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Consumer Footprint

Basket of Products indicator on Food

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The calculation of life cycle indicators (in this case the Consumer Footprint indicators) is subject to periodical refinement, improvement and evolution. The present report describes the main methodological elements and results. For the latest versions (including updates, improvements or errata corrige), please refer to the dedicated webpage of the EPLCA website: http://eplca.jrc.ec.europa.eu/?page_id=1517.
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Abstract

The EU Consumer Footprint aims at assessing the potential environmental impacts due to consumption. The calculation of the Consumer footprint is based on the life cycle assessment (LCA) of representative products (or services) purchased and used in one year by an EU citizen. This report is about the subset indicator of the basket of product (BoP) on food.

The BoP food is built to assess the impact associated to food consumption in Europe from raw material extraction to end of life. The reference flow is the amount of food consumed by an average citizen in a reference year. It consists of a process-based life cycle inventory model for a basket of products that represent the most relevant food product groups, selected by importance in mass and economic value. The 19 products in the basket are: pork, beef and poultry meat, milk, cheese, butter, bread, sugar, sunflower oil, olive oil, potatoes, oranges, apples, mineral water, roasted coffee, beer, pre-prepared meals, wine, and pasta.

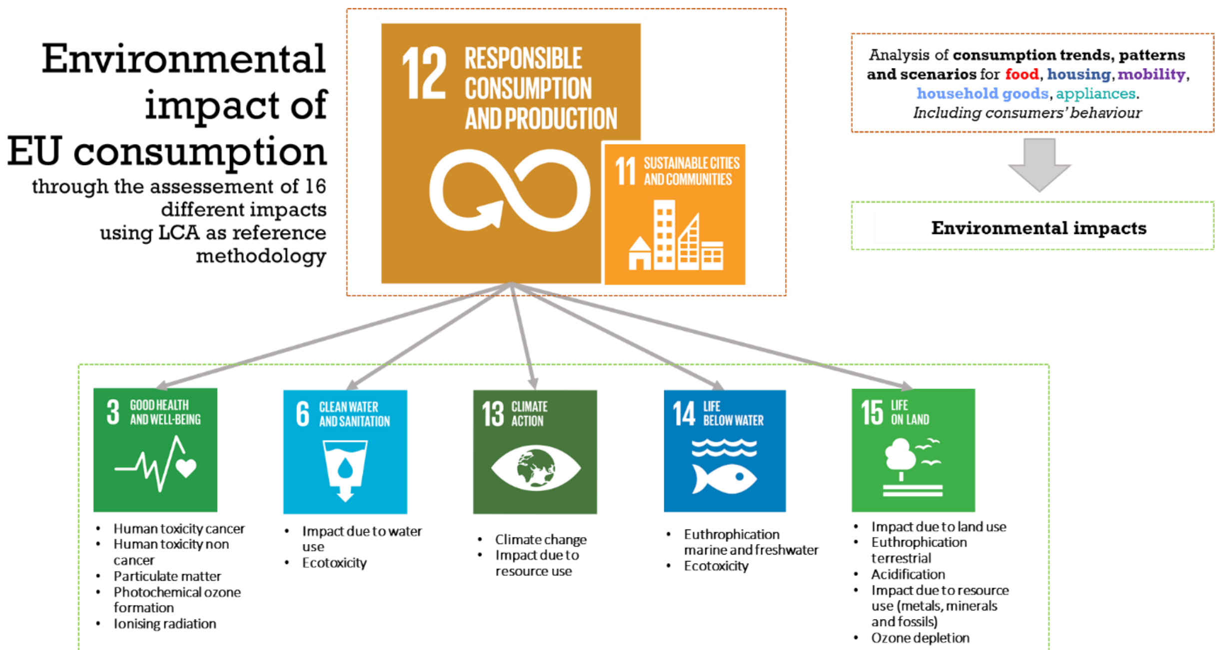
The consumer footprint for the BoP food is assessed using 15 environmental impact categories as for the ILCD LCIA method and running a sensitivity for a number of impact categories with updated models. Results show that agriculture is the life cycle stage of the food system with the larger contribution to most of the impact categories. The product groups that emerge as hotspots in most of the impact categories are meat products, dairy products, and beverages. The main impact for the life cycle of meat products comes from the emissions due to agricultural activities for the production of feed. Direct emissions from animal husbandry (methane, dinitrogen oxide, ammonia, etc.) contribute as well. Normalized results show that the BoP food contributes significantly to several impact categories, with a different ranking depending upon the adopted normalisation reference (European or global). Ecotoxicity, human toxicity, eutrophication, acidification, water depletion and climate change are among the leading impacts. Since many LCA study on food are limited to the assessment of climate change related emissions, the BoP food baseline aims at helping to understand the wider array of impacts associated to the food system of production and consumption.

Moreover, the Consumer Footprint BoP food baseline has been assessed against 5 scenarios, referring to improvement options related to the main drivers of impact. In fact, the scenarios act on the hotspots identified within the baseline and refer to the most relevant eco-innovations and behavioural changes identified through a review of the scientific literature. Scenario 1 and Scenario 4 act on the nutrients cycle, with the aim of recovering nutrients either at the production stage or the end of life stage. Scenario 2 acts at the end of life stage as well, by assuming an improvement of the efficiency of the waste water treatment in Europe. Scenario 3 is a first attempt to address the benefits of behavioural changes, with an example of reduced amount of meat consumed. Scenario 5 regards the topic of food waste prevention, and entails a number of prevention measures, acting at different stages of the food supply chain, including the use phase. The scenarios tested on the baseline of the BoP food provided insights on the potential for reducing environmental impacts of food consumption in Europe. Each scenario acts on a different component of the BoP (in term of either products, life cycle stages or composition of the basket). As the scenarios are different in type it was found out that the was a large difference on the different scores and savings among the investigated impact categories. In general, among the scenarios assessed, the options that allow for a higher reduction of impacts are the ones acting on the drivers of freshwater eutrophication, such as recovery of nutrients from urine or improvement of the wastewater treatment. It is important to highlight that results of scenarios shall be analysed considering a certain "uptake factor" across EU (it is not realistic to assume 100% change across EU27). It is also recommended to consider the combination of improvement actions, to cover a wider range of impacts and to maximize the potential of impact reduction, both at the scale of the single citizen and of the whole Europe. An example has been provided in the case of combined actions for the scenario on food waste prevention.

1 The European Union (EU) Consumer Footprint

Assessing the environmental impact due to consumption of goods and services is a crucial step towards achieving the sustainable development goal related to responsible production and consumption (SDG 12). As part of its commitment towards more sustainable production and consumption, the European Commission has developed an assessment framework to monitor the evolution of environmental impacts associated to the European consumption adopting LCA as reference methodology (EC-JRC, 2012a; EC-JRC, 2012b). The present study is expanding the initial assessment framework to ensure a more complete and robust evaluation of the impacts, addressing SDG 12, partially SDG11 (on sustainable cities and communities) and assessing impact on a number of environmental impact categories related to other SDGs, mainly the ones addressing ecosystems and human health. Assessing environmental impact of consumption is primarily linked with SDG 12, and it implies the evaluation of the level of decoupling of environmental impact from economic growth, and related consumption patterns. However, assessing impact of production and consumption means, as well, understanding to which extent production and consumption may have an impact on other SDGs (Box 1).

Box 1 Overview of the link between SDGs, assessing the environmental impact of consumption and calculating this impact with Life Cycle Assessment



The assessment framework aims to support a wide array of policies, such as those related to circular economy, resource efficiency and ecoinnovation. The environmental impact of EU consumption is assessed adopting two sets of life cycle-based indicators: the Consumption footprint and the Consumer footprint, which have a complementary role in assessing impacts (Box 2).

The Consumer footprint adopts a bottom-up approach, aiming at assessing the potential environmental impact of EU consumption in relation to the impacts of representative products. In fact, the Consumer footprint is based on the results of the life cycle assessment (LCA) of more than 100 representative products purchased and used in one year by an EU citizen. The Consumer footprint allow assessing environmental impacts along each step of the products life cycle (raw material extraction, production, use phase, re-use/recycling and disposal).

For the calculation of the Consumer footprint, the consumption of European citizens is split into five key areas (food, housing, mobility, household goods and appliances). For each area, a respective Basket of representative Products (BoP) has been built based on statistics on consumption and stock of products. For each of the five BoPs, a baseline scenario has been calculated, taking as reference the consumption of an average EU citizen.

This report focuses on the BoP food, which is one of the 5 key areas of consumption identified for calculating the consumer footprint.

The developed LCAs are in line with the International Life Cycle Data system (ILCD) guidelines and follow, to the extent it is possible and relevant, the environmental footprint methods as published in the Communication "Building the Single Market for Green Products" (EC, 2013). The quality of the models has been ensured by periodical consistency checks and model refinements. In order to allow for periodical updates, the models has been built with a parametric approach. Hence, for example, the amount and structure of consumption could be updated to more recent reference years using data on apparent consumption (i.e. BoP composition and relative relevance of representative products) taken from Eurostat.

The baseline models allow identifying the environmental hotspots along the products lifecycle and within the consumption area of each specific BoP. The results of the hotspot analysis are, then, used as a basis for the selection of actions towards environmental burden reduction, covering shifts in consumption patterns, behavioural changes, implementation of eco-solutions, or a combination of the previous ones. For each of the actions, a scenario has been developed, by acting on the baseline model and simulating the changes associated to the specific intervention. The LCA results of each scenario are then compared to the results of the baseline, to identify potential benefits or impacts coming from the implementation of the solution tested, as well as to unveil possible trade-offs.

Complementary to the Consumer Footprint is also developed by JRC the Consumption footprint indicator. The consumption footprint is basically a top-down approach, aiming at assessing the potential environmental impact of EU apparent consumption, accounting for both domestic impacts (production and consumption at country level with a territorial approach) and trade- related impacts. The impacts are assigned to the country where the final consumer is located. An overview of the two developed indicators (Consumer and Consumption footprint) is presented in Box 2. As mentioned above this report focuses on the Consumer footprint indicator and in particular to the Consumer footprint Basket-of-product indicator for food.

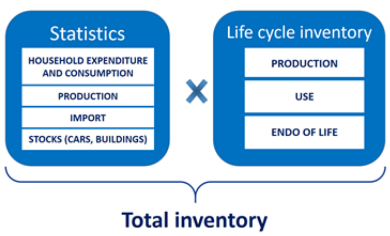
Box 2 Overview of the life cycle-based indicators for assessing the impacts of EU consumption

The life cycle-based indicators for assessing the impact of EU consumption

The Consumer footprint (BOTTOM UP)

LCA of products representative of the consumption of an average EU citizen

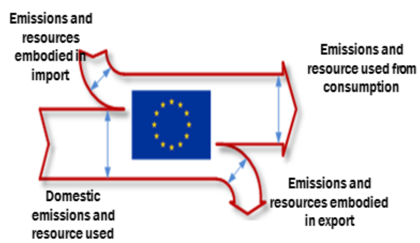
- Focusing on resources used and emissions due to production and consumption during the all life cycle of a product in selected areas of consumption (food, mobility, housing, household products, appliances)
- Combining life cycle data (environmental profiles of products) with consumption statistics



The Consumption footprint (TOP DOWN)

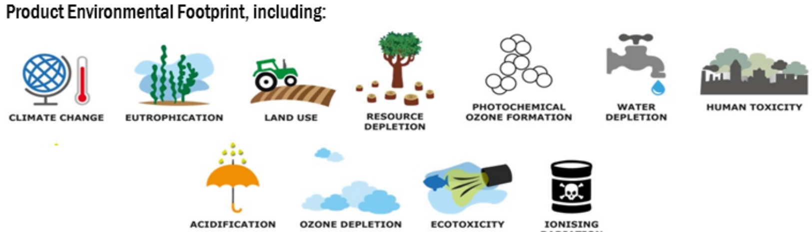
Economy wide assessment of apparent consumption in Europe

- Focusing on resources used and emissions due to production and consumption in one year in all sectors
- Combination of environmental statistics and life cycle inventories of representative products according to trade statistics
- Alternatively though the use of a the Environmentally Extended Input-Output Approach



Life Cycle Impact Assessment

Each emission in the environment and resource used are then characterized in term of potential environmental impacts in the life cycle impact assessment phase, covering the 15 impact categories recommended for the Product Environmental Footprint, including:



Results

Environmental impacts associated to households in Europe. Identification of hotspots in the Life Cycle of the consumed products considering five product categories: Food, Mobility, Housing, Household goods and Appliances. Results could be analysed for different types of consumer behaviours –e.g. average vs pro-environmental.

Each BoP represents a baseline for assessing ecoinnovations scenarios at all life cycle stages, from raw material, production, up to use phase and end of life. This help assessing benefits of sustainable lifestyles.

Environmental impacts of consumption in Europe and for each Member State, including the distinction of impacts in the three categories:

- Direct impacts, that occur because of the use of products and services.
- Indirect domestic impacts, that occur because of the life cycle impacts of products that are produced in the same country where they are consumed .
- Indirect imported impacts that occur because of the life cycle impacts of products that are produced in different countries where they are consumed.

2 Environmental impacts of food

Current patterns of food production and consumption are increasingly considered unsustainable. On the one hand, there is the need to fulfil a fundamental human need for nutrition, and on the other hand, this poses critical threats to the environment. According to EEA (2012) food and drink consumption is found to be responsible for around 20–30 % of environmental impacts caused by consumption in the EU in most impact categories.

The use of Life Cycle Assessment (LCA) to assess the food sector and more generally the food supply chains has been increasing over time. However, there are several challenges to be addressed, mainly due to the intrinsic variability of food systems at any stage (from agriculture to food manufacturing stages) and to specific aspects related to critical impact categories or modelling needs. JRC has coordinated a special volume of the Journal of Cleaner Production specifically dedicated to this topic (Volume 140/2), whose main challenges are reported in the opening paper (Sala et al. 2017).

Most of the studies available in the literature highlight the high contribution of all the life cycle stages of the food production chain to Greenhouse Gases (GHGs) emission (see, for instance: Defra, 2011; Garrone et al., 2014; Garnett 2011). EC-JRC (2006) attributes about 22% of EU GHG emission to the food sector. This is mainly due to the emissions from landfill (food waste put in landfill emits large amount of methane – which has a high global warming potential - and carbon dioxide), and the use of energy in all the production stages (from agriculture - including land use change - to processing, manufacturing, transportation, storage, refrigeration, distribution, retail and use phases) (Padfield et al., 2012; Tuncer and Schroeder, 2011; Lundqvist et al., 2008).

Other environmental impacts associated to food production are natural resource depletion (mainly in the agricultural stage), the alteration of biogeochemical cycles of N and P - used as fertilizers in agriculture – (Smill, 2002), water consumption (Lundqvist et al., 2008) in agriculture and in the food manufacturing stages, land use (Meier et al., 2014) and biodiversity loss from use of pesticide, land use change and reduction of natural ecosystems for food and feed cultivation (EEA, 2012). Moreover, food waste along the whole food production chain is a relevant source of impacts (WRAP, 2015; EEA, 2016; Beretta et al., 2017).

Some food sectors generate higher environmental impacts than others do. Beef, butter and cheese generally have higher environmental burdens, especially related to their carbon footprint and material intensity, while vegetables, cereal products, potatoes and fruit such as apples, when consumed in proper season, generally have much lower impacts (EEA, 2012). This is confirmed by meta-analysis studies (e.g. Clune et al. 2016, Clark and Tilman 2017, Nijdam et al. 2012, Tilman and Clark 2014, De Laurentiis 2017) that have collected large bodies of LCA studies to draw some general conclusions on the hierarchy of impacts across different food categories. Mostly focusing on greenhouse gas emissions (although presenting in some cases additional impact categories as in the case of Clark and Tillman 2017), these studies reach similar conclusions in identifying animal based products (and in particular ruminant meat) as those responsible for the highest impacts and fruit, vegetables and grains, as those with the lowest impacts.

Within the livestock sector, feed production is a relevant source of impacts (Noya et al., 2017, Six et al., 2017). Feed-related emissions (including land-use change) account for about 3.3 Gt CO_2-eq, that is, about half of total emissions from livestock supply chains (Gerber et al., 2013; LEAP, 2014).

In general, the agricultural phase is the one that generates the largest impacts within the food supply chain. According to EEA (2016), agricultural activities for production of food, fibres and fuel in Europe account for 90% of ammonia emissions, 50-80% of nitrogen load in freshwater bodies, affecting water quality and aquatic ecosystems, 10% of greenhouse gas emissions (including 80% of methane emissions), contributing to climate change.

Several 'bottom up' product-oriented Life Cycle Assessments (LCAs) have been carried out to specifically assess the impacts of the most representative foods consumed in a specific region. For example, Foster et al. (2006) carried out an LCA study of food types that are representative of the foods on a list of 150 highest-selling items provided by a UK retailer. Munoz et al. (2010) assessed Spanish food consumption by carrying out an LCA of the annual composition of Spanish food purchases by households, catering, restaurants and institutions. Similarly, Eberle and Fels (2016) assessed the environmental impacts of German food consumption and food losses by analysing statistical data on production, trade and consumption.

Some authors have implemented hybrid approaches involving both 'bottom up' and 'top down' methods in order to overcome some of the possible problems arising from truncation errors of the former method and the non-specific nature of the data of the latter. For example, Pairotti et al. (2015) use a hybrid approach to explore the environmental burdens of the Mediterranean diet and compare these to those of an average Italian diet and those of two empirical scenarios of healthy and vegetarian food consumption patterns. Some studies use LCA to assess the impacts of diets (Baroni et al., 2007; Van Dooren et al., 2014; Meier and Christen, 2013) and the potential savings related to dietary changes(Fazeni and Steinmüller, 2011; Saxe et al., 2013). Gephart et al. (2016) applied an optimisation algorithm to find the optimal diet composition for minimising the associated carbon footprint, nitrogen footprint, water footprint and land footprint. Lavers et al. (2017) combine material flow analysis with LCA by selecting 71 representative products used as proxies to assess the environmental impact of urban areas using life cycle impact characterisation factors.

Most of the studies in the literature address the environmental assessment of single products, but only a few adopt a consumption-oriented approach to assess the impact of the food supply chain in large geographical areas. However, studies at meso- and macro scales are fundamental in providing decision makers with information for making a transition to more sustainable production and consumption patterns, by decoupling environmental impacts from responses to societal needs, while still ensuring economic growth.

At the macro scale, environmental impacts associated with consumption have traditionally relied on a 'top down' approach, such as using the sectorial economic information of input-output tables. The basic idea of those approaches is to calculate the physical material flows of economic sectors and then supplement this with environmental data in order to assess the sustainability of product groups (e.g. Huppes et al., 2008; Tukker et al., 2006; Weidema et al., 2005; Nijdam et al., 2005).

The basket of products food assesses the impact of food consumption in Europe using a bottom-up approach, based on the selection of representative food products and related life cycle inventories. The aim is to define a baseline scenario, modelled considering the statistics about food consumption by an average European citizen, as a reference for evaluating the potential improvements coming from eco-innovation and behavioural changes in the food sector.

An example of how the BoP food can support analyses on the food system in Europe is the study "Energy use in the EU food sector: State of play and opportunities for improvement" by Monforti-Ferrario et al. (2015). The study makes use of the baseline model of the BoP food as a basis for a detailed analysis on energy use in the European food sector and related areas of improvement. Similarly, the study by Cristóbal et al. (2018), starts from the results of a scenario on food waste prevention applied to the BoP food (Scenario 5 in the present report) to build an optimization function to prioritize food waste prevention measures at the EU scale, considering potential environmental effects and economic constraints.

3 Basket model for food

In order to comprehensively assess the impact of consumption at EU level, in 2012 the European Commission's Joint Research Centre developed a lifecycle-based methodology that focuses on specific representative products which are then up-scaled to overall EU consumption figures, named the Basket of Products (BoP) indicators (EC-JRC, 2012b). The project (called LC-IND) focused on indicators that measure the environmental impact of the consumption of products by the average European citizen, focusing on housing, food and transport, via the identification and environmental assessment of the most representative products of each category (basket of products). The initial BoPs developed in the LC-IND projects were revised extensively in the context of LC-IND2 project, to improve the quality of the models and to allow for a better assessment of the scenarios based on circular economy principles.

This report describes the scope and the structure of the basket of product (BoP) food, including the Life Cycle Inventory (LCI). Aim of this section is to enable the reader to understand how the BoP is modelled, to better interpret the results and, ultimately, to replicate the exercise.

3.1 Description of the BoP composition

The BoP food is built to assess the impact associated to food consumption in EU-27[1]. The reference flow is the amount of food consumed by an average EU-27 citizen in the reference year 2010.

This section illustrates the work done for the Basket of Products (BoP) indicators building on the work done by JRC and the University of Bari as reported in Notarnicola et al. 2014 and further elaborated in Notarnicola et al. (2017). The model originally developed by Notarnicola and colleagues in 2014 has been extensively revised in the context of this study to improve the quality of the models and to allow for a better assessment of the scenarios based on circular economy principles.

The BoP food consists of a process-based LCI model for a basket of products that represent the most relevant food product groups, selected by importance in mass and economic value, to depict the average consumption for nutrition of EU citizens in 2010 (Notarnicola et al., 2017). The product groups in the basket are: pork, beef and poultry, milk, cheese, butter, bread, sugar, sunflower oil, olive oil, potatoes, oranges, apples, mineral water, roasted coffee, beer, pre-prepared meals, wine and pasta. For each product group in the basket, an inventory model based on a representative product has been developed. The impact of each representative product is then multiplied by the mass of products in that product group that is consumed in one year by an average EU citizen.

A quantitative and qualitative analysis of the structure of EU-27 food consumption (during the years 2000-2010) was performed, including an analysis of international trade. This led to the selection of products that are representative of apparent food consumption for the year 2010. Specific data on apparent consumption (defined as Production - Exports + Imports) were taken from Eurostat and FAO databases, as well as from specific nutrition and food consumption literature concerning current emerging consumption trends (e.g. EEA, 2012; EC, 2014). The final selection of products for the basket was based on the following steps:

— firstly, the consumption data was subdivided into main food categories, namely meat and seafood, dairy products, crop-based products, cereal-based products, vegetables, fruit, beverages, pre-prepared meals,

[1] The orginal model refers to 2010 as reference year and, hence, to EU 27

— amongst these categories, the food products with the largest apparent consumption in terms of mass and economic value were chosen for inclusion in the basket,

— it was verified that products which had already been identified as being responsible for large environmental burdens (e.g. meat and dairy products - Foster et al., 2006; Tukker et al., 2006; Gerber et al., 2013) were included in the BoP,

— the BoP also includes products that are representative of emerging food consumption trends and types of food and beverages whose consumption has been increasing during the past decade, independent of the magnitude of their environmental impact and the extent of their apparent consumption (e.g. pre-prepared meals),

— finally, the BoP includes wine and pasta as representative products, to ensure full correspondence with the list of food products covered by Product Environmental Footprint (PEF) pilots.

Table 1 illustrates the products selected for BoP food (reference year 2010, country coverage EU-27) and the respective data on their apparent consumption (source: Eurostat, 2014a).

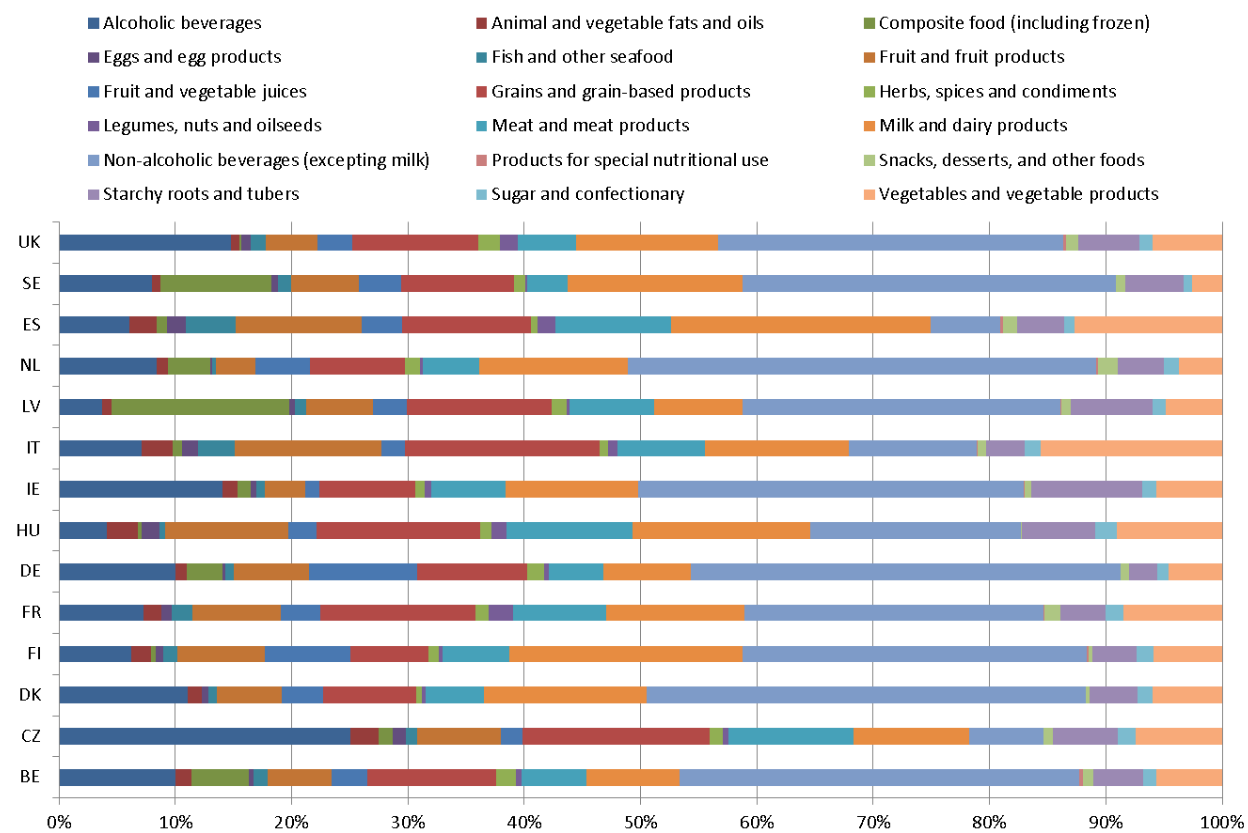
Table 1. Composition of the BoP food in terms of product groups, representative products and related quantities (referred to the reference flow, i.e. food consumption of an average EU-27 citizen in the reference year 2010)

Product Group	**Representative product**	**Per-capita consumption (kg/pers.*yr^{-1})**	**% of total per-capita apparent basket consumption**
MEAT	Pig meat	41.0	*7.1%*
	Beef meat	13.7	*2.4%*
	Poultry meat	22.9	*4.0%*
DAIRY	Milk & Cream	80.1	*14.0%*
	Cheese	15.0	*2.6%*
	Butter	3.6	*0.6%*
CEREAL-BASED PRODUCTS	Bread	39.3	*6.9%*
	Pasta	8.2	*1.4%*
SUGAR	Sugar	29.8	*5.2%*
OILS	Sunflower oil	5.4	*0.9%*
	Olive oil	5.3	*0.9%*
VEGETBLES	Potatoes	69.1	*12.2%*
FRUIT	Oranges	17.4	*3.0%*
	Apples	16.1	*2.8%*
COFFEE	Coffee	3.5	*0.6%*
BEVERAGES	Beer	69.8 L	*12.2%*
	Wine	24 L	*4.2%*
	Mineral water	105 L	*18.3%*
PRE-PREPARED MEALS	Meat based dishes	2.9	*0.5%*

Source: Eurostat (2014a)

The annual consumption of the BoP amounts to 572 kg per inhabitant per year. The BoP consumption is thus representative of 61% of the total apparent yearly consumption per inhabitant (933.2 kg/inhabitant) of all food and beverage products reported in the Eurostat-Prodcom database. As for the economic value, the BoP food covers 45.6% of the apparent consumption of food by European citizens (568 € per inhabitant per year, out of 1,246 € per inhabitant per year, calculated as apparent consumption from Prodcom data). The choice of Prodcom database as a basis to calculate the apparent consumption of food is due to the completeness of the database itself and to the need of identifying the share of imported products (either intermediate or finished product) in support to supply chain modelling. Another approach could be the use of consumption data, like the ones reported in the Comprehensive Food Consumption Database by EFSA (2011). It includes data from 32 dietary surveys from 22 European Member States where the daily consumption of several food categories are provided. EFSA surveys are not exhaustive but can be useful to provide a picture of the food consumption pattern in Europe, differentiated by Member States. An example is provided in Figure 1, showing the weight shares of 18 food categories for an adult consumer in 14 EU Member States.

Figure 1. Mean daily consumption in weight shares of 18 food categories for an adult consumer in 14 EU Member States



(source: EFSA, 2011, in Monforti-Ferrario et al., 2015)

4 Life Cycle Inventory of the BoP

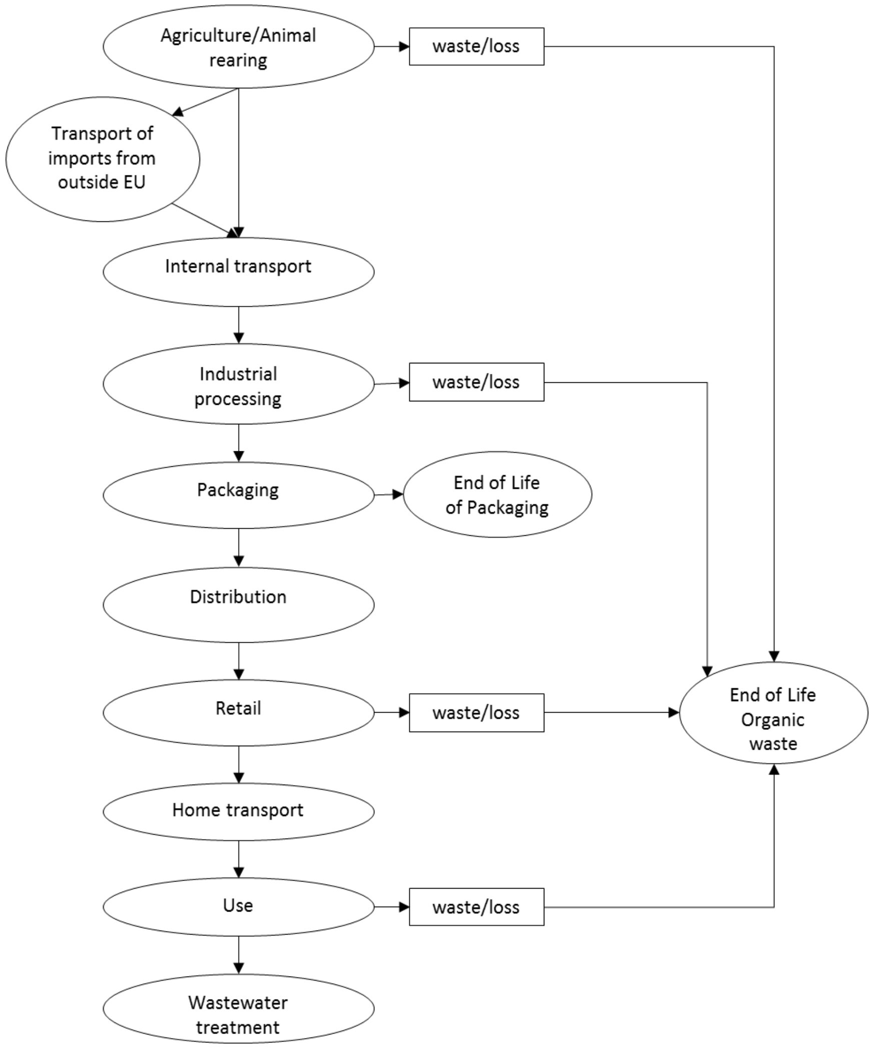
The reference system is the EU-27 per capita consumption in 2010 for the products listed in Table 1. The functional unit is defined as the average food consumption per person in the EU in terms of food categories (including the food losses at each stage).

Life Cycle stages considered in the food chains of the representative products are reported in Table 2. Figure 2 illustrates the system boundaries of a generic representative product included in the BoP food.

