is processed before it becomes edible food (another 17%, half of which becomes food, and the other half becomes feed or fuel or other goods), and what happens with the other 75% of agricultural materials (not considering forestry or aquaculture).
- Track these flows for the years 2018, 2019 and 2020.
- Track not only the harvest goods, but also all harvest-by-products for each agricultural commodity.
- Track these flows for most countries in the world separately, or for groupings of countries.
- Track these flows for around 140 different agricultural commodities, or for 364 different final products, including also forestry products and aquatic products.
- Track these flows in different units: either in kilotons of mass, or in tons of protein content, or in tons of fats content, or in billion kcals of energy, or in tons of bioavailability adjusted protein content. Units can be expressed either in totals per year, or in per person per day/per year.
- Track these flows in exports and imports of each country.
- Track in detail, which livestock species in which country is consuming how much of each feed stock, and is contributing how much food, or protein to a country's food supply.
- Retrieve the top 5 export destinations or import sources for each agricultural commodity for each country.
- Retrieve the inventory number of animals for each country.
- Retrieve the top ten producing countries for each agricultural commodity.
- Download any of the displayed pictures as a png file, or retrieve the numerical values creating the picture as an excel file.
- Use any of this information or the downloads with a free-to-use CC-BY-ND 4.0 license.
- Explore all sources used to create PLANET in a fully accessible and transparent documentation. No black box.

1. The PLANET Food System Explorer Tool

1.1 PLANET Mission

PLANET is a web-based interactive tool that allows users to explore the intricate dynamics of the global and national food systems with validated and up-to-date publicly available primary data.

The intention of PLANET is to support global, national and regional public policy, as well as commercial and scientific decision-making by providing easy-to-use access to validated and comprehensive data, in particular with regard to the role of livestock in the food system. PLANET itself does not advocate for particular food system policies or positions.

The functionalities, computations and assumptions driving the data models and visualization on PLANET shall be as transparent and neutral as possible to users. The neutrality of the data presentation is verified and guaranteed by this transparency.

Access to PLANET is free of charge and available to every person on a not-for-profit basis.

PLANET stands for **P**rojecting **L**ivestock, **A**griculture, **N**ature, **E**cology and **T**echnologies.

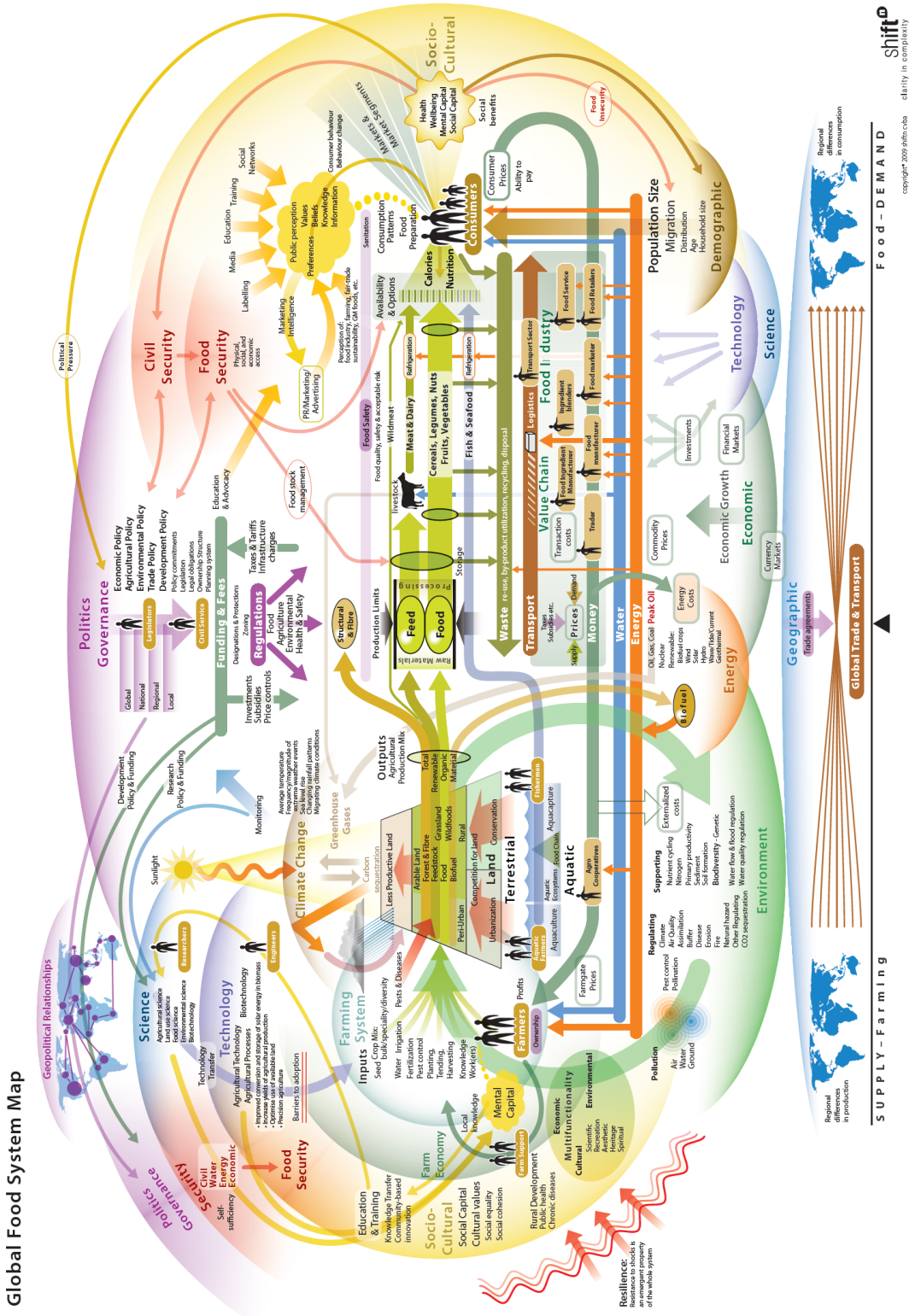
1.2 Copyright, License and Affiliation

PLANET is primarily provided on the GOALSciences website, the Global Observatory on Accurate Livestock Sciences. GOALSciences is an initiative created and promoted by the Global Food and Agribusiness Network (GFAN) as a science-based not-for-profit public service to the global livestock stakeholder community. GFAN is directed by Prof Dr Peer Ederer and is registered as a commercial entity in Switzerland.

PLANET and GOALSciences operate under Swiss law and Swiss data protection rights.

Figure 1.1: Global food system map

The global food system is among the most complex systems that humanity has devised. Over time, PLANET intends to represent as many dynamics as possible of this food system in its model and also permit scenarios modelling. In its first few release versions it begins with modelling the material flows from farming to food provision.



1.3 PLANET Basic Structure

The main visualization engine of PLANET is a Sankey flow diagram. The diagram shows the flow of materials from left to right through different category stages of the food system.

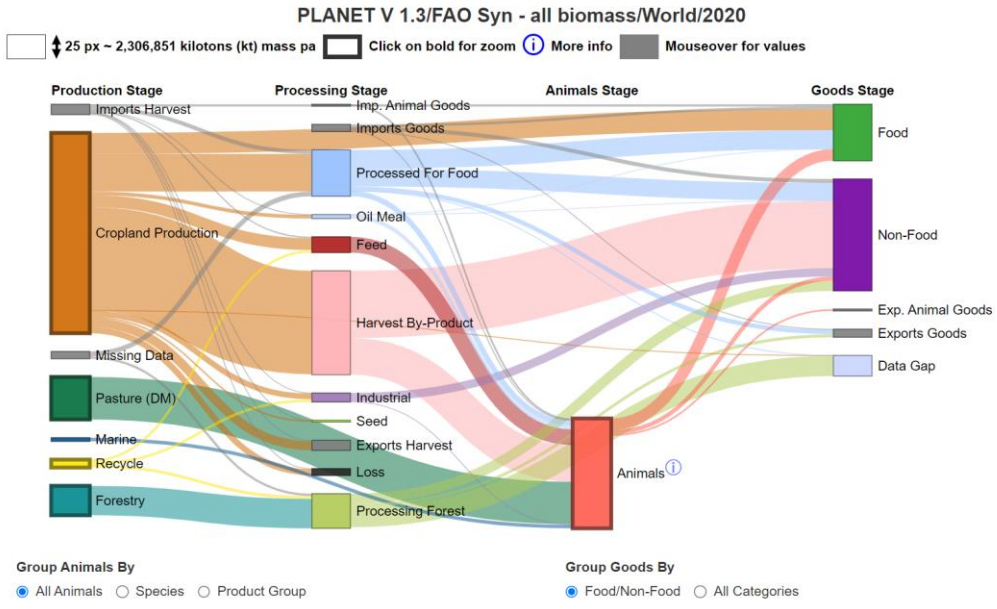
The height of the nodes and links of the Sankey represent the amount of material and is always to scale on the same picture. The legend in the top left provides the scale and the unit of measurement. Different pictures have different scales. Mouseover over nodes or links will show the corresponding value, for instance global cropland production amounts to 19,150,644 kilotons of materials, based on FAOStat in the year 2019 and GOALSciences assessment for harvest by-products based on Professor Wirsenius and other sources.

The basic default structure of PLANET V 1.3 shows several stages:

- Production stage: harvest amounts from crop lands, pastures, aquatics, forestry or recycled material streams
- Processing stage: converting the harvest materials into intermediate products for food, feed, seed or industrial utilization.
- Animals stage: production of animal-sourced products such as meats, dairy, eggs, honey, wool, leather, fifth quarter by-product or other.
- Goods stage: Providing agricultural goods ready for consumption in categories such as raw foods, processed foods, transformed foods, animal feeds or non-food goods.
- Some pictures also display a Trade stage, where the flow of exports and imports are shown in order to display the flow of domestic supply.
- With further development of PLANET, additional stages will be incorporated.

Several “Selection” functions provide multiple layers and combination of detail. These functions are explained in detail in the following sections.

Figure 1.2: Default PLANET V 1.3 Sankey



1.4 PLANET Technology Stack and Requirements

1.4.1 PLANET Software Code:

- Data-Modelling (DM) engine coded in R. The DM engine computes data from the primary data sources. As new or updated datasets become available, the DM engine will provide a new computation. Updates do not occur in real time. A change log with the version of datasets is provided on the website.
- Data-Presentation (DP) engine coded in R-Shiny with proprietary modifications in Javascript. The DP engine collects the pre-computed data from the database and generates each picture in real-time. Therefore, the generation may have some latency.
- Visualization of pictures in an InlineFrame on a Typo3-coded web page.
- PLANET is hosted securely on an Amazon Web Services (AWS) cloud.

1.4.2 Display Control:

- A minimum number of 992 pixel screen width display is required, otherwise PLANET will not show. Thus some older mobile phones will not work for PLANET.
- Mobile phones will typically not allow the Mouseover functionality.
- Optimized for all latest versions of Chrome, Firefox, Explorer, Edge, Opera or Safari on either Windows, Mac, Android or iOS.

1.4.3 Version Control:

PLANET model versions:

- The 0.5 beta version soft-launched in July 2021 for public review and testing.
- The 1.0 version released on 18 January 2022 was the first fully documented and validated release.
- The latest release was finalized as V 1.3 on 17 February 2023.
- First digit releases (2.0, 3.0…) refer to the release of significant changes of the basic structure of the PLANET model. These may include methodology additions such as new stages, significant modeling tools or scenario tools. Such releases are expected on an annual basis and will be broadly announced.
- Second digit releases (1.1, 1.2…) refer to the regular release of new functional enhancements and inclusion of new datasets within the current basic structure. They will be announced on the GOALSciences communication channels. Such releases are expected several times a year.
- Third digit releases (1.01, 1.02…) refer to corrections or debugging fixes of existing functions. They will not be announced but are recorded in the change log.

Data source versions:

There are several sources of primary data, some of which are frequently updated. PLANET strives to always use the most up-to-date source material. An excel table on the website keeps record which data sources from which date are in use. It also keeps record of all changes in functionalities throughout the different versions

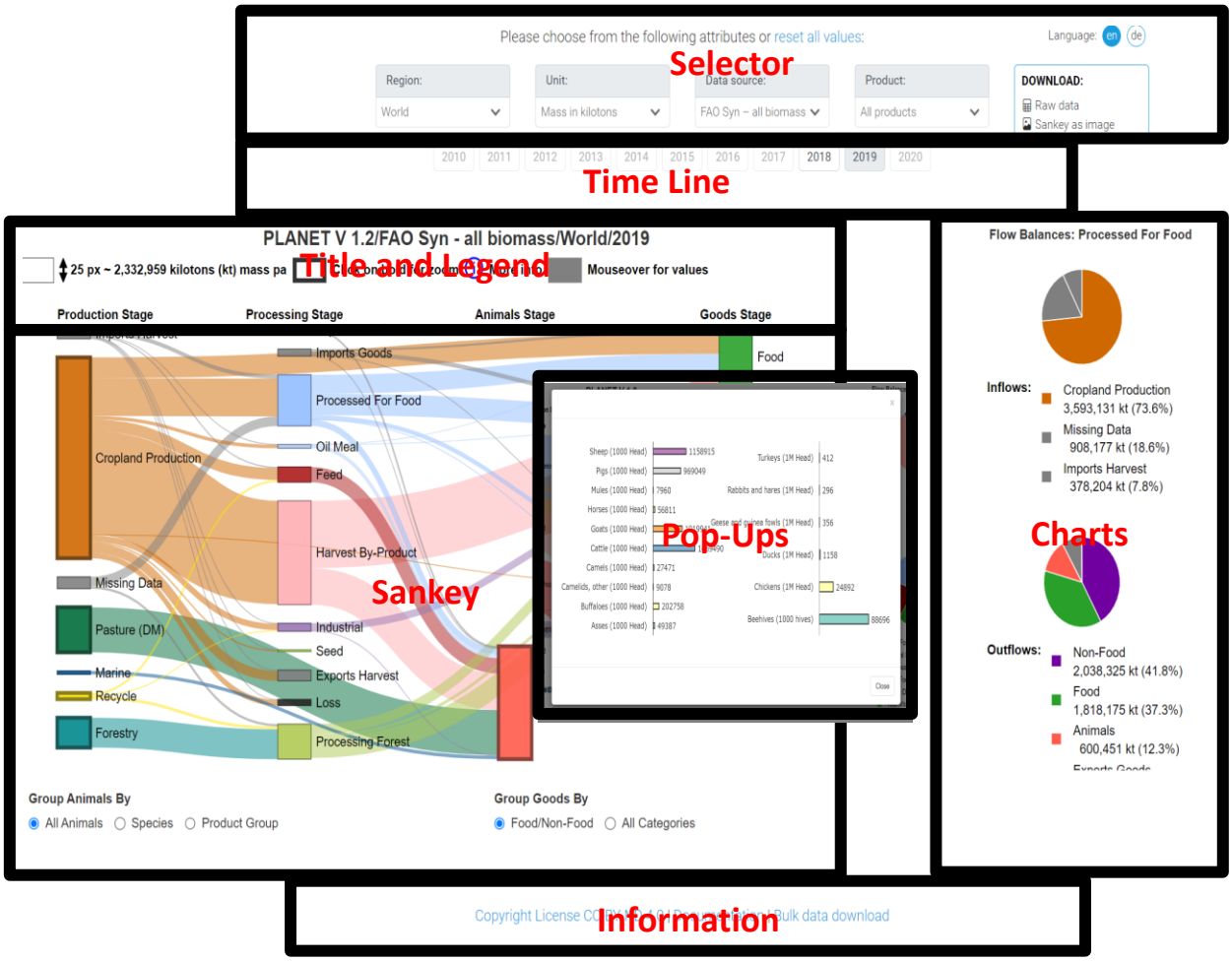
https://goalsciences.org/about/change-log

1.5 Functionalities of PLANET 1.3 Version

The display picture consists of the following areas:

- Sankey area with radio buttons for level of display detail
- Selector area
- Time-line area
- Title and legend area
- Charts area
- Information area
- Pop-up areas

Figure 1.3: PLANET display areas



1.5.1 Sankey Area with Nodes, Links and Radio Buttons:

a) Color Coding of Nodes and Links

The basic idea of a Sankey diagram is that every flow of a material comes from somewhere and goes to somewhere and that, in principle, all flows should be accounted for. Nodes are places where the flows come from and go to and links represent the flows of the material between the nodes. While a Sankey diagram can flow in any direction, in PLANET the materials always flow from left to right, even if this is not denoted by an arrow.

Both the nodes and the links are color coded:

At the production stage:

- Brown tone colors are for cropland productions
- Dark green tone colors are for permanent pastures and forest production
- Dark blue tone colors are for marine sourced foods
- Yellow colors are for recycled goods flows
- Bluegreen and light green colors are for forestry products

At the processing and goods stages:

- Medium green tone colors are for fruits, vegetables and raw foods
- Light blue tone colors are for processed and transformed foods
- Red tone colors are reserved for animals and their respective feed flows
- Pink tone colors are reserved for harvest by-products
- Purple tone colors are for industrial and non-food products
- Grey tone colors are for exports, imports, losses and wastes

Inside the zoom levels, the colors usually follow logical assignments, such as light yellow for cereals, dark brown for roots, light green for vegetables, yellow for dairy and red for meats.

Attention: FAOStat does not provide data on water-based beverages. FAOStat accounts only for the solid materials flows of ingredients such as fruits or sugars, but does not show the weight of the water included in the beverages. In industrialized countries, the total weight of processed beverages roughly equals the total weight of foods. A future version of PLANET will also show beverages as an option.

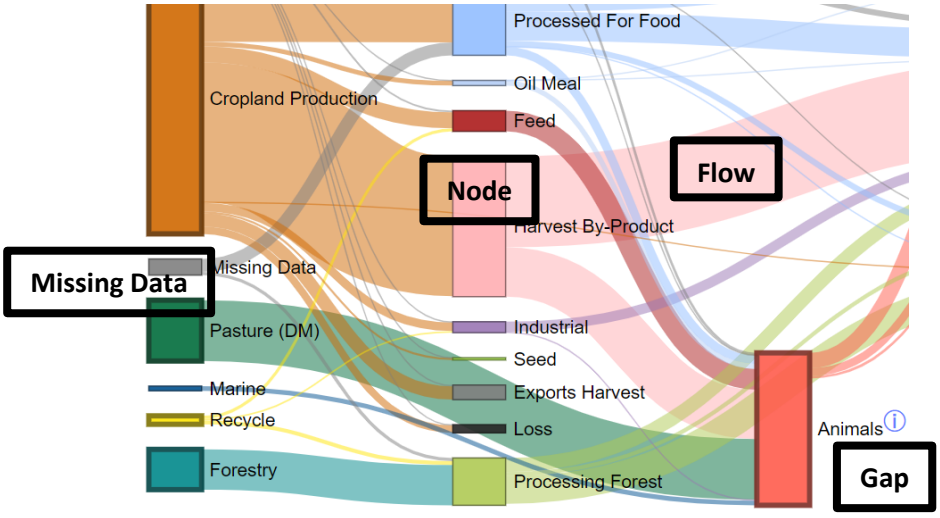
b) Nodes, Flows and Gaps in the Sankey Diagram

The basic idea of a Sankey flow diagram is that every node should have the same amount of material flowing into it as flowing out of it.

In PLANET 1.3 there are two exceptions:

- The outflows of animals are only foods and consumable goods, thus leaving a gap on the outflowing side of the node. Other animal outflows are not yet accounted for in PLANET 1.3. These other outflows are manure excretions, exhaled humidity and sweat, metabolic energy conversion with resultant exhaled gases, and waste materials. Future PLANET versions will provide complete animals materials flows.
- For some countries and some commodities, FAOStat uses a statistical category called "Residual". Such residuals are statistical artefacts in cases when FAOStat could not make their calculations to balance or lacks information. The Sankey flow diagram does not show the residuals explicitly. If these are inflowing gaps, then they are called "Missing Data". On outflowing gaps, they are called "Data Gap".

Figure 1.4: PLANET nodes, flows and gaps



c) Radio Buttons

Radio buttons allow selection of some display logics for the Sankey flows.

- The left set of radio buttons called "Group Animals By" allows the choice to view the animals as a collective element (default setting) or to split the animals into species or product groups (figure 1.5).
- The right set of radio buttons called "Group Goods By" allows the choice to view the goods stage only by the two major categories of Food or Non-Food, or to split it into all categories which are currently structured by the PLANET (figure 1.6)
- The radio buttons underneath the first level of zoom on animals allows to sort the data either by "Product Type" or by "Species". The data is in each case the same, only the zoom sequence is changed. The choice can only be made on the animal level (figure 1.7).

Figure 1.5: PLANET display choice for animals

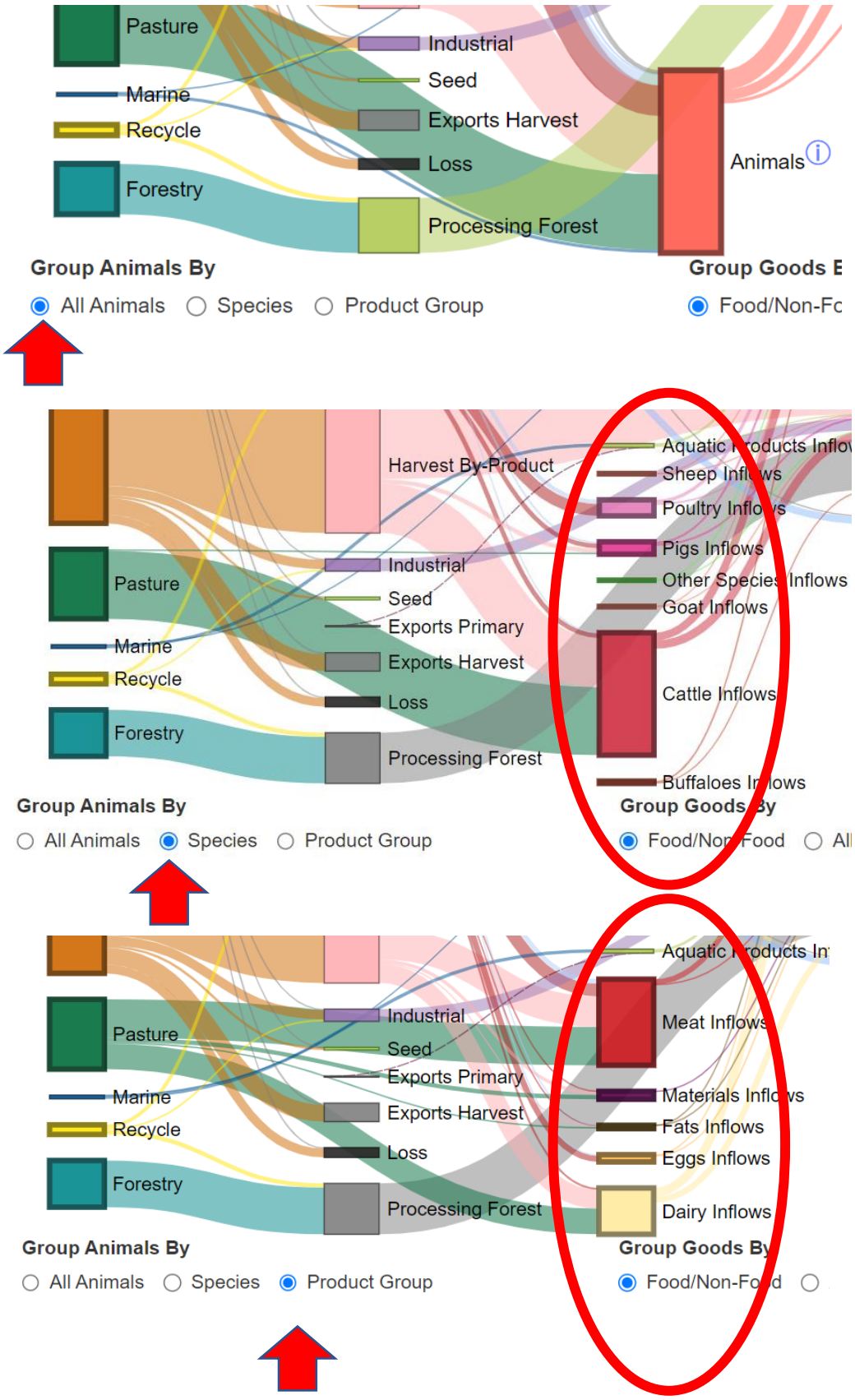


Figure 1.6: PLANET display choice for goods stage

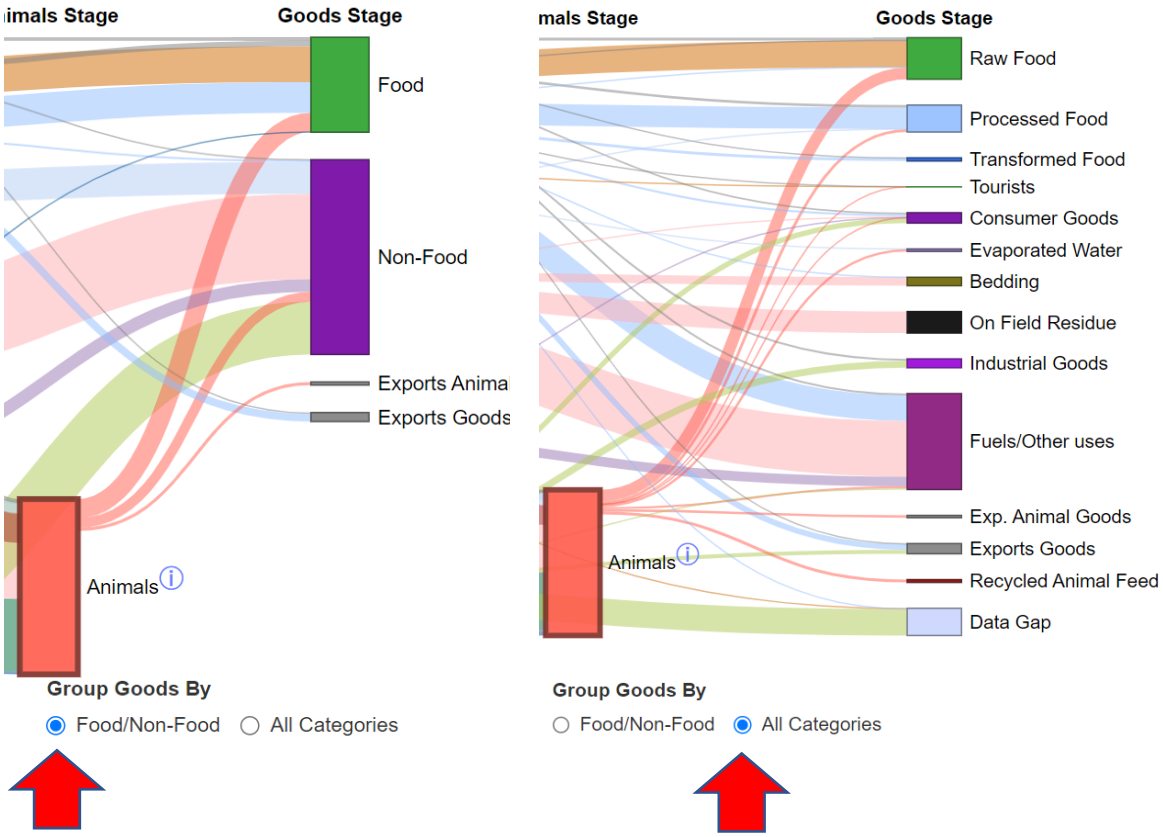
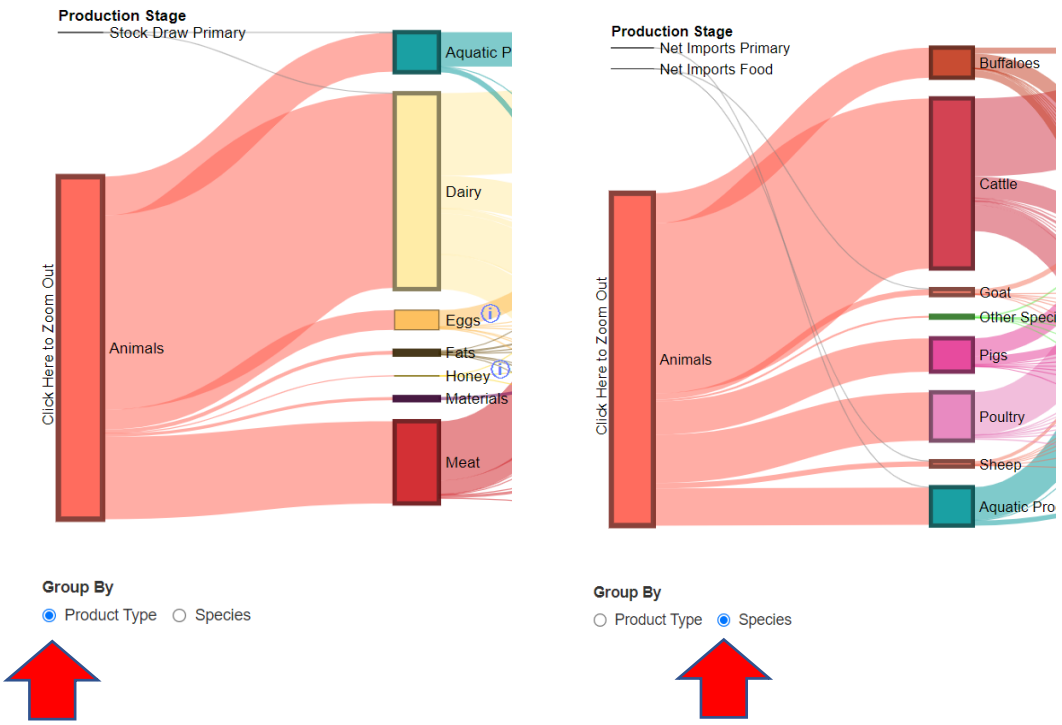