Table 2. Summary of life cycle stages and related activities included in the BoP food

Life Cycle stage	Activities included
Agriculture/breeding	Cultivation of crops
	Animal rearing
	Food waste management
Industrial processing	Processing of ingredients
	Slaughtering, processing and storage of meat
	Chilled or frozen storage
	Food waste management
Logistics	International transport of imports
	Transport to manufacturer
	Transport to regional distribution centre
	Distribution
	Transport to retailer
	Food waste management
Packaging	Manufacture of packaging
	Final disposal of packaging
Use	Transport of the products from retailer to consumer's home
	Refrigerated storage at home
	Cooking of the meal
End of life	Final disposal of food waste
	Wastewater treatment and auxiliary processes due to human excretion

Figure 2. System Boundaries for the LCI of a generic representative product in the BoP Food



The process-based lifecycle inventories were developed for each lifecycle stage of the selected representative products, updated to the year 2010, via the following approach:

1. A literature review was carried out concerning existing LCA studies of the single basket products (including the screening studies conducted by some PEF pilots).
2. The approaches of such reviewed studies, for each lifecycle stage of each product, were assessed for appropriateness for the present study via the implementation of a pedigree matrix[2].
3. Once the approach was selected for the assessment of each representative product (see Table 3 for an overview of the sources used), the respective processes were tailored to account for the average EU situation (e.g. energy mix, production of pesticides and fertilisers – see following paragraphs).

[2] The pedigree matrix (PM) is a post-normal approach to assign uncertainty to input data, used in the ecoinvent database (Frischknecht and Rebitzer, 2005, Weidema et al., 2013). The pedigree matrix considers information about the quality of each primary input and output datum in terms of reliability, completeness, temporal correlation, geographical correlation and further technological correlation.

Table 3. Overview of LCI datasets relative to the agriculture/production phase (source: Notarnicola et al., 2017)

Representative products	Activities	Data source and geographical scope
Coffee	- Production of coffee cherries - Green coffee production (wet process)	Coltro et al. (2006), Brazil Salomone (2003)
	- Coffee roasting for the production of soluble coffee - Coffee roasting for the production of ground coffee	Humbert et al. (2009)
Beer	- Barley cultivation - Malt production - Beer production	Blonk Consultants (2014), EU Kløverpris et al. (2009) Schaltegger et al. (2012)
Mineral water	- Treatment of natural water - Bottling water	Vanderheyden and Aerts (2014), Belgium
Bread	- Wheat cultivation - Production of wheat flour from dry milling - Bread production	Blonk Consultants (2014), EU Renzulli et al. (2015) Espinoza-Orias et al. (2011)
Pasta	- Durum wheat cultivation - Soft wheat cultivation - Eggs production - Pasta manufacturing	PEF pilot screening model, Europe
Beef	- Beef cattle breeding - Slaughtering beef cattle for the production of beef meat - Beef meat processing	Blonk Consultants (2014), Ireland
Pork	- Pigs breeding - Slaughtering pigs for the production of pig meat - Pig meat processing	Blonk Consultants (2014), Netherlands
Poultry	- Broilers breeding - Slaughtering broilers for the production of poultry meat - Poultry meat processing	Blonk Consultants (2014) , Netherlands
Milk	- Dairy cattle breeding - Processing of raw milk for the production of standardised full milk	Blonk Consultants (2014), Netherlands Fantin et al. 2012
Butter	- Processing of raw milk for the production of cream - Production of butter	Djekic et al. (2014), Europe
Cheese	- Processing of raw milk for the production of standardised skimmed milk - Production of cheese	Djekic et al. (2014), Europe
Sugar	- Sugar beet cultivation - Production of sugar from sugar beet	Blonk Consultants (2014), Germany
Sunflower oil	- Production of sunflower seeds	Blonk Consultants (2014), Europe

Representative products	Activities	Data source and geographical scope
	- Crude sunflower oil production from crushing (solvent process) - Refining sunflower oil	
Olive oil	- Olive cultivation - Extra virgin olive oil production from milling olives - Bottling extra virgin olive oil	Notarnicola et al. (2013), Italy
Potatoes	- Potato cultivation	Blonk Consultants (2014), Germany
	- Storage of fresh potatoes for fresh consumption - Storage of fresh potatoes for the production of chips and frozen potatoes	EPD (2012)
	- Production of frozen potatoes - Production of chips	Ganesh (2013)
Apples	- Apple cultivation - Selection, conditioning and storage	Milà i Canals et al. (2007), Europe Cerutti et al. (2014)
Oranges	- Orange cultivation - Selection, conditioning and storage	Pergola et al. (2013), Italy
Pre-prepared meals based on meat	- Cultivation of carrots, onions, tomatoes - Production of processed ingredients (chicken meat, refined sunflower oil, tomato sauce)	Frischknecht et al. (2007) EC (2006), EU
	- Pre-processing the ingredients - Manufacturing of pre-prepared meals	Schmidt Rivera et al. (2014), EU
Wine	- Production of grapes - Production of must - Wine-making	PEF pilot screening model, Europe

4.1 Key assumptions for performing the Life Cycle Assessment

As illustrated in Figure 2, all food systems, at various stages of their lifecycle, include the production of scraps or other materials that may often be considered to be co-products. Therefore, the problem of the allocation of environmental burdens is present in almost all food chains. This problem is further complicated by the fact that the mass of the co-products very often greatly exceeds the mass of useful food products obtained; for example, in the case of olive oil manufacturing, 2.1 kg of husks are produced for every kg of olive oil. Performing the allocation on the basis of mass would result in the displacement of a large part of the impact burden associated with the food chains to the co-products rather than to the product for which the supply chain was built (Notarnicola et al., 2012). Based on these considerations, the environmental impacts incurred during food production are allocated on an economic basis.

As regards the use of fertilisers in the agricultural stage of each product, emissions of N_2O from managed soils and CO_2 emissions from lime and urea application have been estimated according to the IPCC methodologies (IPCC 2006a). Ammonia emissions to air and the nitrate leaching in the soil were also estimated by applying the calculation suggested by the IPCC guide. It is assumed that all nitrogen that volatises converts to ammonia, and that all nitrogen that leaches is emitted as nitrate. It is estimated that 5% of phosphorus applied through fertilisers is emitted to freshwater resources (Blonk Consultants, 2014).

Pesticides are among the most important inputs in the agricultural phase, and have a significant impact on ecological and human toxicity. The approach indicated by Sala et al. (2014) was followed in order to estimate the consumption of pesticides. This approach consists of a framework developed to assist the quantification of pesticide fractions, starting from different levels of publicly available data. The data used for the estimation of the quantities of pesticides used in various crops were obtained from the EC (2007). The emissions of pesticides during their use were assessed, assuming that 100% of the active pesticide ingredient is emitted to soil (de Beaufort-Langeveld et al., 2003).

The analysis of farming systems required data on animal growth, enteric emissions and feed production. The animal breeding models taken into account in this study for the various types of products (dairy products, and meat from beef, pork and poultry) are those reported by Blonk Consultants (2014). In particular, the animal enteric fermentation and the type of manure management used in the production of livestock products were accounted for. The feed production processes were also taken into account. The inventories regarding the livestock were calculated according to the approach indicated by the IPCC in Vol.4 chapter 10 (IPCC, 2006b).

Logistics consists of international trade, local distribution and retail. In the present study, trade from outside of the EU is called international trade and it was considered for all products in the basket (with the exception of pre-prepared meals, for which data on imports per country were not available). The countries of origin and amount of imports were considered in relation to domestic production. Transport from those countries, which represents the source of at least 90% of total EU imports of a specific product, was considered in the study, as transoceanic transport by ship plus road transport from the production site to the departure port and from the arrival port to the distribution centre (see section 4.4 for details). This transport is allocated to a percentage of the product in the LCI model, corresponding to the share of imported intermediate food products out of the amount of that kind of product which is included in the BoP. Distribution consists of transport by lorry from the manufacturer/farm to a regional distribution centre, and the further transport by lorry from the regional distribution centre to the retailer. The total distance travelled was assumed to be 500 km for all products. If refrigerated transport is needed, a 20% increase in fuel consumption was assumed (Lalonde et al., 2013). The energy consumption associated with the time during which the product is stored in a retail facility was considered using data from the Danish LCA Food database (Nielsen et al., 2003).

The use phase is assumed to consist of: i) consumer transport (a 4 km transport by passenger car from the consumer’s home to the retailer and back) and ii) domestic consumption.

The end-of-life phase includes the treatment of food scraps and unconsumed foods, together with the environmental assessment of human metabolism products, modelled according to the method of Muñoz et al. (2007). Specifically, each basket product was considered in terms of its nutritional composition (e.g. fibre/carbohydrate/protein) in order to account for the impacts of human excretion (Ciraolo et al. 1998).

Different data quality requirements were implemented in order to choose the inventory data that were most appropriate for the present study and approach. Data quality was assessed in a pedigree matrix focusing on the parameters of: time-related coverage, geographical coverage, technology coverage, completeness and consistency.

Specifically, the most representative datasets for each product in the basket were identified by applying the above mentioned data-quality requirements to the collected existing LCA literature concerning the basket products. LCI data sources of the agriculture and production stages of the BoP food are summarised in Table 3. All of the agricultural datasets, taken from the literature or from databases, have been modified in order to adapt them to the method and assumptions previously reported.

Foreground data were obtained from scientific literature and direct industrial sources. Background data were mainly taken from the Agrifootprint (Blonk Consultants, 2014) and Ecoinvent v.3 (Frischknecht et al., 2007, Weidema et al., 2013) databases. For the electricity profile the dataset for the European energy mix “Electricity, low voltage {Europe without Switzerland}| market group” (from Ecoinvent 3.2 library) from ecoinvent was used. Country-specific import data for the BoP food were taken from the Eurostat international trade database for the year 2010 (Eurostat, 2015). Distances and modes of transport used in import countries were also accounted for.

4.2 LCI of Agricultural/breeding stage

Table 4 and Table 5 show the inventories of the agricultural phase of the different products that pertain to one ha of cultivated area per year. Mineral water is excluded because there is no agricultural phase in its lifecycle. Table 4 reports data regarding products and co-products, fertilizers and pesticides used, consumption of diesel for agricultural operations, and electricity used to pump water for irrigation. The outputs are the emissions to air, water and soil that derive from the use of fertilizers and pesticides.

Table 5 gives a detailed inventory of pesticides applied to the different crops, in which the weights of the different active ingredients applied to one ha of crops are reported together with the percentage of active ingredient contained in commercial pesticides. The emissions from the combustion of diesel (taken from the Agri-footprint database, Blonk Consultants, 2014) in agricultural machinery have not been reported in this table, but are considered in the inventory. As regards water use, according to data in the inventories, no water input is applied in the cultivation of wheat, barley and coffee.

Table 6 shows the inventories of the breeding phase of animal-derived products. There are four inventories related to the rearing of dairy cows that produce milk, which is also the basis for the production of cheese and butter, and to the rearing of beef cattle, pigs and broiler chickens that will be sent to slaughter. The main data are taken from the Agrifootprint database. The table reports the feed used, the water consumed and energy inputs, together with the emissions deriving from manure management and the enteric fermentation of ruminants and (in minor amounts) non-ruminant animals. Losses of milk in this stage have also been considered, assumed to be 3.5% of milk produced (source: Agrifootprint. Blonk consultants, 2014).

Table 4. Inventories of the agricultural phase of different products (per cultivated ha per year) (modified from Notarnicola et al., 2017)

		apple	barley	wheat	coffee	olives	orange	potato	sugar beet	sunfl. seeds	grape
Products	t	31.4	5.7	7.1	9.0	5.8	25.0	41.6	58.9	1.3	1.6
Coproducts (total weight)	t	-	4.0	4.0	-	-	-	-	-	-	-
Inputs											
Fertilisers											
N	kg	62	145	149	238	30	240	100	150	57	4
P_2O_5	kg	4	10	19	26	7	100	101	40	50	2
K_2O	kg	47	14	17	233	7	180	131	140	21	9
Lime fertiliser	kg	52	329	327	1057	0	0	365	291	400	0
Compost	kg	0	0	0	0	0	0	0	0	0	150
Water	m^3	3 000	0	0	0	654	4 000	351	186	33	5
Pesticides (total weight)		Weight of active ingredient divided by the respective % content (reported in Table 5)									
Diesel	kg	231.7	131.2	138.5	161	78.7	250	243.9	164.5	92.6	33.1
Electricity	kWh	952	0	0	0	771	3 200	1 446	0	305	12
Outputs											
Emissions to air											
N_2O direct emissions from fertilisers	kg	0.97	3.97	3.92	3.74	0.471	3.77	3.60	8.12	1.34	0.11
N_2O indirect emissions from fertilisers	kg	0.32	1.46	1.43	1.2155	0.15	1.23	1.37	3.21	0.48	0.05
NH_3 air emissions from fertilisers	kg	7.53	43.82	42.38	28.9	3.64	29.14	43.42	107.27	13.79	0.4
CO_2 from fertilisers	kg	43.3	234.1	235.8	669.4	0.0	233.5	204.7	202.4	189.0	1.78
Emissions to water											
NO_3 from N fertilisers	kg	82.37	336	331.48	316.2	39.86	318.86	303.96	686.47	113.29	17.9
P from fertilisers	kg	0.1	1.3	1.3	0.6	0.2	2.2	3.5	2.2	1.2	0.02
Emissions to soil											
Pesticides		100% active ingredient (reported in Table 5)									

Table 5. Inventories of pesticides use in the agricultural phase of the BoP products (kg per cultivated ha per year) (source: Notarnicola et al., 2017)

pesticides (active ingredient)	% active ingredient in the pesticide		apple	barley	wheat	coffee	olives	orange	potato	sugar beet	sunfl. seeds	grape
Azoxystrobin	25	kg		0.09	0.09							
Captan	50	kg				1.50						
Carbaryl	85	kg				1.20						
Carboxin	29.5	kg									0.47	
Chloridazon	65	kg								0.50		
Chlorpyrifos	44.5	kg	0.80			1.20		1.20			0.10	
Copper	50	kg				0.03	0.0					3
Dimethoate	38	kg					0.53		0.150			
Diquat	17	kg							0.300		0.10	
Epoxiconazole	12.5	kg								0.13		
Ethephon	21.7	kg		0.09	0.09							
Ethofumesate	20.8	kg								0.54		
Fluazinam	38.8	kg									0.43	
Fosetyl-aluminium	80	kg						0.45				3
Glyphosate	40	kg	0.70	0.27	0.27	2.00	0.24	4.00		0.45		0.704
Mancozeb	75	kg	2.00					0.45	4.80			
Mcpa – sodium salt	25	kg		0.30	0.30							
Methomyl	25	kg							0.05			
Mineral oil	100	kg	1.60				0.16	1.20	0.30			
Pencycuron	22.9	kg		0.33	0.33							
Phenmedipham	16.2	kg								0.71		
Propiconazole	25.5	kg		0.11	0.11							
Prosulfocarb	78.4	kg							0.60			
Sulfur	80	kg	2.10							0.47		
Tebuconazole	25.8	kg									0.10	
Trinexapac-ethyl	26.6	kg		0.05	0.05							
Unspecified pest.												2

Table 6. Inventories of the breeding phase of animal-derived products (source: Notarnicola et al., 2017)

		Milk	Beef cattle for slaughter	Pigs for slaughter	Broilers for slaughter
Products	kg	1 000	1 000	1 000	1 000
Coproducts (total weight)	kg	25	-	-	-
Inputs					
Feed					
Grass	kg	1 364	21 376	0	0
Grass silage	kg	0	7 666	0	0
Maize silage	kg	717	0	0	0
Compound feed	kg	219	1 563	0	1 679
Mix of by-products	kg	105	0	0	0
Pig feed	kg	0	0	2 057	0
Water	m^3	2	138	9	3
Heat from gas	MJ	57	0	99	1 179
Diesel	kg	0	130	0	0
Electricity	kWh	58	304	13	48
Outputs					
Emissions to air					
Methane, biogenic (from enteric fermentation)	kg	15.94	194.84	14.47	0.00
Methane, biogenic (from manure management)	kg	6.32	54.92	4.04	0.60
N_2O (direct)	kg	0.04	0.36	0.27	0.00
N_2O (indirect)	kg	0.05	0.51	0.16	0.00
NH_3	kg	3.84	39.29	13.21	13.10
Solid waste losses	kg	35.00	-	-	-

4.3 LCI of industrial processing and packaging

The industrial phase is very different from product to product. The inventory was built for each activity included in the production phase of each product by collecting literature or database data. The main sources of data are reported in Table 3. Table 7 reports the amount of packaging inventoried for each product.

Table 7. Amounts of packaging per typology, per 1-kg or 1-L packaged product (modified from: Notarnicola et al., 2017)

	Unit	Glass	Paper	Cardboard	Corrugated board box	Aluminium	LDPE	HDPE	PET	PP	PS
Mineral water*	g								23		
Beer	g	522		32		3					
Wine**	g	700			58						
Coffee - soluble	g	2 600	4		54	14					
Coffee - ground	g				14	16					
Apples***	g										3
Oranges	g				84						
Potatoes - fresh	g							4			
Potatoes-frozen	g					4			8		
Potatoes - chips	g					20			20		
Bread	g									4	
Pasta	g			6	40		11				
Olive oil	g	786	7		47	6	8				
Sunflower oil	g				24				43		
Sugar	g		15								
Milk*	g								28		
Cheese	g				115						
Butter	g					15					
Beef	g						4				33
Pork	g						4				33
Poultry	g						4				33
Pre-prepared meal	g				42		28		69	8	
* referred to as 1-L product		** referred to as 0.75-L product				*** only 20% of product is packed					

4.4 LCI of logistics

Logistics consists of international transportation from outside the EU, transport of raw materials to the processing site, transport of processed goods from industry to retailing and the retailing stage itself. For the inventory of the international transport of goods, the share of imported goods in the total (production + imports) was calculated. For each kg of imported goods, the inventory of transport for each mode was also calculated, considering the different exporting countries, means of transport and distances. No import of finished products is assumed for pre-prepared meals. Only green coffee is totally imported from abroad, while for all the other products in the basket the share of imports compared to the total available amount of product is quite low (or very low in some cases).

The transport of imported products is assumed to occur from the capital of the exporting country to the city of Frankfurt, which is considered a central destination for the arrival of imports in Europe. For exporting countries directly connected to Europe by land, such as Switzerland or Belarus, only a transport by lorry is considered from the capital of the exporting country to the city of Frankfurt. For the others, the transport is considered to be composed by: a transport by lorry between the capital of the exporting country and the country's main port; a transport by ship from the port of the exporting country to the main European ports and, finally, a transport by lorry between the port of destination and the city of Frankfurt. Rotterdam and Marseilles are considered as the European ports of arrival of the goods. The distances are calculated by using www.sea-distances.org and Google maps (Table 8). This transport is allocated to a percentage of the final product in the LCI model, corresponding to the share of imported goods out of the total apparent consumption of that kind of product.

Table 8. Summary of the share of imported food products, sea transport distance and road transport distance for each representative product

Product Group	Representative product	Import (%)	Sea transport (t*km) per kg of product imported	Road transport (t*km) per kg of product imported
MEAT	Pig meat	0.11%	7.28	0.45
	Beef meat	2.94%	9.87	0.95
	Poultry meat	1.34%	7.34	2.07
DAIRY	Milk & Cream	0.02%	0.35	0.59
	Cheese	0.97%	6.08	0.19
	Butter	1.96%	18.25	0.61
CEREAL-BASED PRODUCTS	Bread (wheat)	4.2%	2.19	0.29
	Pasta	0.72%	5.85	1.12
SUGAR	Sugar	4.53%	0.43	0.10
OILS	Sunflower oil	4.04%	1.66	0.81
	Olive oil	2.77%	0.93	0.87
VEGETBLES	Potatoes	0.75%	2.55	1.04
FRUIT	Oranges	11.83%	8.76	0.92
	Apples	7.11%	12.4	0.88
COFFEE	Coffee	100% (green coffee)	7.78	1.57
		1.76% (roasted coffee)	0.40	0.49
BEVERAGES	Beer	0.71%	7.31	1.02
	Wine	11.12%	13.09	0.80
	Mineral water	0.18%	0.19	1.29
PRE-PREPARED MEALS	Meat based dishes	-	-	-

For some products, refrigeration is needed both for the transports and the retailing. Therefore, the use of refrigerants (both load and leakage) has been included in the inventory of refrigerated/frozen storage in walk-in cooler/freezer, blast freezing at the processing plant; refrigerated transport and refrigerated/frozen storage in display cabinets at the supermarket. Refrigerant R404A has been considered as baseline scenario, as it is the most commonly used refrigerant in Europe. The LCA data for the production of the refrigerants have been sourced from Bovea et al. (2007). Other refrigerants have been tested with a sensitivity analysis (Annex 2). Table 9 reports the details of refrigerant use (load and leakage) included in the baseline model.

Table 9. Inventory data for refrigerant load and leakage included in the model. Data refer to 1 kg of food

		Blast freezing[a]	**Storage in walk-in coolers[b]**	**Storage in display cabinet[b]**	**Refrigerated transport 500 km[c]**	**Refrigerated transport 250 km[c]**	**Refrigerated transport international[c]**
BEEF							
R404A load	mg	n/a	120[d]	1480 g	2.60	1.30	4.93
R404A leak.	mg	n/a	20[d]	220 g	0.58	0.29	1.11
PORK MEAT							
R404A load	mg	n/a	38.36[d]	1480 g	2.60	1.30	2.34
R404A leak.	mg	n/a	5.75[d]	220 g	0.58	0.29	0.53
POULTRY							
R404A load	mg	n/a	21.92[d]	1480 g	2.60	1.30	10.74
R404A leak.	mg	n/a	3.29[d]	220 g	0.58	0.29	2.42
MILK							
R404A load	mg	n/a	n/a	68.49	2.60	n/a	3.06
R404A leak.	mg	n/a	n/a	10.41	0.58	n/a	0.69
CHEESE							
R404A load	mg	n/a	n/a	1023	2.60	n/a	0.99
R404A leak.	mg	n/a	n/a	180	0.58	n/a	0.22
BUTTER							
R404A load	mg	n/a	n/a	1023	2.60	n/a	3.17
R404A leak.	mg	n/a	n/a	180	0.58	n/a	0.71
APPLES							
R404A load	mg	n/a	770[e]	n/a	n/a	n/a	n/a
R404A leak.	mg	n/a	120[e]	n/a	n/a	n/a	n/a
ORANGES							
R404A load	mg	n/a	380[f]	n/a	n/a	n/a	n/a
R404A leak.	mg	n/a	60[f]	n/a	n/a	n/a	n/a
POTATOES							
R404A load	mg	10	n/a	230	2.60	n/a	n/a
R404A leak	mg	0.53	n/a	30	0.58	n/a	n/a
PRE-PREPARED MEALS							
R404A load	mg	10	n/a	47.76[f]	2.60	n/a	n/a
R404A leak	mg	0.53	n/a	7.16[f]	0.58	n/a	n/a

n/a: not applicable.
[a]Data based on blast freezers manufacturers' data.
[b]Data based on DEFRA (2008).
[c]Data based on DEFRA (2008) and UNEP (2003).
[d]Storage takes place at the processing plant.
[e]Storage takes place at the distribution center.
[f]Sourced from Schimdt Rivera et al., 2014.

4.5 LCI of use phase

The use phase consists of consumer home transport and domestic consumption. The purchased amount of the various products in each mode of travel was estimated to prepare the inventory of this phase. The assumption is that 30 products are bought in a single purchase, including food and non-food products; the impact of transport is therefore allocated between the purchased products considering that each product is one of thirty items purchased (3.33% of the transport burden) (Vanderheyden and Aerts, 2014).

As regards home preparation, the following operations are considered together with the specific energy consumption (Foster et al., 2006):

- Boiling: 2 MJ of natural gas/kg product (coffee, potatoes)
- Frying: 7.5 MJ of natural gas/kg product (potatoes, sunflower oil)
- Baking: 0.75 kWh electricity/ kg product (potatoes)
- Heating of milk: 0.01 kWh/L product
- Cooking of pasta: 0.5 kWh/kg electricity and 2.3 MJ/kg natural gas
- Cooking of pre-prepared meal: 0.3 kWh/meal electricity

For meat products, the same assumptions used in the pilot phase of the Environmental footprint on meat has been applied, as detailed in Table 10.

Table 10. Inventory data for the cooking stage of meat products. Data refer to 1 kg of meat (source: Technical Secretariat for the Red meat pilot (2015). PEF pilot Red Meat; Screening study, V.1.0)

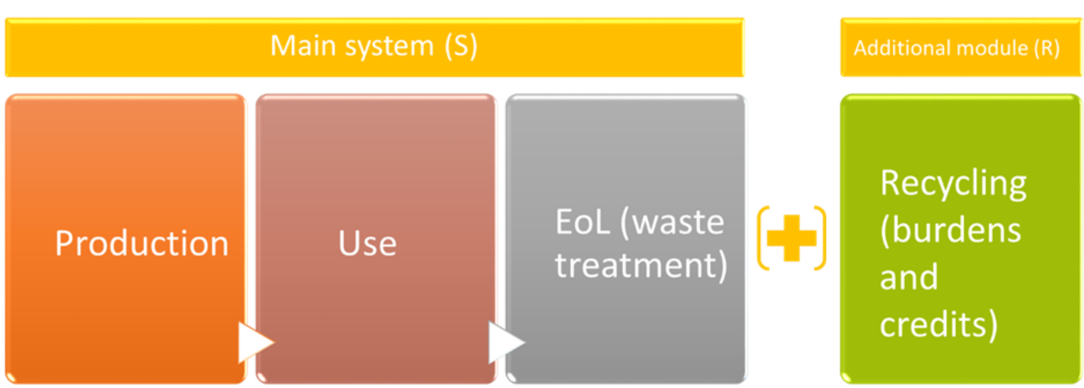
		Beef	**Pork**	**Poultry**
Electricity	kWh	0.14	0.14	0.14
Natural gas	MJ	2.03	2.03	2.03
Sunflower oil	g	4.21	4.21	4.21
Drinking water	g	197	197	197
CO_2 air emissions	g	113.88	113.88	113.88
CH_4 air emissions	g	0.002	0.002	0.002
N_2O air emissions	g	0.0002	0.0002	0.0002
NO_x air emissions	g	0.10	0.10	0.10

Refrigerated storage at home is included in the life cycle of beer (14 days), milk (2 days), butter (4 days), meat (2 days), and frozen potatoes (10 days). The electricity consumption of the domestic refrigerator is assumed equal to 2.3 Wh/L per day and the electricity consumption of the freezer is assumed equal to 4.2 Wh/L per day (Nielsen et al. 2003).

4.6 LCI of End of Life

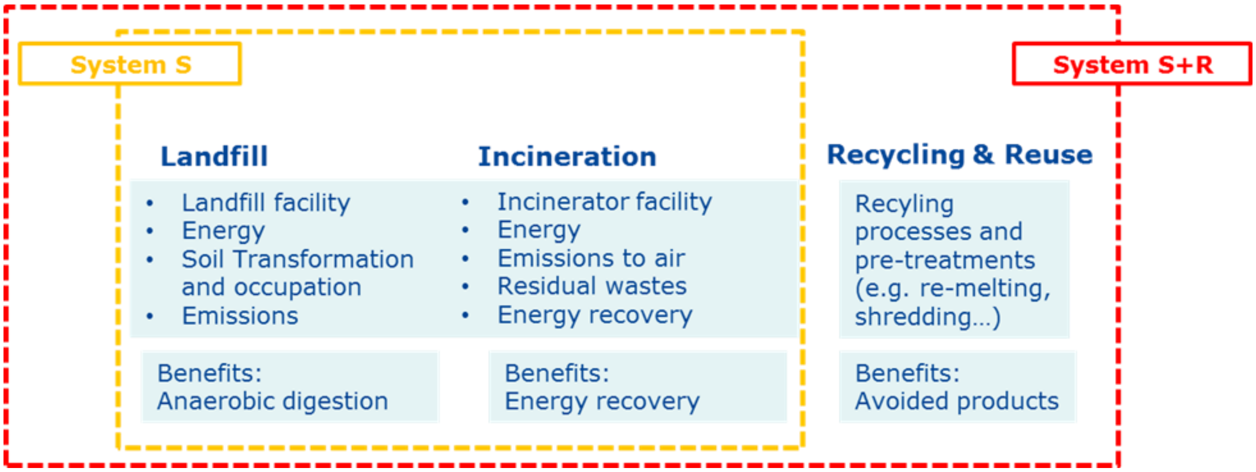
The end of life (EoL) stage in the BoP is modelled in a way that allows to separate the burdens and benefits of recycling from the rest of the system, in order to provide a clearer picture of their contributions to the total impact. Two systems are identified: "S", referring to the system excluding recycling activities, and "R". Figure 3 illustrates the approach followed for the BoPs' models.

Figure 3. Illustration of the approach adopted to model EoL as waste treatment and recycling, as systems "S" and "R"



The sum of the two, named System "S+R" is the one which allows to evaluate in a more comprehensive way those aspects which are of interest also in the context of circular economy: the additional module "R" quantifies burdens and benefits of activities such as recycling and reuse. Details on activities included in each system are provided in Figure 4.

Figure 4. EoL activities included in System S, R and S+R



In the BoP food, the end-of-life phase includes the solid waste treatment of food scraps and unconsumed foods, and the wastewater treatment of the waste excretion of human metabolism. Specifically, as mentioned in the previous section, the model by Muñoz et al. (2010) was used to assess the environmental impact of human excretion. Since the original model assumes the percentages of treatment in UK in 2005, the percentage of secondary and tertiary treatment has been modified accordingly to Eurostat data, by considering the average share of secondary and tertiary treatment of EU-27 in 2010 (weighted average value based on the population of each Member State).

Data on food losses were obtained from the FAO (2011) which highlights the losses that occur along the entire food chain, and makes assessments of their magnitude.

Data on food scraps and unconsumed foods are input into a waste treatment scenario based on Eurostat data (Eurostat, 2014b) concerning the disposal of waste in the EU-27. The statistics about food waste before consumption indicate the following disposal treatments: 8% of food waste is sent to landfill, 5% is incinerated, and 87% is sent for other recovery treatment. As it is assumed that such a recovery treatment is 80% composting and 20% anaerobic digestion for biogas production (Jungbluth et al., 2007), it is estimated that 69.6% of total waste is composted while 17.4% is anaerobically digested. For food waste at the household, Eurostat data report the following statistics: 59.9% to landfill, 33.3% to energy recovery and 9.8% to recovery other than energy recovery.

Also the end of life of packaging materials was modelled following the distinction of the systems S and R, then summed in the system S+R, used for the hotspot analysis. EoL of packaging is included in the packaging stage and it is modelled according to statistics on the share of material going to recycling, incineration or landfilling. Details of the datasets used to model the two systems are provided in Annex 1.

5 Results of baseline's hotspot analysis

The inventory of the BoP food (reference flow: amount of food consumed by an average EU-27 citizen in one year) has been characterised using ILCD v. 1.08 (EC-JRC, 2011). In Table 11 and Table 12, the results for the whole basket and for one citizen are reported. The characterised results have been normalized with ILCD EU-27 normalisation factors (NFs) (Benini et al., 2014) (Table 13) and ILCD Global normalization factors (Sala et al., 2016) (Table 14). Impacts due to long-term emissions have been excluded. Results in Table 11 and Table 12 refer to the systems S, R and S+R, for comparison. Results of the hotspot analysis refer only to the System S+R, including burdens and credits associated to recycling activities.

Table 11. Characterized results for the whole BoP food baseline (impacts of food consumption in EU in 2010).

Impact category	Unit	System S+R	System S	System R
Climate change	kg CO_2 eq	1.03E+12	1.00E+12	2.56E+10
Ozone depletion	kg CFC-11 eq	9.93E+05	9.87E+05	6.08E+03
Human toxicity, non-cancer	CTUh	8.34E+05	8.08E+05	2.63E+04
Human toxicity, cancer	CTUh	1.34E+04	1.26E+04	7.51E+02
Particulate matter	kg $PM_{2.5}$ eq	4.79E+08	4.99E+08	-1.96E+07
Ionizing radiation, effects on human health (HH)	kBq U^{235} eq	2.44E+10	2.15E+10	2.90E+09
Photochemical ozone formation	kg NMVOC eq	1.87E+09	1.72E+09	1.55E+08
Acidification	molc H^+ eq	1.64E+10	1.62E+10	1.76E+08
Terrestrial eutrophication	molc N eq	6.95E+10	6.87E+10	7.85E+08
Freshwater eutrophication	kg P eq	2.59E+08	2.56E+08	3.17E+06
Marine eutrophication	kg N eq	7.21E+09	7.08E+09	1.30E+08
Freshwater ecotoxicity	CTUe	2.90E+12	2.41E+12	4.91E+11
Land use	kg C deficit	9.90E+12	9.89E+12	1.06E+10
Water resource depletion	m^3 water eq	2.21E+10	2.09E+10	1.24E+09
Resource depletion	kg Sb eq	1.93E+07	1.71E+07	2.23E+06

Table 12. Characterized results for the F.U. of the BoP food baseline (impacts of food consumption by an average EU citizen in 2010).

Impact category	Unit	System S+R	System S	System R
Climate change	kg CO_2 eq	2.04E+03	1.99E+03	5.10E+01
Ozone depletion	kg CFC-11 eq	1.98E-03	1.96E-03	1.21E-05
Human toxicity, non-cancer	CTUh	1.66E-03	1.61E-03	5.23E-05
Human toxicity, cancer	CTUh	2.66E-05	2.51E-05	1.49E-06
Particulate matter	kg $PM_{2.5}$ eq	9.54E-01	9.93E-01	-3.91E-02
Ionizing radiation, effects on human health (HH)	kBq U^{235} eq	4.86E+01	4.29E+01	5.77E+00
Photochemical ozone formation	kg NMVOC eq	3.73E+00	3.42E+00	3.09E-01
Acidification	molc H^+ eq	3.26E+01	3.23E+01	3.50E-01
Terrestrial eutrophication	molc N eq	1.38E+02	1.37E+02	1.56E+00
Freshwater eutrophication	kg P eq	5.15E-01	5.08E-01	6.31E-03
Marine eutrophication	kg N eq	1.43E+01	1.41E+01	2.59E-01
Freshwater ecotoxicity	CTUe	5.78E+03	4.80E+03	9.78E+02
Land use	kg C deficit	1.97E+04	1.97E+04	2.11E+01
Water resource depletion	m^3 water eq	4.40E+01	4.15E+01	2.46E+00
Resource depletion	kg Sb eq	3.85E-02	3.41E-02	4.43E-03

In general, the results of the contribution of system R does not affect significantly the results of system S+R. This is probably due to the high impact of the agricultural and production stages of the food chain, which largely offset the small benefits coming from the recycling of packaging and composting of food at the EoL.

Table 13. Normalized results, ILCD EU-27, BoP food baseline

Impact category	**System S+R**		
	Value (tot. BoP)	**Value (per person)**	**%**
Climate change	1.13E+08	2.24E-01	2.5%
Ozone depletion	4.60E+07	9.15E-02	1.0%
Human toxicity, non-cancer effects	1.57E+09	3.12E+00	34.3%
Human toxicity, cancer effects	3.62E+08	7.20E-01	7.9%
Particulate matter	1.26E+08	2.51E-01	2.8%
Ionizing radiation HH	2.16E+07	4.30E-02	0.5%
Photochemical ozone formation	5.90E+07	1.17E-01	1.3%
Acidification	3.46E+08	6.88E-01	7.6%
Terrestrial eutrophication	3.95E+08	7.86E-01	8.7%
Freshwater eutrophication	1.75E+08	3.48E-01	3.8%
Marine eutrophication	4.27E+08	8.49E-01	9.4%
Freshwater ecotoxicity	3.31E+08	6.59E-01	7.3%
Land use	1.33E+08	2.64E-01	2.9%
Water resource depletion	2.72E+08	5.41E-01	6.0%
Resource depletion	1.91E+08	3.81E-01	4.2%
TOTAL	*4.56E+09*	*2.24E-01*	*100%*

Table 14. Normalized results, ILCD Global, BoP food baseline

Impact category	**System S+R**		
	Value (tot. BoP)	**Value (per person)**	**%**
Climate change	1.95E-02	2.67E-01	3.5%
Ozone depletion	6.16E-03	8.46E-02	1.1%
Human toxicity, non-cancer effects	2.55E-01	3.50E+00	45.6%
Human toxicity, cancer effects	5.03E-02	6.90E-01	9.0%
Particulate matter	5.44E-03	7.47E-02	1.0%
Ionizing radiation HH	1.28E-02	1.75E-01	2.3%
Photochemical ozone formation	6.68E-03	9.16E-02	1.2%
Acidification	4.28E-02	5.87E-01	7.6%
Terrestrial eutrophication	5.70E-02	7.83E-01	10.2%
Freshwater eutrophication	1.47E-02	2.02E-01	2.6%
Marine eutrophication	3.69E-02	5.06E-01	6.6%
Freshwater ecotoxicity	3.56E-02	4.89E-01	6.4%
Land use	1.12E-02	1.54E-01	2.0%
Water resource depletion	2.88E-04	3.95E-03	0.1%
Resource depletion	5.23E-03	7.18E-02	0.9%
TOTAL	*5.59E-01*	*7.68E+00*	*100%*

The most relevant impact category is human toxicity non-cancer effects both in the case of normalization with EU-27 references and in the case of normalization with global references. When applying the EU-27 set, human toxicity non-cancer contributes to 34.3% of the impact, whereas its contribution increases to 45.6% when applying the global normalization set. The second most relevant impact category is marine eutrophication (9.4%) in the case of EU-27 NFs. If the global reference is used, the second most relevant impact category is terrestrial eutrophication, which contributes to 10.2% of the overall impact of the BoP (8.7% in the case of EU-27 NFs). It is worthy to note that the contribution of toxicity-related impact categories should be further checked when improved impact assessment models for toxicity-related impacts will be available. In fact, there are some known issues related to the robustness of the impact assessment models for toxicity-related impacts. According to Zampori et al. (2017), only 50% of the elementary flows contributing to toxicity are characterised by the impact assessment models currently available. EC-JRC is looking at the improvement of the issues and that limitations of current model and the way forward are discussed in Saouter et al. (2017a and 2017b).

As a sensitivity analysis, the BoP food has been analysed with a revised version of the ILCD method (called here "LCIA-LCIND2"), where some impact categories were updated with a selection of recent impact assessment models and factors. The updated list of impact assessment models used in the LCIA-LCIND2 method is presented in Table 15. Differences with ILCD are highlighted in green. Results of characterization and normalization with the LCIA-LCIND2 method are presented in Table 16 for the whole BoP food baseline and in Table 17 for the F.U. of the BoP food baseline (impacts of food consumption by an average EU citizen in 2010).

Table 15. Impact categories, models and units of LCIA-LCIND2 impact assessment method. Differences with ILCD (EC-JRC, 2011) are highlighted in green

Impact category	Reference model	Unit
Climate change	IPCC, 2013	kg CO_2 eq
Ozone depletion	World Meteorological Organisation (WMO), 1999	kg CFC-11 eq
Human toxicity, non-cancer	USEtox (Rosenbaum et al., 2008)	CTUh
Human toxicity, cancer	USEtox (Rosenbaum et al., 2008)	CTUh
Particulate matter	Fantke et al., 2016	Deaths
Ionising radiation, human health	Frischknecht et al., 2000	kBq U^{235} eq
Photochemical ozone formation, human health	Van Zelm et al., 2008, as applied in ReCiPe, 2008	kg NMVOC eq
Acidification	Posch et al., 2008	molc H^+ eq
Eutrophication, terrestrial	Posch et al., 2008	molc N eq
Eutrophication, freshwater	Struijs et al., 2009[3]	kg P eq
Eutrophication, marine	Struijs et al., 2009	kg N eq
Ecotoxicity, freshwater	USEtox (Rosenbaum et al., 2008)	CTUe
Land use	Bos et al., 2016 (based on)	Pt
Water use	AWARE 100 (based on; UNEP, 2016)	m^3 water eq
Resource use, fossils	ADP fossils (van Oers et al., 2002)	MJ
Resource use, minerals and metals	ADP ultimate reserve (van Oers et al., 2002)	kg Sb eq

Also in this case, after normalization the contribution of human toxicity, non-cancer effect is the most relevant one (38.7%). However, it has to be underlined that the impact assessment models for toxicity in the LCIA-LCIND2 are the same as in the original version of ILCD. The contribution of water use and fossil resources is slightly higher than in ILCD.

[3] CF for emissions of P to soil changed from 1 to 0.05 kg P_{eq}/kg

Table 16. Characterized and normalized results for the whole BoP food (impacts of food consumption in EU in 2010) with LCIA-LCIND2 method, applied to the system S+R

Impact category	**Unit**	**Characterization**	**Normalization (values)**	**Normalization (%)**
Climate change	kg CO_2 eq	1.15E+12	1.98E-02	3.0%
Ozone depletion	kg CFC-11 eq	1.45E+06	9.02E-03	1.4%
Human toxicity, non-cancer	CTUh	8.34E+05	2.55E-01	38.7%
Human toxicity, cancer	CTUh	1.34E+04	5.03E-02	7.6%
Particulate matter	Death	1.19E+05	2.91E-02	4.4%
Ionising radiation, human health	kBq U^{235} eq	2.44E+10	1.28E-02	1.9%
Photochemical ozone formation, human health	kg NMVOC eq	1.89E+09	6.75E-03	1.0%
Acidification	molc H^+ eq	1.64E+10	4.28E-02	6.5%
Eutrophication, terrestrial	molc N eq	6.95E+10	5.70E-02	8.7%
Eutrophication, freshwater	kg P eq	2.50E+08	4.94E-02	7.5%
Eutrophication, marine	kg N eq	7.21E+09	3.69E-02	5.6%
Ecotoxicity, freshwater	CTUe	2.90E+12	3.56E-02	5.4%
Land use	Pt	1.11E+14	1.15E-02	1.8%
Water use	m^3 water eq	1.94E+12	2.45E-02	3.7%
Resource use, fossils	MJ	6.65E+12	1.48E-02	2.3%
Resource use, minerals and metals	kg Sb eq	1.02E+06	2.55E-03	0.4%

Table 17. Characterized and normalized results for the F.U. of the BoP food baseline (impacts of food consumption by an average EU citizen in 2010) with LCIA-LCIND2 method, applied to the system S+R

Impact category	**Unit**	**Characterization**	**Normalization (values)**	**Normalization (%)**
Climate change	kg CO_2 eq	2.29E+03	2.72E-01	3.0%
Ozone depletion	kg CFC-11 eq	2.89E-03	1.24E-01	1.4%
Human toxicity, non-cancer	CTUh	1.66E-03	3.50E+00	38.7%
Human toxicity, cancer	CTUh	2.66E-05	6.90E-01	7.6%
Particulate matter	Death	2.38E-04	3.99E-01	4.4%
Ionising radiation, human health	kBq U^{235} eq	4.86E+01	1.75E-01	1.9%
Photochemical ozone formation, human health	kg NMVOC eq	3.76E+00	9.26E-02	1.0%
Acidification	molc H^+ eq	3.26E+01	5.87E-01	6.5%
Eutrophication, terrestrial	molc N eq	1.38E+02	7.83E-01	8.7%
Eutrophication, freshwater	kg P eq	4.97E-01	6.78E-01	7.5%
Eutrophication, marine	kg N eq	1.43E+01	5.06E-01	5.6%
Ecotoxicity, freshwater	CTUe	5.78E+03	4.89E-01	5.4%
Land use	Pt	2.21E+05	1.58E-01	1.8%
Water use	m^3 water eq	3.85E+03	3.36E-01	3.7%
Resource use, fossils	MJ	1.32E+04	2.04E-01	2.3%
Resource use, minerals and metals	kg Sb eq	2.02E-03	3.49E-02	0.4%

5.1 Contribution by life cycle stages

Details on product group contribution and relevance of impact categories are provided in Table 18. The contribution of life cycle stages is summarized also in Figure 5. Agriculture is the life cycle stage with the larger contribution to most of the impact categories.

Table 18. Contribution of different life cycle stages to the impact categories (based on the characterized inventory results before normalization and weighting). The life cycle stages in orange are the ones identified as "most relevant" for the impact category, which are the ones contributing to more than 80%.

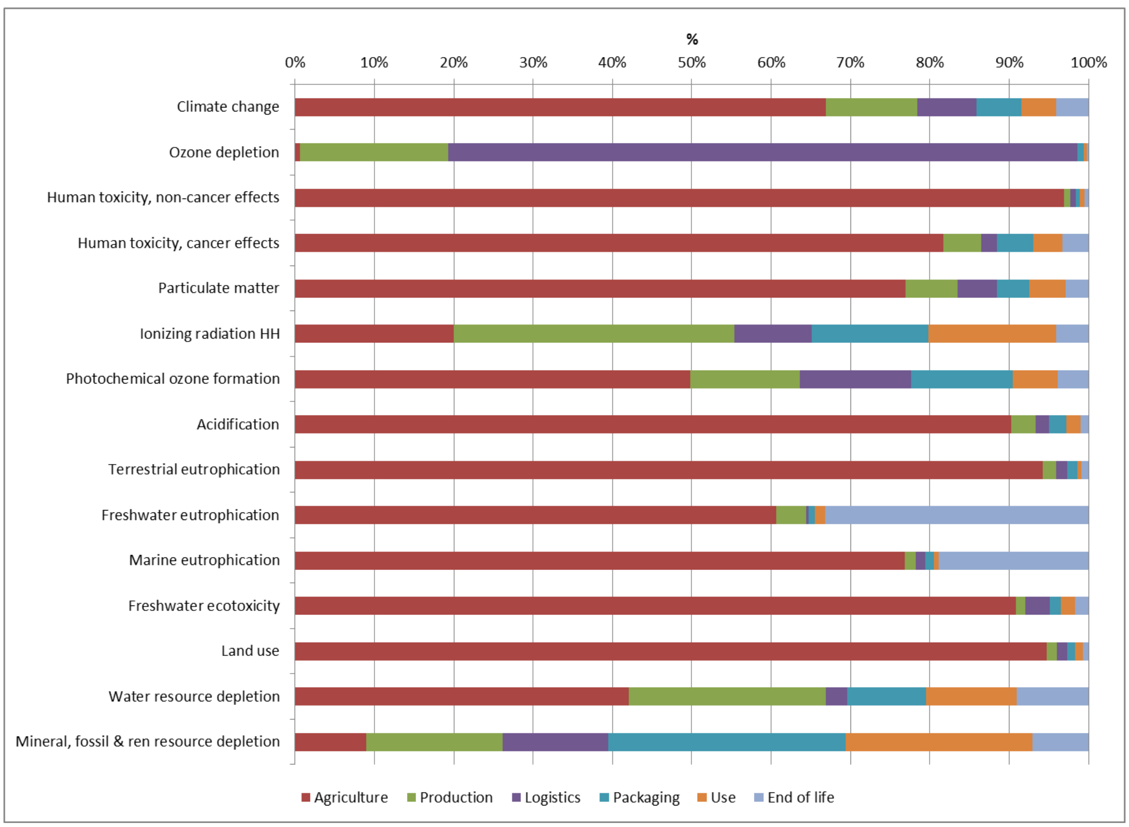
Climate change		**Human tox, non-cancer effects**		**Particulate matter**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Agriculture	67.1%	Agriculture	97.0%	Agriculture	77.1%
Production	11.2%	Production	0.8%	Production	6.3%
Logistics	7.5%	Logistics	0.6%	Logistics	5.0%
Packaging	5.7%	Use	0.6%	Use	4.6%
Use	4.4%	Packaging	0.5%	Packaging	4.1%
End of life	4.1%	End of life	0.5%	End of life	2.9%
Ozone depletion		**Human toxicity, cancer effects**		**Ionizing radiation HH**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Logistics	79.2%	Agriculture	81.8%	Production	34.3%
Production	18.7%	Production	4.6%	Agriculture	20.3%
Packaging	0.8%	Packaging	4.5%	Use	16.4%
Agriculture	0.6%	Use	3.7%	Packaging	14.9%
Use	0.5%	End of life	3.3%	Logistics	9.9%
End of life	0.2%	Logistics	2.1%	End of life	4.2%
Photochemical ozone formation		**Acidification**		**Terrestrial eutrophication**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Agriculture	50.0%	Agriculture	90.4%	Agriculture	94.3%
Production	13.6%	Production	3.0%	Production	1.6%
Logistics	14.0%	Packaging	2.2%	Logistics	1.4%
Packaging	12.8%	Logistics	1.7%	Packaging	1.2%
Use	5.7%	Use	1.7%	End of life	0.9%
End of life	3.9%	End of life	1.0%	Use	0.6%
Freshwater eutrophication		**Marine eutrophication**		**Freshwater ecotoxicity**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Agriculture	60.7%	Agriculture	76.9%	Agriculture	90.9%
End of life	33.2%	End of life	18.9%	Logistics	3.1%
Production	3.7%	Production	1.3%	Use	1.8%
Use	1.3%	Logistics	1.2%	End of life	1.7%
Packaging	0.9%	Packaging	1.1%	Packaging	1.4%
Logistics	0.3%	Use	0.5%	Production	1.2%
Land use		**Water resource depletion**		**Resource depletion**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Agriculture	94.7%	Agriculture	42.7%	Packaging	30.1%
Production	1.3%	Production	23.7%	Use	23.8%
Logistics	1.3%	Packaging	11.6%	Production	16.6%
Packaging	1.0%	Use	10.1%	Logistics	13.4%
Use	1.0%	End of life	9.2%	Agriculture	9.0%
End of life	0.7%	Logistics	2.8%	End of life	7.1%

The majority of the contribution to impact is due to three processes related to animal feeding: "grass, at dairy farm", "grass, at beef farm", "Maize silage, at dairy farm" (source: Agrifootprint database - Blonk Consultants, 2014). These processes are the major contributors to human toxicity cancer effects and non-cancer effects, terrestrial eutrophication and marine eutrophication.

As for the elementary flows, human toxicity impacts (both cancer and non-cancer) are dominated by the emission of metals to water and to soil, especially chromium VI, chromium, zinc, copper and lead. These flows derive again from the agricultural process related to animal feeding, and more specifically from manure. Despite delayed emission may represent an issue as highlighted by several studies (e.g. Pettersen and Hertwich 2008, Hauschild et al.2008), in this context we accounted only for short and mid-term emission (maximum 100 years). If we include long-term emissions in LCIA, the impact to HT-cancer is about twice as before (from 2.66e-05 CTUh/person*year^{-1} to 5.1e-05 CTUh/person*year^{-1}). This does not apply to HT-non cancer.

Elementary flows of metals (especially copper and zinc, both to water and to soil) coming from the same animal feed related activities contribute also to freshwater ecotoxicity impacts, jointly with the use of pesticides (e.g. chlorpyrifos). Again, if long-term emissions of metals are included the impact is more than three times higher (from 5.78e03 CTUe/person*year^{-1} to 1.84e04 CTUe/person*year^{-1}). Other relevant contributions from agricultural processes derive from ammonia released by animal husbandry activities (e.g. for acidification potential) and manure management related to grass grazing for animal feeding (contributing to terrestrial eutrophication).

Figure 5. Contribution of life cycle stages to impact at the characterization stage



Industrial processing present overall a smaller share of the overall impact. Hotspots are related to potential impacts on ODP and IR, mainly due to emission of CFC-114, CFC-11, Halon 1301 Carbon-14 in air, Radon-222 in air and Cesium-137 in water which occur during the electricity production. Also water and mineral and fossil resource depletion are quite relevant, suggesting to look for improvement in terms of resource efficiency and waste reduction and emission reduction.

Packaging of products in the BoP contribute mainly to resources depletion (water and other resources). Relevant processes refer to the production of the raw materials used, e.g. aluminium, glass, PET and paper (even fi mitigated by the credits from recycling at the end of life) and also to energy use in some packaging production processes (e.g. glass production, blow moulding of plastic, etc.).

Logistics contributes largely to ozone depletion potential, due to the emissions of refrigerants used in refrigerated transport and storage. Logistics and use phase contribute to the depletion of mineral and fossil resources (especially fuels) and to water resource depletion. Finally, the only impact categories to which EoL shows significant contribution are freshwater and marine eutrophication, due to the human metabolism of food, i.e. the emissions of nutrients in sewage from human excretion (and related treatment).

5.2 Most relevant elementary flows

Table 19 reports the most relevant elementary flows for each impact category. Within each impact category, for the flow that contributes the most, the main process from which it originates is specified (marked with *). The inventory networks of the most important flow(s) are reported in Annex 3.

Table 19. Contribution of elementary flows to each impact category considered in the ILCD method

Climate change		**Human tox, non-cancer effects**		**Particulate matter**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Carbon dioxide, fossil*	28.2%	Zinc to soil	91.8%	Ammonia	65.2%
Methane, biogenic	22.8%	Mercury to soil	2.3%	Partic., < 2.5 um	18.0%
CO_2, land transformation	15.3%	Lead to soil	1.6%	Sulfur dioxide	11.2%
Dinitrogen monoxide	15.3%	Zinc to air	1.2%	Partic., < 10 um	3.1%
Carbon dioxide	10.9%				
*Electricity, low voltage, DE		*Grass, at beef farm		*Beef cattle for slaughter	
Ozone depletion		**Human toxicity, cancer effects**		**Ionizing radiation HH**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
CFC-113*	92.9%	Chromium to water*	55.3%	Carbon-14 to air	88.1%
Halon 1301	1.9%	Chromium to soil	21.3%	Cesium-137 to water	4.9%
HCFC-124	1.9%	Chromium VI to water	13.2%	Radon-222 to air	4.1%
		Chromium to air	3.9%		
		Chromium VI to soil	3.0%		
*Refrigerant R404A		* Grass, at beef farm		*Electricity, low voltage, FR	
Photochemical ozone formation		**Acidification**		**Terrestrial eutrophication**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Nitrogen oxides*	69.7%	Ammonia*	86.3%	Ammonia to air*	91.0%
Nitrogen dioxide	8.1%	Sulphur dioxide	6.9%	Nitrogen oxides to air	8.0%
NMVOC, unsp. origin	8.0%	Nitrogen oxides	5.9%		
Methane, biogenic	5.7%				
Sulphur dioxide	3.8%				
* Transport, freight, lorry		*Beef cattle for slaughter		*Beef cattle for slaughter	

Freshwater eutrophication		**Marine eutrophication**		**Resource depletion**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Fertiliser, applied (P component), to soil*	37.3%	Nitrate to water*	67.6%	Indium*	69.3%
Phosphorus, total to water	32.1%	Nitrogen tot, to water	18.0%	Cadmium	8.3%
Manure, applied (P component), to soil	19.9%	Nitrogen oxides to air	7.1%	Nickel	3.8%
Phosphate to water	6.5%	Ammonia to air	6.0%	Tantalum	2.7%
* Pig feed		*Wastewater treatment		* Zinc (in aluminium packaging)	
Land occupation		**Water resource depletion**		**Freshwater ecotoxicity**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Occupation, arable*	98.4%	Water, unspecified natural origin, IT*	11.6%	Chlorpyrifos to soil*	21.2%
*Grass, grazed in pasture		Water, cooling, unspecified natural origin, DE	11.4%	Copper to soil	19.6%
Land transformation		Water, unspecified natural origin, PK	11.3%	Zinc to soil	13.7%
From forest to arable*	65.2%	Water, cooling, unspecified natural origin, PL	8.2%	Folpet to soil	11.9%
From grassland to arable	6.4%	Water, cooling, unspecified natural origin, FR	4.9%	Zinc to water	3.8%
From forest to mineral extraction site	4.7%	Water, unspecified natural origin, DE	4.5%	Chlorothalonil to soil	3.1%
		Water, cooling, unspecified natural origin, SA	4.4%	Antimony to air	2.6%
		Water, cooling, unspecified natural origin, ES	4.2%	Chromium to water	2.5%
		Water, unspecified natural origin, US	3.3%	Isoproturon to soil	2.1%
		Water, unspecified natural origin, FR	3.2%	Cyfluthrin to soil	2.0%
		Water, cooling, unspecified natural origin, UA	3.1%	Cypermethrin to soil	1.7%
				Prochloraz to soil	1.4%
				Alachlor to soil	1.1%
*Soybean production		* Electricity, low voltage, DE		*Coffee cherries, Brazil	

As already mentioned before, the cultivation of grass as animal feed and the breeding of cattle are the most contributing processes across the impact categories considered, together with electricity production (contributing to climate change, ionising radiation and water depletion).

The inclusion of cooling as a contributor to water depletion is debated and represents one of the main differences between the model recommended in the ILCD method (Frischknecht, 2009) and the model in the LCIA-LCIND2 method (Boulay et al., 2016). If the impact of cooling is excluded (not consistently with the original method) when assessing the BoP with ILCD, the contribution of the elementary flow "Water, unspecified natural origin, IT" is 24.6%.

Moreover, it has to be specified that there is a known issue about the impact category Resource depletion. The highly relevant contribution of the elementary flow for Indium is partially due to the allocation method chosen in the ecoinvent database (economic allocation) for the dataset of zinc-lead-indium production. In addition to this, it has to be noted that the ILCD method includes the assessment of minerals and metals and of energy carriers under the same indicator. A sensitivity analysis on the impact of resource depletion has been run, using the indicators included in LCIA-LCIND2 method. These indicators assess the impact of minerals and metals and of energy carriers separately. The contribution by elementary flows for the indicators that are different between the ILCD method and the LCIA-LCIND2 method (namely resources, water, land use and particulate matter) is reported in Table 20.

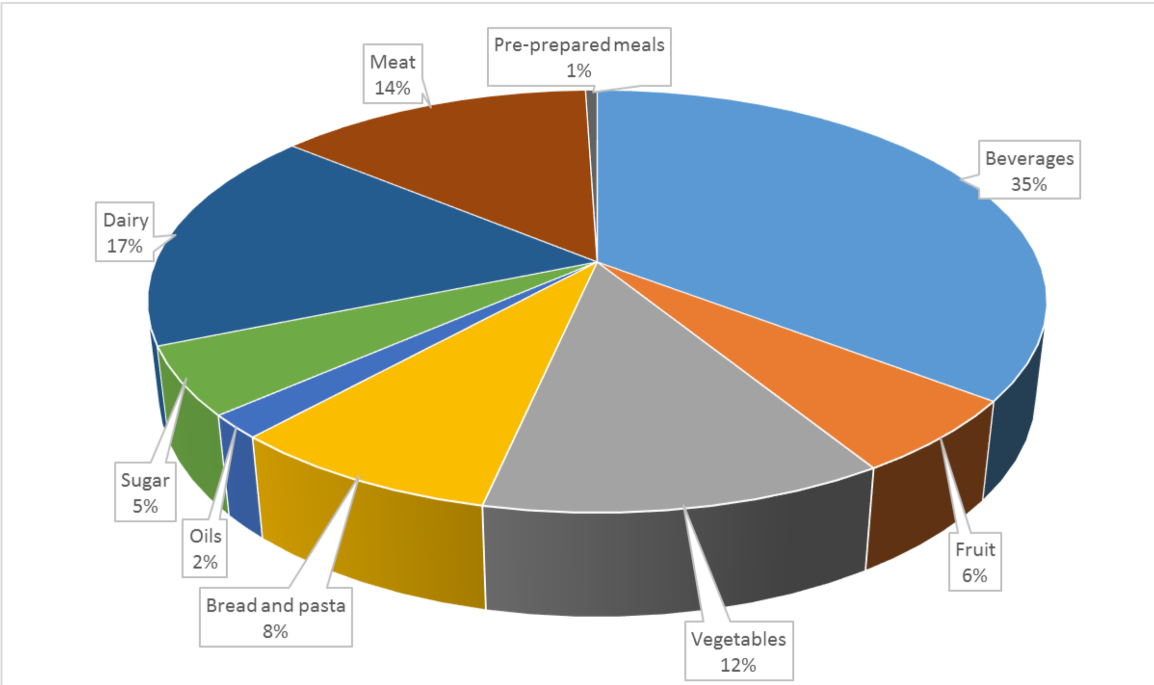
Table 20. Most relevant elementary flows for resource depletion, water scarcity, land use and particulate matter, when applying LCIA-LCIND2 method

Resource use, minerals and metals		**Resource use, fossil**		**Particulate matter**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Cadmium*	22.4%	Oil, crude*	34.8%	Ammonia*	82.3%
Lead	16.3%	Natural gas	32.0%	Particulates, < 2.5 um	10.0%
Gold	14.0%	Coal, hard	13.9%	Sulfur dioxide	3.1%
Copper	9.2%	Uranium	13.0%	Particulates, < 10 um	3.0%
Iodine	8.7%	Coal, brown	5.8%	Nitrogen oxides	1.4%
Bromine	7.6%	Peat	0.2%		
Silver	7.2%				
* Zinc-lead mining		*Transports		*Beef cattle for slaughter	
Water use (country)		**Land occupation**		**Land transformation**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Water balance in unspecified country*	56.2%	Occupation, arable*	95.1%	From forest to arable*	78.0%
Water balance in IT	19.4%	Occupation, permanent crop, vine	2.4%	From grassland to arable	6.2%
Water balance in US	8.9%				
Water balance in RoW	4.8%				
Water balance in PK	2.3%				
*Tap water		*Grass, grazed in pasture		*Soybean, at farm	

5.3 Contribution by product groups

The share (in weight) of each product group is reported in Figure 6. The figures helps better understanding the relative influence of the share in mass to the final characterised results.

Figure 6. Share of product groups (weight) in the F.U. of the BoP food

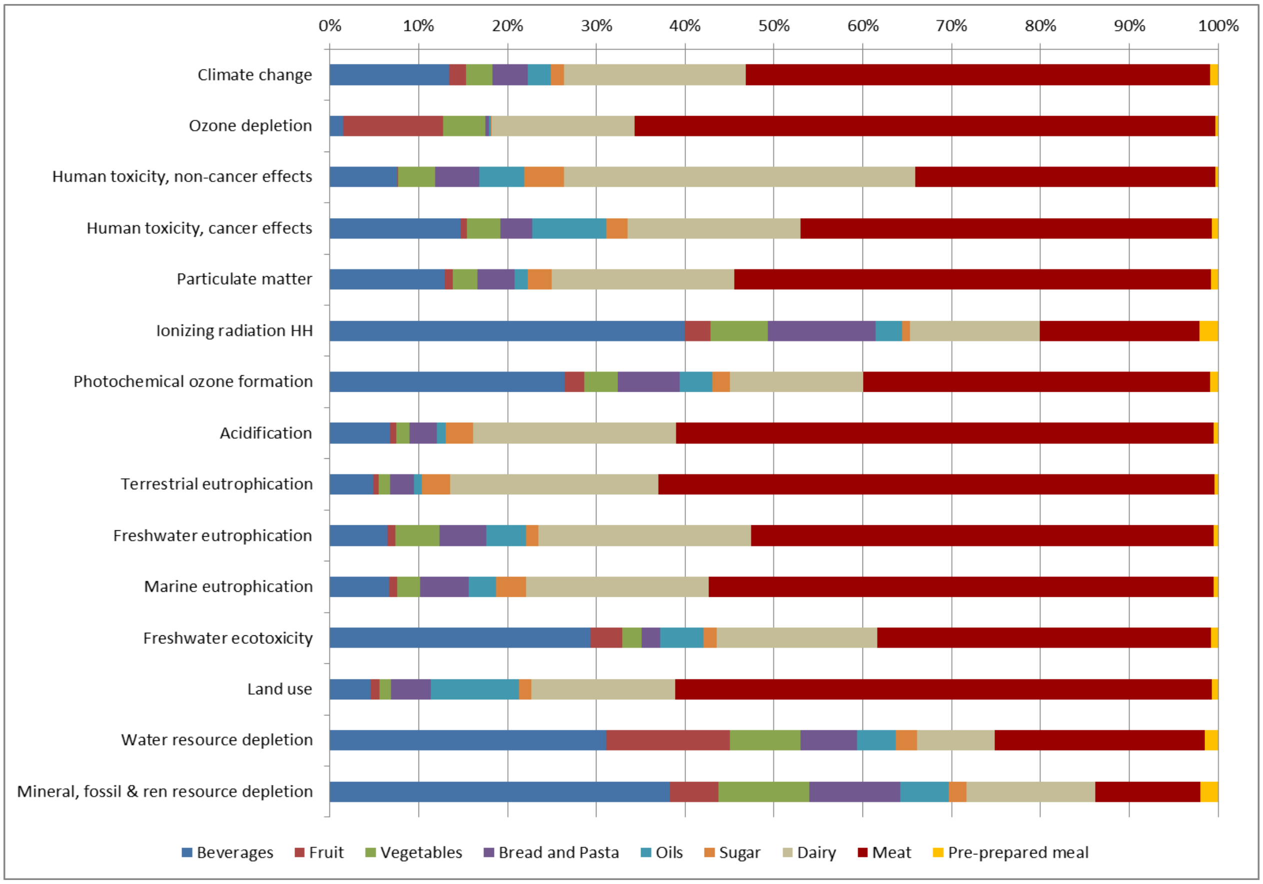


The product groups that emerge as hotspots in most of the impact categories, even if with different levels of contribution, are meat, dairy products and beverages (Figure 7).