Figure 1.7: PLANET display choice for animal portion of Sankey

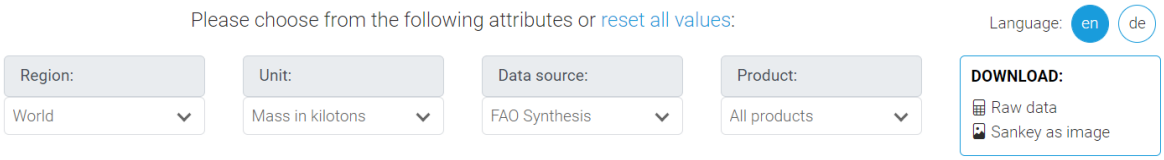


1.5.2 Selector Area:

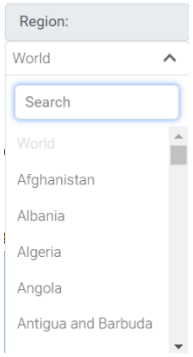
PLANET parameters can be chosen by four different selectors, plus a language choice and download options. Three of these selectors (countries, units and products) will retain their value while the user zooms into different pictures. Thus, when the user zooms into "Apples" and then changes the country, the new country will also display the picture for Apples. Likewise, if the user zooms into a country, and then changes the unit, the country will remain the same.

Occasionally, there is no data for a combination of selectors. For instance, Switzerland does not produce sorghum, and therefore if these two selected, then no picture can be shown. Instead, there will be a signal that there is no data for this selection.

Figure 1.8: Available Selectors



- Region / countries selector: Alphabetic listing of 178 countries. The list of countries is taken from the FAOStat Food Data Tables source.

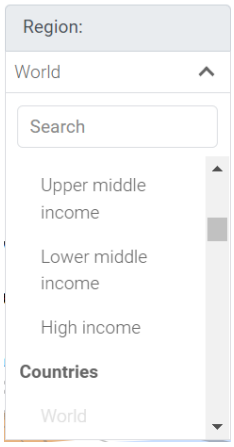


  - At FAOStat the countries are usually shown in their anglicized short form (UN designation), with the non-anglicized exceptions of Cabo Verde, Côte d'Ivoire, Eswatini and Timor-Leste.
  - For PLANET, some countries' UN names were slightly abbreviated (e.g. United Kingdom, Tanzania, Dem Rep Congo or USA). For better identification the two Koreas were named North and South Korea.
  - The 178 countries for which Food Data Tables are available include four different territories for China: China mainland, China Taiwan, China Hong Kong, China Macao.
  - The United Nations currently has 193 members. Various reasons apply why not all of these UN members are captured by the FAOStat Food Data Tables. Bhutan, for instance, does not have a law for collection of statistics. Other countries are very small, such as Andorra, or do not have any significant amount of food production, such as Singapore.
  - The UN Dept of Economic and Social Affairs, Population Dynamics (UNPD), tracks the population numbers of 236 different territories. The difference of 43 of these territories to the 193 UN members are that they are either countries but not member of the UN (applies to Palestine, Holy See, Kosovo) or are not included by the population numbers of the sovereign country they are associated with (eg Puerto Rico of the USA, Greenland for Denmark etc), and therefore need to be separately considered.
  - FAOStat provides food production numbers on 196 countries/territories, thus 18 more than the Food Data Tables.

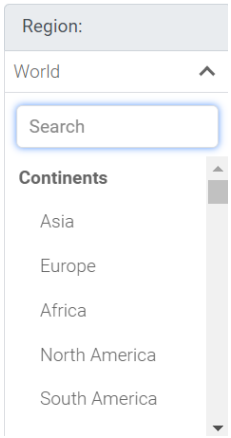
  Future versions of PLANET will incorporate the available data on as many countries and regions as possible.

- Region / groups: The groups are taken from UN Population Dynamics (UNPD) and World Bank:
  https://population.un.org/wpp/Download/Standard/Population/
  The food system type classification are taken from the website of
  https://www.foodsystemsdashboard.org/

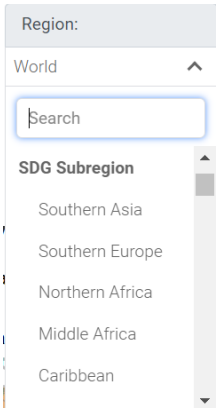
  Five different groupings are implemented:
  - Income Group (as defined by World Bank) with the choice of (due to their size and thus distorting impact, PLANET also provides income groups without mainland China and India)
    - Low income
    - Lower middle income
    - Upper middle income
    - High income
    - Upper middle income without China, mainland
    - Lower middle income without India
    - China mainland
    - India



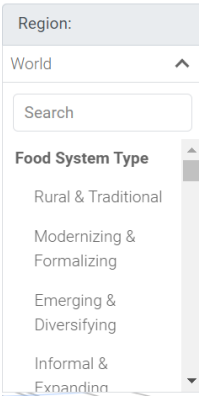
  - Geographic Continent
    - Asia
    - Europe
    - Africa
    - North America (which includes Central America and Caribbean)
    - South America
    - Oceania (Australia, New Zealand, Papua New Guinea and all Pacific Islands)



  - SDG Regions (SDG=Sustainable Development Goal)
    - Eastern and South-Eastern Asia
    - Central and Southern Asia
    - Northern Africa and Western Asia
    - Sub-saharan Africa
    - Europe
    - Northern America
    - Latin America and Caribbean
    - Pacific
    - ANZ (Australia and New Zealand)
  - SDG Subregions
    - Eastern Asia
    - South-Eastern Asia



- Central Asia
- Southern Asia
- Western Asia
- Northern Africa
- Western Africa
- Middle Africa
- East Africa
- Southern Africa
- Northern Europe
- Eastern Europe
- Western Europe
- Southern Europe
- Northern America
- Caribbean
- Central America
- Southern America
- Melanesia
- Polynesia
- Micronesia
- ANZ

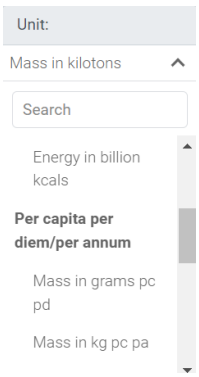


- Food System Type Classification
  - Rural & Traditional
  - Informal & Expanding
  - Emerging & Diversifying
  - Modernizing & Formalizing
  - Industrialized & Consolidated
  - Import Dependent (this category was added by PLANET for small and island-bound countries which are not classified otherwise)

The allocation of all 178 FAOStat countries to the respective groups are listed in this excel spreadsheet:

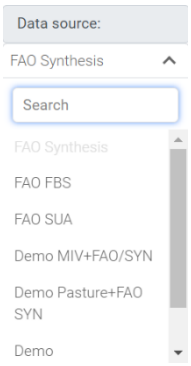
➢ Excel download: S VI a) Country groups 23 December 2022

- Units selector: choice of units of display
  Each unit is available totals per year, or as per person per year and per day



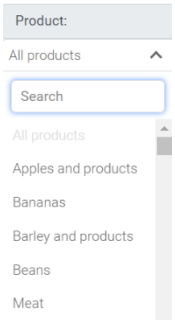
  - Mass in kilotons: the standard unit of FAOStat
  - Protein content in tons: shows only the amount of protein content in the materials, measured in tons. The protein computations are explained in chapter 3.1
  - Adjusted protein content in tons: shows the amount of protein content in the materials, measured in tons, adjusted by DIAAS scores (digestible indispensable amino acid score), which indicate the bioavailability of the different sources of protein to the human metabolism. The adjusted protein computations are explained in chapter 3.2
  - Fat content in tons, based on FAOStat
  - Energy content in billion kilocalories, based on FAOStat
  - Biomass carbon in tons (not yet implemented in PLANET 1.3)
  - Monetary value in USD (not yet implemented in PLANET 1.3)

- Sources selector: Choice of sources. The data core of PLANET consists of the FAOStat data. FAOStat data is not a single database but is structured in several interrelated datasets. The food supply chain is represented in the Supply Utilization Accounts (SUA) and the Food Balance Sheets (FBS), which are combined in PLANET in a Synthesis version. Details are explained in chapter 2. Other FAO datasets include a Trade Matrix, Livestock Herd Size, Crops and Livestock Products, or Land Use, Land Cover and Inputs which are used by PLANET for Pop-ups, and are explained in chapter 3.



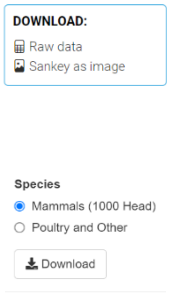
  - "FAO/Syn - all biomass 1.3" is the default synthesis setting for the PLANET 1.3 version. This version uses the same logic as Synthesis 1.2, which refined the 1.0 Synthesis version by allocating second or third downstream processing stages as evidenced by FAOStat SUA tables to either food or feed streams. Thus Synthesis 1.2 typically shows slightly higher feed numbers than Synthesis 1.0 (see chapter 2.9 for more details). Furthermore, it includes all other available data from FAO (not only SUA and FBS), plus the harvest by-product and grasslands assessments on the basis of Stephan Wirsenius, plus by-product refinements from various other sources (see chapter 4 and Change Log Data Sources for details)
  - "FAO/Syn Wirsenius 1.2" is similar to Synthesis 1.2, but uses the harvest by-product and grasslands assessments on the basis of Stephan Wirsenius only (see Chapter 4.1). Since there was no methodology change between 1.2 and 1.3., it continues to be named as 1.2.
  - "FAO Synthesis 1.0" combines the two FAOStat food supply sources of SUA and FBS into one comprehensive picture, but does not use any other data sources. Therefore, it does not show any harvest-by-products.
  - "FAO FBS 1.0" displays only the Food Balance Sheets of FAO. It, therefore, does not represent a complete picture of the material flows.
  - "FAO SUA 1.0 " displays only the Supply Utilization Accounts of FAO. It, therefore, does not represent a complete picture of the material flows.
  - "Demo Resources/Outcomes is an outlook how future versions of PLANET will incorporate data from resources and outcomes.
  - More sources will be implemented with future versions.

- Products selector: Choice of any of 364 products or product categories which are curated by the FAOStat source. The choice of products is co-determined by the choice of sources, as not all products are available for all sources. For instance, with the FAO SUA source, there is the product "whey" for which data is presented. With FAO FBS source or FAO Synthesis, the product "whey" is not shown, and therefore is also not available for product selection.

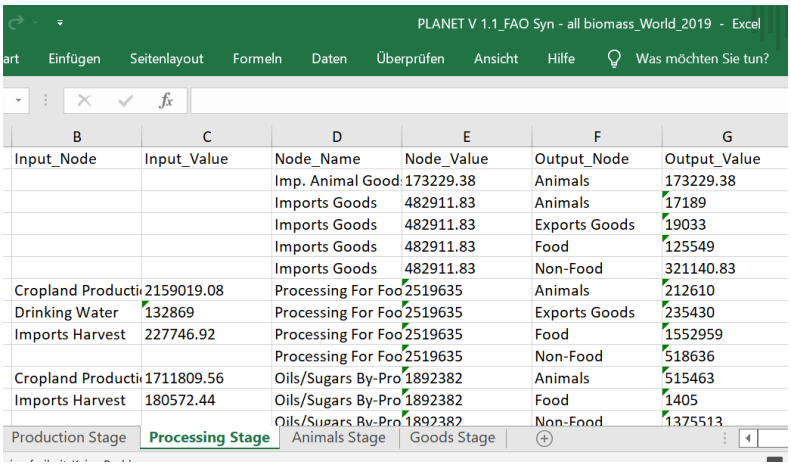


- Languages (PLANET 1.3 only displays in English). Other languages such as German, French, Spanish, Italian and Portugese will be made available in future versions of PLANET.

- Downloads: both a png of the Sankey picture and an excel sheet with the numerical values related to this picture can be downloaded. If you are interested in the bulk data, then please contact the PLANET team how this can be arranged. The complete bulk data set comprises many million rows of data.



  - The Raw Data download will extract an excel file with all numerical values that are shown in the current picture. Each stage is represented by a tab. Within each stage, the values are shown: the input flows towards a node in this stage, the value of the node itself, and the output flows from a node in this stage.
  - A png picture of the Sankey diagram can be downloaded.
  - Pop-up windows have their own download buttons.
  - Supplement Tables are available for download under the Documentation section.

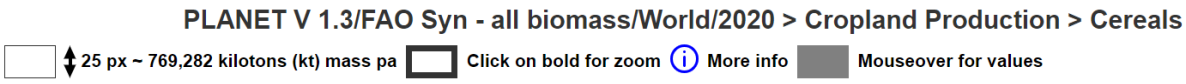


B	C	D	E	F	G
Input_Node	Input_Value	Node_Name	Node_Value	Output_Node	Output_Value
		Imp. Animal Good	173229.38	Animals	173229.38
		Imports Goods	482911.83	Animals	17189
		Imports Goods	482911.83	Exports Goods	19033
		Imports Goods	482911.83	Food	125549
		Imports Goods	482911.83	Non-Food	321140.83
Cropland Producti	2159019.08	Processing For Foo	2519635	Animals	212610
Drinking Water	132869	Processing For Foo	2519635	Exports Goods	235430
Imports Harvest	227746.92	Processing For Foo	2519635	Food	1552959
		Processing For Foo	2519635	Non-Food	518636
Cropland Producti	1711809.56	Oils/Sugars By-Pro	1892382	Animals	515463
Imports Harvest	180572.44	Oils/Sugars By-Pro	1892382	Food	1405
		Oils/Sugars By-Pro	1892382	Non-Food	1375513

1.5.3 Title and Legend Area:

The title displays the current version/the choice of sources/the region/the reference year/ and then the > product zoom levels of the Sankey for better orientation.

Figure 1.9: Title and legend to Sankey

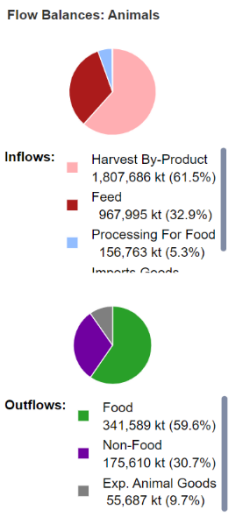


The legend displays from left to right:

- The small white box is 25 pixels high. For each picture it will show the value, the unit, and the reference period that are represented by these 25 pixels (in PLANET 1.3 the period is either total per annum (pa), per capita per annum (pc pa), per capita per diem (pc pd).
- All bold-marked nodes in the Sankey can be clicked for either zooming in or zooming out into levels of detail.
- ⓘ buttons can be clicked on to open up a Pop-up field.
- All nodes and links will display the underlying value at mouseover (usually not possible on smart phones).

1.5.4 Charts Area:

Figure 1.10: Pie charts showing percentage distributions



A mouseover on a node in the Sankey diagram will automatically generate pie charts showing the percentage distributions of the respective inflows and outflows of that node.

The legend to the pie-charts displays both the percentage distribution of the node, and the absolute amounts.

The pie-charts are currently not available for download.

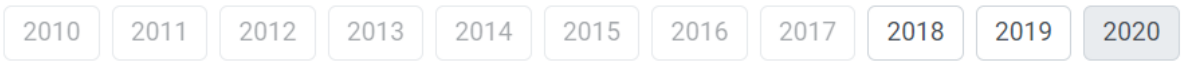
Future versions will also display other charts in this area.

1.5.5 Time Line Area

The reference year in PLANET 1.3 is the year 2020. FAOStat provides data only with a two-year delay. Thus the 2020 data were released in December 2022.

In the 1.3 version it is possible to select data for 2018, 2019 and 2020. The additional years and decades will be made available in future versions.

Figure 1.11: Time line area options



1.5.6 Information Area:

General information is provided here:

- Providing the Copyright License CC-BV-ND 4.0. The link will forward to the CC website.
- Documentation links to this document and other source files. Also includes the change log excel file where the source data locations and dates of download are recorded.
- Reference to Bulk data download.

Figure 1.12: Information area options

1.5.7 Pop-ups:

In various places throughout the Sankey diagram, Pop-up windows can be opened by clicking on the ⓘ button. PLANET 1.3 implemented four different Pop-ups:

- Clicking on either export or import on the country level shows the top 5 export destinations and import origins of the particular product in a particular country. This data is taken from the Trade Matrix dataset, see chapter 3.
- Clicking on animals on the country level displays the number and species of livestock in that country, according to FAOStat data, see chapter 3.
- Clicking on product categories or products on the world level will display the top 10 producing countries either in absolute terms or per capita, as calculated by PLANET based on FAOStat.
- In forestry products there is one pop-up showing the composition of pulp products

Figure 1.13: Trade pop-up showing the top 5 export or import countries of a product

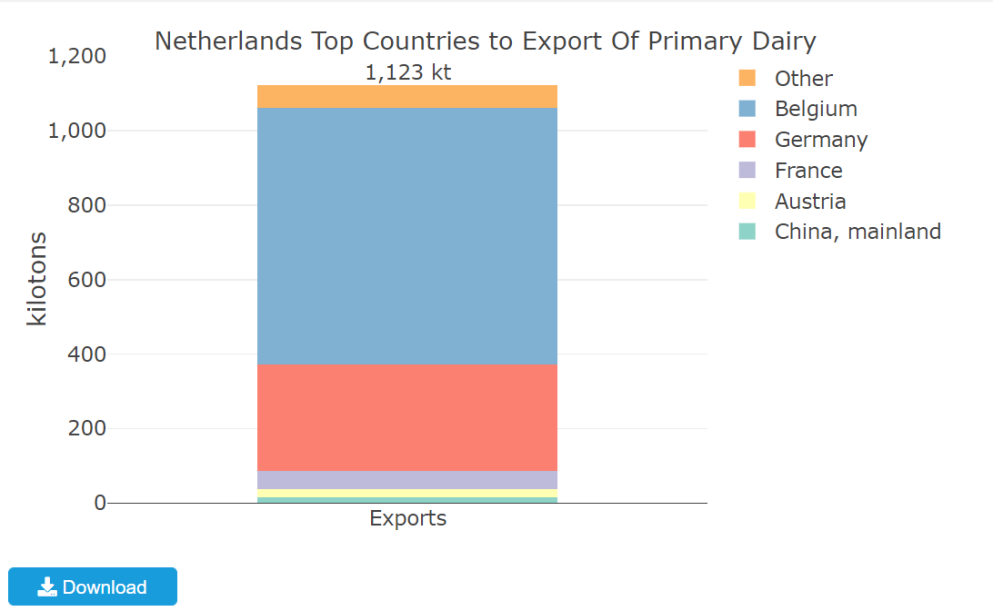


Figure 1.14: Livestock pop-up showing number and species in a given country

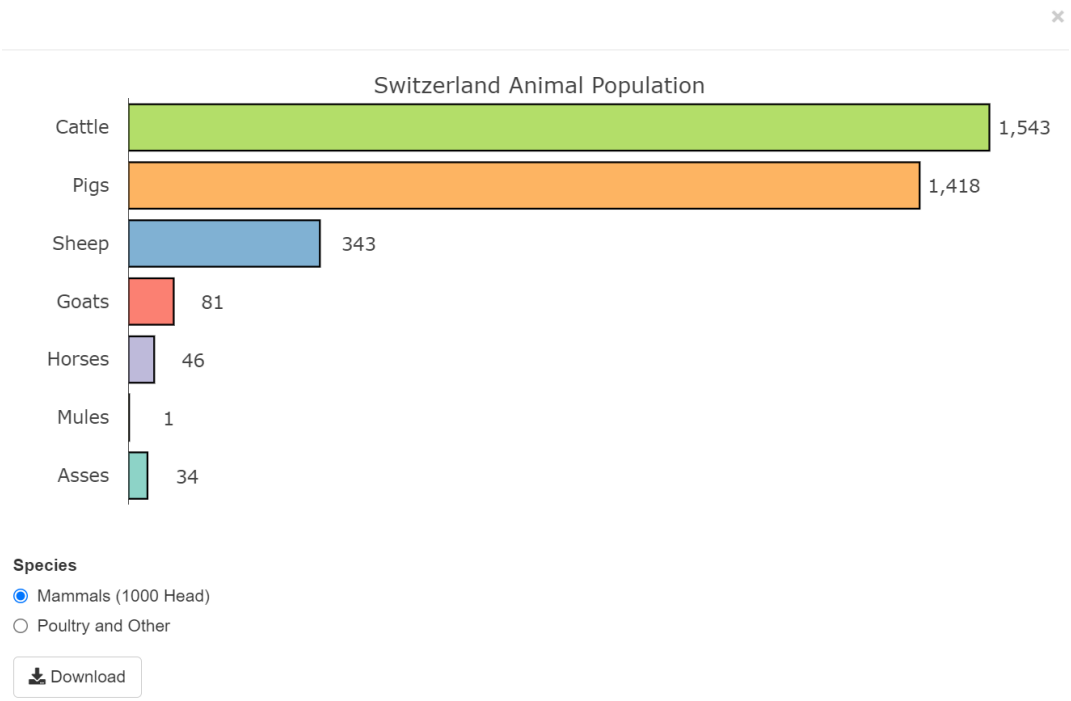


Figure 1.15: Products pop-up showing the top 10 producing countries in grams/capita/year