The main impact for the life cycle of pork and meat beef products comes from the emissions due to production of feed (mainly compound feed, but also grass silage and grass in pasture). Direct emissions from animal husbandry (methane, dinitrogen oxide, ammonia, etc.) contribute as well. Dairy products, as co-product of meat, share the same contribution. In both product groups, the processing phase is less relevant than the agricultural one.

Beverages emerge as hotspot in several impact categories. The impact on water resource depletion is due to the water content in the products. Impacts on ionizing radiation and resource depletion, coming mainly from beer and coffee products, are related to the electricity used for the processing of the product and the production of packaging materials (especially glass), even if partially compensated by the credits of recycling at the end of life of packaging.

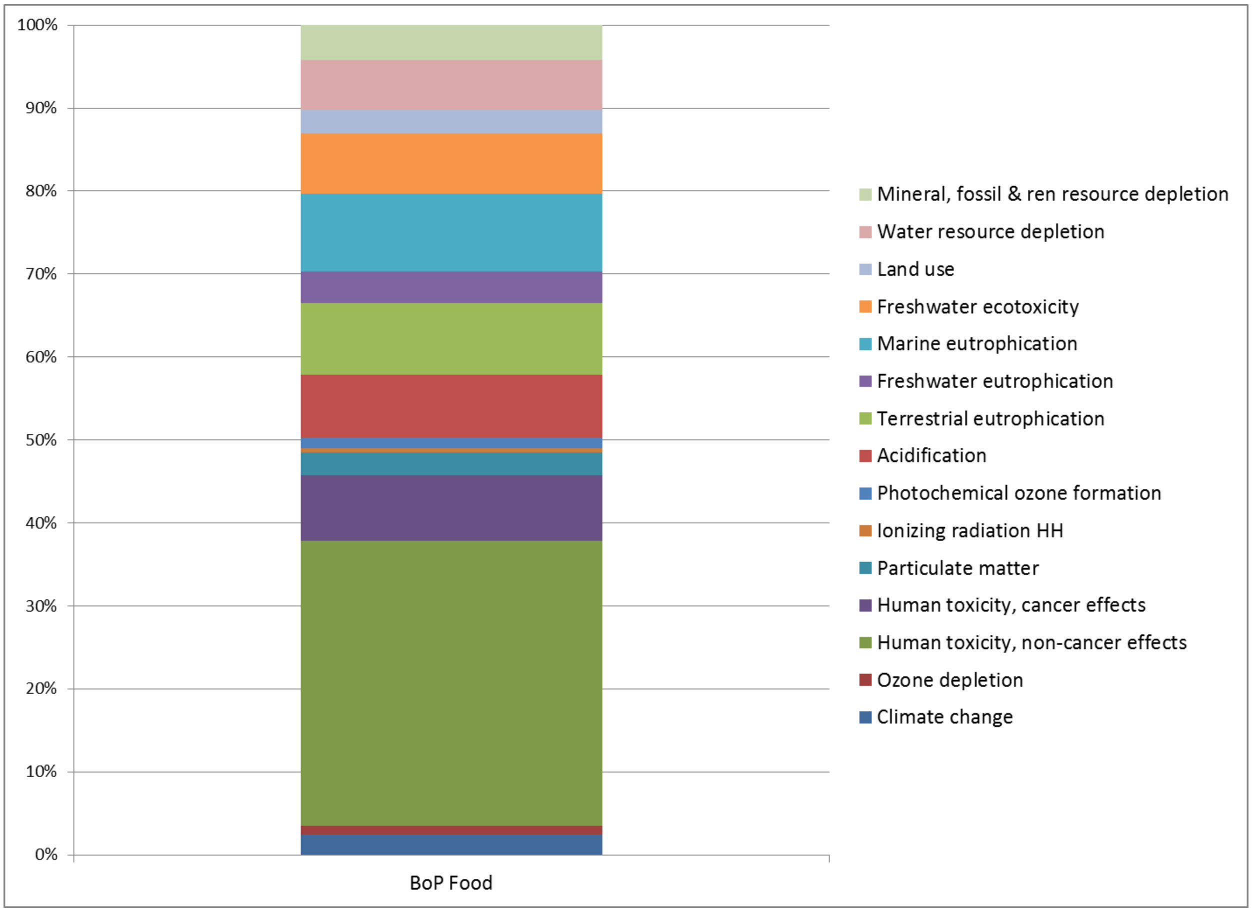
Figure 7. Product group contribution at the characterization stage



5.4 Relevance of impact categories

If results of the BoP per citizen are normalised referring to the average impact per person in EU-27 (Benini et al., 2014) and applying equal weighting, the impact category Human toxicity-non cancer effects has the highest relevance (34%) compared to the others (Figure 8). Human toxicity-non cancer is the most relevant impact category for most of the product groups (e.g. beer, wine, potatoes, bread, meat and dairy). In the case of meat and dairy products, the largest contribution to this impact category comes from the emissions of metals to soil during the cultivation of feed products for animal husbandry. As mentioned before, this contribution should be further checked when improved impact assessment models for toxicity-related impacts will be available, because the possible overestimation of the impacts due to metals is a known problem.

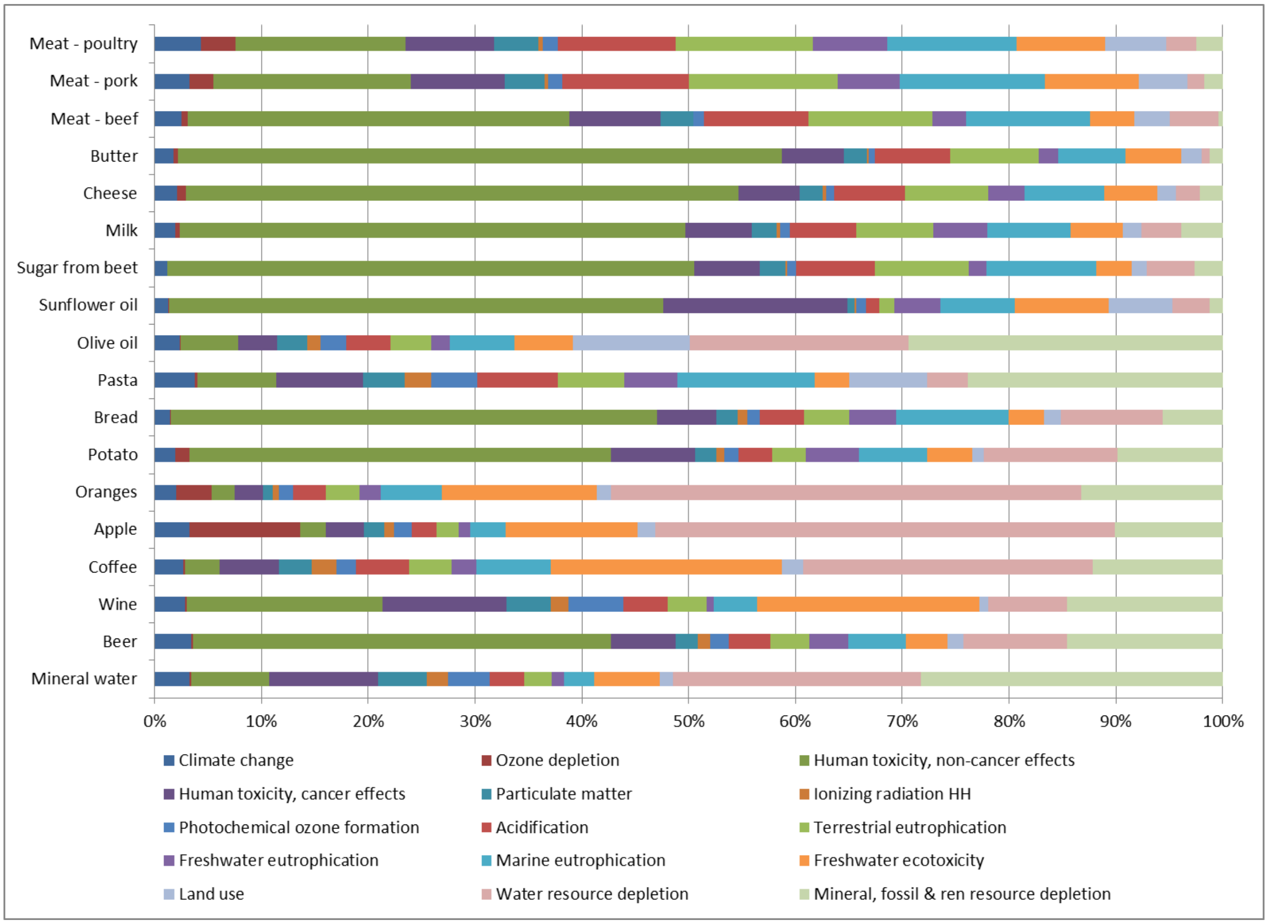
Figure 8. Results of normalization EU-27 and equal weighting of impact categories for the BoP food



The second most relevant impact is related to terrestrial and marine eutrophication. Each of the two contributes to 9% of the overall impact of the BoP. Over 70% of this contribution comes from meat and dairy products, and especially beef and pork meat contribute to 50% of the eutrophication potential (both terrestrial and marine) of the whole basket.

As shown in Figure 9, water depletion (that contributes to 6% of the total impact of the basket) is the most relevant one for some products: mineral water (23%), coffee (27%), apples (43%) and oranges (44%).

Figure 9. Relevance of impact categories (according to normalization EU-27 and equal weighting) in the product groups of the BoP food



6 Main hotspots identified

Several sensitivity analyses on the impact assessment method used for characterization, the normalization and weighting sets have been carried out, to test the robustness of the hotspot analysis results. Details are reported in Castellani et al. (2017). All the analyses carried out on the identification of hotspots for the food sector, including the hotspots analysis presented before, the sensitivity analyses presented in Castellani et al. (2017) and a review on hotspots identified in sectorial study available in literature (summarized in section 2), helped to identify the following hotspots for the food production and consumption chain:

- In terms of impact categories: Human toxicity, ecotoxicity, eutrophication, and acidification. Toxicity-related impacts are generated mainly by the emission of metals from agricultural activities. Since the overestimation of metals at the impact assessment is a known problem, this hotspot should be further checked when more robust impact assessment methods for toxicity would be available. Eutrophication is mainly generated by the effluents of wastewater treatment, after human consumption of the food.
- In terms of life cycle stages: agriculture, which contributes to over 85% of impacts in 11 impact categories out of the 15 considered in ILCD (Notarnicola et al., 2017), followed by end of life, which generates eutrophication impacts due to the human metabolism of food (i.e. related wastewater treatment), and industrial processing, especially for what concerns water depletion.
- In terms of products: food products related to animal husbandry and related feeding, such as beef, pork and poultry meat and dairy products. Another hotspot, even if only for some impact categories, is beer (as representative for beverages product group), mainly because of the energy intensive process for producing packaging glass.
- A hotspot that is cross-cutting among products, life cycle stages and impact categories is the food loss and waste happening throughout the whole food supply chain, from agriculture to food consumption of households (WRAP, 2015; EEA, 2016, Beretta et al., 2017).
- Other environmental impacts associated to food production, but not fully captured in LCA, are the alteration of biogeochemical cycles of N and P – e.g. used as fertilizers in agriculture –, and impacts due to land use on biodiversity. This is one of the issues that limit the possibility to use LCA to compare organic and non-organic food products, as discussed more in section 7.1.

7 Ecoinnovations relevant for the BoP Food

This section illustrates the main findings of a literature review on eco-innovation for the area of consumption covered by the BoP. It is summarized as a list of areas of improvement, some of them specifically related to one BoP, others cross-cutting among BoPs, and the related information needed to drive the further selection. These areas of improvements and related eco-innovation constitute a long list of possible scenarios that may be tested on the BoP model.

Based on the areas of concern identified by the hotspot analysis, possible improvements and eco-innovation needed in the food supply chain to make these strategies operational were identified. The reviewed documents about eco-innovation in the food sector are scientific papers, technical reports and Best Available Technologies Reference documents (BREF).

With reference to the hotspots identified by the LCA analysis and the scientific literature on food production chains, the main areas of eco-innovation are the ones listed in Table 21.

To address the problems related to animal-based products, the proposed solutions are to reduce the amount of feed needed per animal (e.g. improving efficiency of feed by adding synthetic amino acids) and the recovery of food waste as source of animal feed. Both solutions are aimed at reducing the impacts from feed production. Better manure management is another way to reduce emissions from manure storage and processing, e.g. by storing it on covered floors to reduce leakages or to recover it via anaerobic fermentation, in order to produce biogas. Finally, also in animal breeding practices (especially for pigs and poultry) there could be ways to reduce environmental impacts (e.g. by energy and water saving measures applied to animal housings). The most relevant one, with reference to hotspot of human toxicity related to metal emissions, is the possibility to reduce the amount of metals (especially Cu and Zn) supplied to pigs through the feed.

In agricultural activities, the hotspot of nutrients losses can be addressed both at the input stage and at the output stage. There are several agronomic measures that allow to reduce nutrients input to crops, including the avoidance of oversupply, whereas several technical solutions allow to recover nutrients at the end of life, e.g. from human urines or food waste at the industrial or household stage. Organic agricultural practices are another proposed option to reduce impacts from agricultural activities.

The most relevant solutions for the processing stage are related to the implementation of energy and water saving measures, because these two issues are the ones with the highest improvement potential, as identified also by several BAT documents (EC, 2005; EC, 2006; EC-JRC, 2015). The consumption of ready-made products by European citizens is increasing over time. The preparation of ready-made meals and ready-made products (such as fresh-cut vegetables) is an activity that produces additional impacts if compared to less-processed food. Therefore, a reduced consumption of ready-made products by citizen can be an additional improvement option. However, However there are impacts also associated with meals preparation at home, and due to the efficiency of scale the ready-made meal could be in some cases (or could become, with technological improvements) more efficient.

Several improvements are proposed also for catering services, especially for what concerns sustainability strategies in the purchase of food and the type of cooking system adopted.

Logistics, and especially refrigerated transport of food, can be a relevant source of impacts on resource consumption, climate change, air emissions and ozone depletion (due to refrigerants used in refrigerated transport and refrigerated storage units). Therefore, some documents (including the draft version of the green public procurement –GPP- criteria on food catering services) promote the consumption of locally produced food or, more in general, to reduce the transport distance. For refrigerated transport, a more efficient use of refrigeration units (e.g. to switch them off when not needed) can contribute as well.

The reduction of packaging mass per unit of product is a solution well known since long time. However, a careful evaluation of the alternatives should be made, because in some cases it may be necessary to increase the environmental impact of packaging in order to reduce food waste and related impacts (Williams and Wikström, 2011).

Solutions for the problem of food waste are numerous and include waste prevention strategies, industrial symbiosis at the processing stage, recovery of waste at the end of life (e.g. to produce animal feed, as mentioned before) and avoiding landfilling of organic waste.

Eutrophication from wastewater treatment was another hotspot that emerged from the assessment of the baseline. With reference to this, in addition to all the measures to optimize nutrients cycle listed before, Muñoz and colleagues (2010) stress the importance of improving the efficiency of wastewater treatment. This can be done by promoting a wider use of tertiary treatment, to remove nutrients from the effluent.

Finally, since meat and dairy products production chains have a higher environmental impact, several studies model the possible environmental impact reduction through dietary shift (e.g. comparing the environmental impact of different dietary protein choices).

Table 21. Overview of ecoinnovation options relevant for the area of consumption of the BoP food and the link with possible scenarios

Hotspots	**Areas of eco-innovation**	**Proposed solutions and eco-innovation**	**References**
Animal-based products	Feed	Reducing the feed intake per animal to reduce the overall feed need	Sonesson et al., 2016
		Using food waste as feed for animals	Chen et al., 2015 Röös et al., 2016 Girotto et al., 2015 San Martin et al., 2016 De Meester et al., 2012
	Manure management	Less nitrogen and phosphorous are present in manure due to higher feed efficiency with the use of synthetic amino acids and phytase for increased phosphorous uptake	Sonesson et al., 2016
		Anaerobic digestion of the manure to produce biogas	Sonesson et al., 2016 Weidema et al, 2008;
		Manure storage with floor coverage	EC-JRC, 2015
	Animal breeding	Energy and water saving measures for pigs and poultry housings	EC-JRC, 2015
		To avoid oversupply of Cu and Zn in animal diets	Dourmad and Jondreville, 2007 Weidema et al., 2008
		Improved nutritional strategies to reduce ammonia emissions	EC-JRC, 2015

Hotspots	Areas of eco-innovation	Proposed solutions and eco-innovation	References
Agricultural activities	Nutrients	Measures to reduce nutrients' input	Röös et al., 2016 Schröder et al., 2011 Ma et al., 2011 Suh et al., 2011 Van Vuuren et al, 2010 Kahiluoto et al., 2014 Kirchmann and Thorvaldsson, 2000
		Recovery of N and P	Cordell et al., 2011 Dawson et al., 2011 Diaz-Ambrona and Maletta, 2014 Petzet and Cornel, 2013 Gliessmann 2015
	Organic agriculture	Application of organic agricultural practices	Coley et al., 2009 Deike et al., 2008 Gomiero et al., 2008 Longo et al., 2017 Schader et al., 2016 French Ministry for Agriculture, Food and Forests, 2010
Food processing (including slaughterhouses)	Improved efficiency in energy and water use	Energy saving measures	Sonesson et al., 2016 EC, 2006 EC-JRC, 2015 EC, 2005
		Water saving measures	Sonesson et al., 2016 EC, 2006 EC-JRC, 2015 EC, 2005
	Ready-made	Reduced consumption of ready-made products	Schmidt Rivera et al., 2014
Logistics	Local food	To reduce the distance of supply	Avetisyan et al., 2014 Coley et al., 2009 Edwards-Jones et al., 2008 Sim et al., 2007
	Refrigerated transport	To switch off engine and refrigeration unit when not needed	EC, 2006 Sim et al., 2007
Packaging	Less packaging per product	To reduce the amount of packaging per product	De Monte et al, 2005 Cleary, 2013

Hotspots	Areas of eco-innovation	Proposed solutions and eco-innovation	References
Food waste	Reduction of food waste	Potential and strategies to reduce food waste	Gustavsson, 2010 FAO, 2011 Eurostat, 2011 HLPE, 2014 Garrone et al., 2014 Parfitt et al., 2010 WRAP, 2013 Diaz-Ambrona and Maletta, 2014
	Industrial symbiosis and food waste	Recovery of food waste as animal feed or raw material in industrial processes (e.g. biopolymers or biofuels)	Girotto et al., 2015 Kusch et al., 2014 Papargyropoulou et al., 2014 Pulkkinen et al., 2015 Mirabella et al., 2014 Parfitt et al, 2010 van der Goot et al. 2016
	Food waste treatment	Zero landfill of food waste	Turon et al, 2014 Luque and Clark, 2013 Lin et al, 2013 Pleissner et al, 2013
Wastewater treatment	Improved efficiency of WWT	Improved efficiency of WWT	Muñoz et al., 2010
Catering	Cooking systems	Use cook-warm systems (in which the food is transported warm and then cooked again) instead of cook-chill ones (in which the food is fully cooked and then chilled for transportation)	Fusi et al, 2016
	Sustainability strategies in the purchase of food	A greater use of seasonal products (and field growing); A greater use of less energy-intensive products, considering equal nutritional content; The promotion of local products to boost the local economy in a sustainable way.	Benvenuti et al., 2016 Caputo et al. 2014, EC, 2008 Kahiluoto et al. 2014 Ribal et al., 2016 Saarinen et al., 2012 Wickramasinghe et al., 2016 De Laurentiis et al., 2017
Dietary changes	Dietary choices based on ecological and nutritional values	To reduce the intake of meat and dairy products To reduce the environmental impact of food production through the adoption of more healthy diets	van Dooren et al, 2014 Duchin, 2005 Hallström et al. 2015 Heller et al., 2015 Tukker at al., 2009 Muñoz et al., 2010 Nijdam et al., 2012

Hotspots	Areas of eco-innovation	Proposed solutions and eco-innovation	References
			Meier et al., 2014 Röös et al., 2016 Westhoek et al., 2014 Scarborough et al., 2015 Vanham et al., 2013 Tobler et al., 2011 Vinnari and Tapio, 2009 Vranken et al., 2014 Reijnders and Soret, 2003 Saxe et al, 2013

7.1 Possible synergies with organic farming principles

In the following table (Table 22), for each of the main principles of organic agriculture (according to current EU policies on organic farming[4]) it is indicated the feasibility of modelling the effects these principles when running a case study on an organic agriculture scenario for the BoP food.

Table 22. Overview of principles of organic agriculture and applicability to the BoP food

Organic agriculture principle	Feasibility of implementation in the BoP
Crops are rotated so that on-site resources are used efficiently	Documentation of current assumptions in the background databases used to model the agricultural activities is not fully clear on this topic. In order to model properly the implementation of this principle, further analysis on the datasets is needed.
Chemical pesticides, synthetic fertilisers, antibiotics and other substances are severely restricted	Applicable. According to the results of the hotspot analysis, the largest effect is expected from the reduction of fertilizers and pesticides used to produce animal feed. Antibiotics, even if used in the average practice of animal breeding, are currently not accounted for in the datasets used to model the BoP food.
Genetically modified organisms (GMOs) are banned	GMOs are not modelled in LCA at the moment. A more detailed inventory would be needed to take into account this aspect.
On-site resources are put to good use, such as manure for fertilizer or feed produced on the farm	Applicable. The model already covers this aspect in the modelling of animal feed cultivation.

[4] http://ec.europa.eu/agriculture/organic/index_en

Organic agriculture principle	Feasibility of implementation in the BoP
Disease-resistant plant and animal species adapted to the local environment are used	The current model for the BoP food is representing an average EU situation. This level of specificity is not applicable to the current model.
Livestock are raised in a free-range, open-air environment and are fed on organic fodder	The current model assumes a mix of different types of feed, but none of them organic. A scenario on organic feed can be developed. Feasibility of free-range to be further checked.
Farm animals are freely grazing in the open-air and they are treated according to enhanced animal welfare conditions	LCA does not cover animal or plant welfare and health

7.2 Possible synergies with the ongoing work for the revision of green public procurement criteria for food procurement and catering services

The Green Public Procurement (GPP) criteria for Food and Catering Services are currently under revision. The criteria under discussion cover the following areas[5]:

— Purchase of organic food products

— Promotion of vegetarian food and meals in canteens (e.g. by proposing a fully vegetarian menu once or twice per week, to encourage people to not have meat all days)

— Purchase of marine and aquaculture fish products that are sustainably cached and grown

— Protection of animal welfare

— Reduction of food waste throughout the whole chain (for production of food products to the provision of the services), by optimizing the catering services (e.g. better planning of purchases) and by raising awareness among people attending the canteens (students and adults).

The implementation of the discussed criteria as possible scenarios of eco-innovation and lifestyle changes within the Basket of Product Food is not straightforward. For sure, the topic of food waste can be well captured by the structure of the BoP (and a wide range of scenarios has already been developed on this topic). Regarding organic products, notwithstanding the known limitations of LCA for capturing the full range of benefits coming from organic cultivation, some scenarios could be developed (e.g. on organic cultivation of animal feed, that is responsible for most of the emissions to air and water within the agricultural phase of the BoP).

On the other hand, the topic of vegetarian meals and the change of eating habits is more complicated. The BoP model is structured in a way that allows for easily change the quantities of food purchased and eaten from one product type to another (e.g. reducing the quantity of meat), and some preliminary scenarios has already been developed on this topic. However, the current list of products in the basket does not include products that could be included in a vegetarian meal as a way to substitute meat. For instance, pulses are not included in the baseline (because of low representativeness in terms of purchased volume in EU) and fish

[5] http://susproc.jrc.ec.europa.eu/Food_Catering/

products are not included as well. Pulses and other legumes can be added with the specific aim of creating one or more scenarios on diet change, whereas fish was not included because of lack of inventory data on the production chain[6] and the lack of an LCIA model for the impacts of wild caught fish on the biotic depletion potential (for fish population).

7.2.1 Modelling of catering services

One of the updates under the discussion for the refinement of the baseline in light of the testing of scenarios was the addition of catering and restaurant services. This was seen as relevant especially with the aim of testing the effects of GPP criteria on food and catering services, which are currently under revision (expected release in 2017-2018). However, the final decision was not to include catering and restaurant services as an additional product group in the BoP food. The main reasons that led to this choice are explained below.

Firstly, it has to be acknowledge that catering and restaurant activities are services, whereas all the other product groups in the basket are referred to finished products that citizen can buy from retailers and consume at their home. This difference may be a significant source of imbalance within the BoP. In fact, to correctly model catering and restaurant services, the system should include, at least:

- The restaurant/canteen building
- The furniture and products needed to run the activity (appliances, tables, cutlery, etc)
- All the products used to clean the area where the service takes place and to wash the cutlery and cooking appliances, etc.
- The upstream chain for the supply of food products consumed at the restaurant/canteen
- The transport of products to the site where the service takes place
- Preparation and cooking of meals.

However, the inclusion of these activities within the system boundaries of the BoP food is not straightforward and can lead to double counting of some impacts. For instance, the upstream chain for the supply of food products is already modelled and included for single products themselves. The solution adopted for the pre-prepared meal was to calculate the amount of meat and other food products used for the preparation of the meal and to subtract it from the amount assigned to the single products. This is feasible for a quite simple meal as the one used to model the "pre-prepared meal" product group, but could pose some problems in the case of a more complex menu of an average restaurant or canteen.

In addition, the infrastructures needed to run the restaurant/canteen, such as the building, the appliances, the furniture and other smaller objects, cannot be considered irrelevant, because they are allocated 100% to the service itself. However, this is not the case for food consumed at home, for which the system does not include neither the building nor the appliances, that are dealt with in different and dedicated baskets. Therefore, the inclusion of these items would create an imbalance between food products and food-related services within the same BoP.

Secondly, the current[7] GPP criteria (and the ones discussed in the preliminary documents published in the process of revision) focus primarily on the choice of food to be purchased (e.g. giving preference to organic food). These aspects are fully covered in the current model of the BoP food baseline, so not to adding catering and restaurant services would not prevent the possibility to test the effects of GPP criteria.

[6] This was also one of the reason for discontinuing the PEF pilot on fish products.
[7] As available in November 2017

8 Scenarios of eco-innovation for the area of consumption Food

For the selection of the scenarios for the BoPs in the context of the Consumer Footprint, out of the long list coming from the literature review, priority is given to:

- scenarios that are expected to address the most relevant hotspots identified in the baseline and related to innovations that are at present a niche in the market but are foreseen to become relevant for one of the consumption sector (e.g. for BoP food, priority is given to the scenarios on nutrients recovery, that are expected to reduce the impacts on eutrophication and human toxicity).
- scenarios able to simulate the effect of European policies, especially if in relation to the hotspots of the consumption sector as emerged from the assessment of the BoP baseline (e.g. for BoP food, a scenario simulating the improved efficiency of wastewater treatment can address the hotspot of eutrophication due to nutrients emission at the EoL and simulate the expansion of tertiary wastewater treatment, as required by the Urban Waste Water Directive)
- scenarios related to shift in consumption patterns, e.g. related to change in basket composition or to food waste prevention.

8.1 List of the scenarios tested in the BoP Food

The illustrative scenarios pre-selected to be built and implemented in the model of the BoP food, and finally evaluated against the baseline, are the following:

1) Nutrients cycle: recovery of nutrients by recycling food waste as animal feed:
    a. recycling of food waste at processing plant
    b. recycling of food waste at retailing
    c. recycling of food waste at processing and at retailing.
2) Improvement of wastewater treatment: 100% of wastewater treated with tertiary treatment for the removal of nutrients in EU-27.
3) Diet changes: diets with reduced quantity of meat and dairy products, substituted by a higher consumption of cereal-based products. Two options have been tested: 25% reduction and 50% reduction.
4) Nutrients cycle - recovery of nutrients from urine: separate collection of urine through eco-innovative toilets and recovery of nutrients (as urea) by fertilizing agricultural soil with urine:
    a. long-term storage of urine without any treatment before reuse;
    b. ozonation of urine before reuse, to inactivate pharmaceuticals and hormones.
5) Food waste prevention: prevention of food waste at household and consequent reduction of the quantity of food bought (i.e. reduction of amount of food in the BoP). Several measures for food waste prevention are tested (in brackets, the life cycle stage to which they refer):
    a. Produce Specifications (Agricultural stage)
    b. Manufacturing Line Optimization (Manufacturing stage)
    c. Improved Inventory Management (Retail)
    d. Cold chain management (Retail)
    e. Consumer Education Campaigns (Food consumption at households)
    f. Standardized Date Labelling (Food consumption at households)
    g. Packaging Adjustments (Food consumption at households).

8.2 Scenario 1 – Nutrients cycle – food waste to animal feed

Description and aim:

This scenario aims to assess the effects of introducing a recovery of nutrients across the whole life cycle of food products. The analysis is focused on one specific product (i.e. bread consumed in 1 year by an European citizen), and represents an example of the potential benefits achievable by closing the loop of nutrients by using bread waste as feed for animals.

Area of intervention:

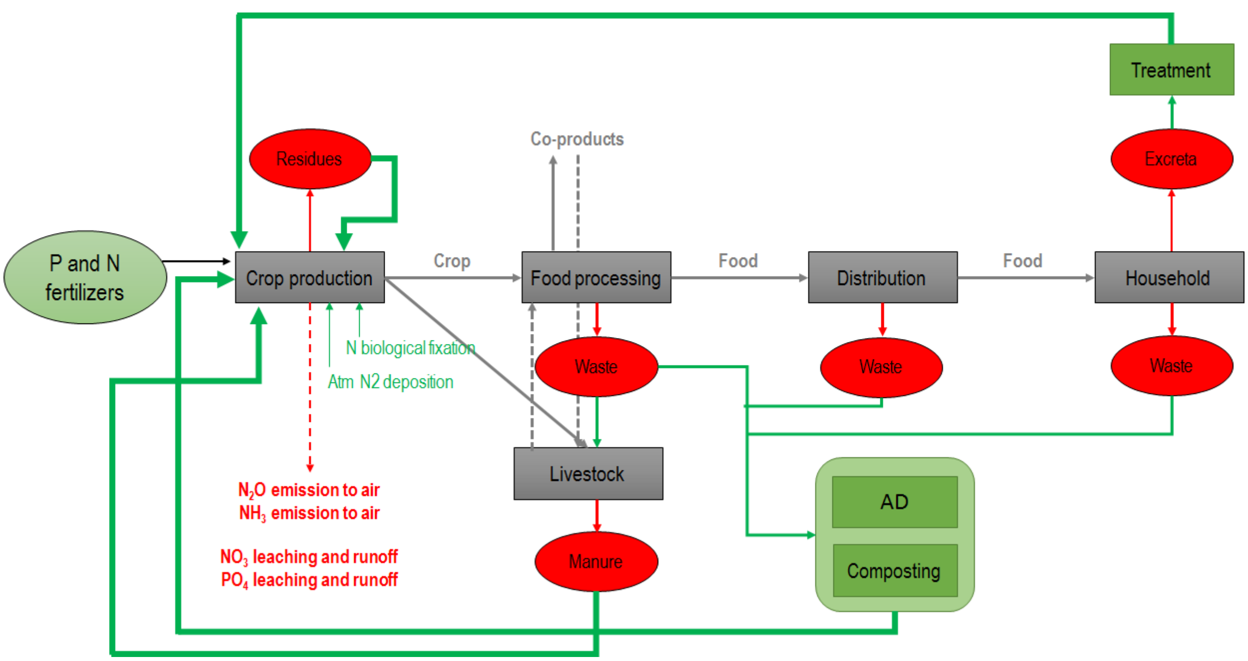
- Hotspot: impacts from feed production
- Only one product (bread)
- Life cycle stage: EoL

Policy relevance: Circular economy package (EC, 2015)

Rationale for building the scenario:

Several scientific papers exploring the possibility of nutrients recovery and describing the nutrients cycle (e.g. Cordell et al., 2011; Schröder et al., 2011; Van Vuuren et al., 2010) have been used as basis to build this scenario. A generic scheme of all the potential recovery cycles of nutrients within the whole life cycle is provided in Figure 10. As can be retrieved from the figure, the waste generated at any stage of the life cycle of food products is assumed to be recovered and ultimately used as fertilizers/amendments in the agricultural field. Moreover, part of human excreta (i.e. liquid excreta) are assumed to be reused as concentrated fertilizer.

Figure 10. The nutrients cycle recovery potential: an overall scheme of the main flows



In this scenario, it is assumed that 100% of waste produced at the processing and retail stages of bread is used as feed (Figure 11) instead of being processed as waste. Losses assumed are 5% at the processing stage (0.05kg for each kg of bread produced) and 2% at retailing. Table 23 lists the amount of waste recovered and used as feed per 1 kg of bread. In the scenario, 100% of the waste from processing and retailing is assumed to substitute an equal amount of feed (i.e. 1 kg of wheat grain avoided per kg of waste reused).