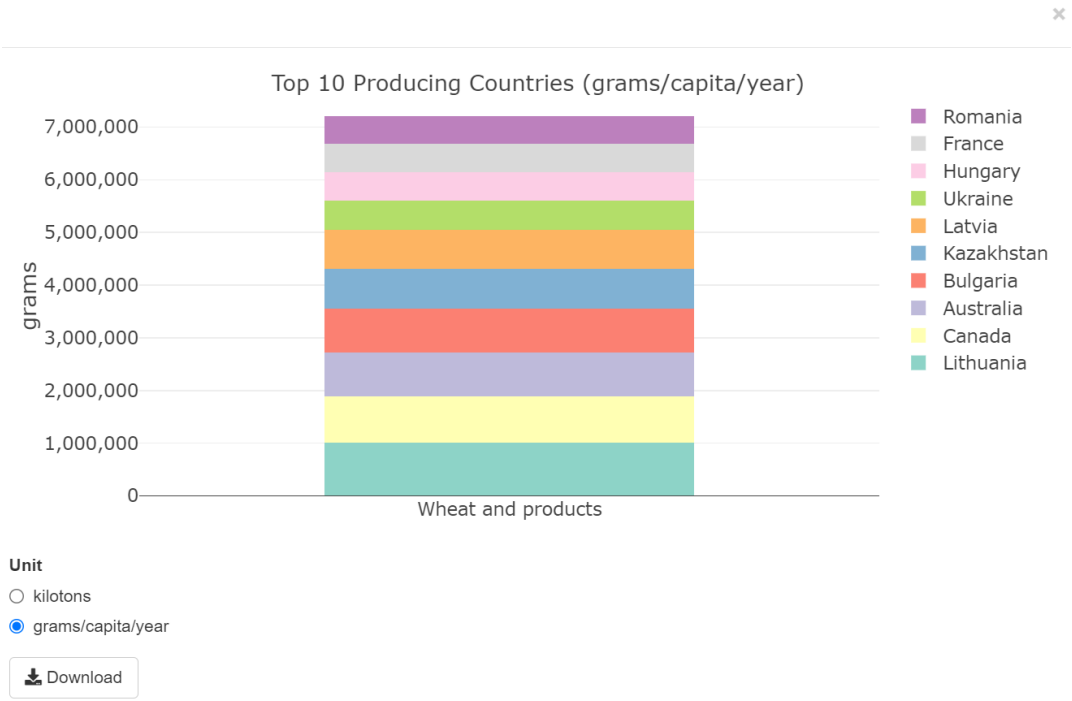
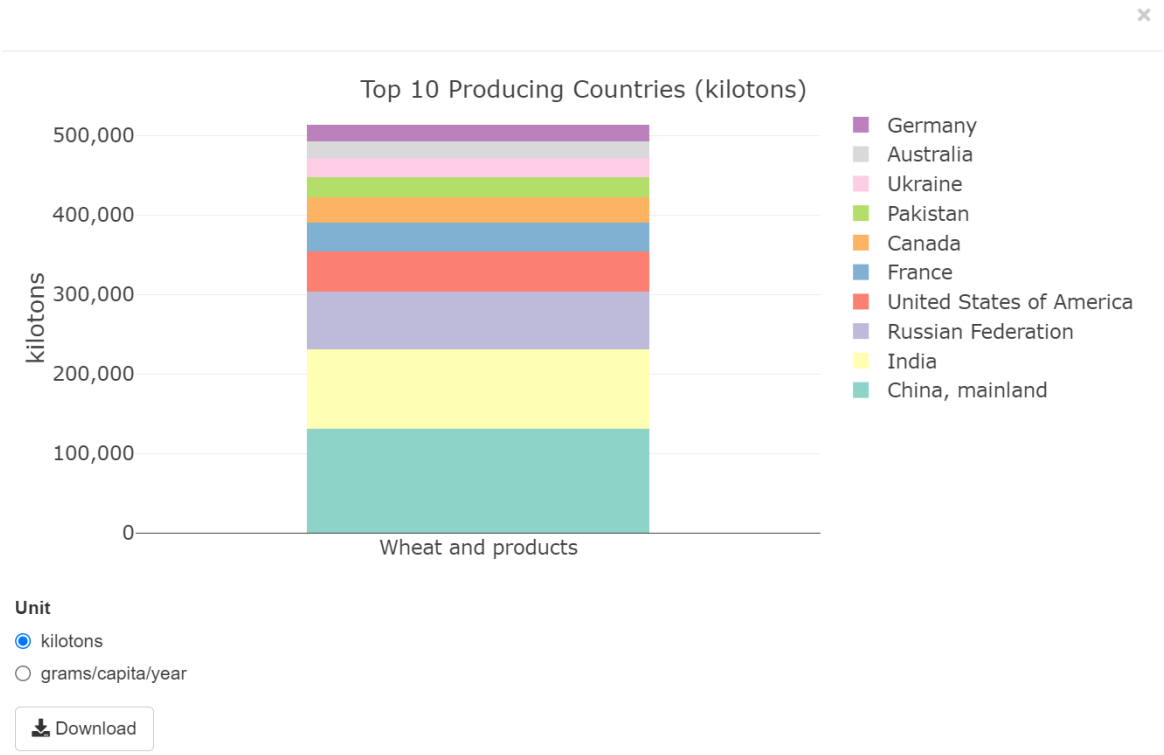


Figure 1.16: Products pop-up showing the top 10 producing countries in total kilotons



2. FAOStat Food Data Tables (FFDT) as the Anchor Data Source Used for PLANET

2.1 Brief History of Food Balance Sheets

The provision of food is the most fundamental human need. Understanding a regional or national food system's ability to produce enough of which food has been fundamental for decision makers since the earliest times of civilization. Among the first written systematic documentations of food availability and food prices are clay tablets from Assyria or papyri from Egypt dating as far back as 4000 years ago. No political system has done well over time, if it did not know how to assure enough food for the people under its governance.

In the modern era, the standard method to understand the production capacity of a food system is to use food balance sheets. Food balance sheets track the food system like a double book keeping accounting system, hence the name: every food that is eaten on one side of the ledger, must have been produced as much on the other side.

Food balance sheets go back to World War I. Later, the first international compilation effort of food balance sheets for comparison purposes, occurred in 1936 at the request of the League of Nations Mixed Committee on the Problem of Nutrition and its Sub-Committee on Nutritional Statistics. When the Food and Agriculture Organisation, FAO, was founded in 1945 as a specialized UN agency, one of its first tasks was to assemble international food balance sheets. From 1961 onwards they are available for most countries and territories and for every year. A methodology change in 2014 makes comparison of data pre- and post 2014 difficult.

Until today, there is only one authoritative and comprehensive source of food data availability which is consistently gathered across most countries of the world, and these are the Food Data Tables compiled by FAO and shown on FAOStat. The starting point of any global food system investigation into current conditions of the food system, any modeling of how the global food system might evolve in the future, or any analysis incorporating international comparison, must start with this data, as there is no other.

2.2 Key Strengths and Weaknesses of FAO Food Data Tables (FFDT)

The main asset of the FFDT are their consistency of methodology and data capture across countries and throughout decades. This provides comparability of the data and make them evidence for long term trends of changes in the food system. The data is compiled by FAO and is made available free of charge to the global research and analysis community (for non-commercial purposes only).

Several restrictions apply to working with FFDT and therefore are also inherited by the PLANET model (or any other food system model). The most important is that the data measures only food availability per country per year. FFDT provide no information how much of this food is consumed, and by who it is consumed. It is not known how much food is wasted or used differently (for instance for pets). It is also not known how the food

is available throughout the season, how it is available across regions within a country, and how it is available to sociodemographic segments of the population. Seasonal, regional or sociodemographic shortages or surplus of food cannot be shown. It is a frequent mistake by analysts, including in scientific communities, not to consider this distinction between annual average availability and actual consumption by season, region or sociodemographic group.

Another restriction is that the food items have only limited specificity so that the nutritional quality of the available food basket can only be measured in vague terms. The limited specificity also makes it difficult to make accurate links to food composition databases. A good overview of the useability of the FFDT for assessment of nutrition can be found in this 2020 scientific publication by Chan-Myae Thar et all in Nutrition Review: https://academic.oup.com/nutritionreviews/article/78/12/989/5859719?login=true

Even though the data assessors in the countries are encouraged to rely on a wide variety of data sources including estimations, they must base themselves on some kind of source. As a result, non-commercial or subsistence production of food is insufficiently included, misestimated or underrepresented in the balances, as these do not easily enter statistical compilations.

Despite attempts in recent years to enlarge the data sets to also showcase other indicators, such as environmental impacts and resource consumption, the underlying data structure suffers from its original design to primarily show human food availability. The data are not readily presented to represent the overall mass flows in the agricultural production system.

The focus on showing food availability creates large gaps in showing the feed situation for animals. Only those amounts which could also potentially become human food consumption, are shown as feed. Those agricultural production amounts that are not usable for human food consumption, are neither mentioned nor shown. In particular, the tables do not show where by-product flows from processing are utilized, nor grassland production for animal feed purposes, nor non-food production crops such as cotton, and also not harvest by-products such as stems, roots or tops. This is a frequent cause of underestimation of the total feed amounts for animals or total agricultural production in general.

2.3 The Data Tables and Data Structure of the FAO Food Data Tables (FFDT)

The basic logic of the FFDT food availability is that for any given food:

- Starting stocks + production + imports = total supply
- Ending stocks + exports + seed + animal feed + waste + non-food uses = other utilization
- Available food = total supply – other utilization

In other words, it would appear that the amount of available food is what is left after all other utilizations are accounted for. In reality, the estimation models for the FFDT are more iterative than that. The various parameters and assumptions that enter into these

models are not sufficiently documented, so that an independent scientific replication is not possible.

In 2014, FAO conducted a large revision of the FFDT system. Therefore, all data exist in two time-lines, pre- and post-2014. PLANET 1.2 uses only the post-2014 data structure. In December 2021, FAOStat released a restructuring of the data from 2010 to 2013, so that it is now possible to compare time line developments back to 2010 with the new data structure. FAOStat intends to reproduce more historical data also in the post-2014 methodology, but has not yet announced a date of when they will be released.

The two main data tables where the above data is captured by FAOStat are the Supply Utilization Accounts (SUA) and the Food Balance Sheets (FBS). They are complementary to each other and both need to be considered for constructing the mass flows. This is best illustrated by the examples following below. Various instruction manuals can be found in the internet on how the FFD tables are constructed. The official FAO guideline is called "Guidelines for the compilation of food balance sheets, 2017", downloadable here:

https://www.fao.org/statistics/methods-and-standards/advanced-search/en/?key=109416

https://www.fao.org/3/ca6404en/ca6404en.pdf

2.4 The FAO-Stat Food Data Tables (FFDT) in PLANET

PLANET allows to select four different FAO-Stat sources:

- FAO-SUA = Supply Utilization Accounts. When selecting the SUA source, then PLANET will show the data as it is presented in the SUA tables without further computations. The SUA tables can be thought of as "Production Forward". All production amounts of materials are captured and it is then displayed towards which next "Uses" these amounts flow downstream.
- FAO-FBS = Food Balance Sheets. When selecting the FBS source, then PLANET will show the data as it is presented in the FBS tables without further computations. The FBS tables can be thought of "Availability Backward". All provided amounts of food materials are captured and it is then displayed from where they originated upstream.
- FAO-Synthesis 1.0. Neither the SUA nor the FBS tables provide the complete picture of the material flows in the food system. Also, confusingly, FAOStat uses the same words to mean different content in the respective SUA and FBS tables. Only through combining both tables and additional computations can the complete picture be shown (as will be illustrated below).
- FAO-Synthesis 1.2 = This source is used as the default setting for the PLANET model. For Synthesis 1.2, additional data sources and assumptions are incorporated to track the mass flows through the food system (see below).

Several examples below illustrate how the FAO-Synthesis 1.0 and 1.2 versions are computed. More details on assignments and assumptions used for the PLANET model are listed in the Supplement Section.

2.5 The Example of German Wheat Production in SUA, FBS and Synthesis 1.0

Both the FBS and the SUA tables show that Germany had 20.26 million tons of wheat production in 2018. Of these, and after proportionally allocating imports and exports, 7.04 mil tons became feed for animals, 0.51 mil tons became seed and 0.67 mil tons are losses. These numbers are respectively shown (with mouseover) in the PLANET SUA, FBS and Synthesis 1.0 source selections. The FAOStat FBS and SUA tables use different units, where FBS counts in kilotons (kt), and SUA in tons (t). PLANET instead shows all flows in kilotons.

In the case of German Wheat, only the FBS table reports a category called Food, namely 7.17 mil tons. That is because wheat products are usually not provided to the end consumer without processing. Therefore, the SUA numbers do not report wheat as being utilized as Food. From a SUA perspective, all materials go into "Processing" first.

The PLANET Synthesis 1.0 version combines the FBS tables and the SUA tables to one picture of mass flows, where both the production supply of SUA and the food availability view of FBS are combined towards one view (one synthesis, see figure 2.1 below).

The FBS tables also show 0.78 mil tons of other non-food "Other Uses". The FBS tables do not specify which other kind of non-food uses is being utilized. They could be consumer goods, industrial goods, fuels, unspecified uses or tourists. The logic for the latter assignment is that tourists do not represent permanent population in a country, and therefore their food consumption takes available food away from the residential population, which could lead to a distortion in the food security presentation. At any rate, in recent years, in those countries where tourists are a significant factor, FAOStat shows a separate tourist utilization, which PLANET also shows.

In general, "Other Uses" for non-food purposes that are produced during a processing stage is shown in PLANET as "Consumer Goods". For different crops, these can be different products. For palm oil, these could be many different products ranging from soaps to cooking oil. For wheat, one consumer good product is wheat starch, which can be used in paper making or hair spray.

"Other Use" flows directly after agricultural production and before processing, are generally shown by PLANET as "Industrial Goods", most of which becomes "Fuels".

In some instances, considerable amounts of food end up in the "Other Uses" category, because it is not known how they are utilized. For instance, some countries such as Ethiopia show large non-food uses of wheat. This appears to be driven by the fact that milling capacity in Ethiopia appears to be about 30% lower than production of wheat. Therefore, only the official milling capacity is considered as food production. Informal or small household milling is not considered and then counts as "Other Uses". These amounts will then not be counted as food supply, and will not be considered in the kilocalorie or protein per person budgets calculated by FAOStat.

The FBS and the SUA tables show different numbers for "Processing" and for "Exports" and "Imports". That is because they refer to different meanings with almost the same word. The SUA "Process**ED"** number shows the amount of the harvest that was processed, in this case most likely milling, which in Germany is 9.28 mil tons. The FBS "Process**ING"** number instead shows the amount of food that was processed/transformed into another

food category, for instance alcoholic beverages, in this case 0.13 mil tons. In the FAOStat logic this is done, in order to avoid double counting of the available food. Whenever one category of food is transformed into another category of food, then the FBS tables show them under the term “Processing”. The FBS tables do not reveal into which other food categories these foods are transformed. In principle these would be the four categories of alcoholic beverages, starches, sweeteners or oils and fats. While in the case of grapes for instance it is clear that this transformation is into wine and thus alcoholic beverage, in the case of wheat or potatoes it is not clear. In some countries it might be alcohol, and in others it might be sweeteners or starches or all of them. Future versions of PLANET shall estimate the flow of these transformed foods as well, however, for the time being the necessary data are not publicly available. In order to differentiate the term “Processing” in the FBS and SUA sources, PLANET renames it as “Transformed Food” if the value derives from the FBS source.

For the FBS tables, FAOStat employs a method called Vertical Standardization. This standardization converts the final food product back into the equivalent value of the original commodity. For instance, in case of wheat, consumers do not eat wheat flour, but they eat bread, pasta or cakes The FBS number does not denote how many tons of bread was provided in Germany, but what was the original pre-processed (pre-milling) amount of wheat equivalent contained in the bread and other products, namely the 7.17 mil tons noted above.

The FBS tables show the total “Imports” and “Exports” related to wheat, while the SUA tables show only the “Imports” and “Exports” of wheat before it was processed. Germany exports both raw wheat and processed wheat (flour or further products such as bread, etc.). The values for the processed wheat exports/imports can thus be computed by deducting the amounts of the SUA tables (before processing) from the amounts of the FBS tables (all trade). In this way, PLANET differentiates between “Ex-/Imports Harvests” and “Ex-/Imports Goods” in its Sankey pictures.

In order to simplify the model, PLANET Synthesis adds “Ex-/Imports” and “Stock Variations” together on the country level. Increasing deposit to stocks are added to “Exports”, and withdrawals from stocks are added to “Imports”.

Attention: The Pop-up function of trade destinations and origins show only ex-/imports without stock variations, which is why the values typically differ from the node size of ex-/imports in the picture.

At FAOStat, losses refer to typically expected production losses from the farm gate to food provision, meaning storage losses or processing losses. In the FAOStat logic, losses do not mean waste incurred in the difference between provided food and consumed food. These would for instance include foods that are discarded by retailers, restaurants or at the consumers, or which spoil prematurely and non-intentionally in food supply chains. The FAOStat numbers only show provided foods, not consumed foods. The amount of waste that is incurred in the difference is not shown in the number of losses.

FAOStat captures only the typical wheat crop. It does not account for the utilization of the stalks or straw production of the wheat. The computation and utilization of harvest-by-products is illustrated and explained in chapter 4.

Attention: The sample illustrations of PLANET are not updated to the most recent version, if it makes no difference to explaining the methodology

Figure 2.1: FAO-Stat Data Tables and PLANET Pictures for German Wheat 2018

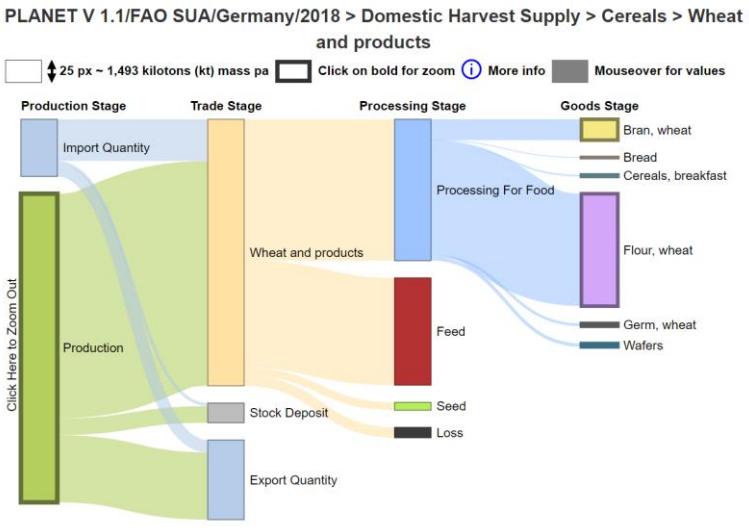
a) FAO-Stat SUA tables for German wheat 2018

Domain	Area	Element	Item	Year	Unit	Value
Supply Utilization Accounts	Germany	Opening stocks	Wheat	2018	tonnes	22654679
Supply Utilization Accounts	Germany	Production	Wheat	2018	tonnes	20263500
Supply Utilization Accounts	Germany	Import Quantity	Wheat	2018	tonnes	3750191
Supply Utilization Accounts	Germany	Stock Variation	Wheat	2018	tonnes	1287166
Supply Utilization Accounts	Germany	Export Quantity	Wheat	2018	tonnes	5228857
Supply Utilization Accounts	Germany	Feed	Wheat	2018	tonnes	7035000
Supply Utilization Accounts	Germany	Seed	Wheat	2018	tonnes	512000
Supply Utilization Accounts	Germany	Loss	Wheat	2018	tonnes	670000
Supply Utilization Accounts	Germany	Processed	Wheat	2018	tonnes	9280668
Supply Utilization Accounts	Germany	Other uses (non-food)	Wheat	2018	tonnes	-
Supply Utilization Accounts	Germany	Residuals	Wheat	2018	tonnes	0

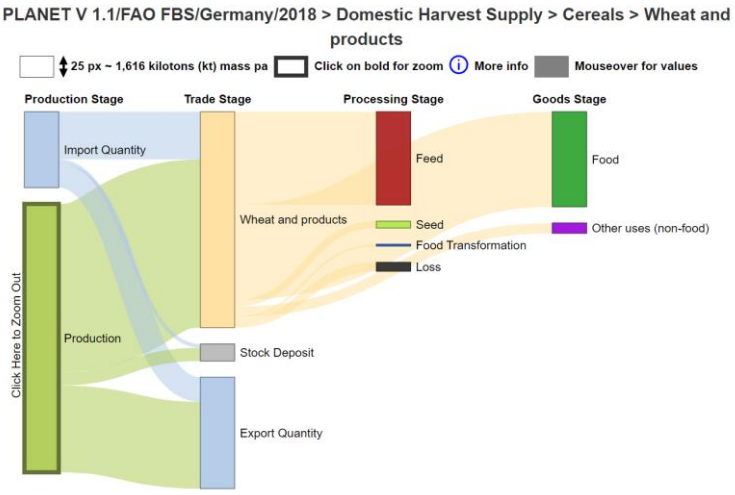
b) FAO-Stat FBS tables for German wheat 2018

Domain	Area	Element	Item	Year	Unit	Value
Food Balances (2010-)	Germany	Production	Wheat and products	2018	1000 tonnes	20264
Food Balances (2010-)	Germany	Import Quantity	Wheat and products	2018	1000 tonnes	5729
Food Balances (2010-)	Germany	Stock Variation	Wheat and products	2018	1000 tonnes	1286
Food Balances (2010-)	Germany	Export Quantity	Wheat and products	2018	1000 tonnes	8405
Food Balances (2010-)	Germany	Domestic supply quantity	Wheat and products	2018	1000 tonnes	16302
Food Balances (2010-)	Germany	Feed	Wheat and products	2018	1000 tonnes	7035
Food Balances (2010-)	Germany	Seed	Wheat and products	2018	1000 tonnes	512
Food Balances (2010-)	Germany	Losses	Wheat and products	2018	1000 tonnes	670
Food Balances (2010-)	Germany	Processing	Wheat and products	2018	1000 tonnes	137
Food Balances (2010-)	Germany	Other uses (non-food)	Wheat and products	2018	1000 tonnes	775
Food Balances (2010-)	Germany	Residuals	Wheat and products	2018	1000 tonnes	0
Food Balances (2010-)	Germany	Food	Wheat and products	2018	1000 tonnes	7172

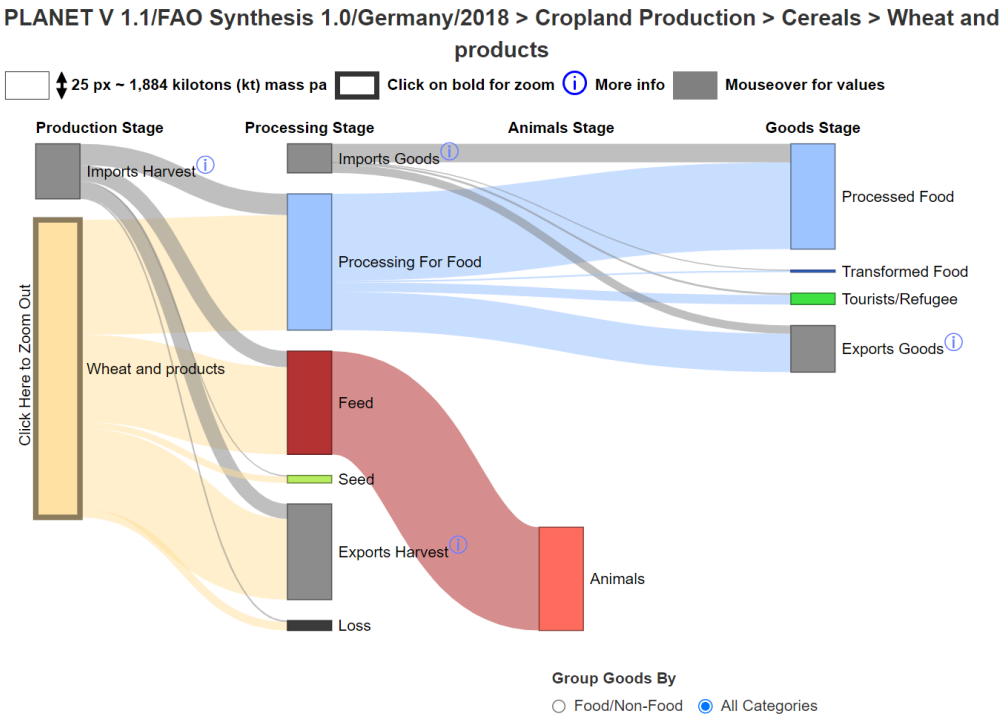
c) PLANET SUA source German wheat 2018



d) PLANET FBS source German wheat 2018



e) PLANET Synthesis 1.0 source German wheat 2018



2.5 The Example of Dutch Potato Production in in SUA, FBS and Synthesis 1.0

The same Synthesis computation logic of German Wheat also applies to the example of Dutch Potatoes. However, here there is an additional category called “Raw Food”. These are food stuffs that are not processed and go straight from the farm gate to the retailer, restaurant or consumer in unaltered or only minimally processed form. In the case of potatoes, these would be unprocessed whole potatoes that become “Raw Food”, while the processed potatoes are for the most part frozen potatoes (i.e. french fries) and starches. The category of “Raw Food” is taken from the number called “Food Supply” in the SUA tables. The amount of “Processed Food” is then calculated by deducting “Food

Supply" in the SUA tables from the "Food" value in the FBS tables. Thus, out of a total production of 6,03 mil tons, and 6,92 mil tons domestically available after trade, "Raw Food" potatoes available to the Dutch is 1.17 mil tons, and "Processed Food" is 0.054 mil tons. The remainder is transformed, turned into other uses goods or exported. As with transformed wheat foods, it cannot be known into which kind of foods the potato foods are transformed. Because of the large amount of potato production in Netherlands there are large amounts of "Transformed Foods" of 0.99 mil tons.

Attention: As with all FAOStat numbers, the category of "Raw Food" does not refer to how it is being consumed, but how it is provided to the customer. Usually, the consumer or the restaurant will cook or otherwise prepare the food as well, but this is not captured by the FAOStat numbers.

The PLANET Synthesis picture shows that Netherlands is an almost net trader of harvested potatoes (1.83 imported minus 1.80 exported = 0.03 mil tons) and a large exporter of processed potatoes (4.42 mil tons; net exports of processed is 3.44 mil tons). The numbers in the Sankey diagram differ slightly from these values because they also incorporate stock fluctuations. Sweet potatoes and yams are comparatively tiny amounts.

As in wheat and all other commodities, PLANET assumes that "Other Uses" in the SUA tables are for "Industrial Goods", and "Other Uses" in the FBS tables after processing, are for "Consumer Goods".