Figure 11. Recycling flows considered in the waste to feed scenario

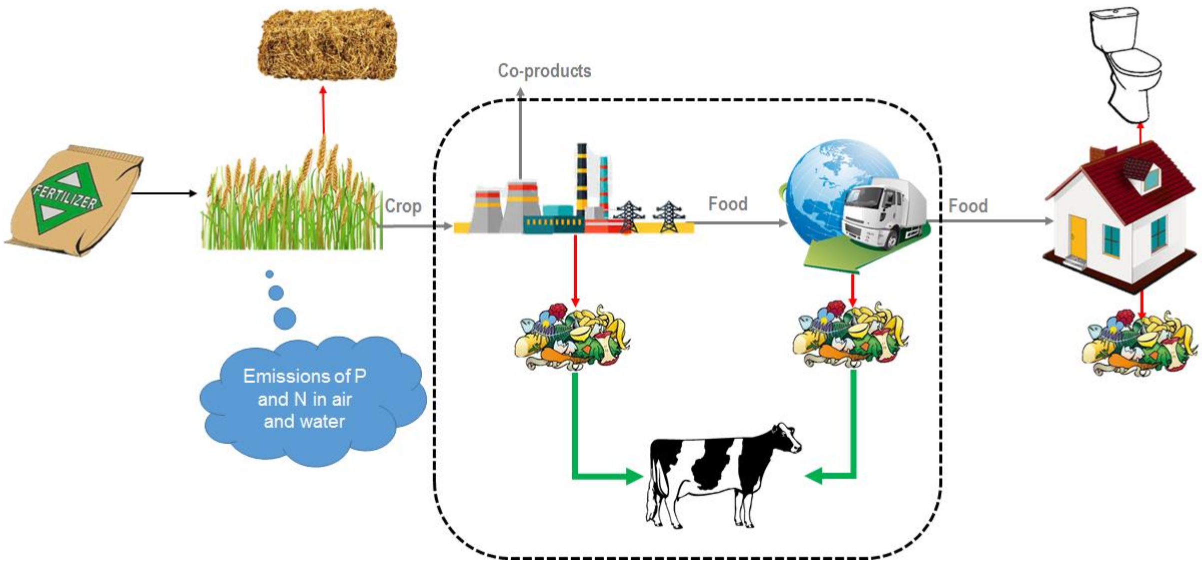


Table 23. Amounts of waste recovered from the processing and retail of bread

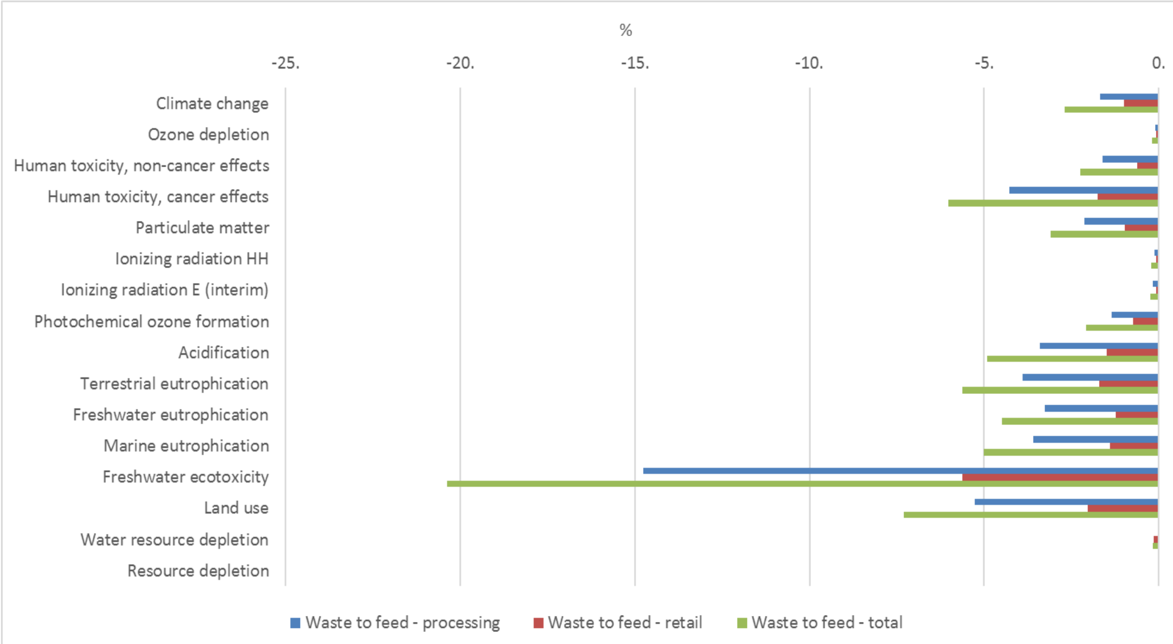
Waste from processing stage (kg/1 kg bread)	Waste from retail stage (kg/1 kg bread)
0.05	0.02

Results

The benefits arising from the use of bread waste as feed are presented in Figure 12. As can be retrieved from the figure, the greatest impact reduction (-20.4%) is obtained for the Freshwater Ecotoxicity category, followed by Land Use (-7.3%). This result is consistent with what was found in the hotspot analysis of the baseline, where the impact of feed production mainly affected the Freshwater Ecotoxicity and Land Use categories. As expected, the life cycle stage that shows the greatest reduction of the environmental burdens is the processing phase, which is where the greater amount of waste is produced (compared to retail).

The recycling of bread as feed for animals is an option already put in place to some extent, especially in cases where the food supply chain is short and the possibility to collect the waste and distribute it to farmers is easier than for more complex supply chains (e.g. the ones including large distribution networks). The most critical issue is in fact the collection and redistribution of waste. The present scenario refers to bread, because it is the most common situation in which this approach is applied. However, it may be implemented also for other types of food. Only in the case of meat waste, due to safety concerns and related legal requirements, a further treatment before the reuse as feed could be required, such as the production of dry feed, obtained through hot treatment and then dehydration of food waste (Salemdeeb et al., 2017). Intuitively, the addition of one further step implies additional environmental burdens. Therefore, the overall potential effect of this specific measure should be carefully analysed.

Figure 12. Results of the implementation of waste to feed scenarios. Results are expressed as % variation compared to the baseline (set as 0).



8.3 Scenario 2 – Improvement of wastewater treatment

Description and aim:

The treatment of wastewater at the end of life of the BoP food was found to be a hotspot for the impact categories freshwater and marine eutrophication, due to the human metabolism of food, i.e. the emissions of nutrients in sewage from human excretion (and related treatment). This scenario is aimed at testing the effects of an improvement in nutrients removal at the wastewater treatment stage, by assuming 100% tertiary treatment for all the wastewater generated by the ingestion of food in the BoP.

Area of intervention:

- Hotspot: impacts coming from wastewater treatment at the EoL (human excreta after food ingestion).
- All products – the treatment is modified for all the products in the basket.
- Life cycle stage: EoL.

Policy relevance:

The Urban Waste Water Directive (91/271/EEC and related amendments) requires tertiary treatment for agglomerations >10 000 population equivalents in designated sensitive areas and their catchments.

According to the Eighth Report on the Implementation Status and the Programmes for Implementation of the Directive (COM (2016) 105; EC, 2016), nearly 75% of the territory in the EU is now designated as sensitive area. 15 Member States have designated their entire territory as such, whereas 13 Member States have identified only certain water bodies as "sensitive".

The same document highlights the need to extend the tertiary treatment to more areas. Therefore, the scenario is aimed at assessing the potential of this action, by simulating an improvement of the amount of water treated with tertiary treatment, from 55% (current average situation in EU-27, represented in the baseline of the BoP food) to 100% (taken as final goal of the directive).

Rationale for building the scenario:

Wastewater treatment can be composed by three steps:

- Primary treatment is a mechanical treatment designed to remove gross, suspended and floating solids from raw sewage.
- Secondary treatment is a biological treatment that removes the dissolved organic matter that escapes primary treatment. The biological process is then followed by sedimentation, to remove the suspended solids. About 85% of the suspended solids and biochemical oxygen demand (BOD) can be removed by a well running plant with secondary treatment.
- Tertiary treatment is an additional treatment that includes removal of nutrients such as phosphorus and nitrogen and practically all suspended and organic matter from wastewater.

The reason for acting on tertiary treatment in the BoP model is twofold: firstly, the Urban Waste Water Directive has specific targets on tertiary treatment; secondary, it is the step that allows for an improvement in the removal of nutrients and related eutrophication potential (that was found as hotspot in the BoP baseline).

The inventory of inputs and emissions for wastewater treatment in the BoP food is based on the model by Muñoz et al., 2007. This model allows for specifying the percentage of wastewater treatment plants with secondary treatment and secondary plus tertiary treatment. The BoP food baseline assumes 46% secondary treatment and 54% secondary and tertiary treatment.

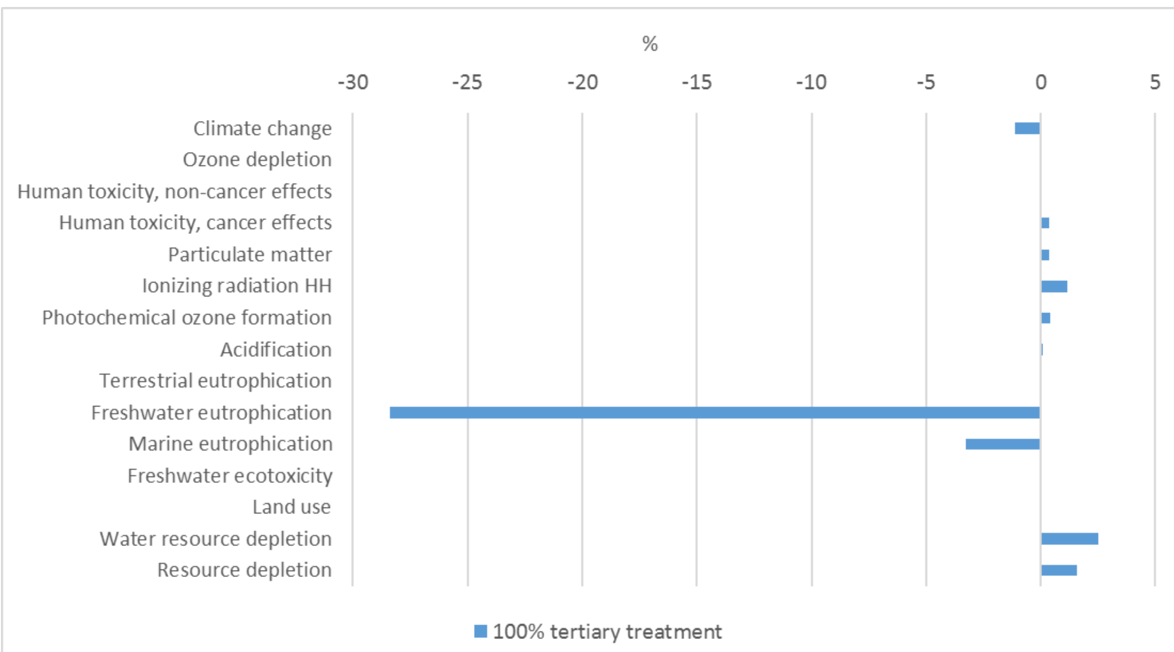
The scenario is built by moving to 100% tertiary treatment for all the wastewater generated by the ingestion of food in the basket. The model by Muñoz was run with the assumption of 100% tertiary treatment for all the products in the basket (because the treatment is modelled according to the food composition in terms of nutrients, proteins, metals, etc.) and data of inputs and outputs for all the products were updated in the BoP inventory model.

It is worth mentioning that there are studies on technologies to recover phosphorus and nitrogen from wastewater to use them as fertilizers. However, this option was not considered in this scenario because its viability, efficiency and economic profitability depend on the specific conditions of the wastewater treatment plant and has to be verified case by case (Sengupta et al., 2015).On the contrary, the recovery of nutrients before wastewater treatment is analysed in scenario 4.

Results

Since the scenario acts on the infrastructures, there is no difference between the implementation for the single citizen and the uptake at the EU-27 scale. Therefore, results are presented only for the whole EU-27 (Figure 13).

Figure 13. Results of the implementation of 100% tertiary treatment scenario to the whole EU-27. Results are expressed as % variation compared to the baseline (set as 0).



The implementation of tertiary treatment for all the wastewater in EU would determine a reduction of the impact of freshwater eutrophication potential (−28%) and, to a lesser extent, of marine eutrophication and climate change.

The performance of some impact categories would instead be worse compared to the baseline due to the additional inputs the tertiary treatment requires (electricity and additives such as chlorine). However, such increase of the environmental burden of this alternative scenario compared to the baseline can be considered negligible as the variation produced is below 5%.

8.4 Scenario 3 – Diet changes

Description and aim:

Since meat and dairy products were found responsible for a relevant share of the environmental impacts (e.g. as global warming potential, eutrophication, human toxicity-non caner effects, etc.), this scenario aims at assessing the effect of a shift to diets with less meat and dairy content compared to the current one. Since the representative products in the BoP food do not cover all the range of food products that can be part of a balanced diet, the present scenario does not represent a suggestion for an improved diet, but has the only aim to check the possible variation in environmental impacts when varying the quantities of meat products in the average annual consumption.

Area of intervention:

- Hotspot: impacts coming from the consumption of meat and dairy products, by assuming a shift in diet and a reduction of the amount of these products consumed by citizens.
- Whole basket – the scenario acts on the composition of the whole BoP
- Life cycle stage: whole life cycle. By changing the composition of the BoP, all the life cycle phases of meat and dairy products are involved.

Policy relevance:

Concerns about animal welfare, reactive nitrogen and greenhouse gas emissions have stimulated public debate in Europe about eating less meat and dairy products (Westhoek et al., 2014). The European strategy on nutrition, overweight and obesity-related health issues is an example of policy that takes into account these concerns. Also the Bioeconomy Strategy "sets out concrete actions to help ensure that consumers have access to sufficient, safe, nutritious and affordable food at all times while decreasing the burden of diet-related diseases, including obesity by promoting healthier diets and by facilitating sustainable and value-based consumption patterns" (EC, 2012).

Rationale for building the scenario:

There are several studies investigating the feasibility and assessing the benefits of dietary changes as shift to diets with less animal-based products (Table 21). In the present scenario, two options on dietary changes are tested and compared with the baseline. The scenarios are built according to the dietary changes as described in Westhoek et al. (2014), based on the IMPRO study on environmental impacts of dietary changes (Tukker et al., 2009). These diet changes consist of a 25% or 50% reduction in the consumption of beef, dairy, pig meat, poultry and eggs, which is compensated by a higher intake of cereals. Wine and pasta were not considered in this scenario. Details on how this shift affect the amount of products in the BoP food are provided in Table 24. The proportion of animal-based products (33% of the food in the baseline) becomes 26% in scenario 3a (25% shift) and 19% in scenario 3b (50% shift).

It is very difficult to predict the level of uptake of dietary changes by European citizens. A Eurobarometer survey run in 2006 (Eurobarometer, 2006) reports that 20% of the interviewees has changed what he or she eats within the last year before the survey. Therefore, for a preliminary assessment of potential effects at the EU-27 scale, an uptake by 20% of the EU-27 population is tested. This means that for 80% of the EU population the basket is composed as it is in the baseline, whereas for 20% of the population the composition of the basket is modified to reflect the two diets presented in Table 24. It is worth noting that the present scenario is not intended as a suggestion for a balanced diet, but just as an example of a diet with reduced meat quantities. In fact, the comparison of dietary scenarios is not straightforward and should also take into account nutritional needs and a balanced composition in terms of nutrients and food types (Ridoutt et al., 2017, Ernstoff et al., 2017; Gephart et al., 2016).

Table 24. Parameters modified in the model for the scenario on dietary changes

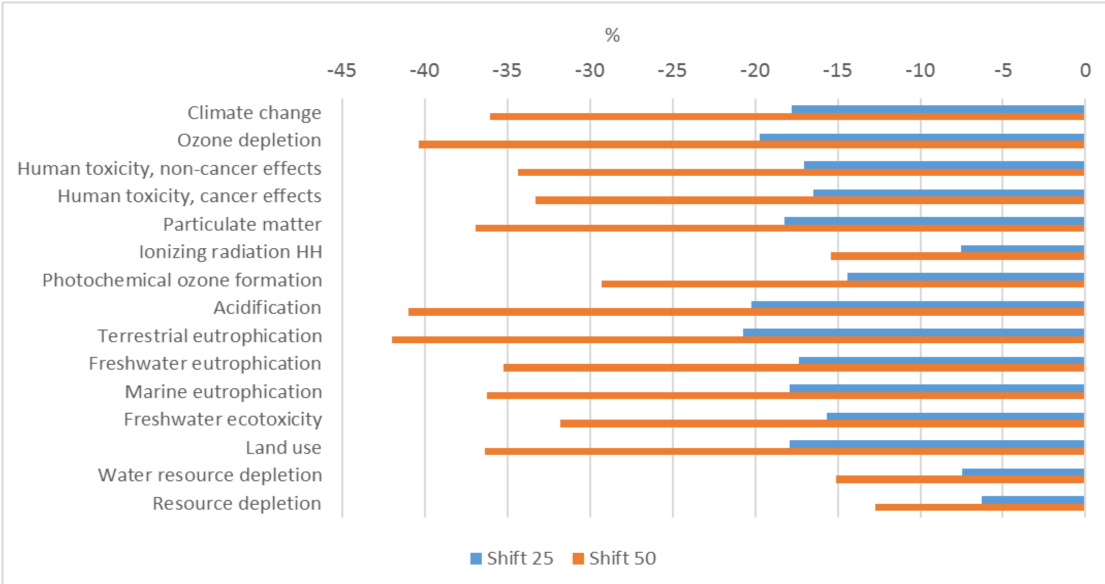
Product Groups	Representative product	Baseline	Scenario 3a: 25% reduction		Scenario 3b: 50% reduction	
		Per-capita cons. (kg/pers. *yr^{-1})	Variation (%)	Per-capita cons. (kg/pers. *yr^{-1})	Variation (%)	Per-capita cons. (kg/pers. *yr^{-1})
MEAT	Pig meat	41	*-25%*	31	*-50%*	21
	Beef	13.7	*-25%*	10	*-50%*	7
	Poultry	22.9	*-25%*	17	*-50%*	11
DAIRY	Milk & Cream	80.1	*-25%*	60	*-50%*	40
	Cheese	15	*-25%*	11	*-50%*	8
	Butter	3.6	*-25%*	3	*-50%*	2
CEREAL-BASED	Bread	39.3	*25%*	49	*50%*	59
SUGAR	Sugar	29.8	*0%*	30	*0%*	30
OILS	Sunflower oil	5.4	*0%*	5	*0%*	5
	Olive oil	5.3	*0%*	5	*0%*	5
VEGETABLES	Potatoes	70.1	*0%*	70	*0%*	70
FRUIT	Oranges	17.4	*0%*	17	*0%*	17
	Apples	16.1	*0%*	16	*0%*	16
BEVERAGES	Mineral water	105	*0%*	105	*0%*	105
	Roasted Coffee	3.5	*0%*	4	*0%*	4
	Beer	69.8	*0%*	70	*0%*	70
PRE-PREPARED MEALS	Meat based dishes	2.9	*0%*	3	*0%*	3

<u>Results</u>

Results are presented for single citizen (Figure 14) and for the whole EU-27 (i.e. including the assumption on the level of uptake of the diet change) (Figure 15).

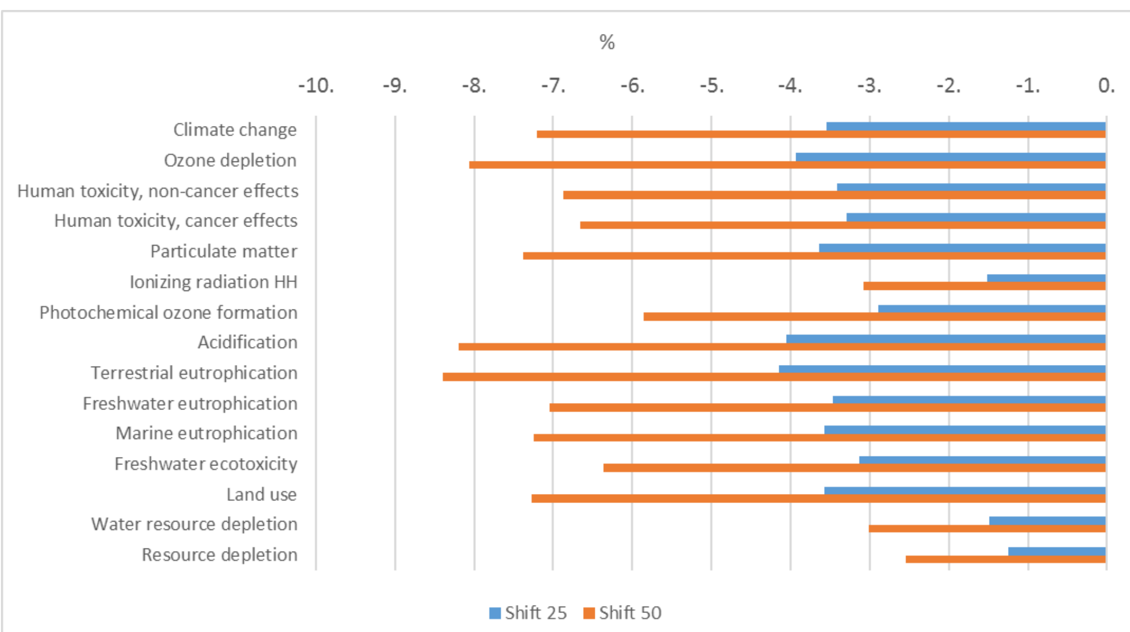
Results of the scenario per citizen show that the partial substitution of meat and dairy products with cereal based ones can reduce the impact generated in all impact categories (Figure 14), with reductions above 40% on ozone depletion potential, Acidification and Terrestrial Eutrophication. This is not surprising, because of the assumptions adopted when building the scenario.

Figure 14. Results of the implementation of diet change scenarios. Results are expressed as % variation compared to the baseline (set as 0). Data refer to 1 citizen.



What is more interesting to note is that, when the scenario is run at the EU-27 scale, the reduction is lower, with highest changes between 8% and 9% reduction on ozone depletion, terrestrial eutrophication and freshwater eutrophication. However, it has to be considered that the assumption made on the level of uptake of the diet changes is quite strong, and that is likely that the real potential for improvement is lower than the one shown in this brief example.

Figure 15. Results of the implementation of diet change scenarios. Results are expressed as % variation compared to the baseline (set as 0). Data refer to EU-27, assuming a shift in diet by 20% of the population.



As largely debated also in previous studies, a change in diet to reduce the amount of animal-based food has the potential to reduce significantly the environmental impact of food consumption by a single citizen. However, the real potential of this kind of improvement for the overall impacts of the BoP food at the EU-27 level depends strongly on the assumption of uptake of dietary changes by European citizens. A deeper analysis on citizen's willingness to change their diet, and especially on diet options that can be considered valid from the point of view of the nutritional content, is needed to allow drawing conclusions on the potential of this solution. There are several factors that can influence the choice of people changing their diet. Gephart et al. (2016) highlight that shifting consumer purchasing habits will require careful consideration of many factors, including consumer understanding, price concerns, food purchasing habits, product availability and personal benefit. The diet proposed in the Livewell study commissioned by the WWF-UK (Macdiarmid et al., 2011) includes both meat and dairy products, though in reduced quantities compared with the current UK diet. The Authors explain that the inclusion of these commodities is intentional, as it is considered unrealistic to expect the population to make radical changes, such as wholly eliminating these food types from their diet by 2020 (less than 5% of the UK population report being vegetarian or vegan). On the contrary, the option analysed in the study implies changing eating patterns to either fewer meat-based meals or smaller quantities within a meal.

Dietary shift at the population scale are more likely to depend on cost and accessibility factors, rather than on environmental benefits (Gephart et al., 2016, O'Keefe et al., 2016). The uptake of dietary changes could be also influenced by policies. Wirsenius et al. (2010) assessed the emission mitigation potential of GHG weighted consumption taxes on animal food products in the EU and found that most of the effect of a GHG weighted tax on animal food can be captured by taxing the consumption of ruminant meat alone.

The results of the optimisation algorithm applied by Gephart et al. (2016) to identify the diet composition that can minimise the associated footprints (carbon, nitrogen, water and land footprint) confirm once more the relevance of a reduced consumption of meat. The optimized diet resulting from their study consists primarily of seafood, vegetables, nuts and starchy roots. This result highlights a critical issue with reference to the modelling of the BoP food: in case a dietary change option is considered suitable for further investigation, the model of the BoP food should be enlarged, because at present it does not include food products that can provide proteins in alternative to meat (such as legumes and seafood).

8.5 Scenario 4 – Nutrients cycle - recovery of nutrients from urine

Description and aim:

The aim of this scenario is to assess the environmental benefits arising from the recycling of urine at the bottom of the life cycle of food products. The analysis is referred both to one single person and to the population of the EU-27. Two types of treatments for the recovery of urine have been taken into account.

Area of intervention:

- Hotspot: nutrients use and related emissions at the EoL (wastewater treatment of human excreta), leading to eutrophication of freshwater
- Whole basket
- Life cycle stage: EoL

Policy relevance: Urban waste water directive (91/271/EEC and related amendments, EC, 1991)

Rationale for building the scenario:

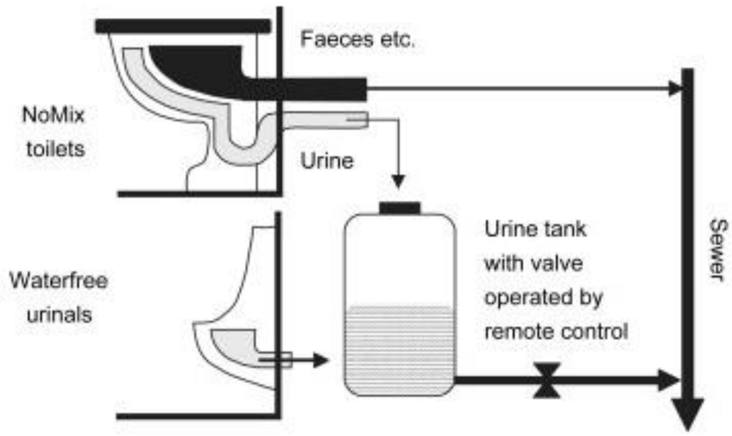
In the generic scheme of all the potential recovery cycles of nutrients within the whole life cycle illustrated in Figure 10 (in the description of Scenario 1), the waste generated at any stage of the life cycle of food products is assumed to be recovered and ultimately used as fertilizers/amendments in the agricultural field. Moreover, part of human excreta (i.e. liquid excreta) are assumed to be reused as concentrated fertilizer. Such practice would allow, on the one hand to reduce the need of mineral fertilizers, entailing savings both in resources depletion and in energy use, and on the other hand to decrease the emissions of eutrophicating agents (Vinnerås and Jönsson, 2002).

Although urine accounts for only 1% of wastewater volume, it contains approximately 80% of nitrogen and 50% of phosphorus in wastewater (Rossi et al., 2009; Zinckgraf et al., 2014), being by far the largest contributor of nutrients to household wastewater (Jönsson et al., 1997). Therefore, the separation of urine from household wastewater is doubly beneficial: on the one hand, it would significantly decrease the nutrient load on the recipients and, on the other hand, represents an opportunity to recover nutrients and conserve water and energy (Jönsson et al., 1997). By recycling the urine to agriculture as a fertilizer in fact, the nutrients are made into resources instead of becoming pollutants (Jönsson et al., 1997, Jimenez et al., 2015).

In the urine source separation toilets (NoMix technology) urine flows through separate pipes to a storage tank that is emptied periodically. NoMix toilets (Figure 16) already exist in Sweden (Larsen et al., 2001). There, urine storage occurs in large and decentralised tanks that are periodically emptied by local farmers who spread the urine directly on their fields (Larsen et al., 2001).

Prior to application, urine should be treated in order to be sanitized and to reduce its microbial load. Long-time storage at ambient temperature is considered a viable treatment option but stronger treatments can be carried out to reach the inactivation of pharmaceuticals and hormones contained in urines (Remy, 2010). To this end, a range of technical options is available, among which ozonation (Remy, 2010). In this analysis, both long-time storage option and ozonation are taken into account. For the latter, a consumption of 1 g O_3 per litre of urine and an energy demand of 15 kWh per kg of ozone is considered (based on Remy, 2010). The yearly volume of urine produced per person is assumed at 547.5 l (Muñoz et al., 2007)

Figure 16. Urine source separation toilet (NoMix technology) (from Rossi et al., 2009)



In order to model this alternative scenario, the following factors have been estimated:

- The amount of nutrients (nitrogen and phosphorous) in human urine per person over 1 year, based on the food products (type and amount) in the basket. The calculations have been made in accordance with Muñoz et al. (2007);
- The amount of N and P recovered form urine, assuming a recovery efficiency of 60% and 46% for N and P respectively (Vinnerås and Jönsson, 2002);
- The amount of avoided wastewater to treat, based on Muñoz et al. (2007);
- The amount of ozone and energy required to treat the urine produced yearly by one person, following the data provided by Remy (2010) and Muñoz et al. (2007).

The model does not include the construction of the additional infrastructure required to separate and store the urine (toilet, separate sewer, tank). These inputs may be considered later on in order to deliver results that are more accurate. Nonetheless, due to the long life span of the above-mentioned infrastructures, their influence on the results is not expected to be relevant. For the implementation of the scenario at the European scale, it is assumed that 10% of the population put in place a NoMix toilet). Table 25 lists the sub-scenarios considered in the analysis. The data inventory for each sub-scenario is reported in Table 26.

Table 25. Sub-scenarios of nutrients recovery from urine

	Long-time storage urine (LTS)	**Ozonation treatment (OT)**	**% of urine separation**
Recovery N and P from 1 person	✓	✓	100%
Recovery N and P from EU-27 population	✓	✓	10%

Table 26. Inventory data for scenario on nutrients recovery from urine. Data are expressed per 1 year

	N recovered (kg/y)	**P recovered (kg/y)**	**Energy (kWh/y)**	**Ozone (kg/y)**	**Avoided wastewater to treat (l)**
LTS 1 person	2.64E+00	1.10E-01	-	-	5.48E+02
OT 1 person	2.64E+00	1.10E-01	8.21E+00	5.50E-01	5.48E+02
LTS EU-27	2.65E+08	1.10E+07	-	-	5.50E+10
OT EU-27	2.65E+08	1.10E+07	8.24E+08	5.52E+07	5.50E+10

Results:

Figure 17 presents the results for scenario on Long-time storage urine (U-LTS) and Ozonation treatment (U-OT) referred to 1 person compared to the baseline, while Figure 18 presents the outcomes of the same scenarios referred to the overall population of the EU-27 (assuming 10% of the population put in place a NoMix toilet).

As can be inferred from Figure 17, if the urine of every citizen of the EU were to be recycled and used as fertilizer, a reduction of the environmental impact is produced for all the categories considered for both the U-LTS and U-OT scenarios. Freshwater and Marine Eutrophication are the most affected ones (approximately -49% and -29% respectively). A decrease of over 10% is obtained for Water and Resource Depletion, while for the remaining categories the reduction of the impact is less than 10%, with Ozone Depletion and Human Toxicity (non-cancer effects) being the least affected ones (less than 1% decrease). The greatest decrease of the environmental burden of both the LTS and OT compared to the baseline is due to the reduction of the wastewater that has to be treated. When comparing the LTS and OT scenarios, the latter appears to be slightly worse than LTS as some additional inputs are needed to carry out the ozonation treatment of urine (electricity and ozone).

Figure 17. Results of the implementation of U-LTS and U-OT scenarios on the entire EU population. Result are expressed as % variation compared to the baseline (set as 0). Data referred to 1 citizen

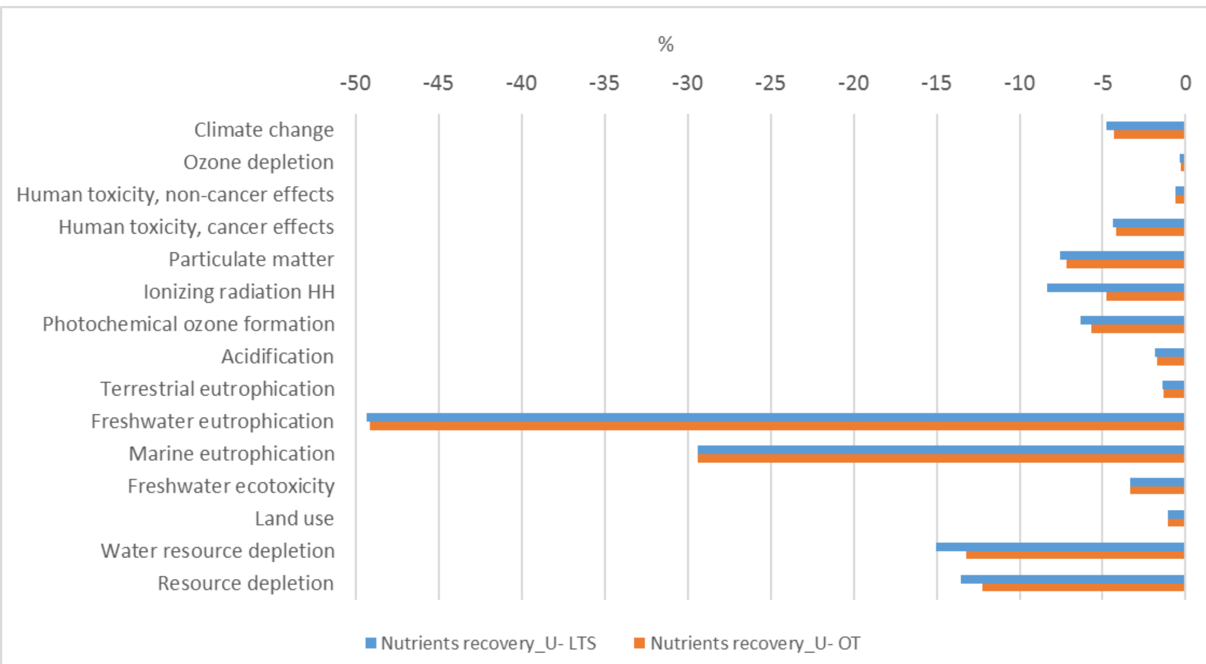
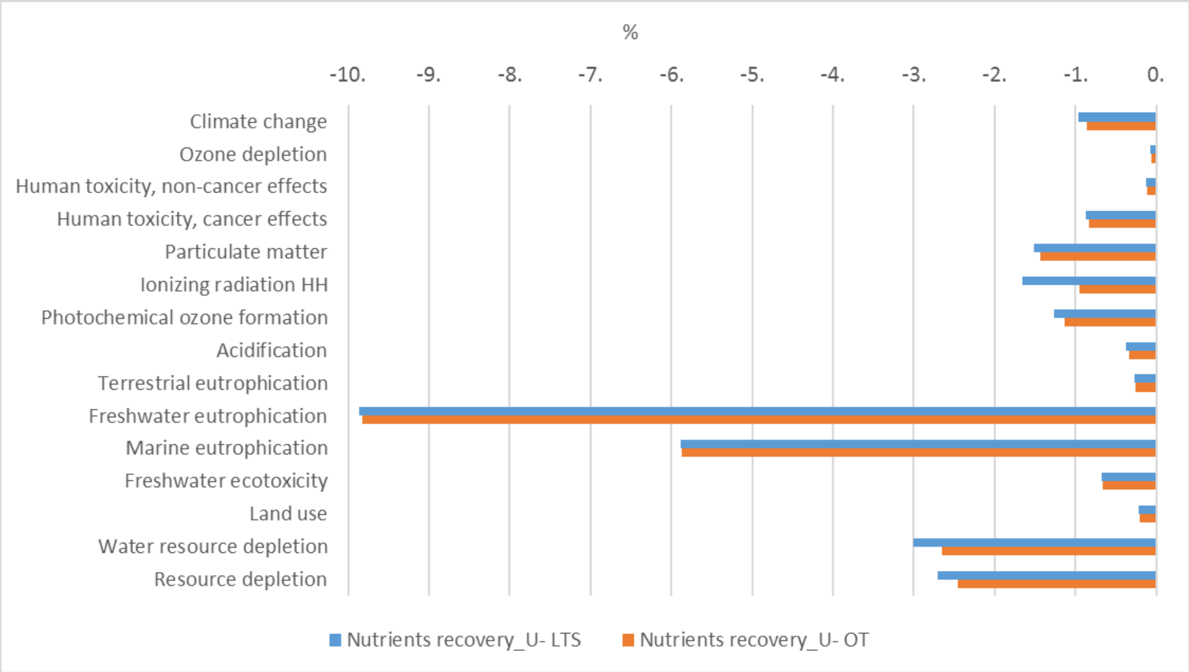


Figure 18. Results of the implementation of U-LTS and U-OT scenarios. Results are expressed as % variation compared to the baseline (set as 0). Data refer to EU-27, assuming that 10% of the population uses a NoMix technology



The benefits arising from the adoption of the NoMix technology by 10% of the EU-27 population are obviously lower than the ones described above. Freshwater and Marine Eutrophication decrease by 10% and 6% respectively, while the improvement of the remaining categories is negligible. There are currently no figures on the expected uptake of such a technology in Europe. Probably it is unrealistic to assume a change in existing buildings, unless in case of a renovation of the building itself or at least of the bathroom. However, it could be interesting to analyse ways to promote the choice of NoMix toilets in the construction of new buildings. This choice could lead to a progressive substitution of the toilets in the building stock over the years. In addition, it has to be considered that the adoption of the NoMix technology implies the construction of additional infrastructures required to separate and store the urine (separate sewer and tank), so it would be easier to install them in new buildings rather in existing ones.

8.6 Scenario 5 – Food waste prevention

Description and aim:

The aim of this scenario is to assess the environmental benefits arising from the reduction of food waste at several stages of the life cycle (from harvesting to final consumption). Several prevention actions are tested, some of them related to prevention at consumption (i.e. at households), others at the post-harvesting stage, production or retailing. Data on the feasibility and expected uptake of the actions are taken from the ReFed study[8], based on the situation in the US.

Area of intervention:

- Hotspot: food waste (impacts coming from waste treatment of organic waste throughout the whole life cycle and impacts of the production chain for food that is produced but not consumed)
- All the product groups in the basket, except beverages and oils.
- All life cycle stages

Policy relevance: 'Roadmap to a resource efficient Europe' (EC, 2011), Circular economy package (EC, 2015) and Sustainable Development Goal 12.3 on food waste.

Rationale for building the scenario:
The methodological approach developed to assess and to compare different options for food waste prevention and management, based on the ReFED study, includes two main steps: i) the quantification of food waste avoided by the considered measure and ii) the calculation of the environmental impact avoided through the action.
Object of the assessment is the entire food life cycle, including the supply chain from the agricultural stage to the retail and the consumption of food and its end of life.
The amount of food waste avoided by each measure is calculated starting from the total amount of food waste generated (called here $Q_{generated}$) and identifying the share of this amount that could be potentially avoided thanks to the considered measure ($Q_{potential}$). For instance, we can say that 100t of food waste are generated each year at the consumption stage by households and that 90% of this amount could be potentially reduced through consumer education campaigns, to educate people to avoid waste (10% is unavoidable waste consisting in inedible food). However, the amount of food waste that is actually avoided could be lower than the addressable quantity, for several reasons (e.g. ineffectiveness of the campaign, low reaction by consumers, etc.). Therefore, the methodology quantifies also the real amount avoided, called here $Q_{prevented}$. The three parameters are described below.

- ${Q_{generated}}_{j,k}$ is the total food waste generated in a stage k of a food supply chain (FSC) *j* by a specific stakeholder or target group, e.g. household food waste. It is the food waste actually being sent to treatment. It includes food waste avoidable and unavoidable.
- ${Q_{potential}}_{i,j,k=p}$ is the maximum amount of food waste that could be potentially prevented in a FSC *j* when action *i* is put in place in the stage k=p. Its calculation is based on the constraints of the action.
- ${Q_{prevented}}_{i,j,k=p}$ is the feasible amount of food waste that actually can be prevented when action *i* is put into place in the stage k=p of the FSC j. It corresponds to the part of ${Q_{potential}}_{i,j,k=p}$ that each target group participating and applying action *i* manage to prevent.

[8] ReFED is a multistakeholder group formed in 2015 committed to tackling food waste at scale in the United States (www.refed.com).

To estimate the final amount of food waste potentially or actually prevented from the generated one, two factors are taken into consideration:

- The Scope factor (S). The absolute amount potentially or actually prevented depends on the extent of the target of the action compared to the size of the system, which for example, for actions targeting citizens, is the total population of the area. S defines the target group as a percentage of the total target. To define the scope (S), it is necessary to consider what resources are available (for example in terms of budget, personnel and organization, etc.). It should be kept in mind that if, for example, a pilot or a general strategy want to be implemented to all the system boundaries, the final results would be different and also the participation factor will change.
- The Participation factor (P). The participation rate defines the users in the target group effectively participating to the action. To estimate participation (P), some approaches could be followed. For example, a survey about the possibility of changing habits (change of diet; accepting a change in the size of menus, etc.) could be done, or some references about the participation reached in the same activities carried out in other places could also be useful.

The total amount potentially and actually prevented is calculated as follows (Eq. 1 and 2, respectively), although in certain cases those factors are not so well differentiated:

$$Q_{potential_{i,j,k=p}} = Q_{generated_{j,k=p}} * S_i \quad (1)$$

$$Q_{prevented_{i,j,k=p}} = Q_{potential_{i,j,k=p}} * P_i \quad (2)$$

The ReFED study presents several actions to reduce food waste at different stages of the FSC (post-harvesting, processing, logistics, retailing and consumption). For each of them $Q_{generated}$, $Q_{potential}$ and $Q_{prevented}$ are estimated for the United States. Since a similar work for Europe has not been done yet, the ratio between the three parameters (but not the absolute values) is used to generate the scenarios applied to the BoP food.

Table 20 illustrates the actions considered for food waste reduction. The ReFED study does not cover all the product groups included in the basket, but focuses on 4 main product groups (grain, produce, meat and milk&dairy). Table 20 reports as well the specification of the BoP's product group affected by each measure. As mentioned before, the ReFED study estimates the scope factor and the participation factor, to derive the amount of food waste that can be actually prevented. This is reported in the table and applied in the scenario. However, since this estimation was based on the US conditions and we cannot ensure that the same estimation is exactly valid also for Europe, for each of the considered actions also the effect of a 100% participation factor is assessed, by assuming that all the waste potentially addressable is prevented. The comparison between the two options allows for an estimation of the range of potential effects achievable with the analyzed action.

The main assumption used in the development of the scenarios is that the amount of food consumed by an average European citizen (F.U. of the BoP) remains the same, whereas the reduction of food waste (at any stage) entails a proportional reduction of the quantity of food bought (or produced, if the reduction is at a stage different from consumption) (Figure 19).

Figure 19. Illustration of the main assumption applied to the food waste scenarios: the amount of food consumed is the same as in the baseline, whereas the amount of food bought is reduced proportionally to the reduction of food waste at consumption. The same logic applies to food waste reduction at other stages of the FSC

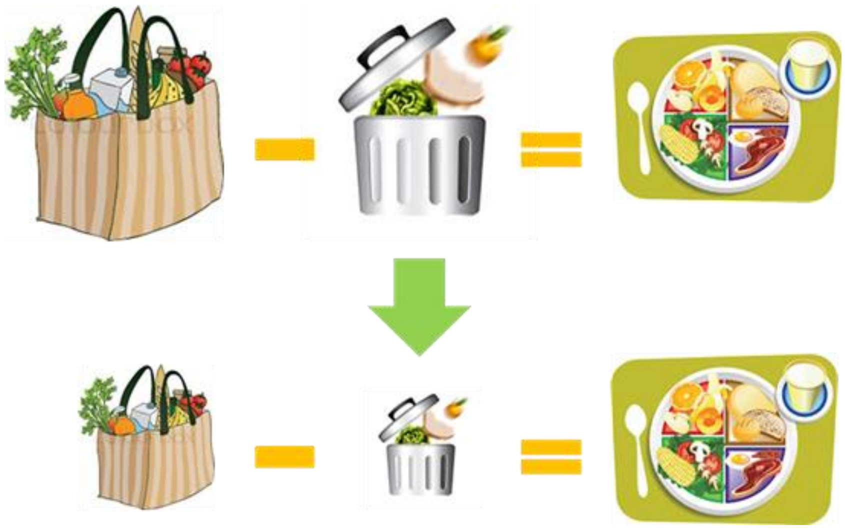


Table 27. Details of the food waste prevention actions implemented in the food waste scenarios

Action	Type of waste	% addressable (S)	% potential (P)	Type of food waste	% reduction applied in BoP food		LC stage to which it is implemented	Product groups to which it is implemented
					Base case	Max		
Produce Specifications Accepting and integrating the sale of off-grade produce (short shelf life, different size/ shape/ color), also known as "ugly" produce, for use in foodservice and restaurant preparation and for retail sale	farm losses	35.6%	7.4%	Fruits and vegetables	2.6%	35.6%	Post-harvest selection (P)	Apples, Oranges
Manufacturing Line Optimization Identifying opportunities to reduce food waste from manufacturing / processing operations and product line changeovers	processing scraps	43.5%	13.3%	Grain, Meat, Produce, Milk&dairy	5.8%	43.5%	Production (PROD)	All products in BoP
Improved Inventory Management Improvements in the ability of retail inventory management systems to track an average product's remaining shelf-life (time left to sell an item) and inform efforts to reduce days on hand (how long an item has gone unsold)	retail	20.0%	7.5%	Grain, Meat, Produce, Milk&dairy	1.5%	20.0%	Retail (R)	All products in BoP
Cold chain management Reducing product loss during storage in retail distribution centres and retailing stores, by using direct shipments and cold chain certified carriers	retail	71.9%	0.8%	Grain, Meat, Produce, Milk&dairy	0.55%	71.9%	Retail (R)	Meat Milk&dairy
Consumer Education Campaigns Conducting large-scale consumer advocacy campaigns to raise awareness of food waste and educate consumers about ways to save money and reduce wasted food	residential	100%	2.2%	Grain, Meat, Produce, Milk&dairy	2.2%	100%	Consumption (HH)	All products in BoP
Standardized Date Labelling Standardizing food label dates and instructions, including eliminating "sell by" dates, to reduce consumer confusion	residential	30.2%	5.0%	Grain, Meat, Produce, Milk&dairy	1.5%	30.2%	Consumption (HH)	All products in BoP
Packaging Adjustments Optimizing food packaging size and design to ensure complete consumption by consumers and avoid residual container waste	residential	10.4%	7.6%	Grain, Meat, Produce, Milk&dairy	0.8%	10.4%	Consumption (HH)	All products in BoP

Results:

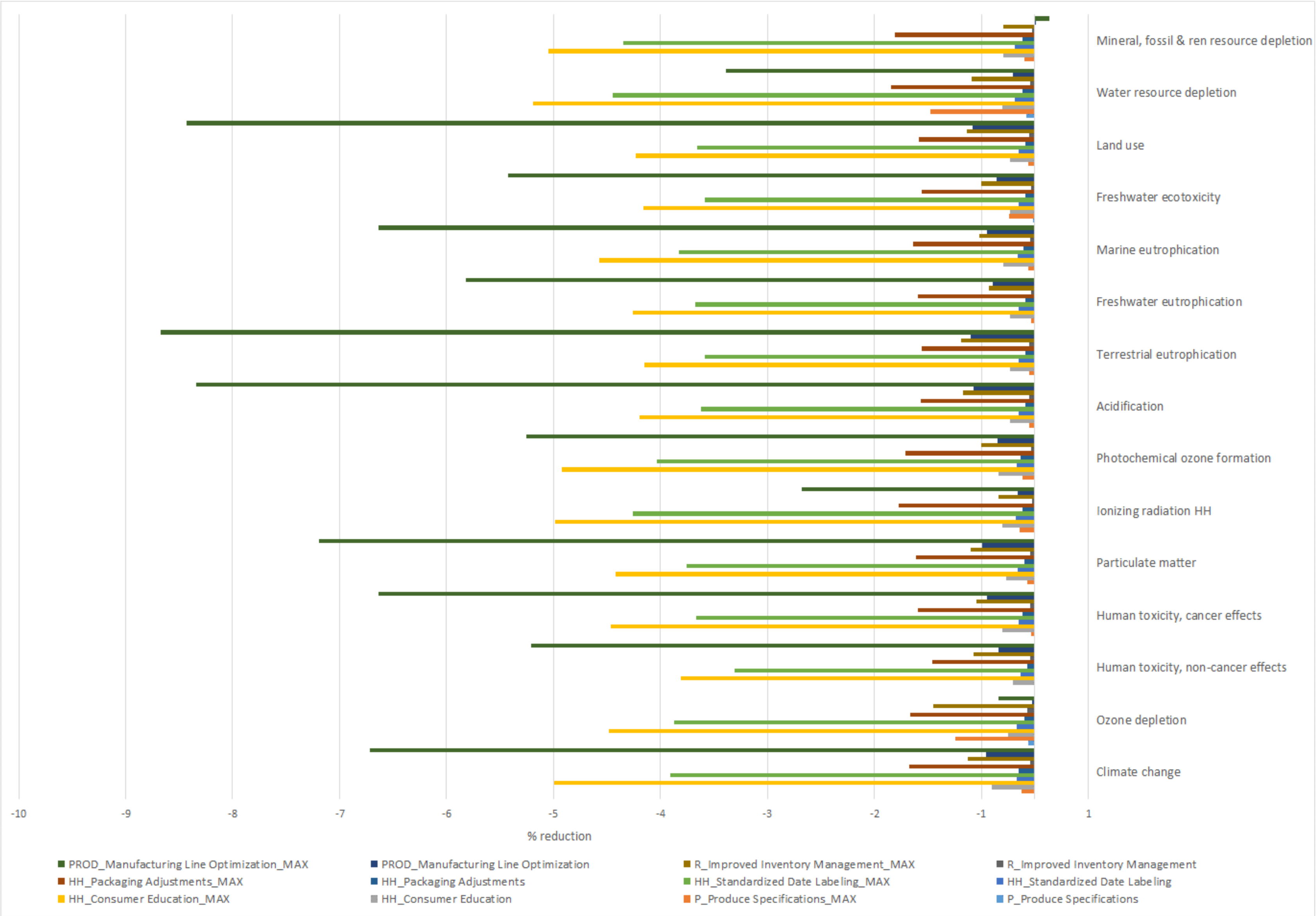
The actions for reducing food waste have a negligible effect on the results of the BoP food (less than 1% reduction across all the impact categories, compared to the baseline scenario) when the participation factor estimated by the ReFED study is applied (Figure 20). When the participation factor is set to 100%, i.e. all the food waste potentially addressable by the action is actually prevented, the effect is significantly higher than before, even if still below 10% of reduction compared to the baseline. Among the set of actions tested, the optimization of the production line is the one that ensures the highest benefits on most of the impact categories, except resource depletion. The second one in terms of relevance of the effect is the action about consumer education campaigns, followed by the other actions to prevent food waste at consumption. The reason behind this is twofold: on one hand, these two set of measures act on the life cycle phases where the amount of food waste produced is higher (production and end of life after consumption, see Table 28). On the other hand, the amount of food waste in these life cycle phases is higher for product groups that are a hotspot for the BoP food (e.g. meat and dairy products) or that are consumed in large quantity by EU-27 citizens (e.g. potatoes).

Table 28. Amount of food waste generated in each phase of the representative products' FSC (source: Notarnicola et al., 2017)

Product Groups	Representative product	kg/pers.*yr^{-1}	Food waste (kg)					
			Agric.	Prod.[9]	Log.[10]	Use[11]	EoL[12]	Total
MEAT	Pig meat	41		17.2	*1.7*	0.05	8.6	**27.55**
	Beef	13.7		4.5	*0.6*	0.02	2.9	**8.02**
	Poultry	22.9		5.5	*0.9*	0.03	4.6	**11.03**
DAIRY	Milk & Cream	80.1	*2.7*	1.4	*0.4*		5.6	**10.1**
	Cheese	15	*4.7*	7.6	*0.5*		0.5	**13.3**
	Butter	3.6	*2.7*		*0.1*		0.1	**2.9**
CEREAL-BASED	Bread	39.3		1.9	*0.8*		9.8	**12.5**
	Pasta	8.2		0.5	*0.2*		2.1	**2.8**
SUGAR	Sugar	29.8					5.1	**5.1**
OILS	Sunflower oil	5.4	*1.8*	0.3	*0.1*		2.8	**5**
	Olive oil	5.3					0.7	**0.7**
VEGETABLES	Potatoes	70.1		9.6	*5.2*		23.0	**37.8**
FRUIT	Oranges	17.4		4.8	*1.9*		5.3	**12**
	Apples	16.1		3.2	*2.0*		4.4	**9.6**
BEVERAGES	Mineral water	105 L						**0**
	Coffee	3.5		0.7			2.8	**3.5**
	Beer	69.8 L						**0**
	Wine	24 L						**0**
PRE-PREPARED MEALS	Meat based dishes	2.9		0.8			0.7	**1.5**
Total per phase			**12.0**	**58.1**	**14.4**	**0.1**	**79.0**	**163.4**

[9] including post-harvest selection
[10] including retail
[11] food wasted in cooking
[12] food not consumed

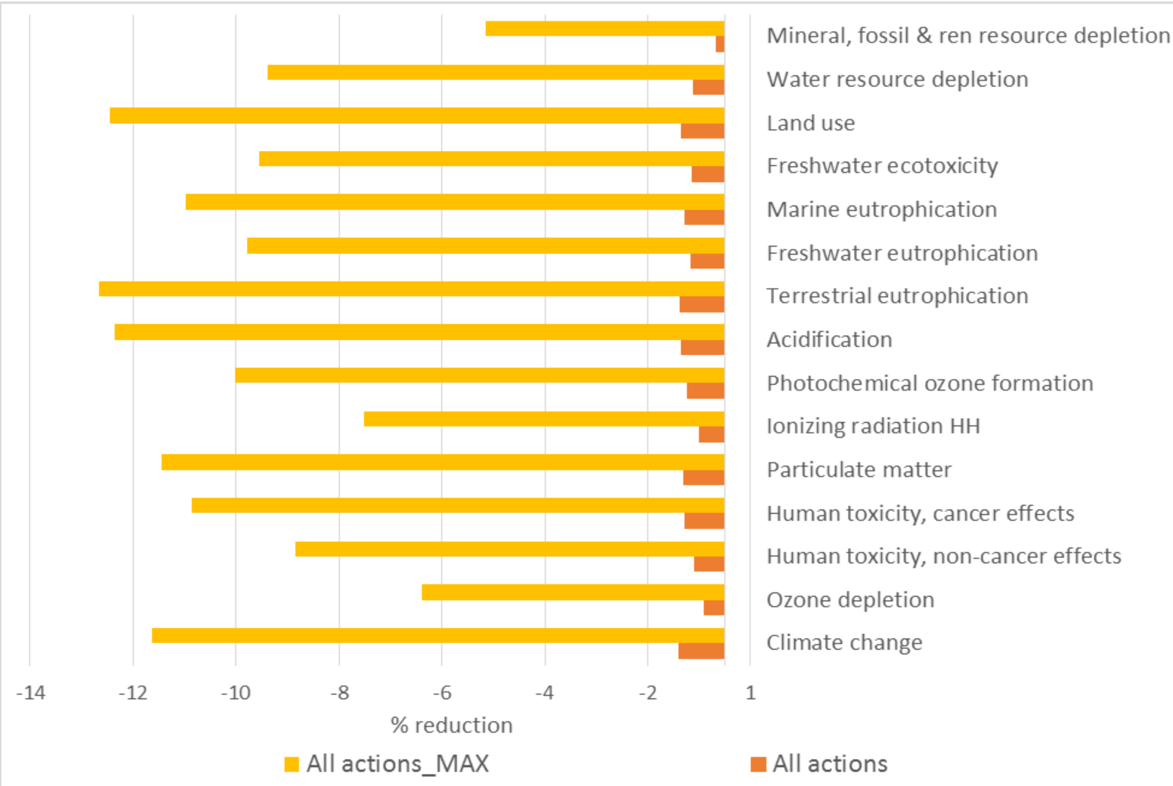
Figure 20. Results of the implementation of the food waste prevention scenarios. Results are expressed as % variation compared to the baseline (set as 0)



It is also interesting to see the results that can be potentially obtained by combining several actions. In the real world, a good prevention strategy would entail a wide set of measures acting jointly at different stages of the food supply chain, and addressing several stakeholders (including citizens, as final consumers). Figure 21 illustrates the potential reduction of impacts coming from the combined implementation of all the actions tested before. Again, when the expected participation is based on data from the ReFed project ("All actions" in the figure), the expected effect is quite limited, whereas, when putting the participation factor to the maximum possible ("All actions_MAX" in the figure), it emerges that the potential for improvement is quite significant. These results highlight the importance of ensuring a wide implementation of the prevention actions throughout the whole food supply chain and the involvement of a wide share of stakeholders, and especially citizens, to maximize the benefits at the EU scale.

It is worthy to consider also that a food waste prevention programme should be designed taking into consideration a defined amount of economic resources that may be allocated to it. Hence, a decision-maker should be able to prioritize measures in order to achieve the highest environmental impact prevention along the whole food life cycle, while remaining within the limits of the available budget. The use of mathematical programming combined with LCA could be a useful way to analyse and compare the options and to support the prioritization in the context of policy making. An example of this approach, applied to the case study of the BoP Food and the food waste prevention measures proposed in the ReFED study is presented in details in Cristóbal et al. (2018).

Figure 21. Results of the cumulative implementation of the actions to the BoP food (either with prevention according to the estimated participation factor and with prevention of all the food waste addressable). Results are expressed as % variation compared to the baseline (set as 0)



9 Summary of main findings from the scenario analysis

Table 29 represents a summary of the results of the scenarios assessed for the BoP food, as variation (%) of impact compared to the baseline scenario. Results that show an increase compared to the baseline are highlighted in red, whereas results that show a reduction are highlighted in green.

Table 29. Summary of results of the scenarios analyzed. Results are expressed as variation (%) compared to the baseline (1)

	GWP	ODP	HTP nc	HTP c	PMFP	IRP	POFP	AP	TEP	FEP	MEP	FETP	LU	WRD	RD
SC.1: Food waste to animal feed (total)	-2.7%	-0.2%	-2.2%	-6.0%	-3.1%	-0.2%	-2.1%	-4.9%	-5.6%	-4.5%	-5.0%	-20.4%	-7.3%	-0.2%	0.1%
SC.2: Improvement of wastewater treatment	-1.1%	0.1%	0.0%	0.4%	0.4%	1.1%	0.4%	0.1%	0.0%	-28.4%	-3.3%	0.1%	0.0%	2.5%	1.6%
SC.3a: Diet changes (25% less meat)	-3.6%	-3.9%	-3.4%	-3.3%	-3.6%	-1.5%	-2.9%	-4.0%	-4.2%	-3.5%	-3.6%	-3.1%	-3.6%	-1.5%	-1.3%
SC.3a: Diet changes (50% less meat)	-7.2%	-8.1%	-6.9%	-6.7%	-7.4%	-3.1%	-5.9%	-8.2%	-8.4%	-7.0%	-7.2%	-6.4%	-7.3%	-3.0%	-2.5%
SC.4a: Recovery of nutrients from urine (LTS)	-1.0%	-0.1%	-0.1%	-0.9%	-1.5%	-1.7%	-1.3%	-0.4%	-0.3%	-9.9%	-5.9%	-0.7%	-0.2%	-3.0%	-2.7%
SC.4b: Recovery of nutrients from urine (OT)	-0.9%	-0.1%	-0.1%	-0.8%	-1.4%	-1.0%	-1.1%	-0.3%	-0.3%	-9.8%	-5.9%	-0.7%	-0.2%	-2.6%	-2.5%
SC.5: Food waste prevention															
SC.5a: Produce Specifications (MAX)	-0.1%	-0.7%	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	-0.1%	-0.2%	-0.1%	-1.0%	-0.1%
SC.5b: Manufacturing Line Optimization (MAX)	-6.2%	-0.3%	-4.7%	-6.1%	-6.7%	-2.2%	-4.7%	-7.8%	-8.2%	-5.3%	-6.1%	-4.9%	-7.9%	-2.9%	0.1%
SC.5c: Improved Inventory Management (MAX)	-0.6%	-0.9%	-0.6%	-0.5%	-0.6%	-0.3%	-0.5%	-0.7%	-0.7%	-0.4%	-0.5%	-0.5%	-0.6%	-0.6%	-0.3%
SC.5d: Consumer Education Campaigns (MAX)	-4.5%	-4.0%	-3.3%	-4.0%	-3.9%	-4.5%	-4.4%	-3.7%	-3.7%	-3.8%	-4.1%	-3.7%	-3.7%	-4.7%	-4.5%
SC.5e: Standardized Date Labelling (MAX)	-3.4%	-3.4%	-2.8%	-3.2%	-3.3%	-3.8%	-3.5%	-3.1%	-3.1%	-3.2%	-3.3%	-3.1%	-3.2%	-3.9%	-3.8%
SC.5f: Packaging Adjustments (MAX)	-1.2%	-1.2%	-1.0%	-1.1%	-1.1%	-1.3%	-1.2%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.3%	-1.3%
SC.5g: Combined food prevention measures	-11.1%	-5.9%	-8.3%	-10.4%	-10.9%	-7.0%	-9.5%	-11.9%	-12.2%	-9.3%	-10.5%	-9.1%	-12.0%	-8.9%	-4.7%

(1) Abbreviations: GWP (Climate change), ODP (Ozone depletion), HTP nc (Human toxicity, non-cancer effects), HTP c (Human toxicity, cancer effects), PMFP (Particulate matter), IRP (Ionizing Radiation HH), POFP (Photochemical ozone formation), AP (Acidification), TEP (Terrestrial eutrophication), FEP (Freshwater eutrophication), MEP (Marine eutrophication), FETP (Freshwater ecotoxicity), LU (Land use), WRD (Water resource depletion), RD (Resource depletion).

The scenarios tested on the baseline of the BoP food provided insights on the potential for reducing environmental impacts of food consumption in Europe. Each scenario acts on a different component of the BoP (in term of either products, life cycle stages or composition of the basket) and, therefore, has different magnitude of impacts on the set of impact categories considered by the ILCD method. For instance, the recovery of food waste as animal feed could reduce the impact on freshwater ecotoxicity by 20% and the impact of land use by 7%. The recovery of nutrients from human urine could contribute significantly to the reduction of eutrophication for freshwater (49%) and marine water (29%) and of water and resource depletion (10% respectively). The introduction of a tertiary treatment step in all the EU wastewater treatment plant could have a significant effect on the quality of the effluents to inland water bodies as well (with a reduction of 28% of the eutrophication potential). Actions related to consumer habits, like the reduction of meat consumption of a better prevention of food waste can have effects distributed over all the impact categories, with higher reduction of specific ones (e.g. up to 40% reduction of the ozone depletion potential thanks to diet changes).

In general, among the scenarios assessed, the options that allow for a higher reduction of impacts are the ones acting on the drivers of freshwater eutrophication, such as recovery of nutrients form urine or improvement of the wastewater treatment. However, it has to be considered that for some of the actions a 100% implementation all over EU-27 should not be taken for granted, and results should be analysed by assuming an "uptake factor". In the case of nutrients recovery from urine, for instance, an assumption of 10% uptake by European households has been made. In this case, the reduction of eutrophication of freshwater decrease from 49% (in the case of 100% uptake) to around 10%. The same applies in the case of diet changes, where it is estimated that only 20% of the European population will be willing to change the eating habits. A different approach is used for the scenarios on food waste prevention, because in this case the results are already upscaled to the whole population. In this case, a crosscutting reduction of impacts is expected, ranging from 1% to 10%, depending on the action implemented.

An interesting option to be further explored is the combination of actions, to cover a wider range of impacts and to maximize the potential of impact reduction, both at the scale of the single citizen and of the whole Europe. An example has been already provided in the scenarios list by summing a selection of actions for food waste prevention. The same approach could be applied to all the scenarios presented (and others to be eventually developed in the future), if the single actions are not overlapping and can be implemented in parallel (e.g. improvement of wastewater treatment and food waste reduction). Of course, in some cases a linear sum of the effects of single actions could not be assumed, because one action could influence the feasibility of the efficiency of another one (e.g. the reduction of food waste at the retailing or production stages could reduce the amount of food waste available to be used as animal feed). In these cases, the modelling structure of the BoP allows for a detailed and effective modelling of the combined scenarios and further assessment of their impact reduction potential.