Figure 2.2: FAO-Stat data tables and PLANET pictures for Dutch potato

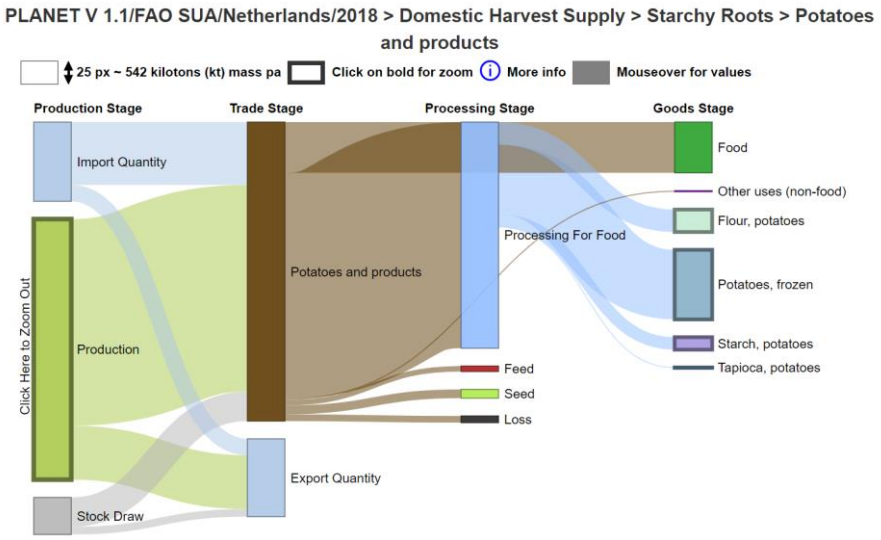
a) FAO-Stat SUA tables for Dutch potato 2018

Domain	Area	Element	Item	Year	Unit	Value
Supply Utilization Accounts	Netherlands	Opening stocks	Potatoes	2018	tonnes	857683
Supply Utilization Accounts	Netherlands	Production	Potatoes	2018	tonnes	6029734
Supply Utilization Accounts	Netherlands	Import Quantity	Potatoes	2018	tonnes	1832039
Supply Utilization Accounts	Netherlands	Stock Variation	Potatoes	2018	tonnes	-857683
Supply Utilization Accounts	Netherlands	Export Quantity	Potatoes	2018	tonnes	1801349
Supply Utilization Accounts	Netherlands	Feed	Potatoes	2018	tonnes	127199
Supply Utilization Accounts	Netherlands	Seed	Potatoes	2018	tonnes	203642
Supply Utilization Accounts	Netherlands	Loss	Potatoes	2018	tonnes	155639
Supply Utilization Accounts	Netherlands	Processed	Potatoes	2018	tonnes	5232465
Supply Utilization Accounts	Netherlands	Other uses (non-food)	Potatoes	2018	tonnes	25000
Supply Utilization Accounts	Netherlands	Residuals	Potatoes	2018	tonnes	0
Supply Utilization Accounts	Netherlands	Food supply quantity (tonnes)	Potatoes	2018	tonnes	1174162

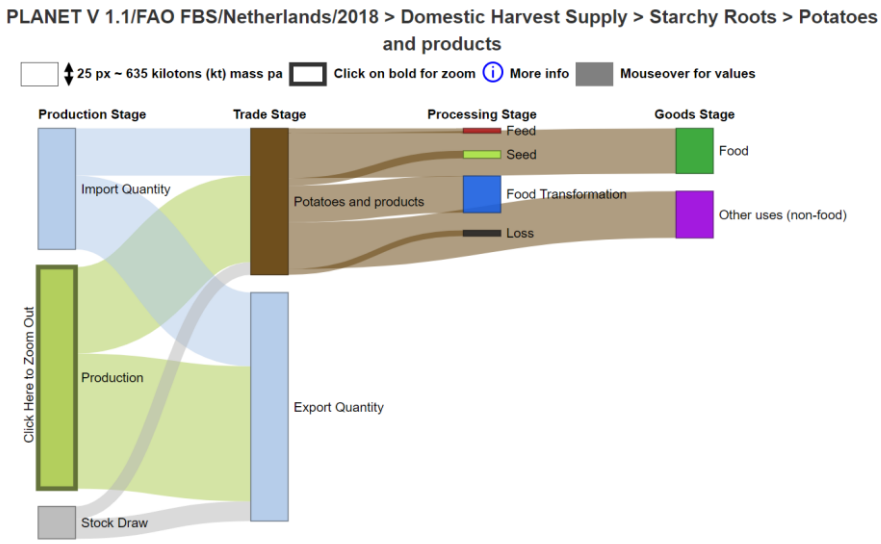
b) FAO-Stat FBS tables for Dutch potato 2018

Domain	Area	Element	Item	Year	Unit	Value
Food Balances (2010-)	Netherlands	Production	Potatoes and products	2018	1000 tonnes	6030
Food Balances (2010-)	Netherlands	Import Quantity	Potatoes and products	2018	1000 tonnes	3293
Food Balances (2010-)	Netherlands	Stock Variation	Potatoes and products	2018	1000 tonnes	-883
Food Balances (2010-)	Netherlands	Export Quantity	Potatoes and products	2018	1000 tonnes	6220
Food Balances (2010-)	Netherlands	Domestic supply quantity	Potatoes and products	2018	1000 tonnes	3985
Food Balances (2010-)	Netherlands	Feed	Potatoes and products	2018	1000 tonnes	127
Food Balances (2010-)	Netherlands	Seed	Potatoes and products	2018	1000 tonnes	204
Food Balances (2010-)	Netherlands	Losses	Potatoes and products	2018	1000 tonnes	156
Food Balances (2010-)	Netherlands	Processing	Potatoes and products	2018	1000 tonnes	998
Food Balances (2010-)	Netherlands	Other uses (non-food)	Potatoes and products	2018	1000 tonnes	1272
Food Balances (2010-)	Netherlands	Residuals	Potatoes and products	2018	1000 tonnes	0
Food Balances (2010-)	Netherlands	Food	Potatoes and products	2018	1000 tonnes	1228

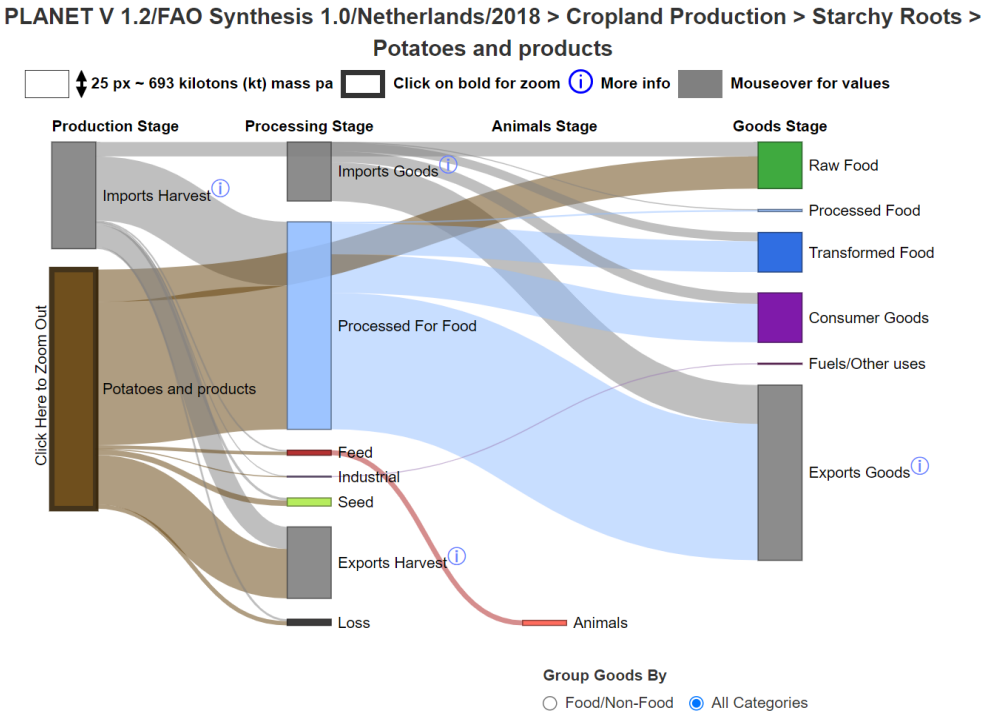
c) PLANET SUA source Dutch potato 2018



d) PLANET FBS source Dutch potato 2018



e) PLANET FAO Synthesis 1.0 source Dutch potato 2018



2.6 The Example of Brazil Soy Bean Production

In 2018, Brazil was the second largest soy bean producer in the world, trailing slightly behind the USA (Brazil: 118, USA 121 million tons). The primary reason for soy bean cultivation is for feed to animals. However, the FAOStat tables show no such entry for feed utilization, neither in the SUA nor in the FBS tables. The reason for this is because the soy beans are oil crops which become processed. In contrast to the other food categories, the oil crops tables must be paired with the corresponding oil product tables: for instance, the SUA tables of soybeans with the FBS tables of soyabean oil, or the SUA of sunflower seeds with the FBS of sunflower oil.

Due to this peculiarity, the by-products of the processing of the oil crops are not shown in these FAOStat tables. It can only be assumed that the “Processed” amount of the oil crops in the SUA tables less the “Production” amount of the resultant oils from the FBS tables, is the equivalent of soy bean by-products (cakes or meals), which will then typically be fed to animals. The PLANET synthesis calculations are: Brazil soy bean processing amounts (SUA): 45.2 mil tons, minus soya bean oil production (FBS): 8.8 mil tons, minus exports of soya bean cake (Trade tables): 16.9 mil tons, equals domestic by-product (soya been cake) for feed: 19.5 mil tons. In the case of oil crop cakes, the Trade table by FAO provides information on Exports and Imports of oil crop cakes.

Attention: As the trade numbers for oil meals are included in the PLANET Harvest Exports or Imports, these “Harvest Exports” include some amount of processed soybeans which are not shown/included in the flow to processing.

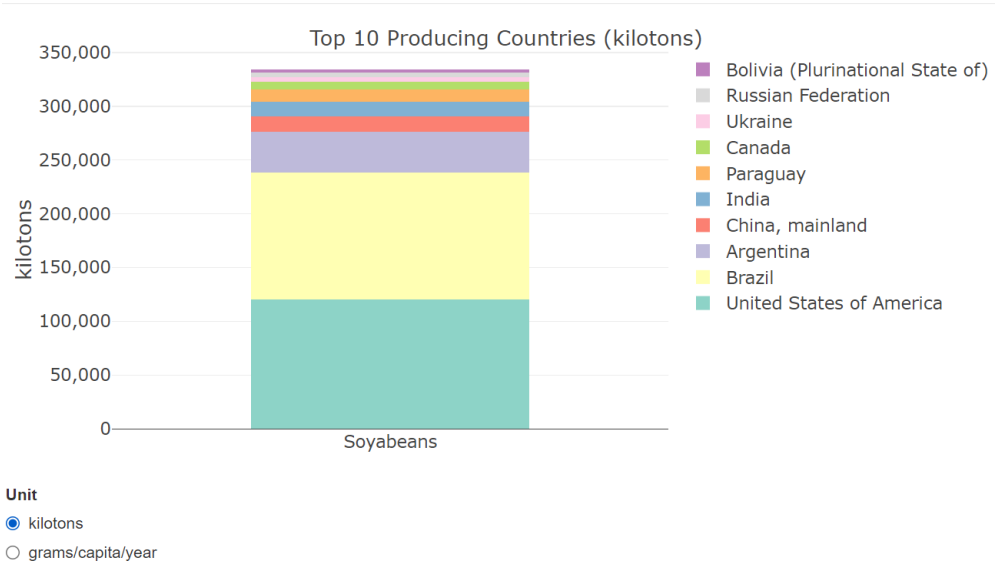
Among the “Processed” amounts that become oils, in Brazil only a 30% portion becomes edible oils and fats. The larger portion of 48% is recorded as “Other Uses”. As these are a post-processing good, PLANET assigns them to be “Consumer Goods”. Soy bean is a major ingredient for instance, in newspaper inks. Also cooking oil uses are counted as consumer goods, because the nutritional value of cooking oil does not enter into the food consumption of the consumer. In other databases that not created by FAOStat, for instance in the American USDA, cooking oil uses are counted as food utilization.

FAOStat provides statistics for 12 different types of cakes. PLANET assigned crops to them according to the following table, and treats them in the same way as with the Brazilian soybean example:

Cake, copra	Coconuts
Cake, groundnuts	Groundnuts, shelled
Cake, palm kernel	Oil palm fruit
Cake, mustard	Mustard seed
Cake, rapeseed	Rapeseed
Cake, sesame seed	Sesame seed
Cake, soybeans	Soybeans
Cake, sunflower	Sunflower seed
Cake, safflower	Safflower seed
Cake, linseed	Linseed
Cake, kapok	Kapok fruit
Cake, hempseed	Hempseed

Figure 2.3: FAO-Stat data tables and PLANET pictures for Brazilian soy beans 2018

a) Top 10 producing countries of soy beans



b) FAO-Stat SUA tables for Brazilian soy bean 2018

Domain	Area	Element	Item	Year	Unit	Value
Supply Utilization Accounts	Brazil	Opening stocks	Soybeans	2018	tonnes	22113537
Supply Utilization Accounts	Brazil	Production	Soybeans	2018	tonnes	117912450
Supply Utilization Accounts	Brazil	Import Quantity	Soybeans	2018	tonnes	186972
Supply Utilization Accounts	Brazil	Stock Variation	Soybeans	2018	tonnes	-13964712
Supply Utilization Accounts	Brazil	Export Quantity	Soybeans	2018	tonnes	83605198
Supply Utilization Accounts	Brazil	Feed	Soybeans	2018	tonnes	1448136
Supply Utilization Accounts	Brazil	Seed	Soybeans	2018	tonnes	1775936
Supply Utilization Accounts	Brazil	Loss	Soybeans	2018	tonnes	0
Supply Utilization Accounts	Brazil	Processed	Soybeans	2018	tonnes	45234864
Supply Utilization Accounts	Brazil	Residuals	Soybeans	2018	tonnes	0

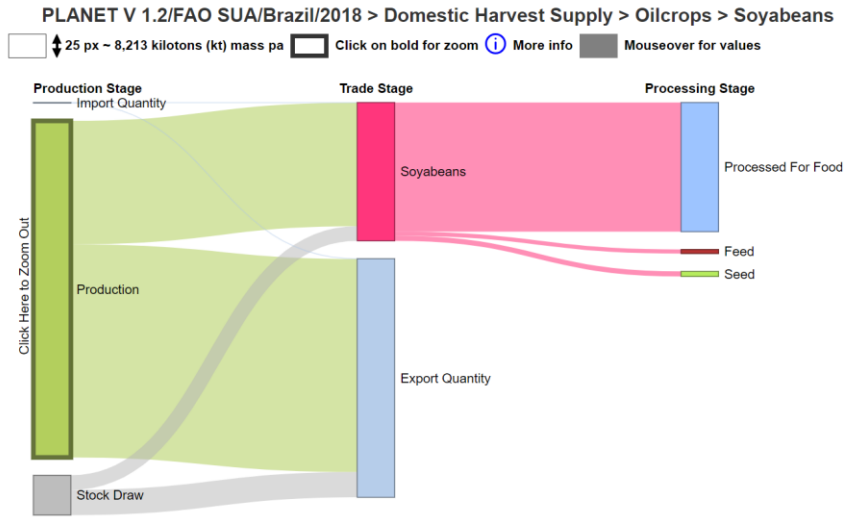
c) FAO-Stat trade tables for Brazilian soy bean cake 2018

Domain	Area	Element	Item	Year	Unit	Value
Crops and livestock products	Brazil	Import Quantity	Cake, soybeans	2018	tonnes	224
Crops and livestock products	Brazil	Export Quantity	Cake, soybeans	2018	tonnes	16862000

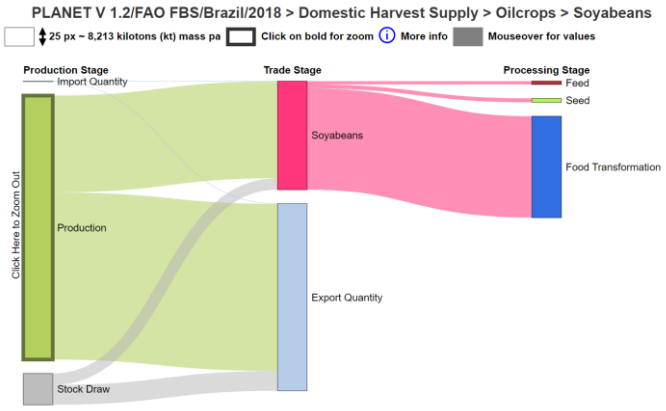
d) FAO-Stat FBS tables for Brazilian soy bean oil 2018

Domain	Area	Element	Item	Year	Unit	Value
Food Balances (2014-)	Brazil	Production	Soyabean Oil	2018	1000 tonnes	8835
Food Balances (2014-)	Brazil	Import Quantity	Soyabean Oil	2018	1000 tonnes	35
Food Balances (2014-)	Brazil	Stock Variation	Soyabean Oil	2018	1000 tonnes	85
Food Balances (2014-)	Brazil	Export Quantity	Soyabean Oil	2018	1000 tonnes	1415
Food Balances (2014-)	Brazil	Domestic supply quantity	Soyabean Oil	2018	1000 tonnes	7371
Food Balances (2014-)	Brazil	Processing	Soyabean Oil	2018	1000 tonnes	501
Food Balances (2014-)	Brazil	Other uses (non-food)	Soyabean Oil	2018	1000 tonnes	4209
Food Balances (2014-)	Brazil	Residuals	Soyabean Oil	2018	1000 tonnes	0
Food Balances (2014-)	Brazil	Food	Soyabean Oil	2018	1000 tonnes	2660

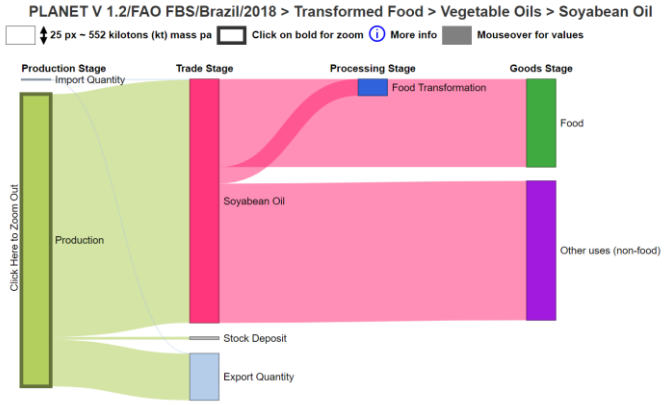
e) PLANET SUA source Brazilian soy bean 2018



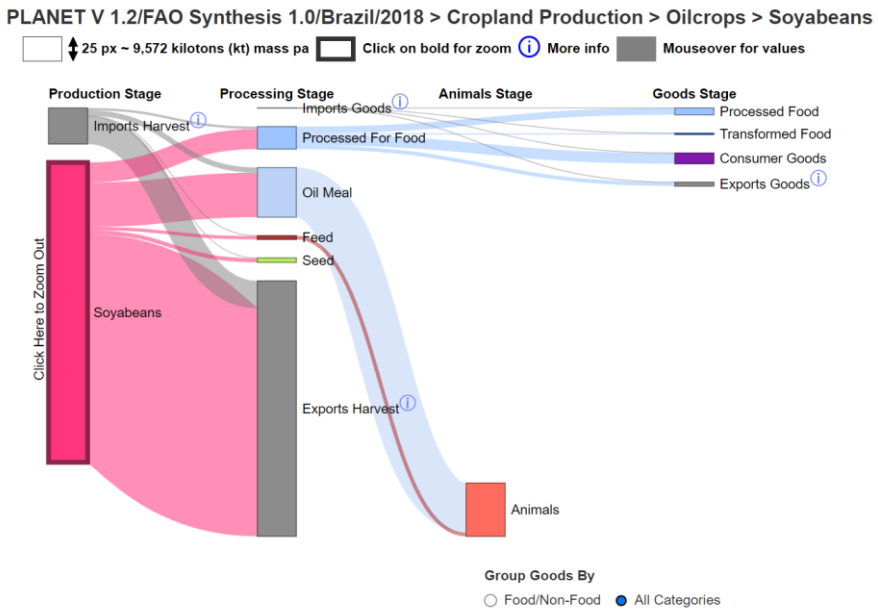
f) PLANET FBS source Brazilian soy bean 2018



g) PLANET FBS source Brazilian soyabean oil 2018



h) PLANET FAO Synthesis 1.0 source Brazilian soy bean and oil 2018

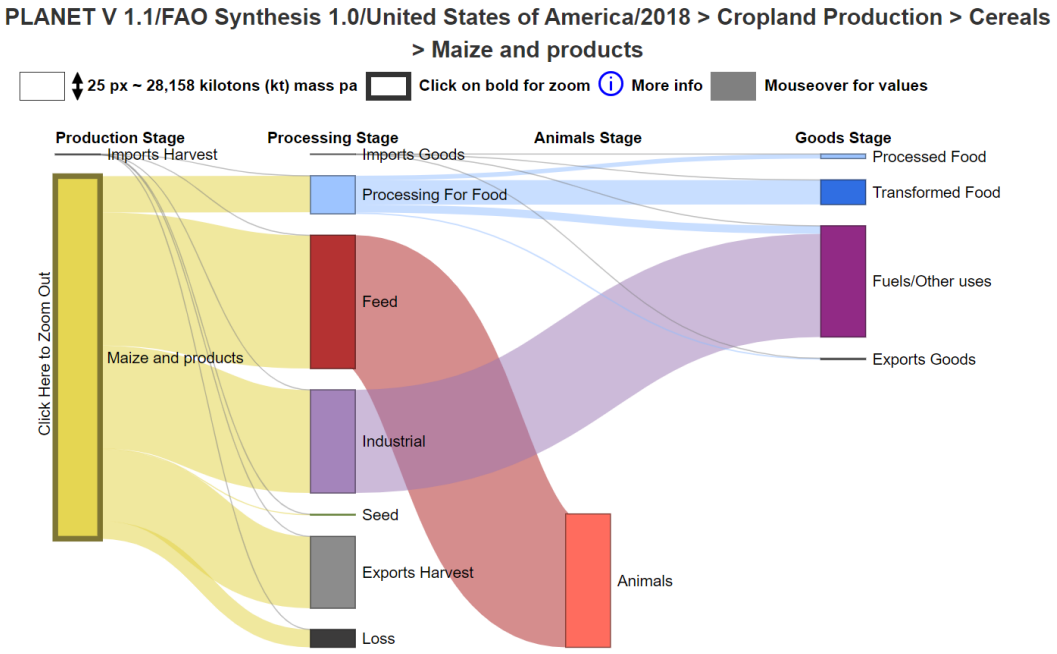


2.7 The Example of USA Maize Production

USA maize production shows that, in some cases, the agricultural production is used directly for industrial purposes, in this case for fuels. 102,7 mil tons are processed into fuels and 133,9 mil tons are processed into feed for animals. 39,3 mil tons are processed towards human foods, of which some become non-food uses as well. It is an American specialty that much of this (25,5 mil tons) is processed into maize flour, which is then further processed into maize starch, which is then further processed into fructose and glucose to become high-fructose corn syrup (HFCS), which is the standard sweetener ingredient product for the US American beverage and food industry. Therefore, PLANET records them as “Transformed Food”. FAOStat does not provide information on which amounts of transformed foods become which kind of categories, but in USA the processed maize flour is the major source for “Sugar and sweeteners”. Fresh corn for eating is not captured under “Maize”, but is captured in the FAO tables under the category of “Other Vegetables”.

Figure 2.4: PLANET USA maize

a) PLANET FAO Synthesis 1.0 source USA maize 2018



2.8 Evaporated Water

In many food-processing steps, evaporation of water is taking place, so that the final product has considerably less weight than the original product. This is a particularly so in the case of milk and sugar crops. PLANET assigns all table milk in the category of “Raw Food” items, whereas all other items such as butter, cheese or cream are “Processed Food”. PLANET assumes that the difference between the weight of all finished dairy products and the weight of the whole fresh cow milk production, represents evaporated water.

In the case of sugar crops, PLANET assumes that all sugar crop production minus resulting sugar food, minus molasses, bagasses and pulp, represents the amount of water that was evaporated during production. The processing losses of coconut water and in palm oil processing are also shown as evaporated water.

The respective calculation steps for sugars are explained in section 4.1.5, including also further alterations which incorporate the flow of harvest and processing by-products which are accounted for by Synthesis 1.2.

Figure 2.5: PLANET Synthesis 1.0 for World Milk Production 2019

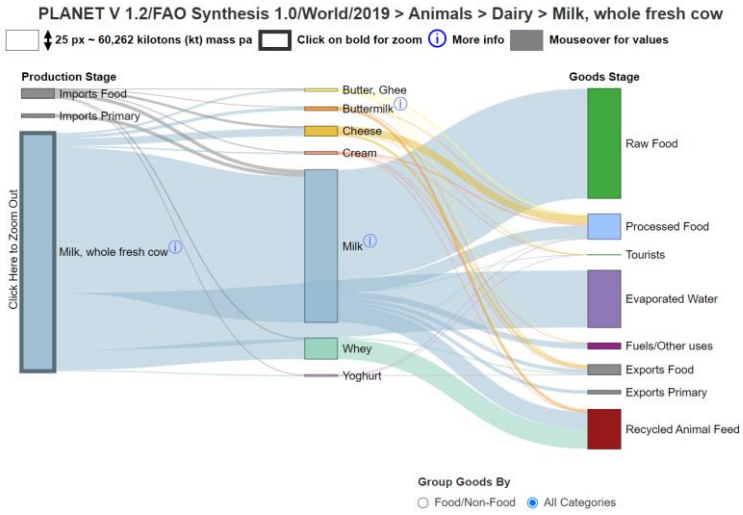
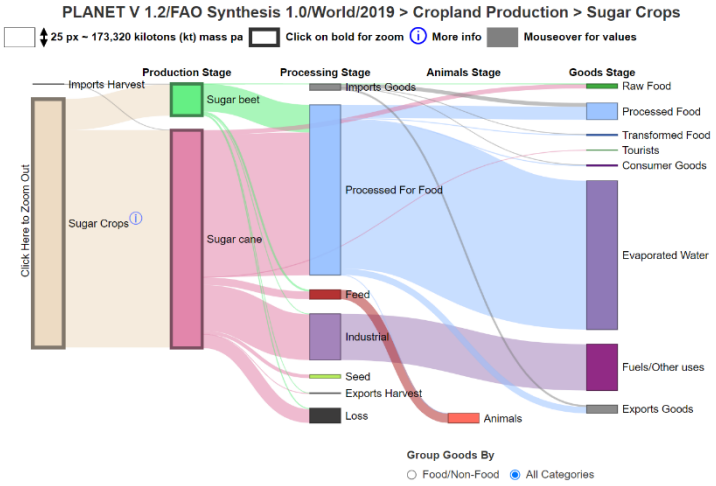


Figure 2.6: PLANET Synthesis 1.0 for World Sugar Crop Production 2019



2.9 Synthesis 1.2 Refinement: Additional Animal Feed Allocations

For some products, for instance “wheat”, the FAOStat commodity tree (see supplement S1) includes additional processing steps. For instance, the primary processing step is milling, followed by secondary steps such as processing “Bran”. The SUA source view allows to follow those additional steps, to the degree that they are provided by the commodity tree. In some occasions, these additional steps will yield more animal feed. Under the Synthesis 1.0 view (which does not display secondary processing steps), this information is ignored. In the Synthesis 1.2 view, this information is utilized in form of a flow from “Processing for Food” to “Animals”.