Besides the tested scenarios, the different ecoinnovations presented in chapter 7 may considered as basis for specific scenarios, for instance : i) the choice of intermediate products: for instance, a study by Six et al. (2017) has shown that the type of feed used in the pork meat production chain can influence the environmental profile of the final product; ii) the consumption of products from organic agriculture (as suggested also by the GPP criteria on food procurement and catering services); iii) the implementation of energy and water saving measures at the processing stage; iv)a more detailed assessment of dietary changes, enlarging the number and type of representative products.

10 Conclusions

The basket of product food is built to assess the impact associated to food consumption in Europe. The baseline model includes a selection of product groups and it is built with a bottom-up approach, using life cycle inventories of representative products for each product group. In total, 19 representative products were modelled: pork, beef and poultry meat, milk, cheese, butter, bread, sugar, sunflower oil, olive oil, potatoes, oranges, apples, mineral water, roasted coffee, beer, pre-prepared meals, wine and pasta.

The use of representative products may reduce the representativeness of the model, because it implies the exclusion of products that are less relevant in terms of the amount consumed. However, the use of a bottom-up approach, with process-based inventories allows for having more detailed life cycle inventories, and it is more useful when modelling scenarios.

The baseline model of the BoP food (representing the annual food consumption of European citizens) was assessed using ILCD impact assessment method and also using a revised version of the ILCD method (called here "LCIA-LCIND2"), where some impact categories were updated with a selection of recent impact assessment models and factors.

According to the results of the hotspot analysis, agriculture is the life cycle stage of the food consumption chain with the larger contribution to most of the impact categories. The product groups that emerge as hotspots in most of the impact categories, even if with different levels of contribution, are meat and dairy products and beverages. The main impact for the life cycle of pork and meat beef products is generated by the emissions due to agricultural activities for the production of feed. Direct emissions from animal husbandry (methane, dinitrogen oxide, ammonia, etc.) contribute as well. Dairy products, as co-product of meat, share the same contribution. In both product groups, the processing phase is less relevant than the agricultural one.

Regarding the relevance of impact categories, the most relevant ones according to the impact assessment methods used are human toxicity (especially for what concerns non-cancer effects), aquatic toxicity and eutrophication. However, these results should be interpreted carefully, because there are some known issues related to the robustness of the impact assessment models for toxicity-related impacts. According to Zampori et al. (2017), only 50% of the elementary flows contributing to toxicity are characterised by the impact assessment models currently available. EC-JRC is looking at the improvement of the issues and that limitations of current model and the way forward are discussed in Saouter et al. (2017a and 2017b).

Among the scenarios assessed, the options that allow for a higher reduction of impacts are the ones acting on the drivers of freshwater eutrophication, such as recovery of nutrients form urine or improvement of the wastewater treatment. A general comment valid for all the scenarios refers to the relevance of the level of uptake of the improvement measure modelled in the scenario. Some options can have a high potential in terms of the reduction of impacts, but can also be difficult to implement at large scale. This can limit their potential effect on the overall impact of the BoP Food (i.e. on the impacts of food consumption in Europe).

The combination of several actions could be a good way to cover a wider range of impacts and to maximize the potential of impact reduction, both at the scale of the single citizen and of the whole Europe. An example has been already provided by summing a selection of actions for food waste prevention. The same approach could be applied to all the scenarios presented (and others to be eventually developed in the future), if the single actions are not overlapping and can be implemented in parallel (e.g. improvement of wastewater treatment and food waste reduction). Furthermore, the combination of mathematical programming and LCA can help to prioritize measures within the limited budget available for the implementation of policies, as proved in Cristóbal et al. (2018).

There are some limitations related to modelling choices that should be considered when interpreting the results of the present study. The most important are the following.

— The use of Prodcom statistics helps to identify the share of products consumed in Europe but produced outside Europe, i.e. the contribution of import to the European food supply chain. However, Prodcom statistics include also intermediate products, so data need to be further elaborated to be used in the BoP framework. Food balance sheets from Faostat provide more accurate (even if less detailed) data on per capita food supply in Europe. By using Faostat data the amount of food supplied in Europe in 2010 is 957 kg/inhabitant, i.e. 2% more than the amount derived from Prodcom data (933 kg/inhabitant).

— The use of representative products implies some strengths but also some weaknesses of the basket model. For instance, the number and type of products included in the BoP (selected according to their relevance in the European average consumption of food) are not sufficient to model detailed scenarios on diet changes, because some of the products that may substitute meat (e.g. legumes) are not included. In case the BoP should be used to model diet shift in the future, this aspect needs to be improved.

— More generally, it is very difficult to capture the variability of agricultural activities (e.g. in relation to specific agricultural practices, aspects related to climatic conditions, variability among product typologies, etc.) in LCA. Some simplified methods have been developed to bridge data gaps and simplify data collection for agricultural and food LCIs (Pernollet et al., 2017). However, the simplification of the inventories, while ensuring more completeness may also limit the possibility to model scenarios on specific aspects that could be less relevant at the level of the single product, but more relevant when considering the overall food consumption (e.g. food waste or wastewater treatment at the end of life).

— Finally, as for all the LCA studies, the use of background databases (in this specific case, the Agri-footprint database and the ecoinvent database), is a source of uncertainty because background data are not directly referred to the system under study. In the BoP food this aspect was partially addressed by adjusting the background datasets to the European average conditions as far as possible.

Notwithstanding the limitations listed above, the work done on the BoP food can be considered a valuable way to highlight the most relevant areas of improvements in the food sector and especially the potential relevance of different types of measures, when they are applied at the European scale.

The possibility to highlight actual potential of improvement measures, usually developed at the product or production chain level, when they are upscaled to the European level is one of the interesting features of the BoP framework. Moreover, the use of a bottom-up approach with process-based inventories of representative products has some limitations related to product representativeness, but at the same time allows for having more detailed life cycle inventories compared to input-output approaches, and it can be more useful when modelling scenarios. More generally, the structure of the BoP food could be useful to identify environmental impacts caused by food consumption in Europe and, more generally, to analyse the food sector and support policy strategies for its improvement.

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List of abbreviations and definitions

BAT	Best Available Technologies
BOD	Biochemical Oxygen Demand
BoP	Basket of Products
BREF	Best Available Technologies Reference
CF	Characterization Factor
EoL	End of Life
FSC	Food Supply Chain
FU	Functional Unit
GHG	Green House Gases
GMOs	Genetically modified organisms
GPP	Green Public Procurement
ILCD	International Life Cycle Data System
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LTS	Long-time storage urine
NF	Normalization Factor
PEF	Product Environmental Footprint

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Annexes

Annex 1. Datasets used to model packaging production and end of life

Production of materials and waste treatment (incineration and landfilling) are included in system S, whereas burdens and benefits from recycling are included in System R (Table 30).

Table 30. EoL Inventory: Module S and Module R for packaging waste in the BoP food

	Production of material	Waste treatment (System S)				Recycling (System R)	
Material	**Ecoinvent process**	**Ecoinvent process (waste treatment)**	**% to landfill**	**% to incineration**	**% to recycling**	**Ecoinvent process (burdens)**	**Ecoinvent process Avoided products (benefits)**
Aluminium	Sheet rolling, aluminium {GLO}| market for | Alloc Def, U + Aluminium removed by milling, average {GLO}| market for | Alloc Def, U	Scrap aluminium {RoW}| treatment of, municipal incineration | Alloc Def, U + Waste aluminium {RoW}| treatment of, sanitary landfill | Alloc Def, U	20.1	10.7	69.2	Aluminium, wrought alloy {RoW}| treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter | Alloc Def, U	Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| market for | Alloc Def, U
	Aluminium removed by milling, average {GLO}| market for | Alloc Def, U						
Cardboard	Corrugated board box {GLO}| market for corrugated board box | Alloc Def, U	Waste paperboard {RoW}| treatment of, municipal incineration | Alloc Def, U + Waste paperboard {RoW}| treatment of, sanitary landfill | Alloc Def, U	11	0.58	83.2	Waste paperboard, sorted {GLO}| market for | Alloc Def, U	Sulfate pulp {GLO}| market for | Alloc Def, U
	Core board {GLO}| market for | Alloc Def, S		11	0.58	83.2		
Glass	Packaging glass, brown {GLO}| market for | Alloc Def, U	Waste glass {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste glass {CH}| treatment of, inert material landfill | Alloc Def, U	21.2	11.2	67.6	Glass cullet, sorted {GLO}| market for | Alloc Def, U	Packaging glass, brown {GLO}| packaging glass production, brown, without cullet and melting | Alloc Def, U
	Packaging glass, white {GLO}| market for | Alloc Def, S		21.2	11.2	67.6		
PE	Polyethylene, high density, granulate {GLO}| market for | Alloc Def, U	Waste polyethylene {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U	44.5	23.6	31.9	Electricity, medium voltage {RoW}| market for | Alloc Def, U	Polyethylene, high density, granulate {RER}|
	Polyethylene, low density, granulate {GLO}| market for | Alloc Def, U						

	Production of material	Waste treatment (System S)				Recycling (System R)	
Material	**Ecoinvent process**	**Ecoinvent process (waste treatment)**	**% to landfill**	**% to incineration**	**% to recycling**	**Ecoinvent process (burdens)**	**Ecoinvent process Avoided products (benefits)**
		+ Waste polyethylene {CH}| treatment of, sanitary landfill | Alloc Def, U					production | Alloc Def, U
PET	Polyethylene terephthalate, granulate, bottle grade {GLO}| market for | Alloc Def, U copia basket + Blow moulding {GLO}| market for | Alloc Def, U copia basket + Plastic processing factory {RER}| construction | Alloc Def, S	Waste polyethylene terephtalate {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste polyethylene terephtalate {CH}| treatment of, sanitary landfill | Alloc Def, U	44.5	23.6	31.9	Electricity, medium voltage {RoW}| market for | Alloc Def, U	Polyethylene terephthalate, granulate, bottle grade {RER}| production | Alloc Def, U
PP	Polypropylene, granulate {GLO}| market for | Alloc Def, U	Waste polypropylene {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste polypropylene {CH}| treatment of, sanitary landfill | Alloc Def, U	44.5	23.6	31.9	Electricity, medium voltage {RoW}| market for | Alloc Def, U	Polypropylene, granulate {RER}| production | Alloc Def, U
PS	Polystyrene, general purpose {GLO}| market for | Alloc Def, U	Waste polystyrene {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste polystyrene {CH}| treatment of, sanitary landfill | Alloc Def, U	44.5	23.6	31.9	Electricity, medium voltage {RoW}| market for | Alloc Def, U	Polystyrene, general purpose {RER}| production | Alloc Def, U

Annex 2. Sensitivity analysis on refrigerants for storage and transport of food

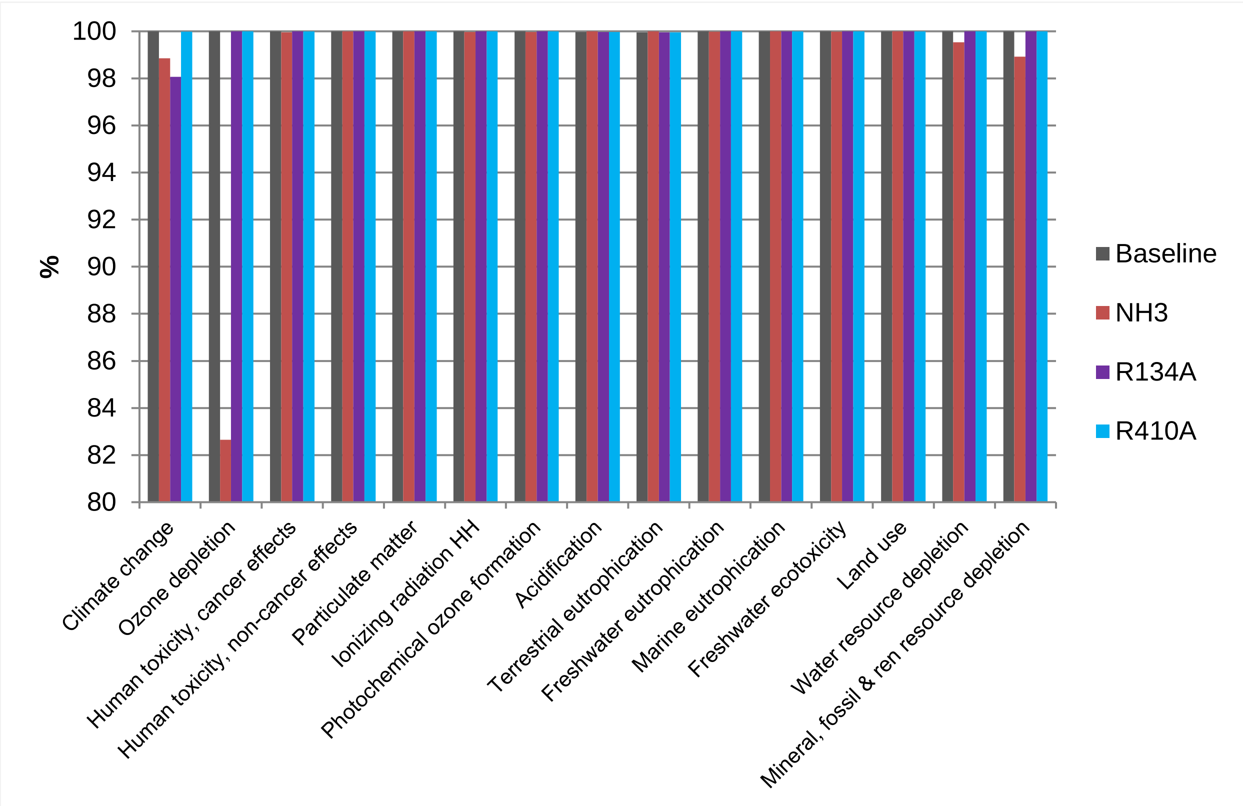
As mentioned in the main text, the refrigerant R404A has been considered as baseline scenario, as it is the most commonly used refrigerant in Europe. The LCA data for the production of the refrigerants have been sourced from Bovea et al. (2007).

To test the robustness of the results and investigate the effect of key assumptions, the following parameters have been considered within the sensitivity analysis:

- refrigerant type for refrigerated storage (walk-in refrigerators/freezers): ammonia instead of R404A;
- refrigerant type for refrigerated transport: R134A and R410A instead of R404A;
- refrigerant type for refrigerated storage in display cabinets: R134A instead of R404A;

Results are reported in Figure 23. As expected, the impact categories that are more sensitive to the change are ozone depletion and climate change (due to the effects of refrigerant emissions) and, to a lesser extent, abiotic resource depletion (due to the production of the refrigerant). Differences due to the use of R134A and R410A instead of R404A are almost negligible, whereas the use of NH_3 as refrigerant in walk-in refrigerators and freezers could lead to a reduction of ozone depletion impacts. This should be taken into consideration in the interpretation of the baseline results.

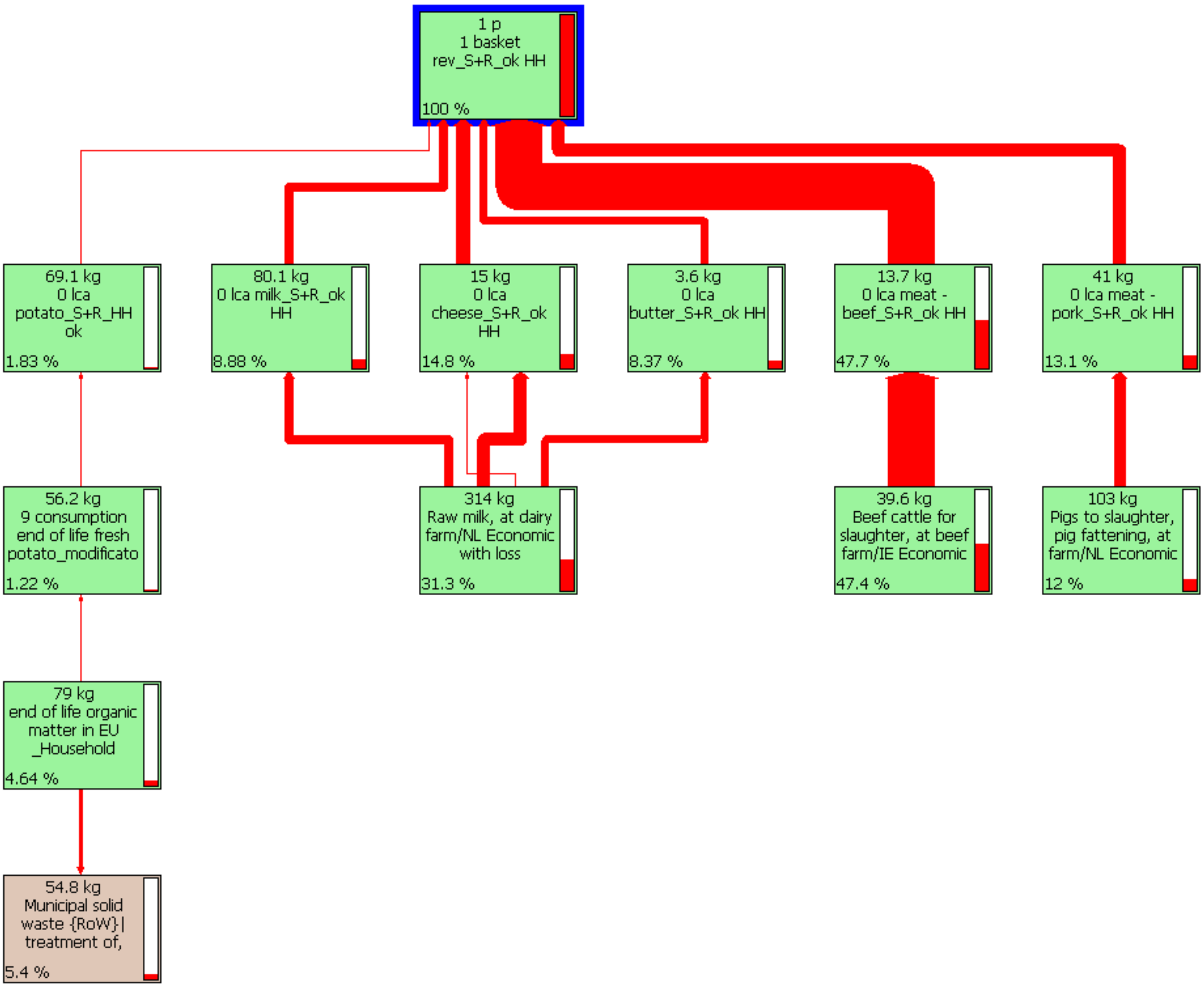
Figure 22. Results of sensitivity to the use of different types of refrigerants. Baseline is the F.U. of the BoP food, with refrigerant R404A used for all the refrigerated storages and transports



Annex 3. Network graphs of the inventory of most contributing elementary flows

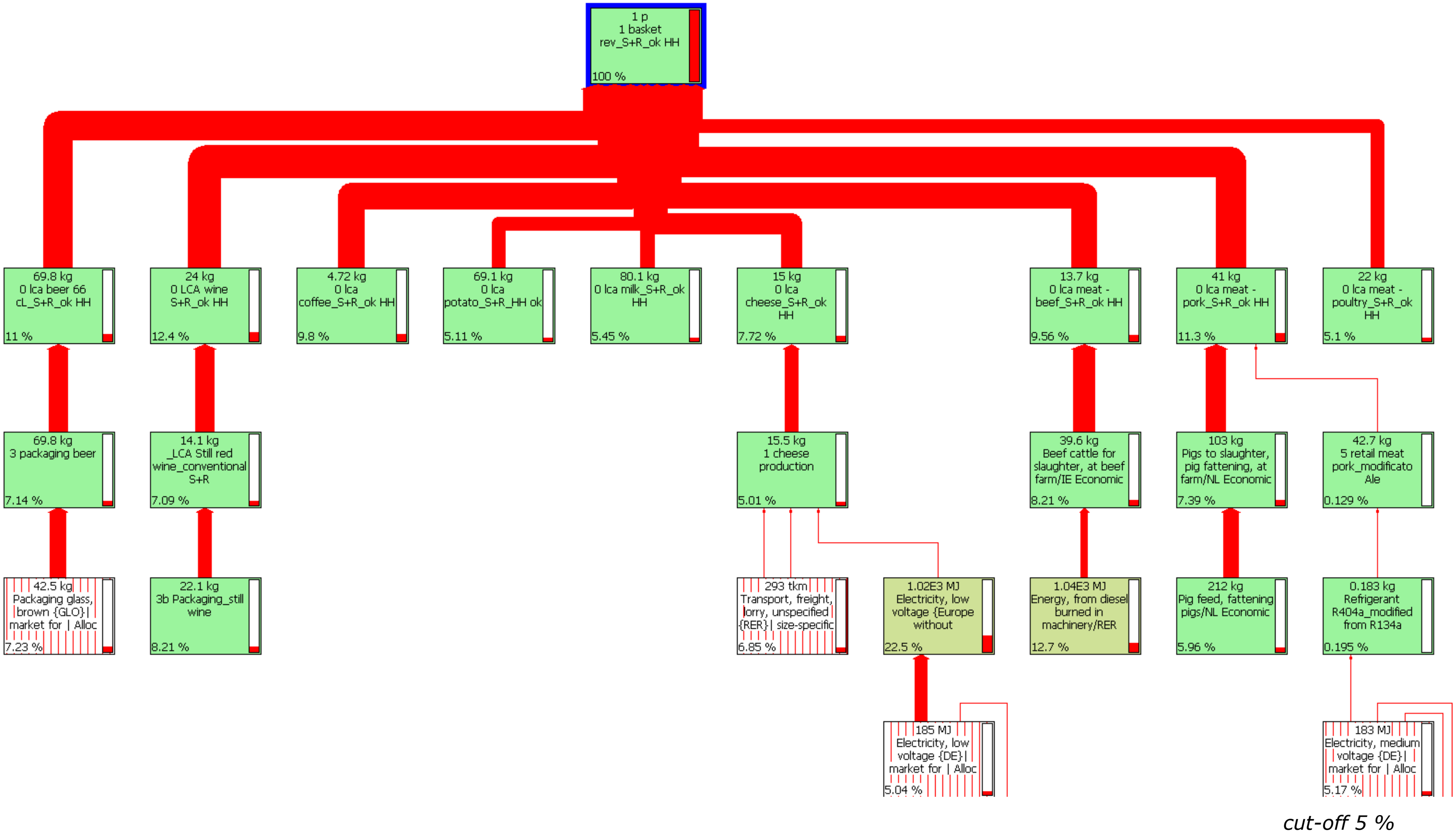
The inventory networks of the most important flow(s) (Table 19) are reported below. The larger the depth of the red arrow going from one process to the related one(s), the larger the contribution of that process to the total amount of the analysed flow in the inventory (e.g., which are the activities that entail higher emissions of nutrients to soil).

Methane, biogenic (contributing to 22.8% of Climate change):

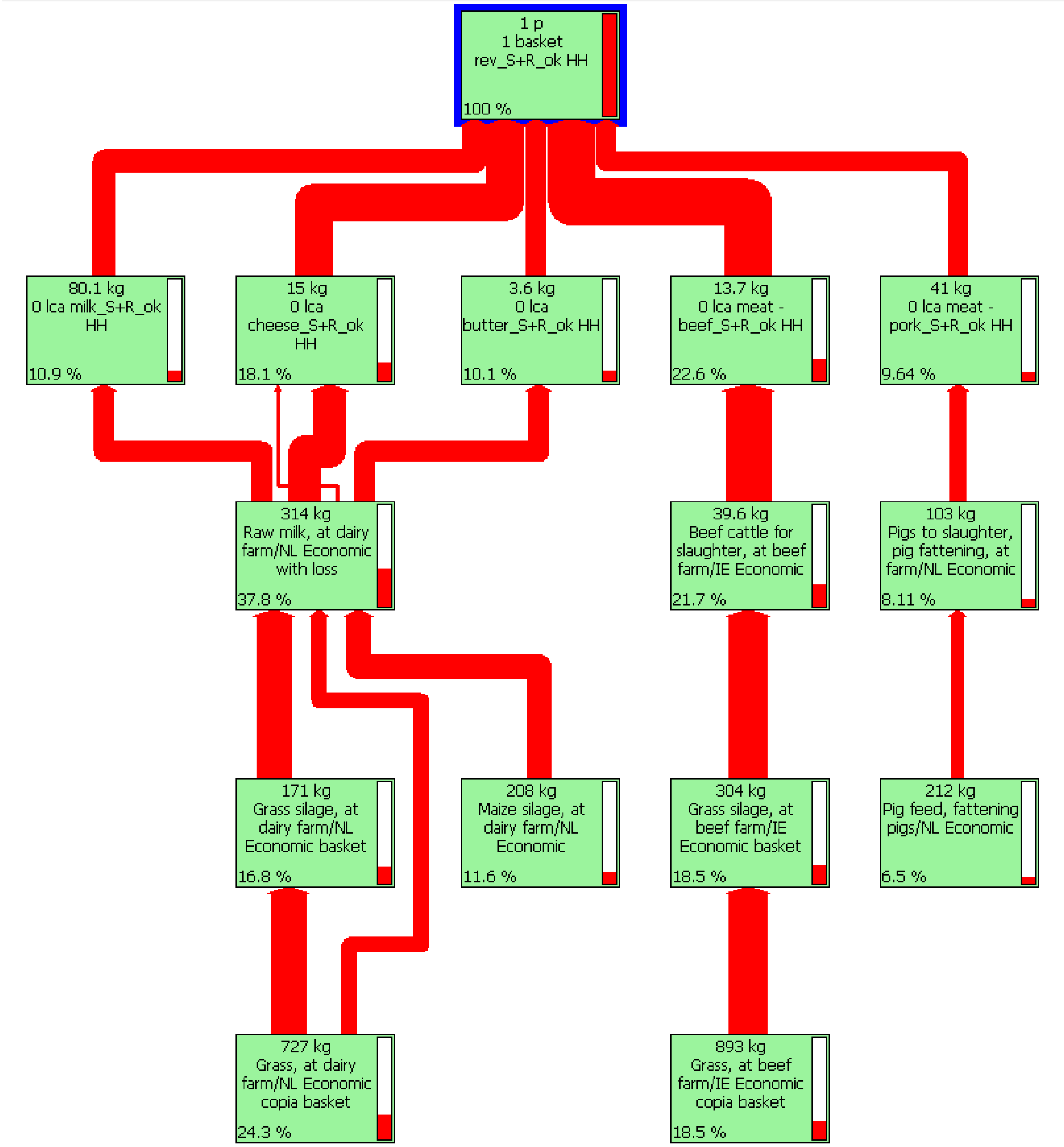


cut-off 5%

CO₂, fossil (contributing to 28.2% of Climate change):

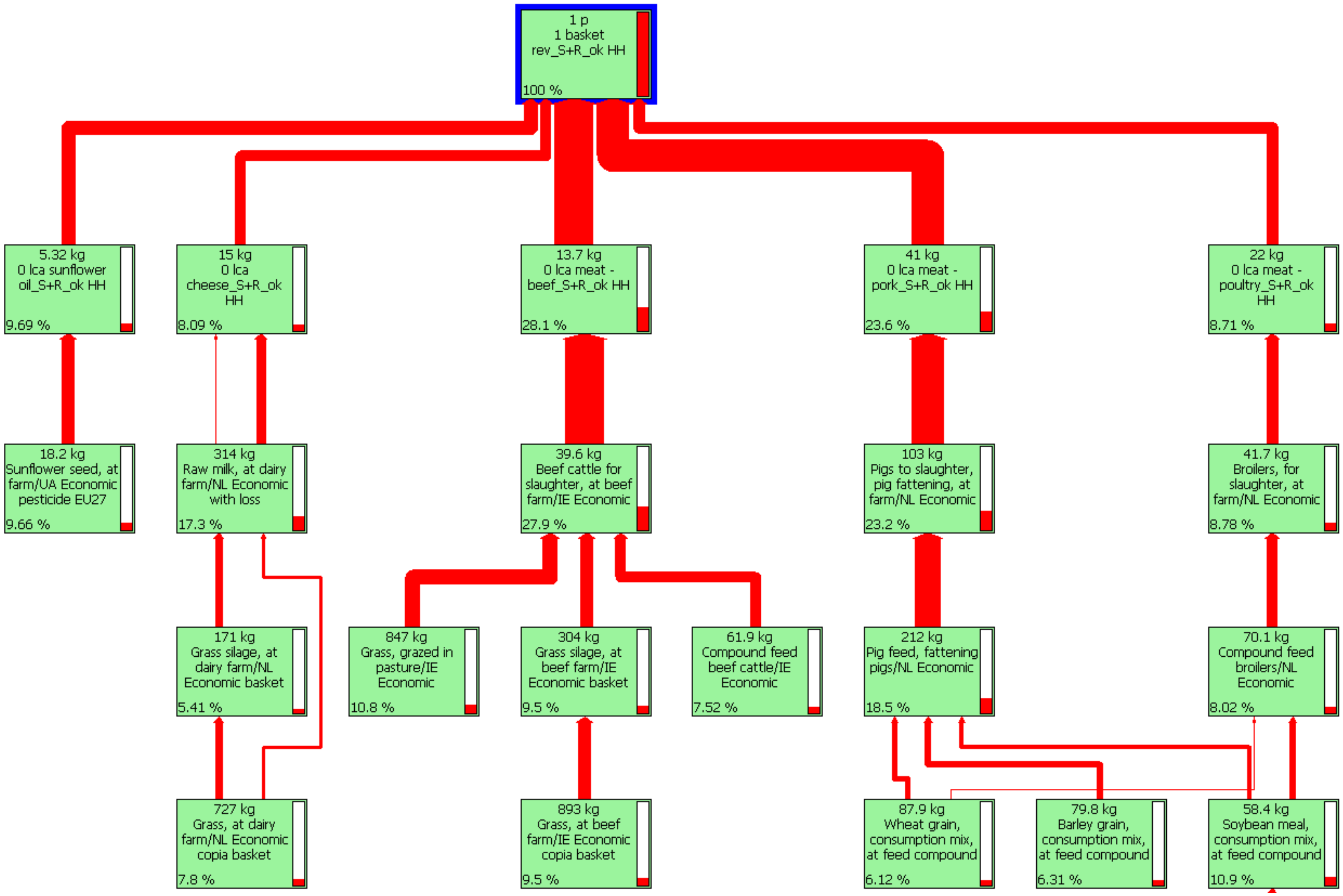


Zinc to soil (contributing to 91.8% of Human tox, non-cancer and 13.7% of freshwater ecotoxicity):

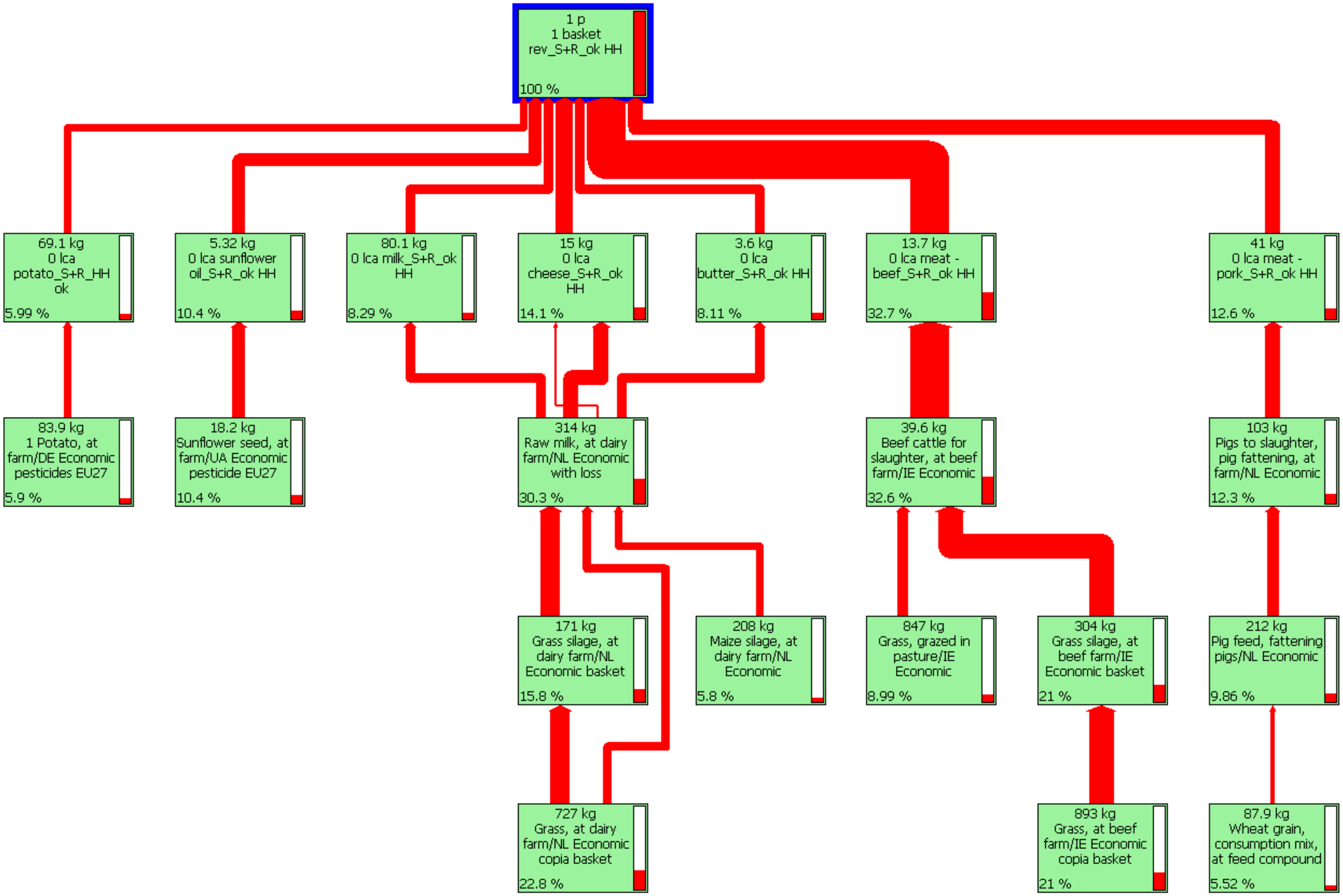


cut-off 5%

Chromium to water (contributing to 55.3% of Human toxicity cancer)