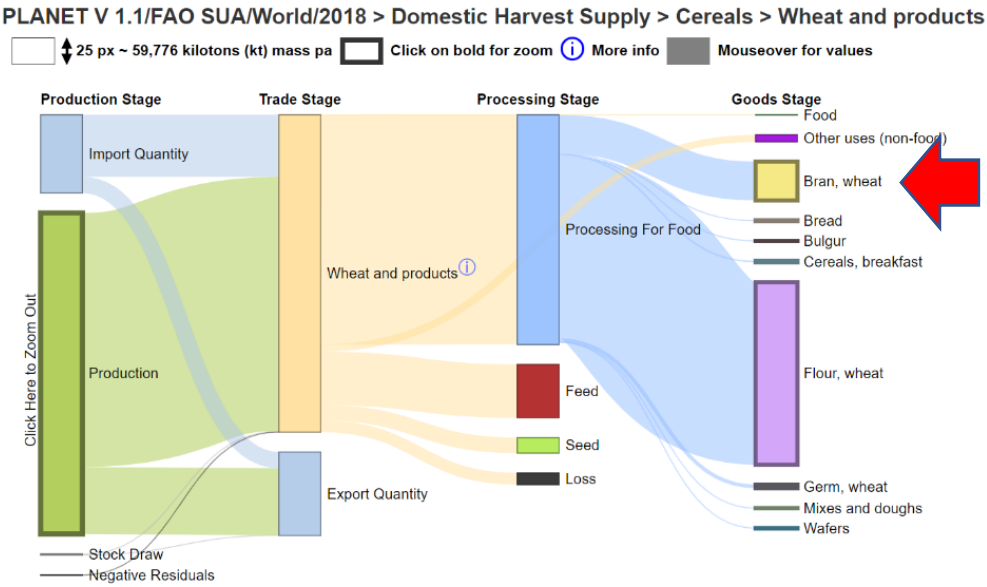
However, due to the vertical standardization method by FAOStat, the corresponding amount of feed is already fully imputed at the “Processed for Food” stage. With now adding an additional outflow from there to Animals, this will open a gap on the inflow side into this category. In order to close this gap, PLANET shows a link called “Missing Data”. Missing Data is also used for those cases where there are residuals in the FAOStat data. Strictly speaking, the data is not missing, but represents a double-counting at the processing stage, resulting from the vertical standardization method of FAOStat.

Chapter 4.2 provides more detail on the various feed allocation of these processing and harvest-by-products for each of the crops. The respective assumptions and flows are also documented in the excel sheet for download:

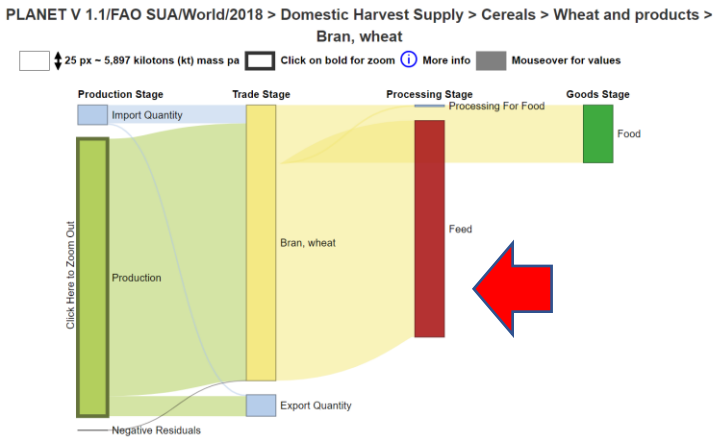
- Excel sheet download: S III Nutrition and Flow Allocation Master Table_23 Dec 2022

Figure 2.7: PLANET world wheat

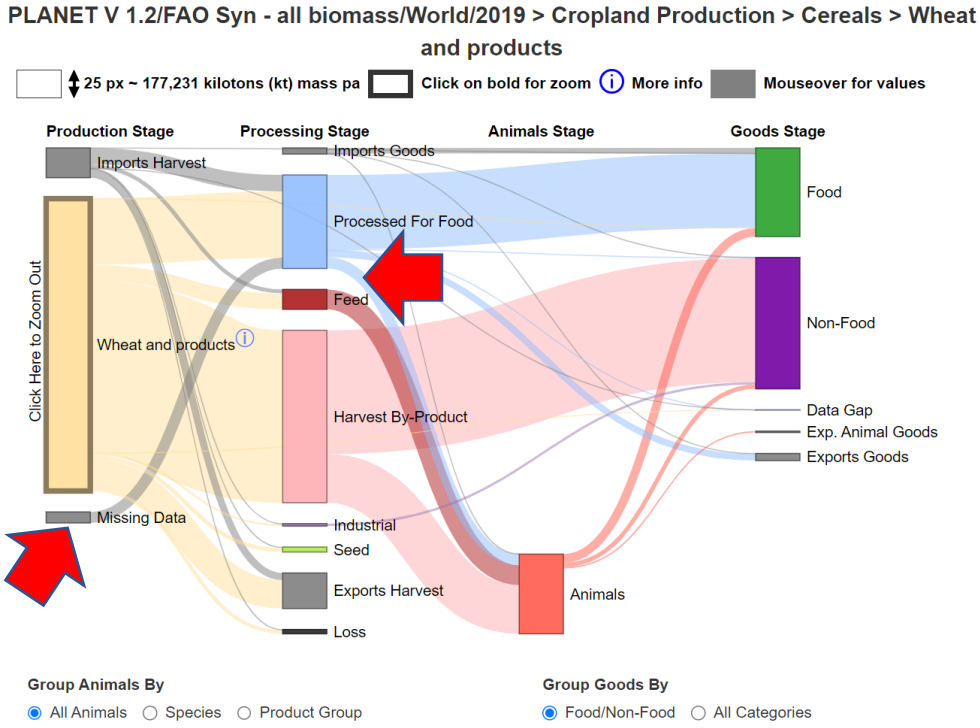
a) SUA source world wheat



b) SUA source world bran as a secondary processing step and additional feed allocation



c) Synthesis 1.2 flow of world bran feed to animals



2.10 Synthesis 1.2 Refinement: Additional Human Food Allocations

Some crops have multiple food processing stages with special significance. Where these are significant, PLANET captures them with additional calculations. These are covered in detail below. Particular feed and non-food allocations are explained in Chapter 4.2.

2.10.1 Maize in Synthesis 1.2

The “Processed Food” category of maize comprises of the sum of the SUA products from maize flour, maize starch and maize germ oil.

2.10.2 Coconuts in Synthesis 1.2

The “Processed Food” category of coconuts comprises of the sum of the SUA products from coconuts desiccated and coconuts oil. Also, the amount of coconut water is estimated to be: the total amount of coconut processed minus 28% shell content minus 2.8 x SUA oil production (because 36% of flesh is oil) minus 2 x SUA desiccated coconut flesh (because moisture content of flesh is 50%) *5.5%, because 5.5% of coconut water is sold as food. The other 94.5% is typically wasted during processing. Note that coconut water is not equal to the more coconut milk. The latter is a processed product made out of coconut flesh.

2.10.3 Groundnuts in Synthesis 1.2

The “Raw Food” category of groundnuts comprises of the sum of the SUA products of groundnuts with shell and groundnuts shelled. The “Processed Food” category of groundnuts comprises of the sum of the SUA products of groundnuts prepared and groundnuts oil.

Attention: In line with FAOStat, PLANET lists groundnuts (peanuts) under “Oil crops” and not under “Pulses and Nuts”.

2.10.4 Palm oil in Synthesis 1.2

The “Processed Food” category of palm oil comprises of the sum of the SUA products of “Oil, palm” and “Oil, palm kernel”. The further processed palm oil products such as margerines etc, are shown under transformed foods.

2.10.5 Olives in Synthesis 1.2

The “Raw Food” category of olives comprises of the sum of the SUA products of olives and olives preserved. The “Processed Food” category of olives comprises of the sum of the SUA products of oil virgin and oil residue.

2.10.6 Soybean in Synthesis 1.2

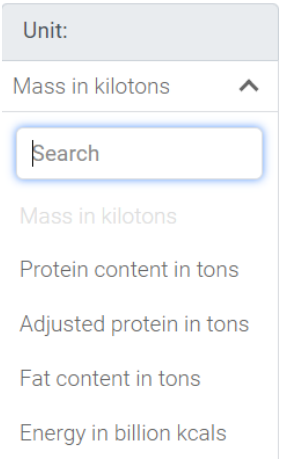
The “Processed Food” category of soybeans comprises of the sum of the SUA products of soyabean oil and soyabean curd, paste and sauces.

2.10.7 Almonds, brazil nuts, cashew nuts, hazelnuts and walnuts in Synthesis 1.2

The “Raw Food” category of these nuts comprises of the sum of the SUA products of nuts with shell and nuts shelled.

3. Further FAOStat Sources Used for PLANET

3.1 Protein, Fat and Kcal Unit Computation



In the Unit Selector it is possible to display the entire Sankey with the unit of tons of protein, tons of fat content and energy content in billion kcals, or in in tons of adjusted protein (see 3.2). This can be done either for total country, or per capita per year, or per capita per day.

FAOStat provides an estimation of the amount of protein which a particular food provides to the population of a country with the unit of grams/capita/year. This value allows the computation of the absolute protein amount embedded in the material flows. PLANET found an inofficial FAO excel sheet on the internet, where the protein content of each food item is provided. The values in this excel sheet correspond to a computation where the grams/capita/year in the data tables are multiplied by the population and 365. Apparently FAOStat assumes that the protein content is the same for the respective food items in each country. The excel sheet was found here (also Supplement III):

http://www.fao.org/fileadmin/templates/ess/ess_test_folder/Food_security/Excel_sheets/Nutritive_Factors.xls

- Excel sheet download: S III FAO Nutritive_Factors_24 Feb 2022

To estimate the protein/fat/energy content of the interim processed stages of the material flows, such as for Feed, Seed, Losses, Non-Foods, Fuels/Other Uses, as well as for the By-products or Distillers products, either the French National Research Institute INRAE-CIRAD-AFZ tables were consulted: https://feedtables.com/, or the website Feedipedia: https://feedipedia.org/ The respective Exports and Imports are calculated with weighted contents of the respective goods represented in the trade flows. The summary of all values used for PLANET is found in this excel sheet:

- Excel sheet download: S III Nutrition and Flow Allocation Master Table_23 Dec 2022

The protein content of aggregations of animal products is estimated to be the weighted average of the constituent products. The same value is also provided to the non-food uses of animal products such as Feed, Loss or Other Uses.

3.2 Bioavailability-adjusted Protein Computation

Proteins from different sources of foods, have different levels of metabolic bioavailability to humans. In order to reflect these, a number of researchers, including a FAO recommendation in 2013, developed the so-called DIAAS-score for foods. DIAAS stands for “Digestable Indispensable Amino Acid Score”. For instance, a DIAAS-score of 0.8 means that the protein

content in a particular food is only 80% available to the human metabolism. Other foods have a value of up to 1.2. A value higher than 1.0 means that this food makes not only its own protein content available, but also facilitates the uptake of other proteins from other foods.

The research to assign DIAAS values is progressing only slowly. Many foods, and also combinations of foods, have not yet been evaluated. Ethical considerations prohibit such experiments on human beings. They are instead conducted on pigs or rodents, with the results being transferred to human biology.

The seminal paper on the subject is commonly considered to be by Marinangelli, 2017:

https://academic.oup.com/nutritionreviews/article/75/8/658/4056218.

The FAO expert consultation paper from 2013 is here:

https://www.fao.org/ag/humannutrition/35978-02317b979a686a57aa4593304ffc17f06.pdf

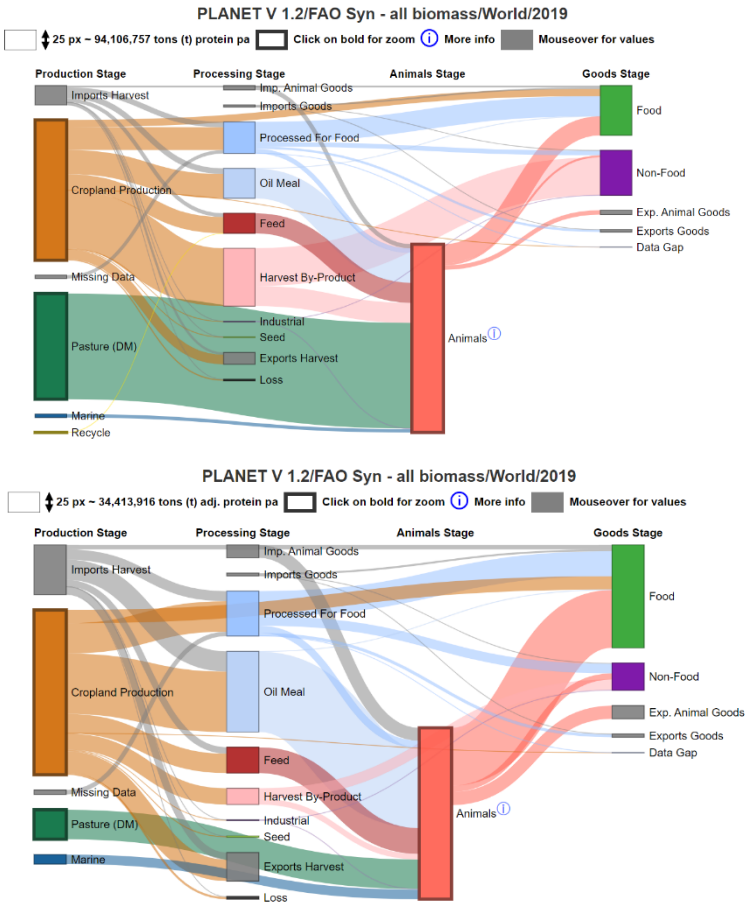
A good summary of the most current DIAAS scores from various researchers is provided by Wikipedia:

https://en.wikipedia.org/wiki/Digestible_Indispensable_Amino_Acid_Score

The DIAAS scores which are assumed by PLANET for all the different foods and biomass flows are shown in this excel summary:

- Excel sheet download: S III Nutrition and Flow Allocation Master Table_23 Dec 2022

Figure 3.1: PLANET World protein view (top) vs adjusted protein view (bottom) 2019

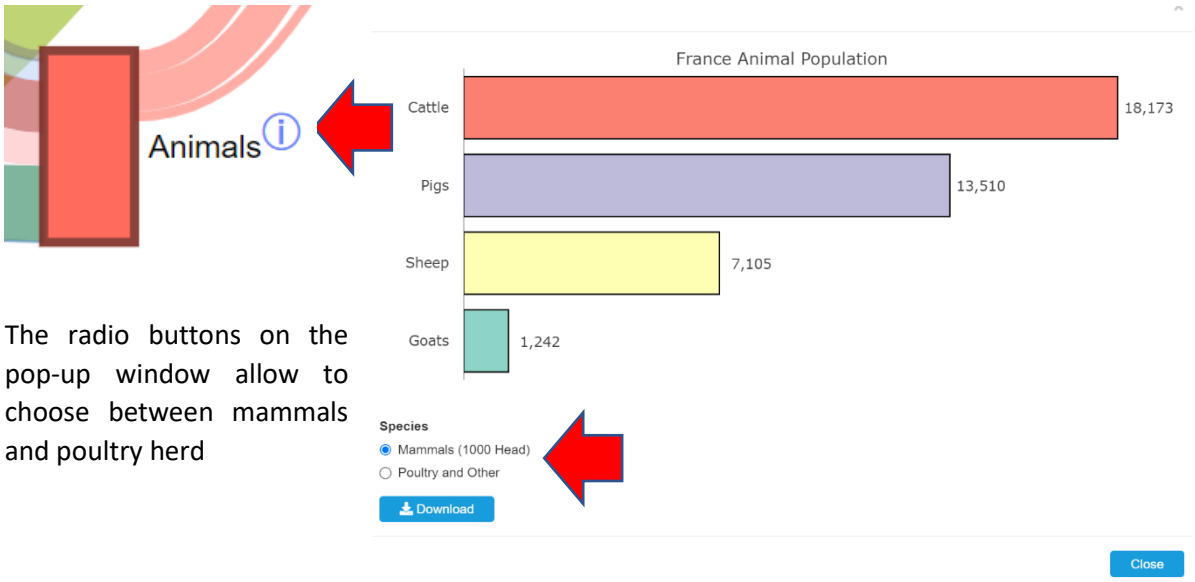


3.3 Animal Stock Data

The Pop-up window for numbers of animals in a country that is accessible on the front page of a country selection, is taken from the FAOStat data page on “Crops and Livestock Products”. FAOStat does not cross-check these stock numbers with the production amounts of dairy and meat, and it also does not provide herd structure numbers. There is trade of live animals among countries, which is not represented in PLANET yet. Trade of live animals relates to the herd structure, which will be implemented in later versions.

https://www.fao.org/faostat/en/#data/QCL

Figure 3.2: Animal stock data pop-up



The radio buttons on the pop-up window allow to choose between mammals and poultry herd

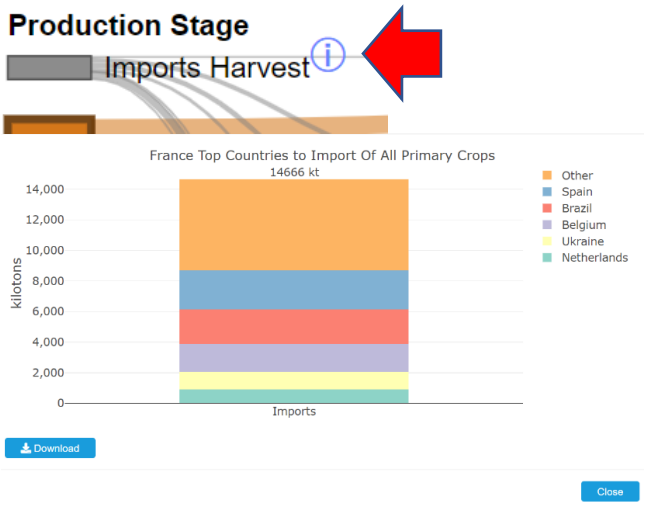
3.4 Trade Data

The values for export and imports in the Trade Top 5 Pop-up window is taken from the FAOStat data set on “Detailed Trade Matrix”.

https://www.fao.org/faostat/en/#data/TM

Attention: When groups of countries are viewed, including World view, then the numbers for Export and Import show the cumulative amount of trade in this view, not the consolidated amount of trade of this group with other countries outside of this group. On a consolidated basis, the World view would not show any trade, because the Earth does not export/import from other planets. This means that the nodes of the “Processing Stage” are inflated by the amount of trade, and only the flow numbers to and from “Processing Stage” represent the actual amounts. This applies only to country groups.

Figure 3.3: Trade top 5 data pop-up



3.5 Forestry Data

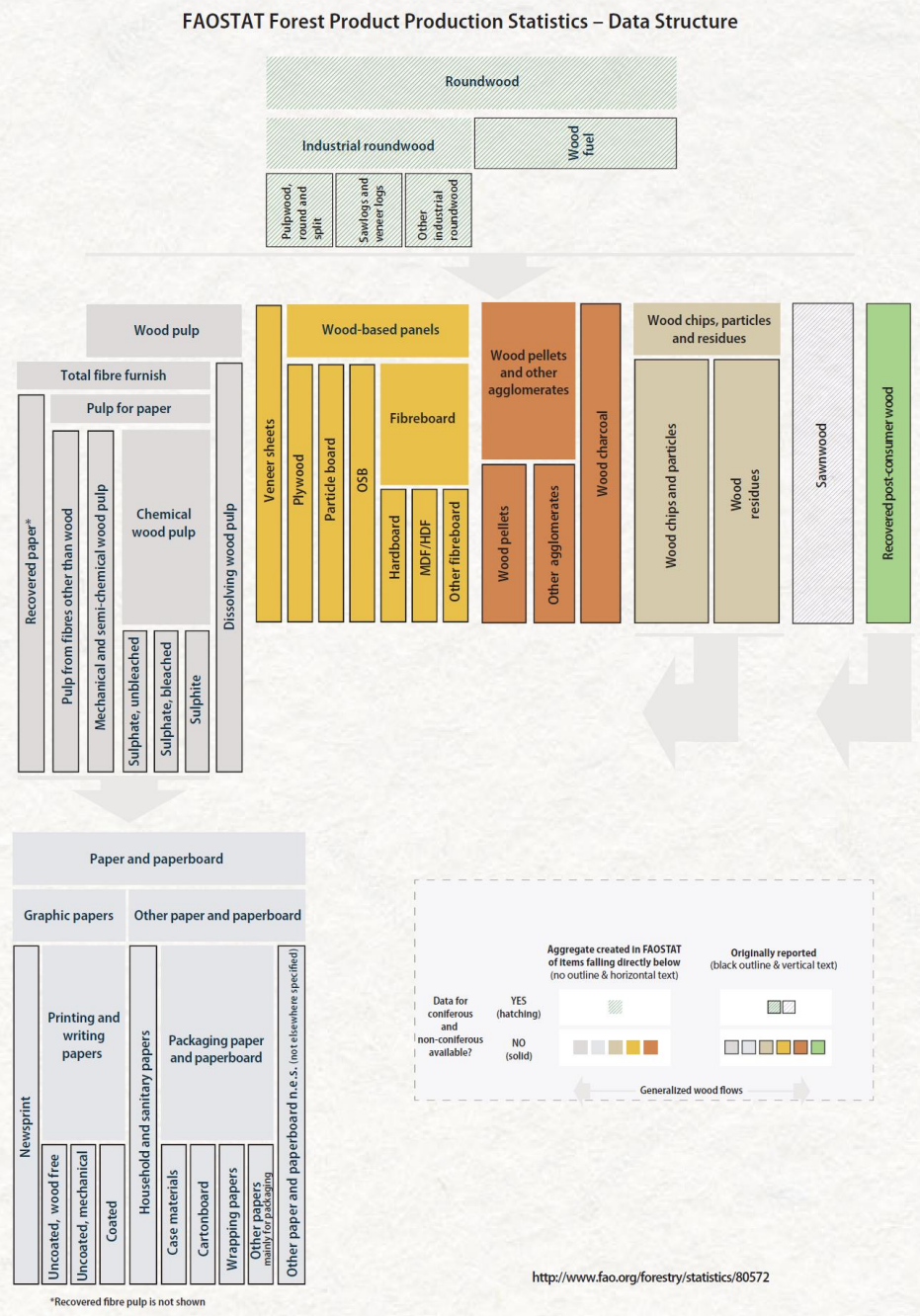
FAOStat provides a detailed account for forestry production and products, which are the source for the forestry nodes shown in the Sankey diagram.

https://www.fao.org/faostat/en/#data/FO

The data is structured according to the scheme provided by FAOStat here:

https://www.fao.org/forestry/49962-0f43c0da7039a611aa884b3c6c642f4ac.pdf

Figure 3.4 Data structure for foresty as provided by FAOStat



The data are structured into the four main categories of “Pulps”, “Panels”, “Sawnwood” and “Wood Fuels”.

In each category, the weight of the final product is substantially smaller than the weight of the raw materials. This can be explained partially by processing losses of water or exhausts (for instance in charcoal production). The second explanation are possible data gaps on the final amounts of industrial or consumer end products. Since it is not possible to tell the difference, PLANET shows the total difference in a category called “Data Gap”.

Attention: The data for “Fuels” looks unreasonable small, especially given the large amount of “Wood Fuel” materials. It is likely that much of the actual amounts for fuels are not correctly recorded by FAOStat and are a big portion of the data gap. Furthermore, there are no figures for trade of forest raw materials. Only final goods show trade statistics. Therefore, there are no trade numbers for forest harvest products

Some of the categories at FAOStat are provided in cubic meter volume rather than weight. These categories were converted into weight based on this document:

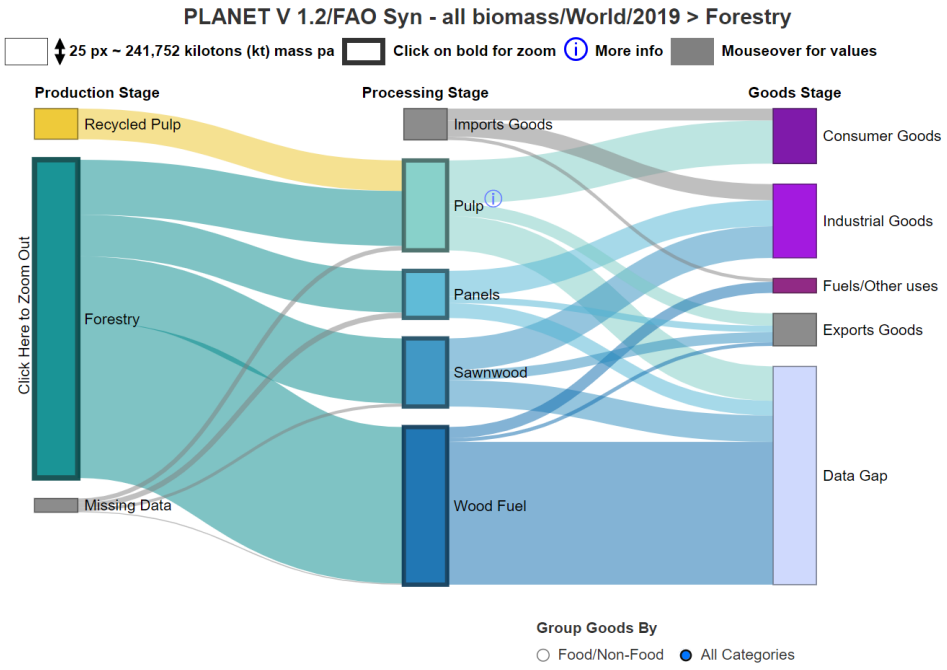
https://unece.org/fileadmin/DAM/timber/publications/DP-49.pdf

And summarized in this excel sheet:

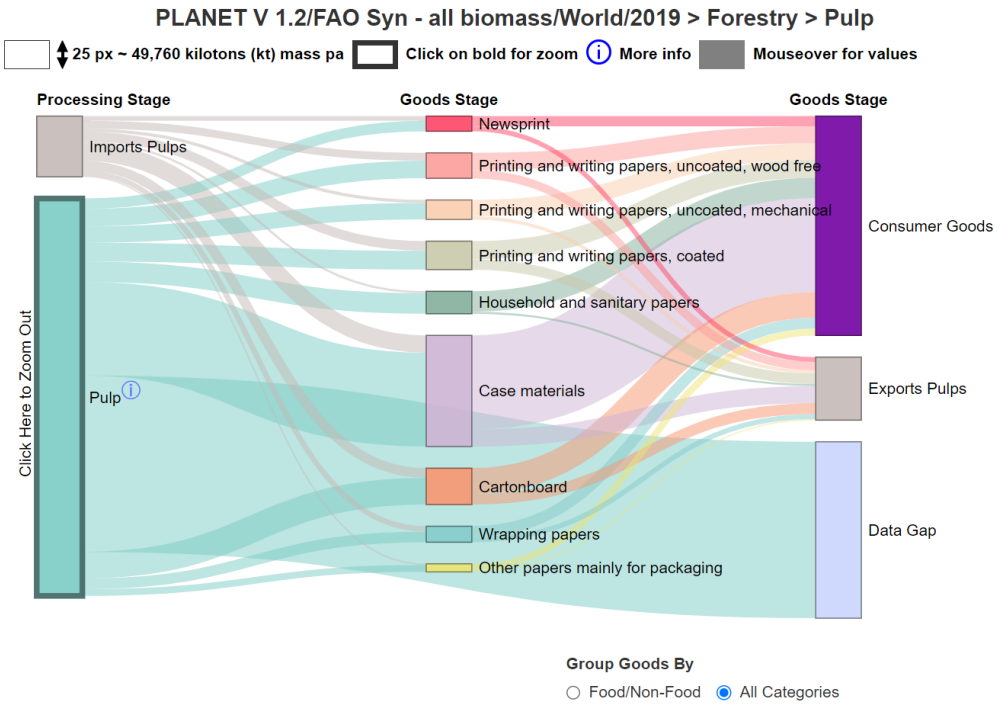
- Excel sheet download: S V c) weight to ton ratios utilized in PLANET based on S V b)

Figure 3.5 Zoom level of forestry products 2019

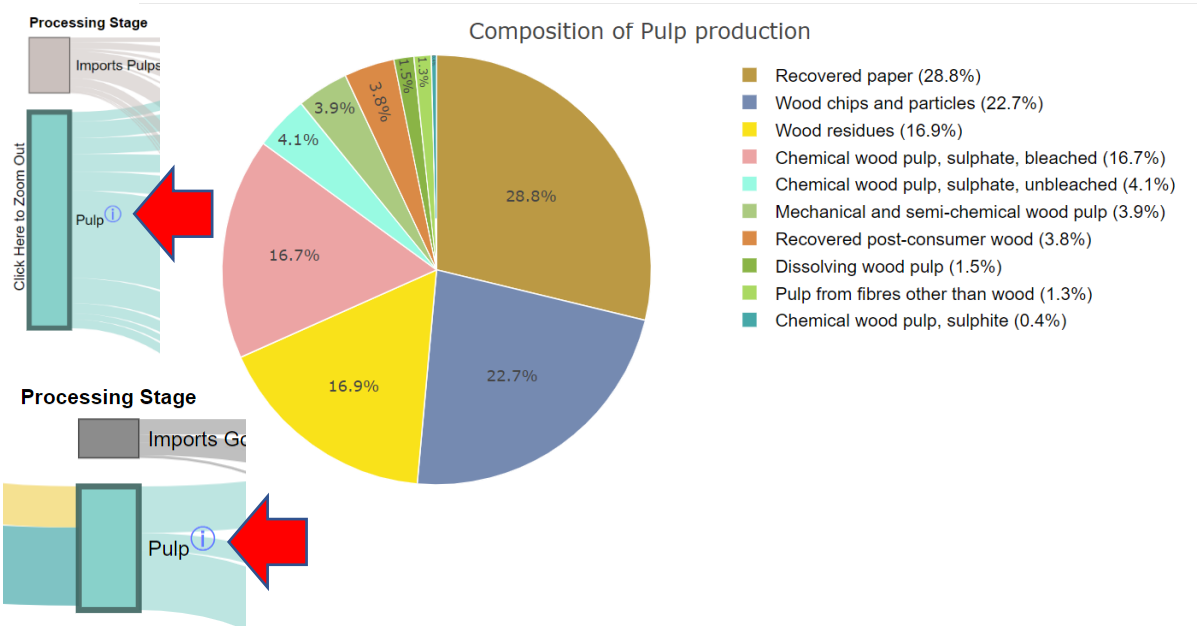
a) Four main categories of forestry product



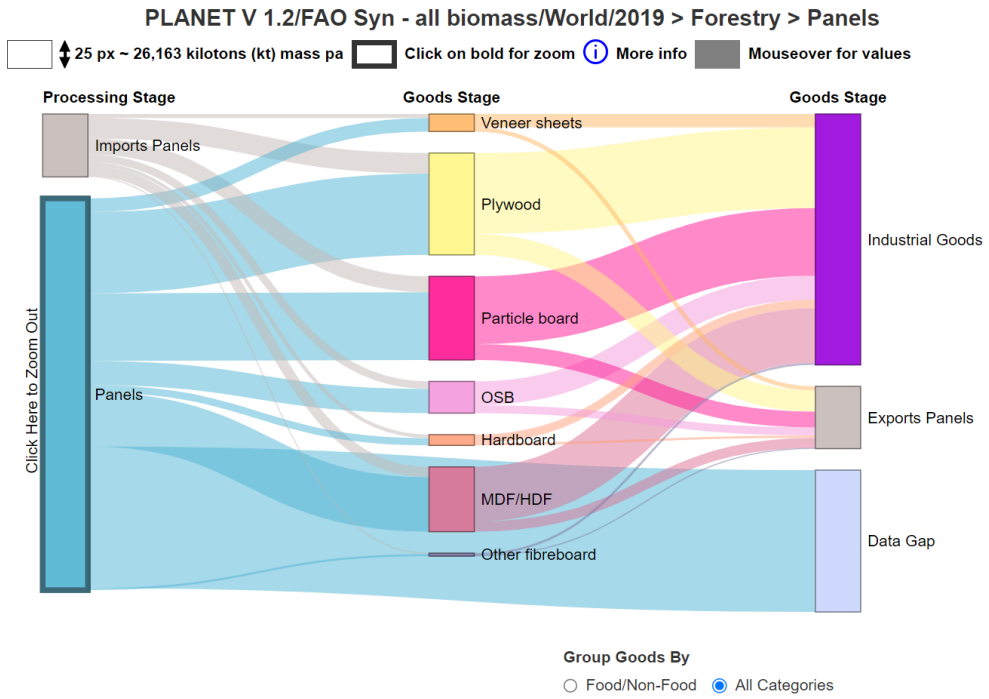
b) Zoom into pulp products 2019



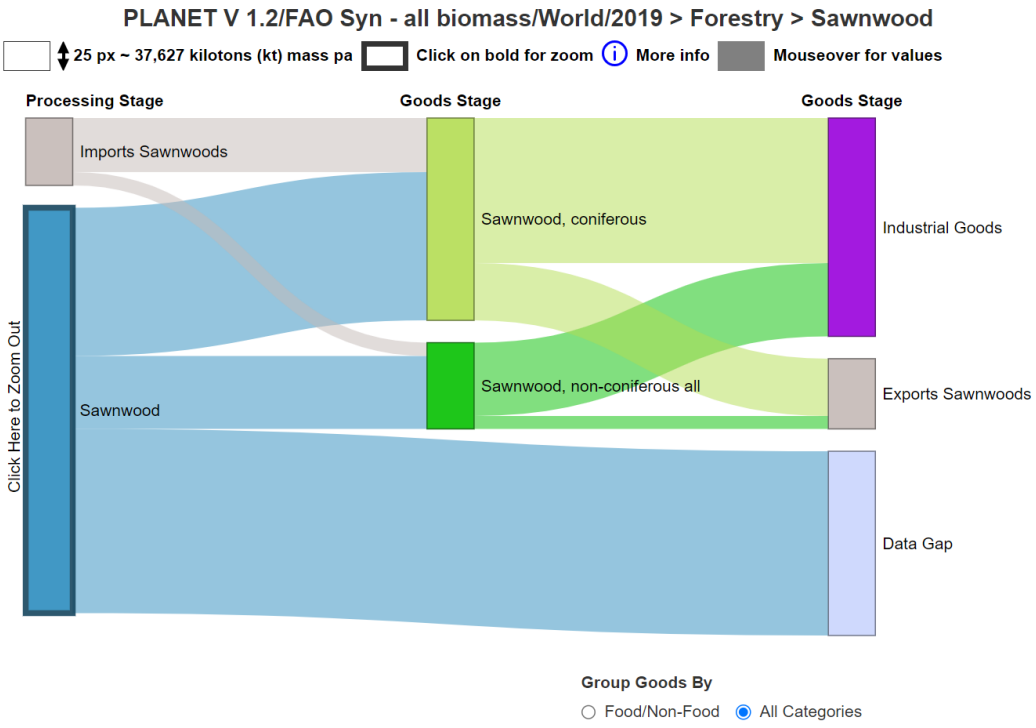
c) Pop-up window for composition of pulp raw material



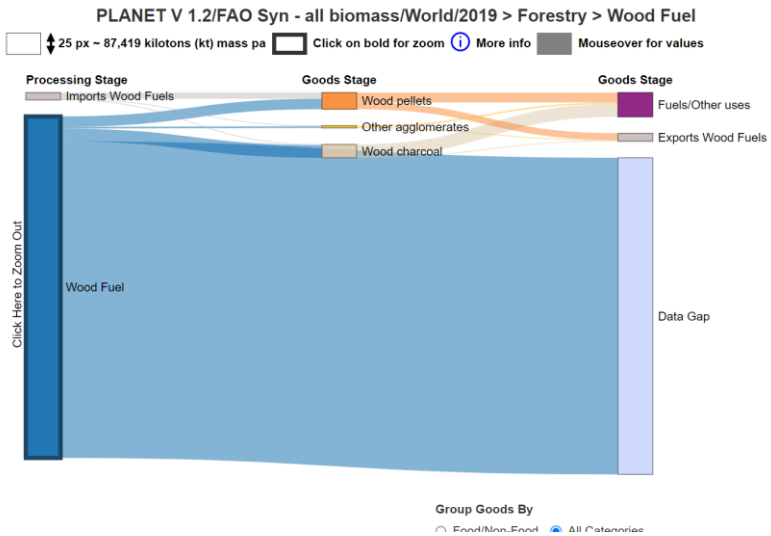
d) Zoom into panels products 2019



e) Zoom into sawnwood products 2019



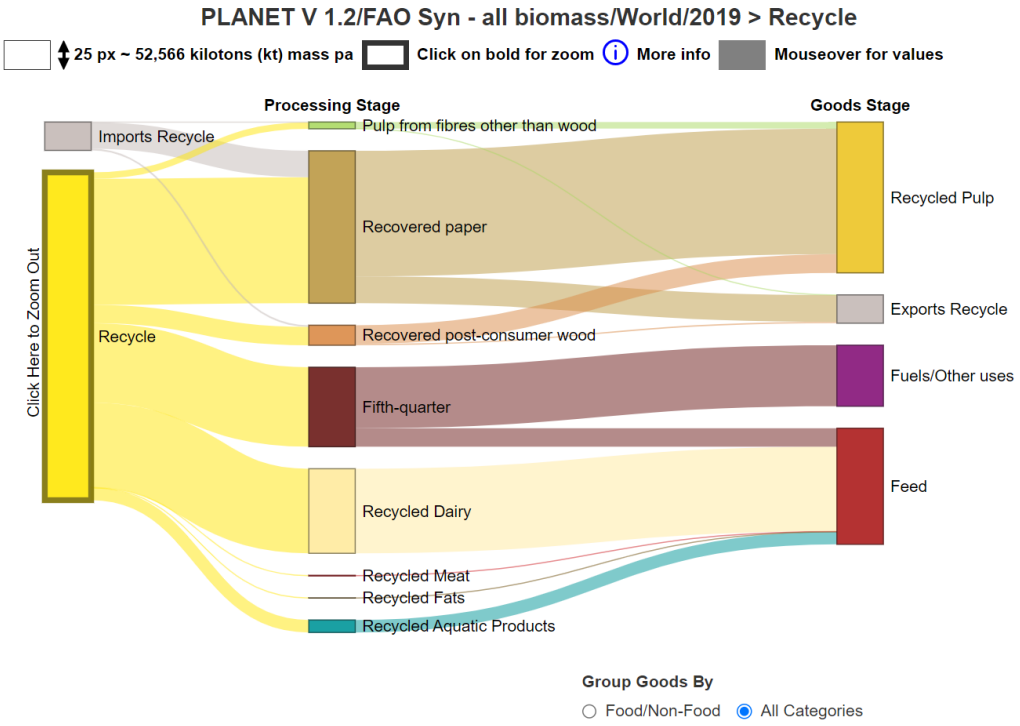
f) Zoom into woodfuel products 2019



3.5. Recycle Data

In PLANET 1.2 there are currently four sources of recycled materials that can be derived from FAOStat sources. The first is pulp sources from recovered paper and other fibres, the second is fifth quarter materials from animal slaughter, the third are whey materials used for animal feed in dairy production, and the fourth are minor material flows from meats, fats and aquatic products which become animal feed as per the SUA tables.

Figure 3.6 Zoom level of recycle material flows 2019



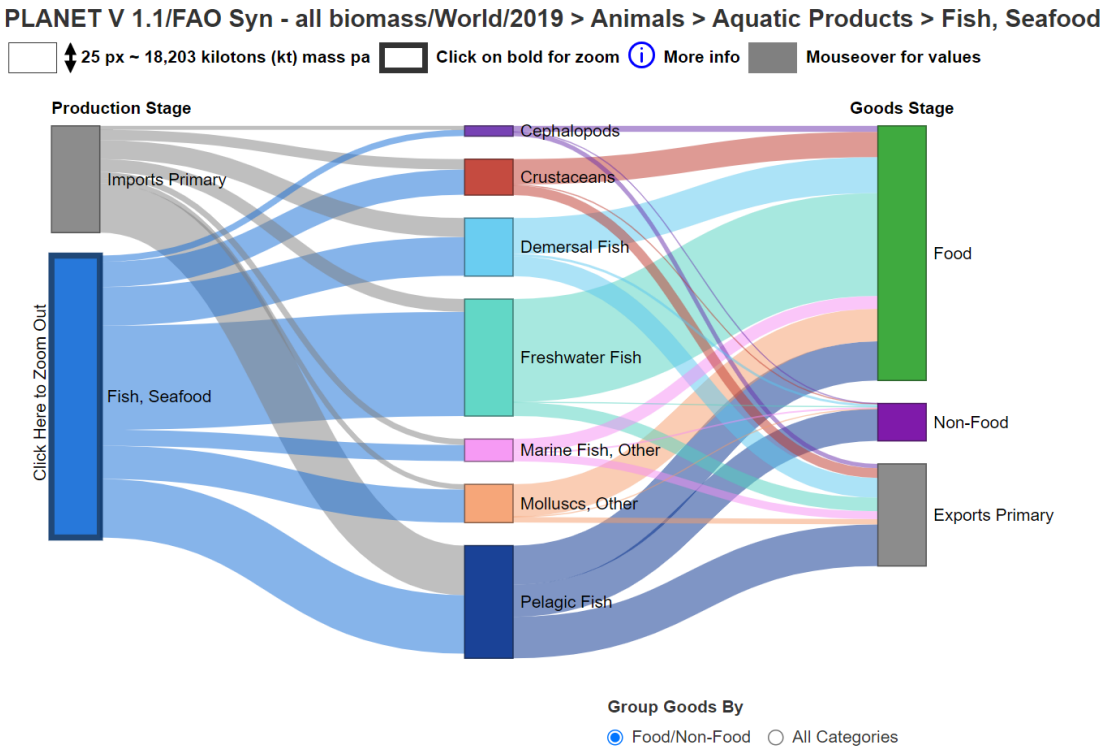
3.6 Aquatic Products Data

In the FBS tables FAOStat provides data on seven categories of fish for food consumption and some respective trade data. FAO also has other more detailed data tables for aquatic products, but they are not available in digital format, and so far PLANET has not made use of them. This will be done in future versions of PLANET.

To follow the same flow logic as for the other production systems, it would be necessary to estimate for each fish species how much feed they are consuming during production. Feed sources can in principle derive from three sources: a) oceanic and riparian feeding by wild fish; b) ocean-sourced fish feed (eg fish meal); c) cropland-sourced fish feed. Until further notice, PLANET will assume a simplistic feed conversion ratio of 2 to 1, meaning that all species require twice the amount of feed than their production weight yields. This amount is then shown under “Marine”.

For some countries, the USDA study group (see section 4.2.1) provides data on soy bean meal provided to aquaculture. Those amounts are then deducted from “Marine” and the flow moves from soybeans to aquaculture.

Figure 3.7 Zoom level of world aquatic products 2019



4. The All-Biomass Calculations for PLANET V 1.3 (no change to 1.2)

FAOStat provides no data on the amount of feed-oriented processing by-products for instance from oil crops, nor harvest by-products, and nor the amount of silage, haylage, grazing or pasture land production as feed for ruminant animals. This represents a large gap in understanding for the composition of material flows in the global food system. The reason is historical, in that the Food Balance Sheets of FAOStat are interested in the agricultural production related to food provision, not for feed for animal provision and also not in agricultural production for consumer and industrial goods.

There are in principle three methods to close this knowledge gap:

1. To measure or estimate the amounts of by-products and grasslands production directly at the source of production and at the point of utilization, comparable to how it is done by FAOStat for food-oriented production
2. To estimate the amounts of by-products and grasslands production as ratios of the main food harvest productions and then allocate the resulting amounts to the various animal species
3. To conduct a backwards calculation: Taking the stock amounts of livestock animals for granted, allows an estimation of how much metabolizable energy they need to consume. Applying typical feeding rations to the various species, it is possible to deduct how much feed must have been produced in a given country, and then calculate this backward to how much crop production this would represent.

The first approach would be the gold standard, but is only rarely available. At this point, detailed estimations exist only for the soybean by-product value chain, produced by a study-group organized by US Department of Agriculture and the US Soybean Export Council.

The second approach has been conducted only rarely consistently on a global basis. One such prominent analysis was partially conducted for the PhD Thesis by Stefan Wirsenius completed at the Chalmers University of Technology in the year 2000, called “Human Use of Land and Organic materials, Modeling the Turnover of Biomass in the Global Food System.” Many of the more recent models keep on referencing to his data and his methods. The absolute data in the thesis are far outdated by now. The thesis used source data of FAOStat from the year 1993, which in turn was based on even earlier dates of data collection. So, the estimated ratios are based on data which is more than 30 years old, and moreover, has never been updated on a comprehensive basis since then. As far as PLANET is aware of, there does not exist a more recent overall estimation of the ratios, so the Wirsenius thesis is the best available.

Nowadays, the most typically used approach in the sciences is the third one. There are various problems with this approach. For one, it assumes that the number of animals is known per country, whereas there are many reasons to assume that these are being consistently wrongly estimated. Another concern is the attribution of which kind of animal feeds is fed to which kind of animals, if it is not clear which kinds of by-products are available. Furthermore, animals may not be optimally fed or being underfed, all of which leads to an overestimation of feed materials. Lastly, the amount of trade of by-products

can also not be estimated in this way. At its core, the Wirsenius study is also such a demand-driven model. However, he also provides cross-checks for supply, which in combination become the basis for the ratios of crop vs by-products production, which are utilized by PLANET.

Over time, PLANET strives to provide as much data as possible according to the first method of using sources of production. Towards this aim, in the area of grasslands production, the PLANET team is engaged in a research project to estimate from satellite imagery the amount of total grasslands production, and how much of this is provided to livestock animals. First results from this research project will be available in the course of 2023.

Selecting the source "FAO SYN – Wirsenius 1.2" in PLANET makes use of all production / by-product ratios as provided by Wirsenius only, and applies these ratios to current FAO-assessed cropland production.

Selecting the source "FAO SYN - All Biomass 1.2" in PLANET replaces and completes some of the Wirsenius ratios with more comprehensive estimates where these are available. They are outlined in chapter 4.2.

4.1 Biomass Calculation of Harvest and Processing By-Products with Wirsenius

In his thesis publication "Human Use of Land and Organic materials, Modeling the Turnover of Biomass in the Global Food System", Wirsenius provided a series of data tables which are utilized by PLANET to estimate biomass flows per country. For further methodology details of how Wirsenius arrived at this tables, we refer to his thesis publication.

https://publications.lib.chalmers.se/records/fulltext/827.pdf

The following outlines how PLANET makes use of Wirsenius data.

4.1.1 Wirsenius Regions:

All data provided by Wirsenius are structured in eight regions: 1.) East Asia, 2.) East Europe, 3.) Latin America & Caribbean, 4.) North Africa & West Asia, 5.) North America & Oceania, 6.) South & Central Asia, 7.) Subsaharan Africa and 8.) West Europe. Within these regions, Wirsenius selected a total of 83 countries from which he took the data of FAOStat and conducted his calculations. These 83 countries represented around 95% of the total global population (Table 3.1, page 57/58 Wirsenius)

- excel download S IV b) Table 3.1 Wirsenius countries and regions

In PLANET these regional values are applied to each country within this region in order to obtain national values per country. This entails various degrees of inexactitude, as climate and culture can vary a lot within a region, and accordingly also agricultural production. Agriculture is different in Sweden versus Portugal, or Canada versus Australia, or Japan versus Thailand, which are respectively in the same region groups. However, at this point, this lack of precision cannot yet be repaired.

4.1.2 Wirsenius Harvest By-Product Production:

The calculations to determine the mass flows of harvest by-products follows three steps:

1.) calculate total amount of harvest by-product on actual weight basis
2.) calculate the share of these harvest by-products that are recovered from the field
3.) calculate the share of these recovered harvest by-products that are used as animal feed.

In his table 3.16 on page 92, Wirsenius provides an estimate of the harvest by-product amount ratios compared to the respective main crop per region. For instance, in Latin America, for every 40 kilogram of soybean produced, there would be 60 kilogram of stalks, leaves and husks produced, whereas in Western Europe the ratio would be 45/55.

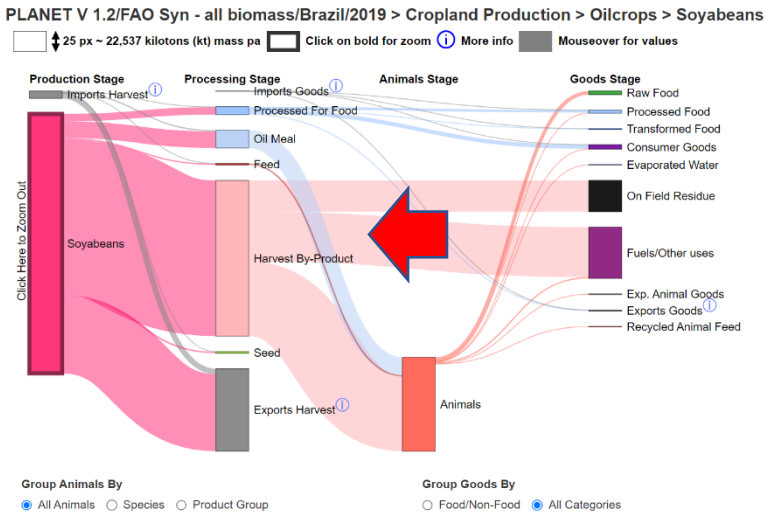
Wirsenius numbers are calculated on a dry matter basis, whereas PLANET calculates on an actual weight basis. Wirsenius provides the dry matter/actual weight ratios in his table 3.22 on page 129 ff). Table 3.22 is used to convert the dry matter basis into actual weight basis.

PLANET uses these two tables for calculating the actual weight harvest by-product stream for each crop commodity in each country (applying the respectively regional value ratios to the production amounts of primary food crops in each country). For those crops that are not mentioned in the 3.16 table, PLANET assumes the values of the next similar crop. The excel table replicates the values of table 3.16 and shows which additional crops were assigned to the respective values.

- excel download S IV c) Wirsenius Table 3.16 harvest by-product production
- excel download S IV d) Wirsenius Table 3.22 actual weight / dry weight

Figure 4.1. PLANET harvest by-product for soybeans in Brazil 2019

(Note that the large amount of “Harvest-By-Product” for Brazilian soybeans represent the 60% of stalks, leaves and husk biomass which a soybean plant produces. The soybean meal for which soybeans are mostly grown is represented by Oil Meal By-Product from Processing. We believe that in reality most of the stalks, leaves and husks are actually left as “On-Field Residue”. However, the below is the result of the Wirsenius allocations, where 50% is allocated to animals (see section 4.1.3.ff))



4.1.3 Wirsenius Harvest By-Product Recovery:

In his table 3.17 on page 94, Wirsenius provides an estimate of the recovery ratios of harvest by-products per crop or crop category per region. For instance, in Latin America, 80% of the soybean stalks and husks would be harvested, while the other 20% remains as on-field residue.

For those crops that are not mentioned in the 3.17 table, PLANET assumes the values of the next similar crop. The excel table replicates the values of table 3.17 and shows which additional crops were assigned to the respective values.

- excel download S IV e) Wirsenius Table 3.17 harvest by-product recovery

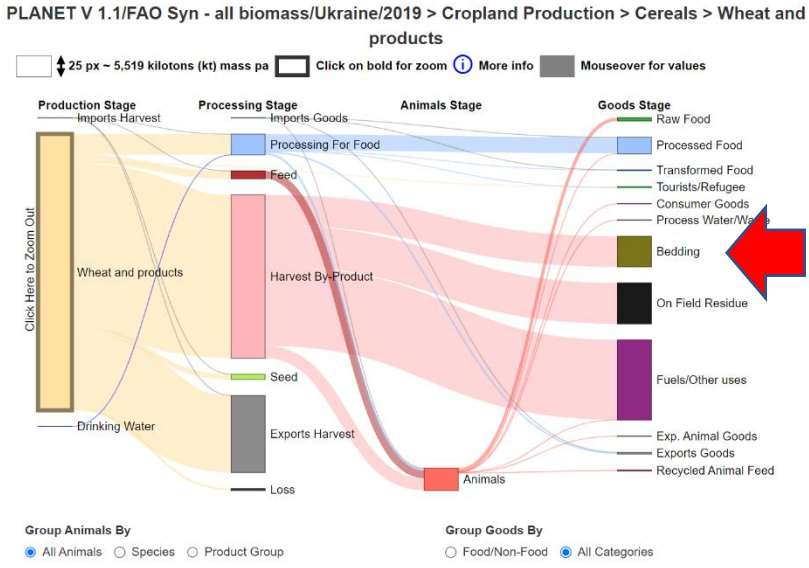
4.1.4 Wirsenius Harvest By-Product Recovery Allocation to Feed:

In his table 3.20 on page 102, Wirsenius provides an estimate of how much of the recovered harvest by-product amounts are utilized as feed per main crop per region. For instance, in Latin America, 60% of the recovered soybean stalks and husks produced would be used as feed, while the other 40% would be used for various other purposes. Mostly, Wirsenius does not specify further what these other purposes might be. Typically, these will be used for fuel, fertilizer or construction materials. In the case of cereals straw, table 3.21 on page 126 allows the calculation that as a global average 28% of cereals straws are used as bedding material for animals. This global average certainly conceals a lot of variation by type of cereal and region, however, a more detailed split is not possible with the Wirsenius data.

For those crops that are not mentioned in the 3.20 table, PLANET assumes the values of the next similar crop. The excel tables replicate the values of tables 3.20 and 3.21 and shows which additional crops were assigned to the respective values.

- excel download S IV f) Wirsenius Table 3.20 harvest by-product recovery allocation to feed
- excel download S IV g) Wirsenius Table 3.21 bedding allocation

Figure 4.2. PLANET harvest by-product for wheat in Ukraine, showing bedding



4.1.5 Wirsenius Processing By-Product Allocations for Sugar Crops:

Sugar crops produce various Processing By-Products, such as pulp, molasse, bagasse and evaporated water.

Much of the sugar crop difference during processing is water that evaporates. Even the non-water by-products, are often fuel instead of feed. The FAO Synthesis 1.2 version, which is also the basis for the Fao Syn - all biomass version of PLANET 1.2 described in this chapter has a more differentiated and accurate display based on the values and methodology provided by Wirsenius and other sources.

PLANET 1.2 adds up the final amount of sugar produced, plus the sugar molasse, plus respectively sugar beet pulp or sugar cane bagasse as the total amount of material yielded from the raw sugar crop. The amount ratios for these products are assumed to be based on Wirsenius table 3.22 on pages 129ff. The difference of this sum to the raw sugar crop is assumed to be water content that becomes evaporated during the production process. It is called “Evaporated Water” in PLANET under the goods stage of the Sankey picture.

Besides “Evaporated Water”, beat pulp, cane bagasse or molasse are processing by-products. Wirsenius table 3.20 on page 102 allocates how much of these are utilized as feed per region, and how much become fuel or other uses.

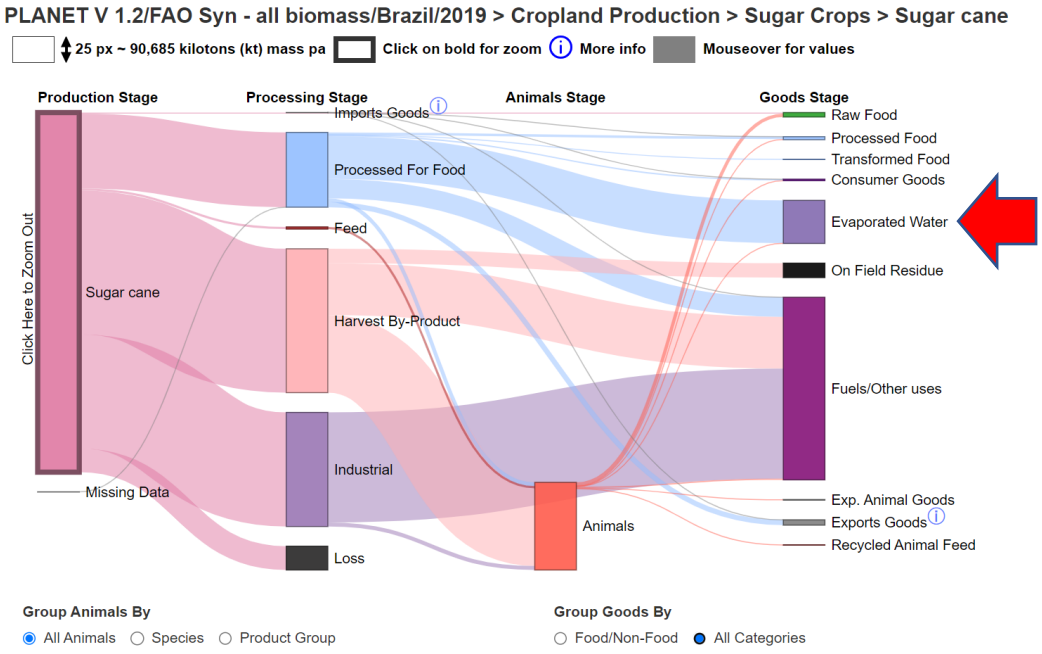
In case of Sugar Crops, PLANET assumes that “Other Uses” in the FAOStat SUA tables are uses for bioethanol fuel production, and are therefore shown as Industrial. Ethanol production produces a by-product called filter cake, which is partially used as animal feed. Therefore, PLANET shows a small flow from “Industrial” to “Feed”. Filter cake amounts to about 3.5% of the total sugar cane amount processed towards ethanol.

In some countries, for instance Myanmar, non-centrifugal sugar (NCS) is commonly produced as a consumer product. This may lead to much smaller amounts of sugar cane bagasse, as the stem might either be part of the final product or is not systematically utilized. Therefore, PLANET excludes the amount of NCS sugar (as per the values by FAOStat) from the above calculation procedure.

Besides the processing of the sugar crop, there are also amounts of sugar beet and sugar cane tops which are harvest by-products. Their allocation to feed, on-field residue or fuel/other uses follows the same logic as described in the steps 4.1.2 to 4.1.4.

- excel download S IV f) Wirsenius Table 3.20 harvest by-product recovery allocation to feed)
- excel download S IV d) Wirsenius Table 3.22 for sugar by-product ratios

Figure 4.3. PLANET sugar crop allocation in Brazil 2019



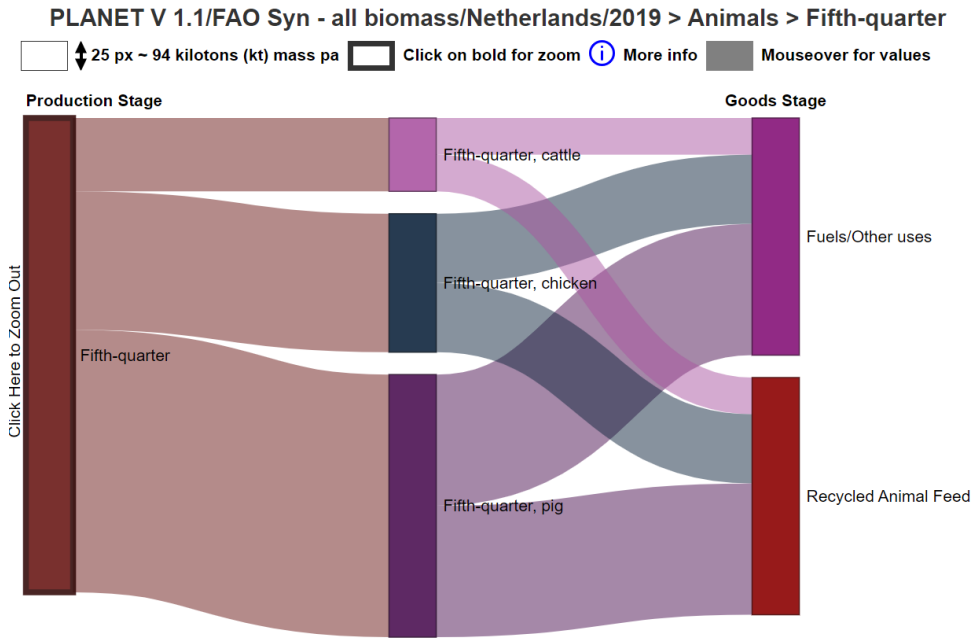
4.1.6 Wirsenius By-Product Allocations for 5th Quarter Animal Products:

Table A.1.I in Appendix 1 (p 258) provides information on the ratios between animal carcass weight used for human food, and the animal non-carcass weight called fifth quarter which is not used for human consumption, respectively for different quality categories of animals in each species. In absence of better knowledge, PLANET calculated the average of each ratio of carcass/non-carcass per species. The non-carcass portion is called Fifth Quarter, and is multiplied with the value of table 3.20 on the respective shares that are used for animal feed to arrive at the number of "Recycled Animal Feed" from non-carcass animals.

FAOStat provides values on the amount of offals and materials that are derived from the animal production. The total amount of fifth quarter as calculated by Wirsenius, less those offals and materials amounts from FAOStata, less the recycled feed amounts, equals the amount which is used for "Fuel/Other Uses".

- excel download S IV h) Wirsenius Table A.1.I carcass composition
- excel download S IV f) Wirsenius Table 3.20 harvest by-product recovery allocation to feed)

Figure 4.4. PLANET animal fifth quarter allocation for Netherlands 2019



4.1.7 Wirsenius Allocation of All Feed Sources to Species:

Wirsenius provides the table 3.23 on page 144ff for values for allocation of all available feed per crop *per five different animal species* and another table 3.24 on page 148ff for values of allocation of all available feed per crop *per region*. However, Wirsenius does not provide a table for the combination of the two, ie crop per species per region. The following calculations estimate the allocation per species per region based on these two tables, and then extrapolates the result to all countries and other species.

The following calculation steps are employed:

1. Calculate the assignment ratios of a given amount of global feed material to each of the five Wirsenius species in 1993 based on table 3.23
2. Adjust the assignment ratios from 1993 to 2018 based on the different number of animal inventory per region as per FAOStat
3. Apply those assignment ratios to the respective amount of feed material that is available in any given country.

Since every country has different amounts of respective feed materials available, this automatically leads to different rations of feed per species and per country.

The resulting overall average feed recipes per species per country are NOT cross-checked whether they provide metabolic optimal efficiency for the animals. Such a comparison will be done in future analyses PLANET.

Some feed materials are missing in table 3.23. Most of them are allocated by PLANET in the same way as maize, or in the case of oil crops and pulses, in the same way as soybeans.

Wirsenius provides data for five different kind of species: a) dairy cattle, b) beef cattle, c) pigs, d) layer chicken for eggs, e) broiler chicken for meat. PLANET estimates feed rations

for the other animals species based on the following scheme: buffalo, camels, goats, sheep, horses, mules and asses receive the same rations as beef cattle, adjusted by respective average body weight. Turkey, geese, duck, guinea fowl, rabbits and rodents receive the same rations as broiler chicken, adjusted by respective average body weight. The body weights are calculated on the basis of the average carcass weights per country per species as can be calculated with FAOStat values of resultant carcass weight per species.

A computation example for French pigs is provided in an excel download

- excel download S IV i) Wirsenius Table 3.23 feed to species allocation
- excel download S IV j) Wirsenius Table 3.24 feed to region allocation
- excel download S IV k) Computation example French pigs for feed sources to species

4.1.8 Wirsenius Allocation of Grazing and Foraging Resources to Species:

The same tables 3.23 and 3.24 on pages 144ff can also be used to estimate the feed consumption of grasslands and animal forage products, for which Wirsenius provides five categories: a) cropland pasture, b) permanent pasture, c) grass-legume forage, d) whole maize forage, e) vegetable forage.

Attention: FAOStat does not provide values for silage, especially maize silage. In PLANET, maize silage is represented by the category of "Whole Maize", based on Wirsenius estimations. As they are listed under the pasture products, they are expressed as dry matter content. The PLANET team could not identify a consistent source of maize silage production in the world, so that the allocation mechanism based on Wirsenius and updated to current herd numbers per country, remain the best available estimate.

As the grazing and foraging resources are not expressed as ratios of food crops, the calculation route is slightly different from the above sections 4.1.1 to 4.1.8:

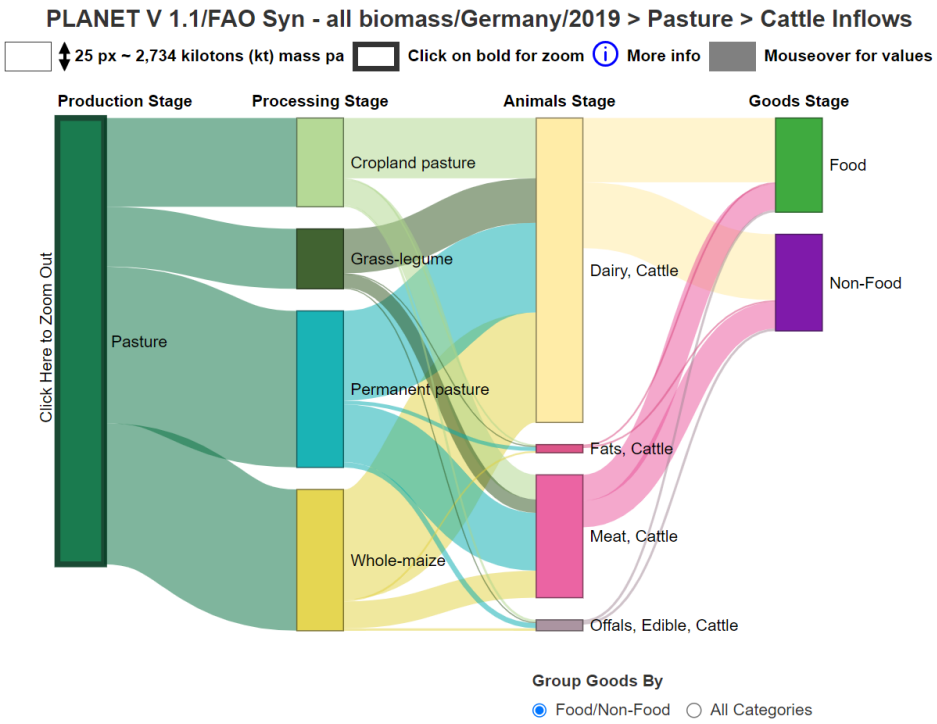
1.) Calculation of total amount of grazing and foraging resources per region as per table 3.24 (which requires converting the per capita values there into absolute amounts)
2.) Split the regional amounts into species allocation as per table 3.23
3.) Adjust those species values from 1993 to 2018 inventory of animals
4.) Assign the resulting regional values to each country in a region on the basis of the number of animals.

The results will not be able to differentiate between typical grazing and non-grazing countries. For instance, Ireland will not be treated differently than Spain, even though Ireland has much higher grazing per animal head than Spain. However, as there is only a regional value available, the model cannot account for this difference at this stage.

In future versions of PLANET which are based on primary data from satellites, it will be possible to adjust to country differences.

- excel download S IV i) Wirsenius Table 3.23 feed to species allocation
- excel download S IV j) Wirsenius Table 3.24 feed to region allocation

Figure 4.5. PLANET Grazing and Foraging Allocation to Animals in Germany 2019



4.2 Additional Biomass Calculations for "FAO/SYN All-Biomass" Source Selection

While Wirsenius's PhD thesis provides the most encompassing published estimation of biomass flows of global agriculture, there are several crops or products flows that are not covered. PLANET has extended the analysis with additional source materials to provide an even more comprehensive coverage of all biomass flows, especially of the harvest-by-products and their allocations to animals or other uses.

The various additional assumptions are documented in PLANET excel sheet S III. The sources to the various assumptions can be made available upon request.

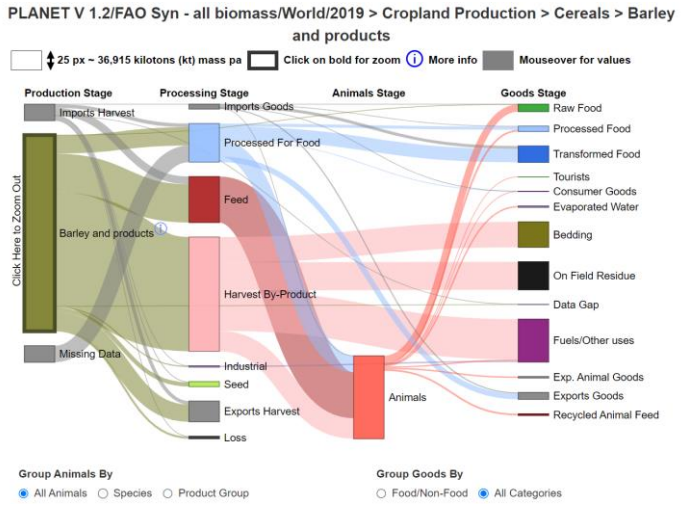
- Excel sheet download: S III Nutrition and Flow Allocation Master Table_23 Dec 2022

Below summarizes all biomass flows which are not covered by Wirsenius.

4.2.1 Cereals, Barley:

The main utilization of barley is not for food, but for making malt for alcoholic beverages (or feed). In the FAOStat/PLANET logic, this food flow is therefore a "Transformed Food". Alcoholic beverage production has a side product called brewers gains (in case of beer) or distillers gains (in case of spirits), which is a typical feed product. PLANET estimates that every kilogram of malt, produces 1.25 kilogram of brewers gains or 1.5 kilogram of distillers gains, with the two being produced at a ratio of 0.85 to 0.15 respectively. While most of the malt production is from barley, other cereals also contribute some shares. For simplicity, all brewers/distillers gains are assigned in PLANET to Barley only.

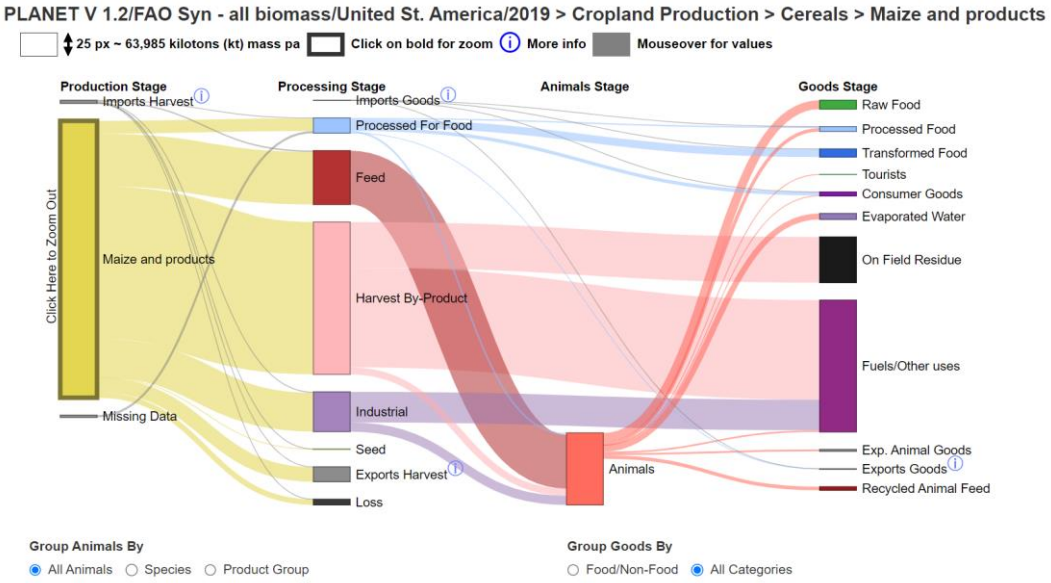
Figure 4.6. PLANET World Flow of Barley, 2019



4.2.2 Cereals, Maize:

Maize has become the world's largest crop by far, producing twice as much biomass as wheat, three times as much as rice, and four times as much as soybeans. Maize is used straight as feed, or it is harvested for silage production. The latter is shown in PLANET under Pasture (see 4.1.8). Also, the large amounts of biomaterial processing for food and fuel produces by-product flows which are usually feed. FAOStat SUA has an item for Feed and Meal Gluten, most of which is derived from maize, and therefore represents a flow from "Processed for Food" to "Animals". Furthermore, when maize is used for bioethanol production, there is a by-product flow called DDGS (Dried Distillers Grains with Solubles) and distillers oil resulting from this process, which is usually feed. Therefore in maize, PLANET shows a flow from "Industrial" to "Animals". In contrast to all other cereals, PLANET does not apply the Wirsenius cereals ratio for bedding to maize, because maize is very seldom used as bedding material.

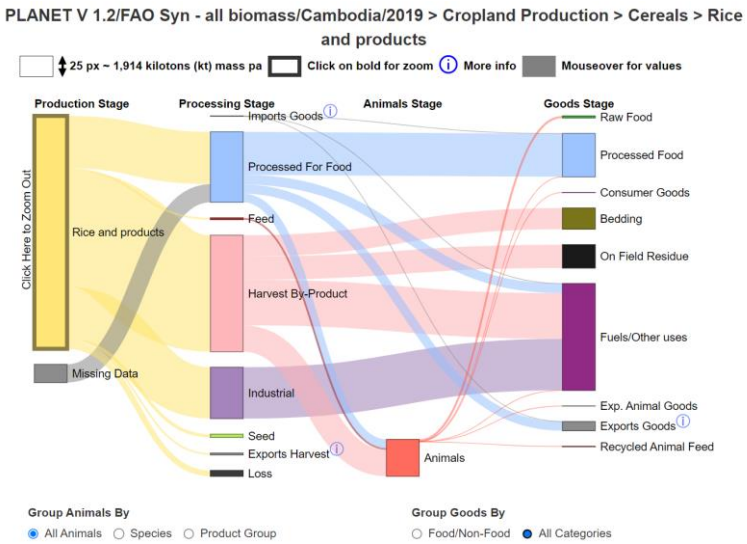
Figure 4.7. PLANET USA Maize, 2019



4.2.3 Cereals, Rice:

Besides the standard paddy rice for typical food consumption, the processing of rice produces two by-product streams which are typically utilized as feed, which are rice broken, and rice bran, both of which are shown as a flow from “Processing for food” to “Animals”. A third component are the rice husks. They are calculated as the difference between SUA rice paddy processed minus milled production minus husked production minus bran production. All of the husks are assigned to animal feed.

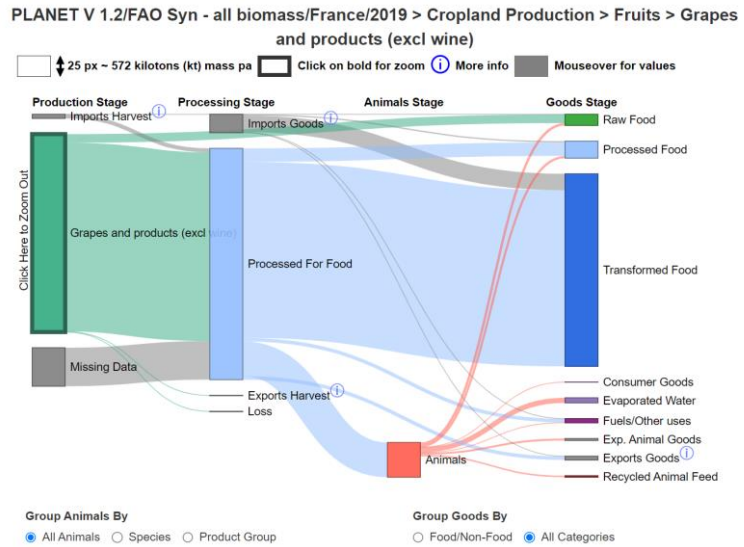
Figure 4.8 PLANET Cambodia, Rice, 2019



4.2.4 Fruits, Apple, Citrus and Grape:

For beverages production from apples, citrus fruits and grapes, there remain solids as by-product which are typically feed for animals. In apples, pomace accounts for 25% of processed food, in grapes it is 20%, and in citrus fruits it is 50% that becomes pulp.

Figure 4.9 PLANET France Grapes, 2019



4.2.5 Fruits, Banana, Dates, Pineapple and Plantains:

Bananas, pineapples and plantains are heavily processed products, yielding peels and pulp. PLANET assumes these values to be 35% for banana peels, and 56% of crowns, peel and core for pineapples, all of which is assumed to become feed for animals. Additionally, these crops produce large amounts of harvest by-products in terms of fronds and stems, which are also partially used as feed, or as fuels and other uses. For bananas and plantains these are assumed to be 0.5 tons for every ton of banana, for pineapples to be three times the production volume of pineapples, and for dates the fronds are 20% of the date production.

Figure 4.10 PLANET India, banana (worlds largest banana producer 3x larger than second placed China), 2019

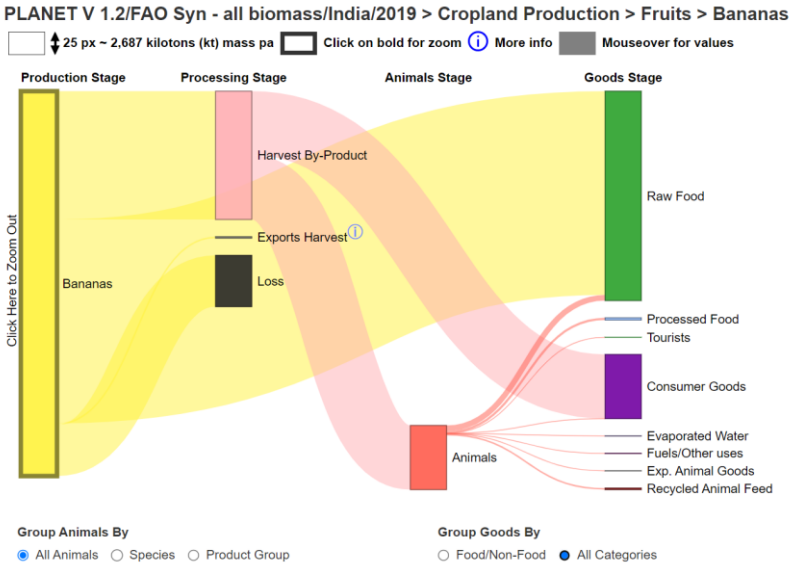
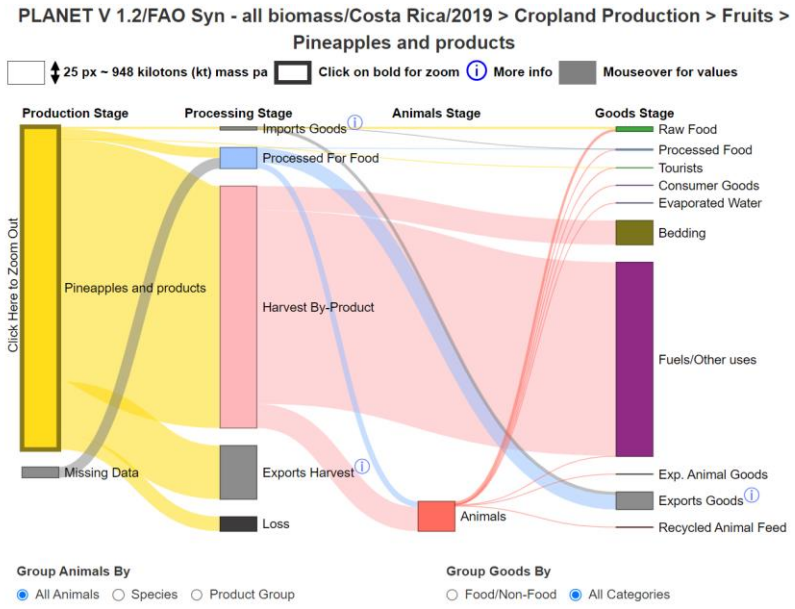


Figure 4.11 PLANET Costa Rica pineapple (worlds largest pineapple producer) 2019

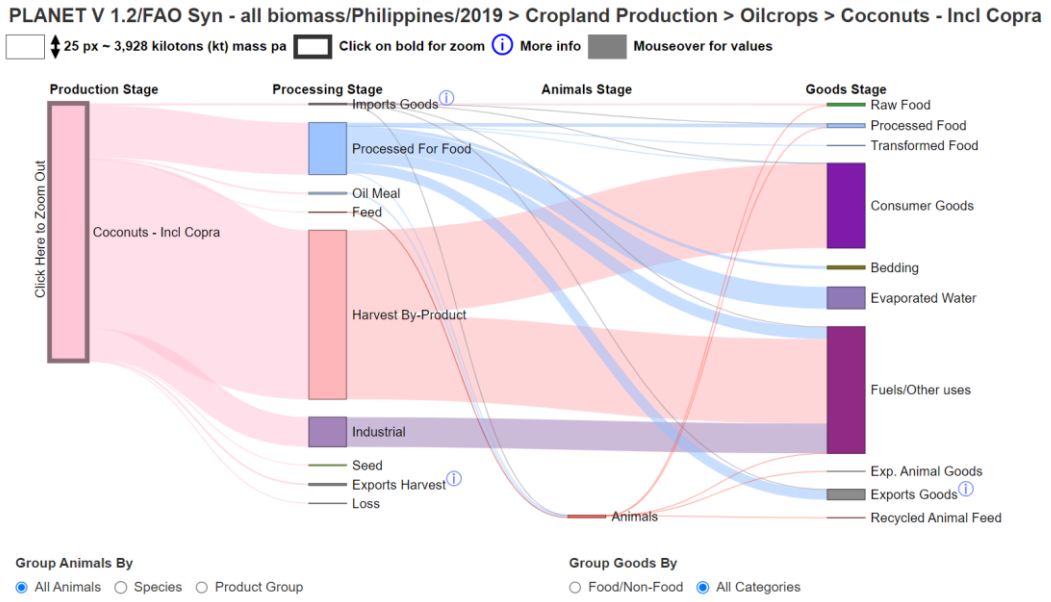


4.2.6 Oil crops, Coconuts:

Coconut trees generate large amounts of different biomass flows, which besides food (see 2.10.2), also produce important feed, fuel and other uses (for instance for construction, furniture or logistics). When the coconut flesh is processed into coconut oil, it leaves 50% coconut meal which is used for animal feed. Besides these primary products, coconuts also have shells (the hard casing), and the husks (the soft casing), and leaves. The shells comprise of 28% of the processed dehusked product, whereas the husk amounts to 91% of the dehusked product. There are about as much leaves (fronds) as coconut production.

Attention: The amount for the flow of oil meal does not at first sight appear to be 50% of the amount of oil produced. That is because the majority of oil meal is exported, which in the Sankey picture is shown as "Export Harvest".

Figure 4.12 PLANET Philippines coconuts, (worlds second largest producer) 2019



4.2.7 Oil crops, palm oil:

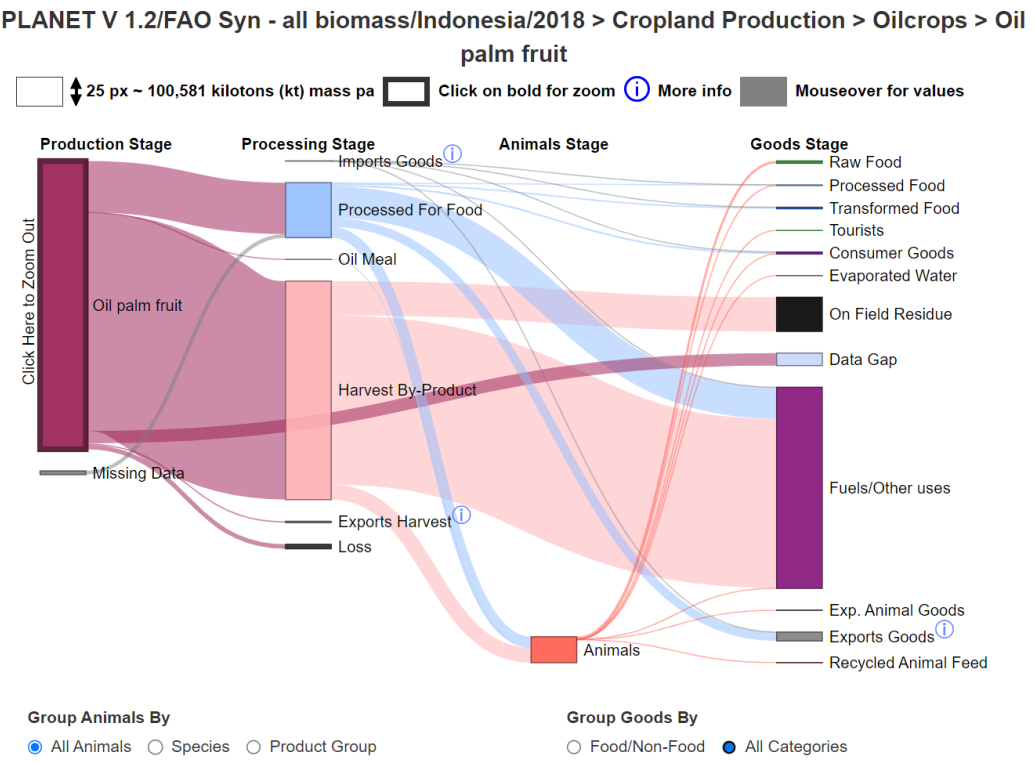
Palm oil production is one of the world's most important agricultural product. It is estimated that in a typical western supermarket, half of all the products contain some kind of palm oil ingredient, both in the food and in the non-food section. The palm tree grows only in a narrow tropical band plus/minus 8 degrees latitude around the equator, which has made Malaysia and Indonesia the two major producers of this crop.

The primary harvested product is called the "Fresh Fruit Bunch", which is a collection of the palm fruits that can weigh up to 40 kilograms. The palm fruits contain oily flesh, and a nutty palm kernel. When processing the palm fruits, two types of oil are produced: palm oil from the palm flesh (around 90%) and the oil extracted from the palm kernel (around 10%). Around 41% of the total material FFB are fibres from the bunches, the fruits and the kernel shells. The most typical use of these fibres is to burn them on the processing site for providing the process heat for pressing the oil. Therefore PLANET allocates this flow to "Fuels".

An additional flow resulting from processing is POME (Palm Oil Mill Effluent), which is partially used as animal feed, and partially for “Fuels/Other Uses”. PLANET assumes a 50/50 split between the two.

The tree itself is also a prodigious producer of biomass. The palm tree is usually used for 20-25 years, and will then be replaced. The weight of the trunk is about as heavy as the weight of all fruit bunches born during its lifetime. PLANET classifies this as “Harvest-by-Product”, and allocates 50% of this to remain on the field, and 50% to be used as “Fuels/Other Uses”.

Figure 4.13 PLANET Indonesia palm oil, 2018



4.2.8 a) Soy Bean Processing By-Products Data by USDA:

A study group organized by the US Dept of Agriculture and the US Soybean Export Council provides an estimate of soybean production and feed to species allocation for 24 countries and the EU. The data is published on:

https://marketviewdb.unitedsoybean.org/?bi=Soy_ConsumptionDetail_Annual

PLANET V 1.2 replaces the Wirsenius soybean meal feed allocations in those countries with these more current estimates.

The excel data sheet provides the source data, as well as shows the differences by country between the Wirsenius methodology estimate and the USDA methodology estimate.

- excel download S V d) Soybean production to species allocation USDA vs Wirsenius

Attention: The USDA data show much higher values for food utilization of soy bean oil than FAOStat. The difference is primarily explained by the different designation of cooking oil. USDA includes this under “Food”, while FAOStat includes it under non-food “Other Uses”.

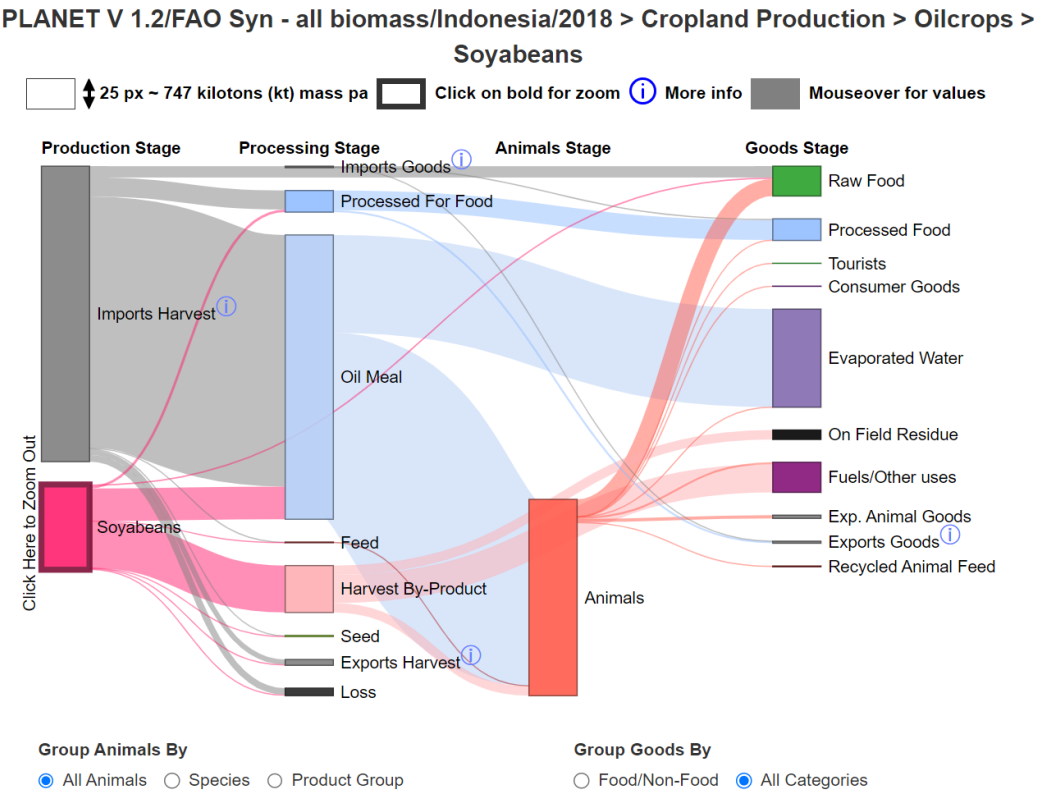
4.2.8 b) Soy Bean Processing By-Products PLANET Allocation:

PLANET assumes in case of “Soy Bean”, that the entire difference between the amounts of primary oil product extracted, and the amounts of materials processed, represents by-product flows that are fed to animals in the form of oil meals or oil cakes. For all other oil crops except “Palm Oil” (see section 4.2.7) PLANET uses the Wirsenius Table 3.20 assumptions (see section 4.1.4), where in most regions only 80% of these cakes are fed to animals. PLANET assumes it is 100%.

As the USDA source provides a value for the amount of soy bean feed produced per country, this provides a comparison for the accuracy of this assumption. For some countries the numbers are close, but in many countries there are sizeable differences.

PLANET assumes that in those countries where the USDA number is smaller than the PLANET value calculated from FAOStat, that this difference constitutes “Evaporated Water” (for instance Indonesia or China). In those countries where the USDA number is larger than the PLANET value, then it is assumed that the difference must have been imported from another country, and was not adequately reflected in the FAOStat trade data. In those cases, the difference amount is added to the amount of imports (for instance in Vietnam or Mexico.)

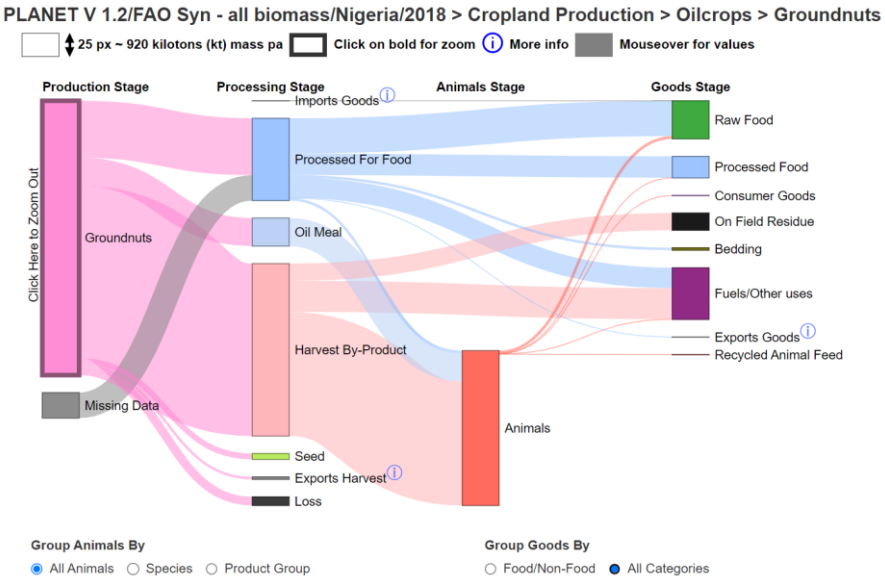
Figure 4.14 PLANET Soy Beans in Indonesia 2019



4.2.9 Groundnuts and other shelled nuts:

For groundnuts, brazil nuts, cashew nuts, hazelnuts and walnuts FAOStat SUA provides figures for processed nuts and shelled nuts, with the implication that the difference are the shells. These shell amounts are allocated as 10% to feed, 10% to bedding and 80% to fuels/other uses.

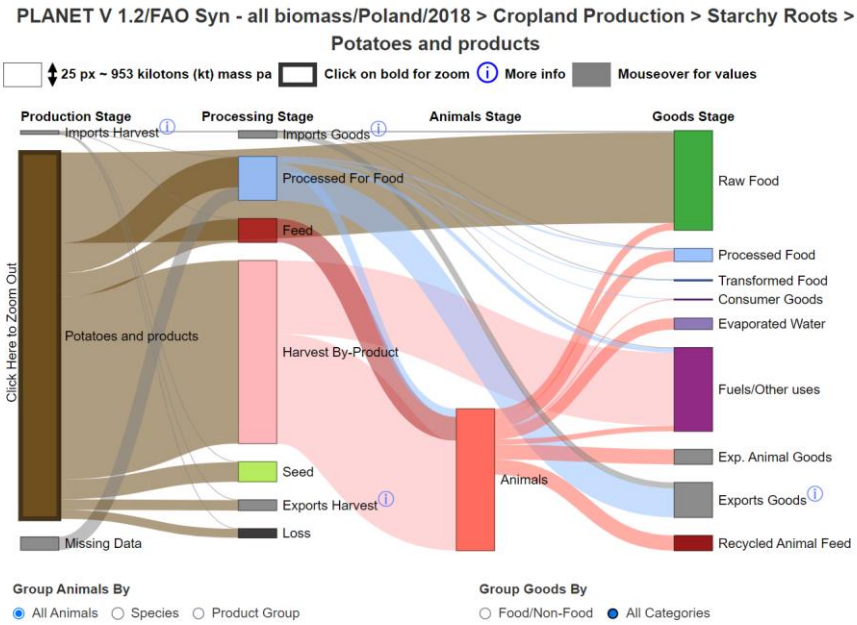
Figure 4.15 PLANET Nigeria, ground nuts (worlds third largest producer) 2018



4.2.10 Starchy roots:

Processing of starchy roots (potatoes, cassava, yams) yields peels which are fed to animals. PLANET assumes the amount of peels to be 10% of the amount of processed foods. Additionally, when potatoes are processed into starch, there is a by-product called potato pulp, in the amount of one third of the starch. PLANET assigns the potato pulps in the same allocations as Wirsenius sugar beet pulp.

Figure 4.16 PLANET Poland, potatoes 2018



5. Feed Allocation per Species Calculations for PLANET V 1.3 (no change to Synthesis 1.1)

5.1 Representation of Feed to Species Allocations in PLANET

Radio Buttons below the animal stage of the Sankey picture allow three different settings:

- All Animals
- By Species
- By Product Group

The “All Animals” view does not differentiate between species or products and provides a total overview of how many mass flows are directed through the total category of animals towards the good stage.

Attention: The “All Animals” view includes trade of finished animal products in its flows. It is therefore accurate in terms of domestic supply of animal products to consumers. The “Species” or “Product Group” view does not include trade of animal products, and therefore only reflects the product flows that were produced by local animals.

The “Species” view splits up the selected crop flows by animal species. For easier graphical clarity, the processing stage is collapsed in this view.

The “Products Group” view splits up the selected crop flows by product categories. For easier graphical clarity, the processing stage is collapsed in this view.

The contribution of crops to the final goods via the animals is calculated proportionally to the mass weight of the flow. For instance, if a crop constitutes 10% of the respective feed of an animal species or a product category, then it is assumed that it also represents 10% contribution to the final product. This is an oversimplification, as the animals will typically require a complete recipe of various feedstocks in order to produce their product contributions, and it is therefore usually not permissible to assume that one part of a feedstock automatically produces a corresponding share of final product. These mass allocations are indicative only for the proportion of mass flows, not reflective of a biological process.

A next version of PLANET will also allow to split up a particular species into its product categories, or split product categories into species.

See earlier figure 1.5 for selection options for animal display and 4.1.8 for computational pathway, including excel example for Spanish pigs.

5.2 Herd Structures and Bottom-up Feed Estimates

Future versions of PLANET will feature an estimate of the herd structure and on this basis also create a bottom-up feed estimate of these animals based on optimal feeding conditions. The bottom-up estimate will then be compared with the top-down estimate provided by the biomass allocation method described in chapter 4.

Supplement Data Tables, Assumptions and Computations

S I. The FAOStat Data SUA Commodity Tree

- Excel sheets download:
- S I a) FAO Commodity Tree ShareSave original FAO File_24 Feb 2022
- S I b) FAO commodity tree parsed and transliterated_24 Feb 2022

In the FAOStat SUA tables, various food items in intermediate stages of processing are shown. For instance, there is a value for wheat, and a value for flour of wheat. The value for this flour of wheat is a result of the processing of wheat. Besides flour, there is also bran, breakfast cereals and germ being produced. When zooming in to flour of wheat, then the SUA tables provide further information about its utilization, for instance how much of it is turned into Macaroni. The information about which products follow from which previous upstream products is provided by a so-called commodity tree. The commodity tree pdf publication which FAOStat provides on its web page is outdated, as it refers to the data structure from before 2014. PLANET found a recent and seemingly currently valid excel sheet-based commodity tree in the internet in order to connect the various food items correctly:

https://github.com/SWS-Methodology/faoswsStandardization

(There select the file ShareSave.csv)

However, 26 items have multiple upstream sources. For instance, “Malt” is derived from many different cereals, but FAOStat does not reveal in which quantities. Therefore, PLANET does not show any values from these 26 items in SUA, as it cannot determine which are its upstream processing-related products. Therefore, the processing for “Barley” shows a large outflowing gap, as most of this would likely be “Malt”. However, in PLANET the SUA and FBS numbers are shown without any computations or assumptions. So PLANET does not provide an estimation, how much of the respective “Malt” is derived from which source, and instead leaves the item unmentioned.

In the FAO Synthesis computed Sankey pictures, all resultant final end uses are summarized under either Processed Foods or Transformed Foods, so that their totals are not missing. The totals can be derived from the FBS tables (see chapter 2 of this documentation).

Table S I.1 Food items which are not shown in the PLANET SUA pictures due to several mentioning at upstream intermediate products

1,"Beverages, distilled alcoholic"
2,"Fruit, prepared nes"
3,"Vegetables, preserved nes"
4,"Alcohol non food"
5,"Vegetables in vinegar"
6,"Fruit, cooked, homogenized preparations"
7,"Juice, fruit nes"
8,"Margarine, short"
9,"Vegetables, frozen"
10,"Fruits, nuts, peel, sugar preserved"
11,"Nuts, prepared (exc. groundnuts)"
12,"Fruit, dried nes"
13,"Oil, boiled etc"
14,"Tallow"
15,"Vegetables, temporarily preserved"
16,"Beer of barley"
17,"Cereal preparations nes"
18,"Glucose and dextrose"
19,"Oils, fats of animal nes"
20,"Vegetables, dehydrated"
21,"Bran, cereals nes"
22,"Cider etc"
23,"Flour, cereals"
24,"Fructose and syrup, other"
25,"Lard"
26,"Malt"

S II. "Other Use" Assignments

FAOStat lumps together all non-food uses of a final product material flow under the term "Other Uses." These can then be industrial, consumer of fuel applications. The category also includes the usage of food for tourists. The logic for the latter is that these are not permanent residents, and thus their food consumption needs to be separated in order to have an accurate view of the food situation for the domestic population of a country. Unfortunately, FAOStat does not provide any further detail about these other uses.

PLANET streamlines "Other Uses", so that all post-processed other uses (as per FBS tables) are assigned to be consumer goods, and all pre-processed other uses (as per SUA tables), are assigned to be industrial goods, and then become fuels/other uses (such as fertilizer, construction materials, etc).

In the earlier PLANET versions 1.0 and 1.1, there were crop-specific allocations to either consumer or industrial goods. PLANET discontinued this assignment, as it believes the current method is less speculative.

S III. Protein, Adjusted Protein, Fat and Calories Content Calculations

- Excel sheet download: S III FAO Nutritive_Factors_24 Feb 2022
- Excel sheet download: S III Nutrition and Flow Allocation Master Table_23 Dec 2022

S IV. Transcribed Data Tables from Stefan Wirsenius Thesis Publication

- S IV a) Wirsenius Thesis: Human Use of Land and Organic Materials 2000 (pdf)
- Excel download S IV b) Table 3.1 Wirsenius countries and regions (p 58)
- Excel download S IV c) Wirsenius Table 3.16 harvest by-product production (p 92)
- Excel download S IV d) Wirsenius Table 3.22 actual weight / dry weight (p 129ff)
- Excel download S IV e) Wirsenius Table 3.17 harvest by-product recovery (p 94)
- Excel download S IV f) Wirsenius Table 3.20 harvest by-product recovery allocation to feed (p 102)
- Excel download S IV g) Wirsenius Table 3.21 bedding allocation (p 126)
- Excel download S IV h) Wirsenius Table A.1.I carcass composition (p 258)
- Excel download S IV i) Wirsenius Table 3.23 feed to species allocation (p 144 ff)
- Excel download S IV j) Wirsenius Table 3.24 feed to region allocation (p 148 ff)
- Excel download S IV k) Computation example for feed sources to species

S V. Other Biomass Data Sources

Forestry:

- S V a) FAOStat Forest Production Statistics Data Structure (pdf)
- S V b) Forestry weight to ton ratios DP 49
- Excel sheet download: S V c) forestry weight to volume ratios utilized in PLANET based on S V b)

Summary of all allocation assumptions:

- S III Nutrition and Flow Allocation Master Table_23 Dec 2022

Source materials for the various estimations of harvest-by-products and flow allocations for the crop materials (for instance in cereals, oil crops or fruits) are available upon request.

Soybeans:

- Excel sheet download: S V d) Soybean production to species allocation USDA vs Wirsenius
- Source of USDA data: https://marketviewdb.unitedsoybean.org/?bi=Soy_ConsumptionDetail_Annual

S VI. Country and Sociodemographic data

Country Groupings by

- Geographic continents
- Income group
- SDG Region
- SDG Subregion
- Food System Types

- excel sheet download: S VI a) Country groups 23 December 2022