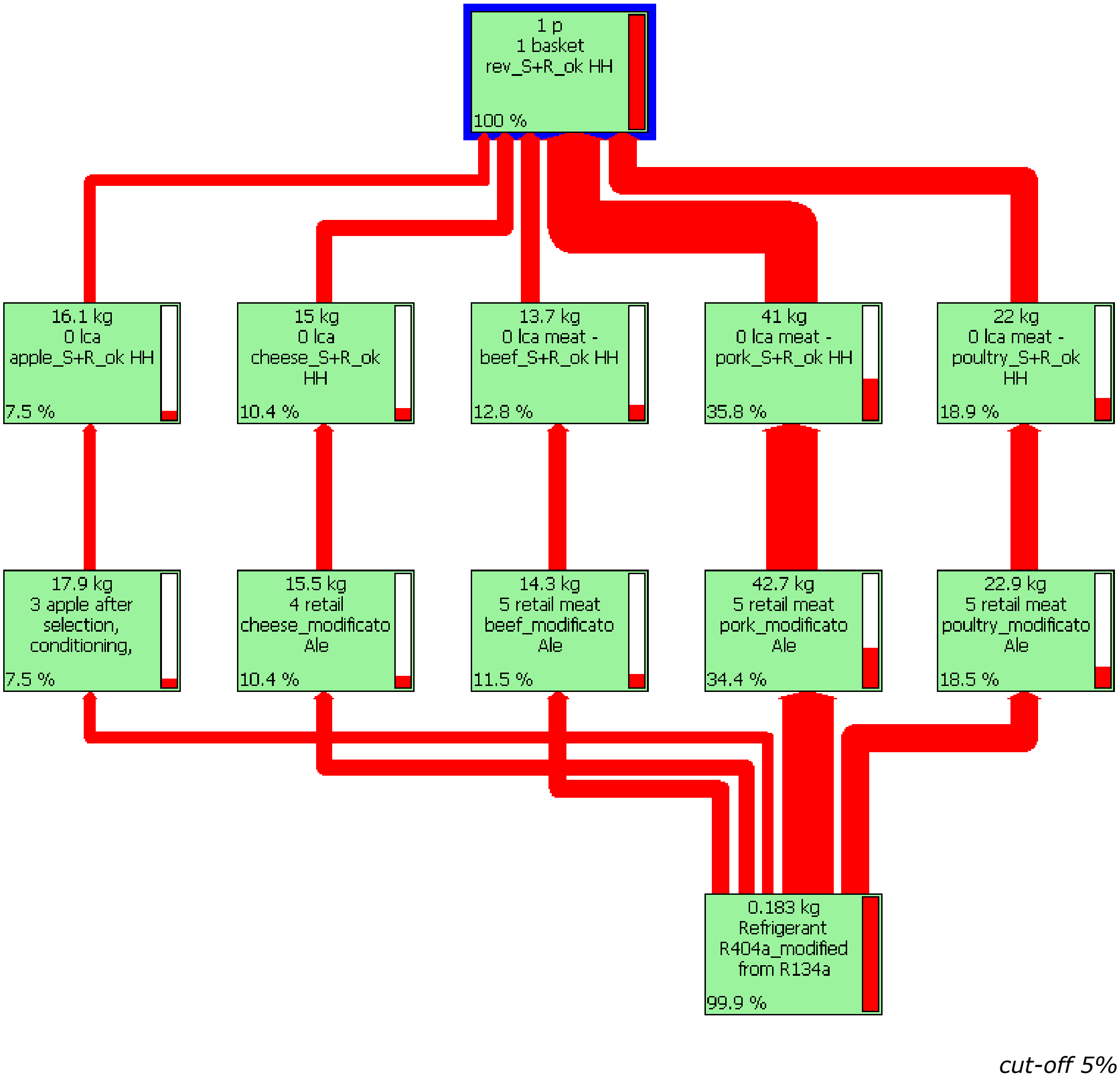


Chromium to soil (contributing to 21.3% of Human toxicity cancer)

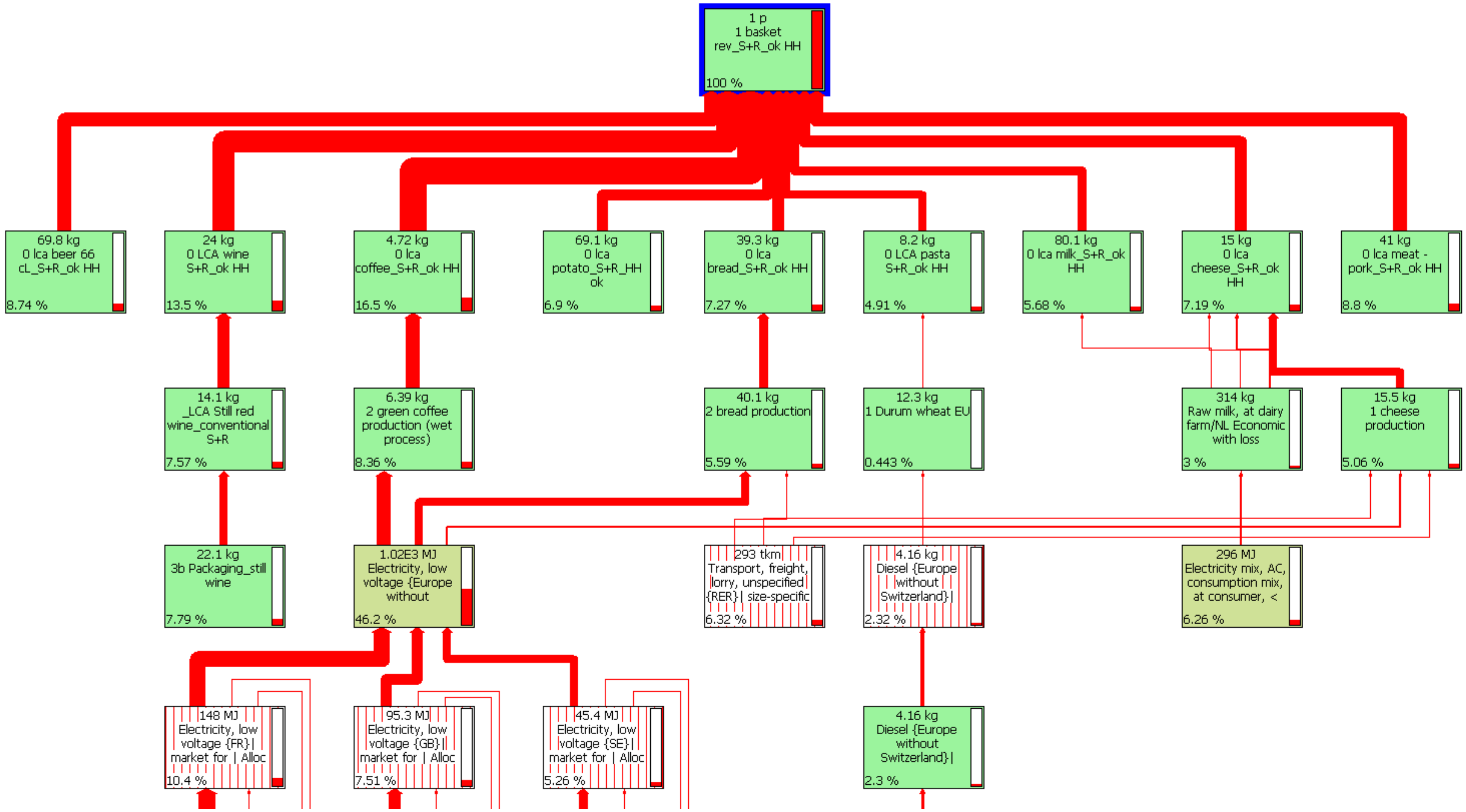


cut-off 5%

CFC-113 (contributing to 92.9% of Ozone depletion)



Carbon-14 to air (contributing to 88.1% of Ionizing radiation)



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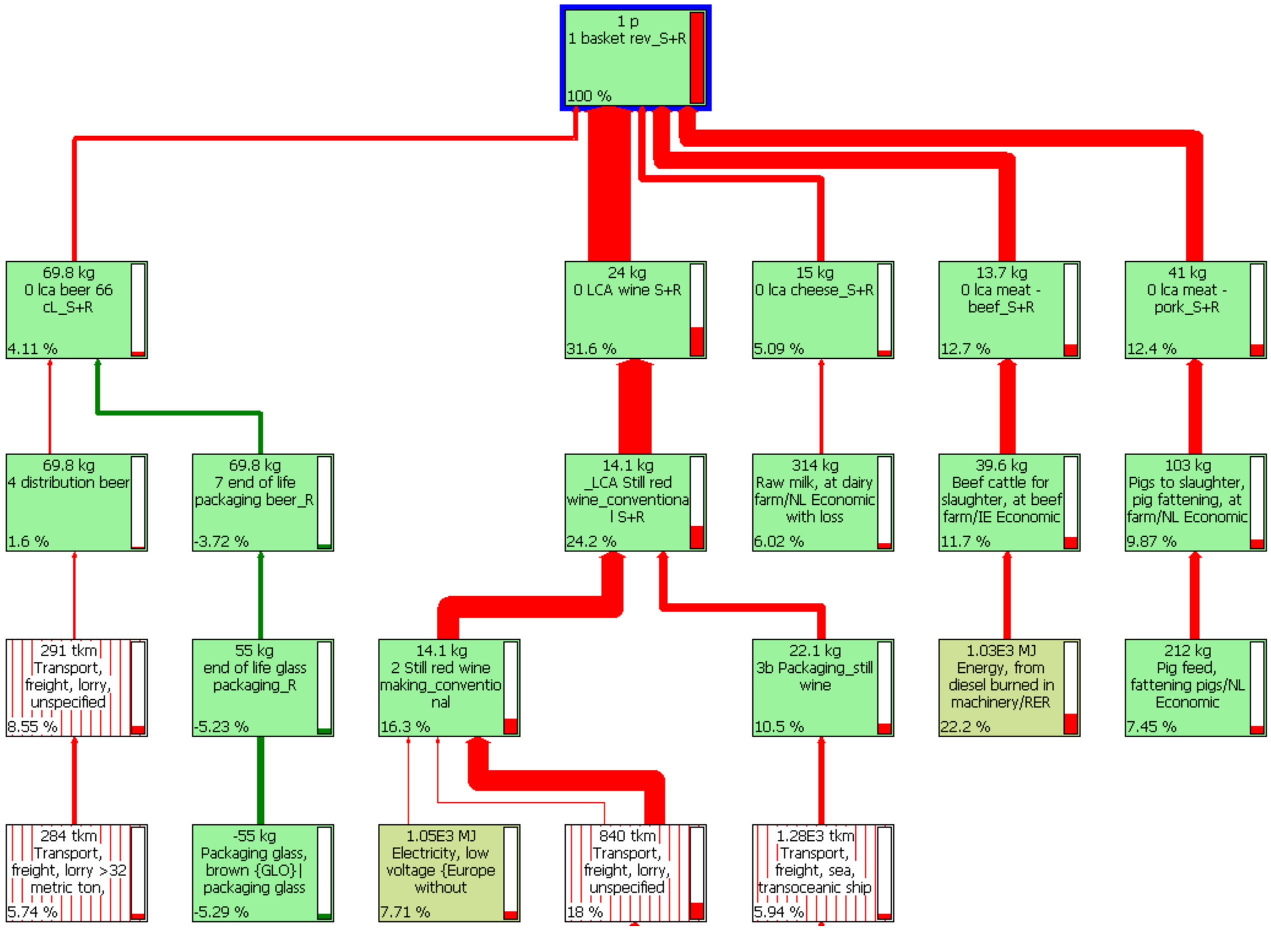
Nitrogen oxides to air (contributing to 69.7% of Photochemical ozone formation)



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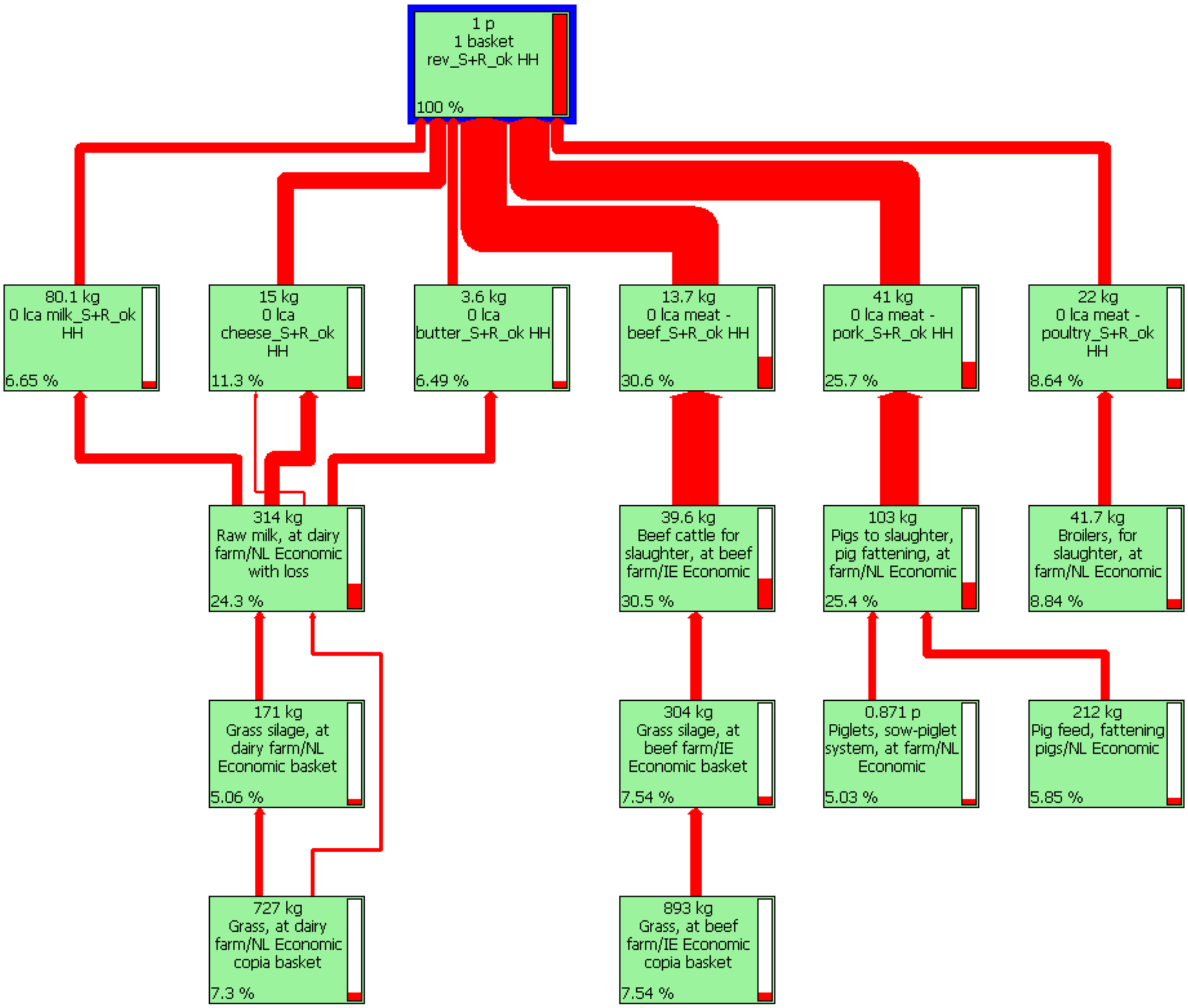
Ammonia to air (contributing to 86.3% of Acidification, 91.0% of Terrestrial eutrophication, 65.2% of Particulate matter)



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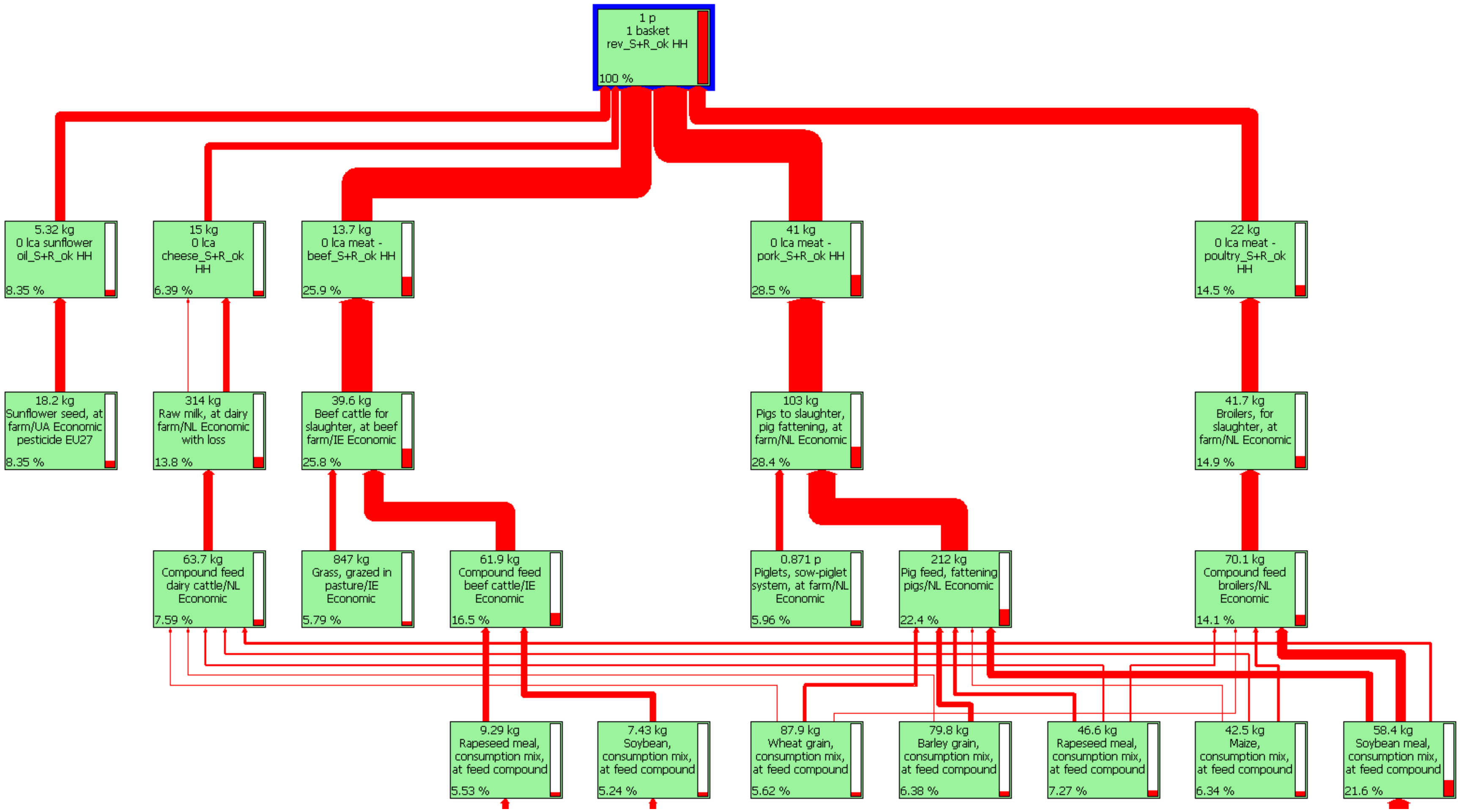
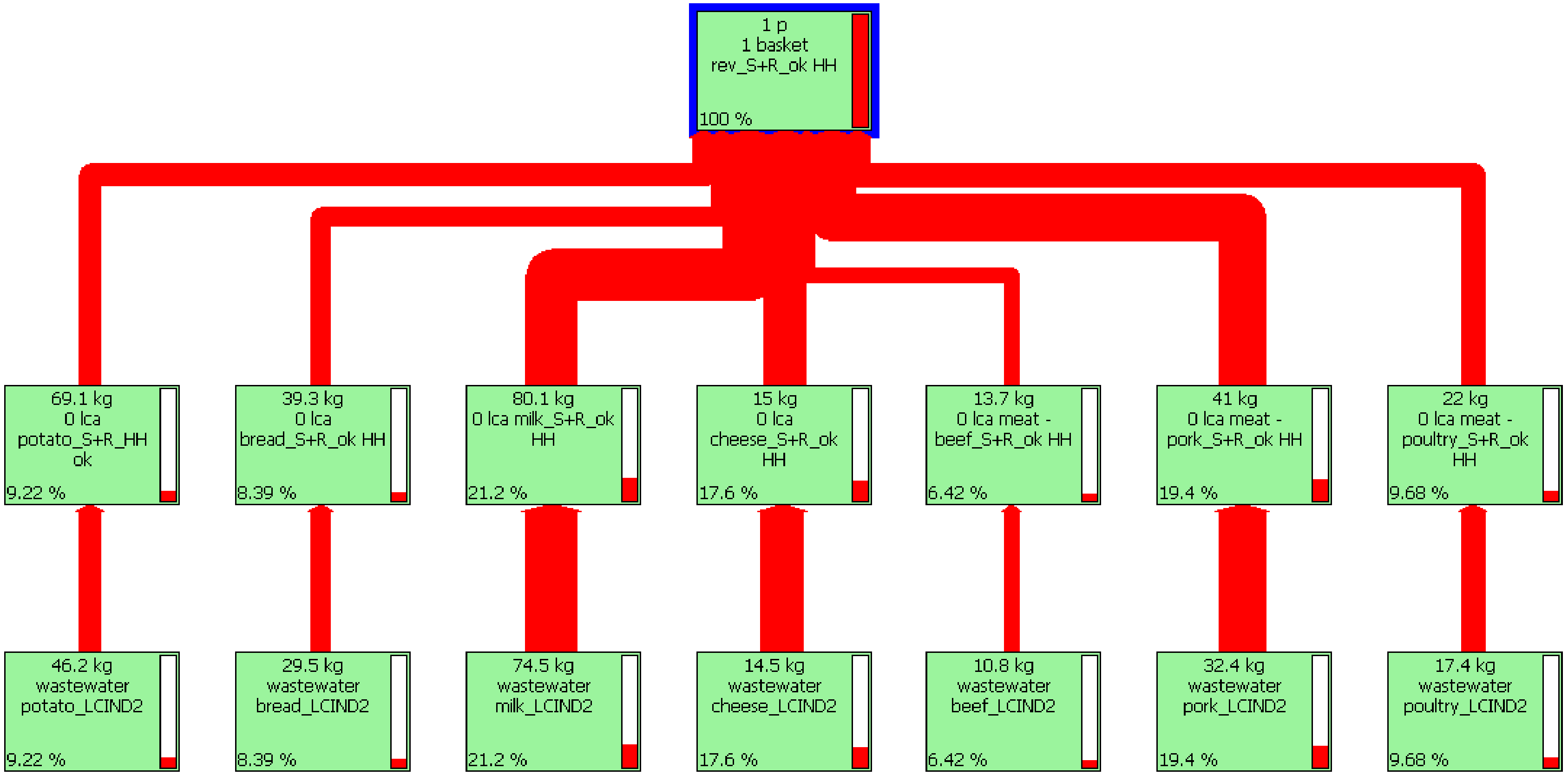
Fertiliser, applied (P component), to soil (contributing to 37.3% of Freshwater eutrophication)



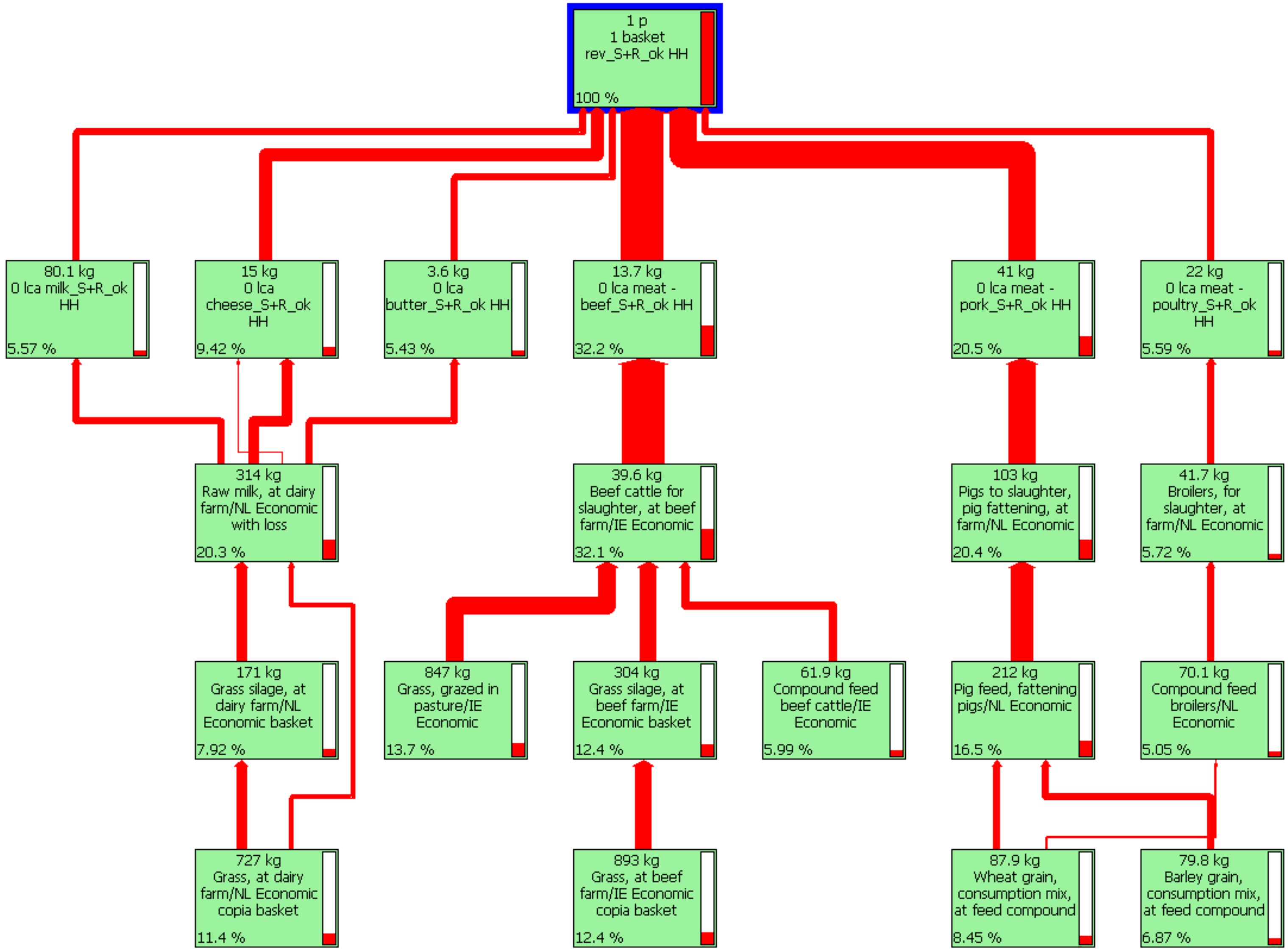
cut-off 5%

Phosphorus, total to water (contributing to 32.1% of freshwater eutrophication)



cut-off 5%

Nitrate to water (contributing to 67.6% of marine eutrophication)



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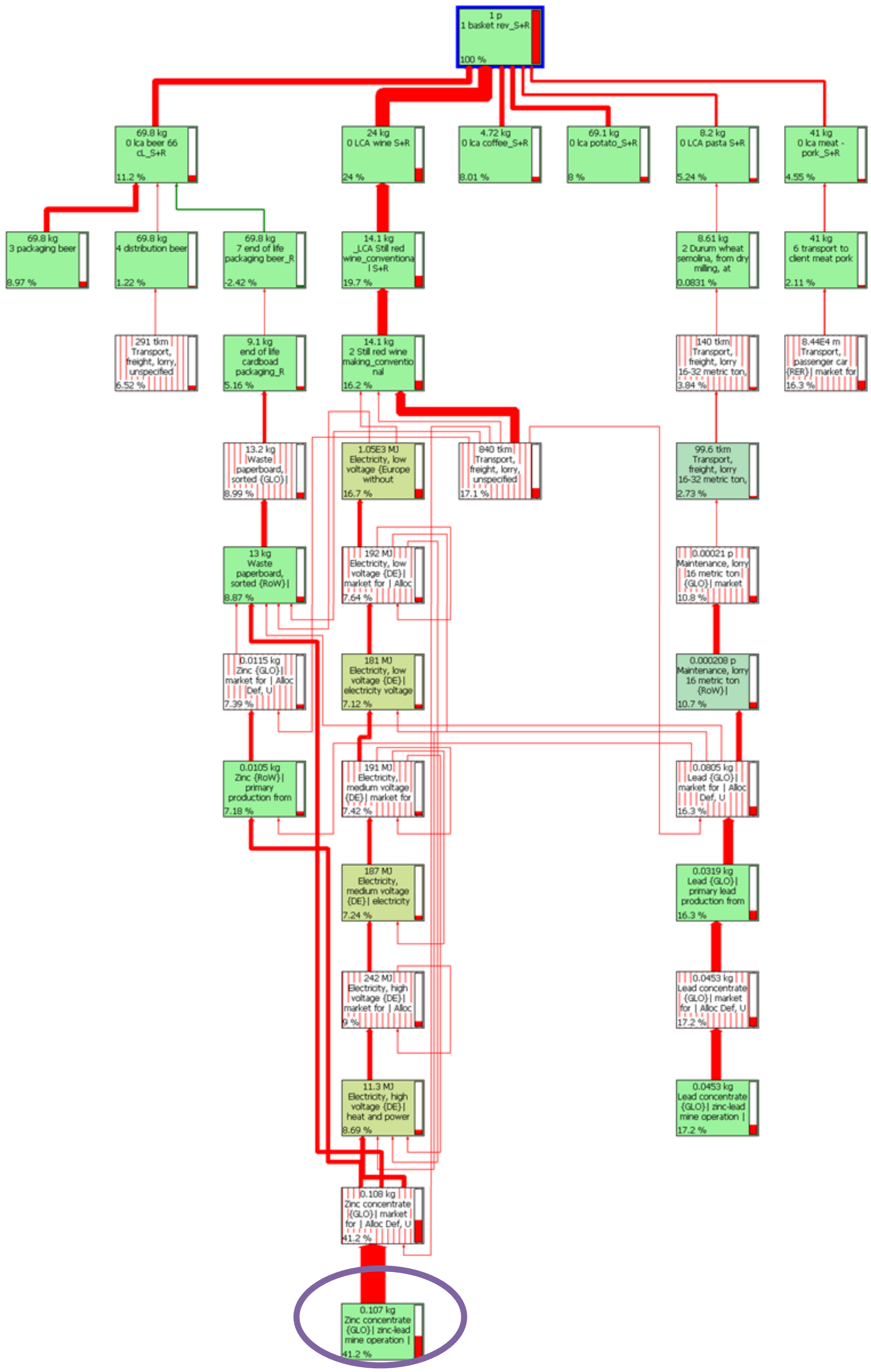
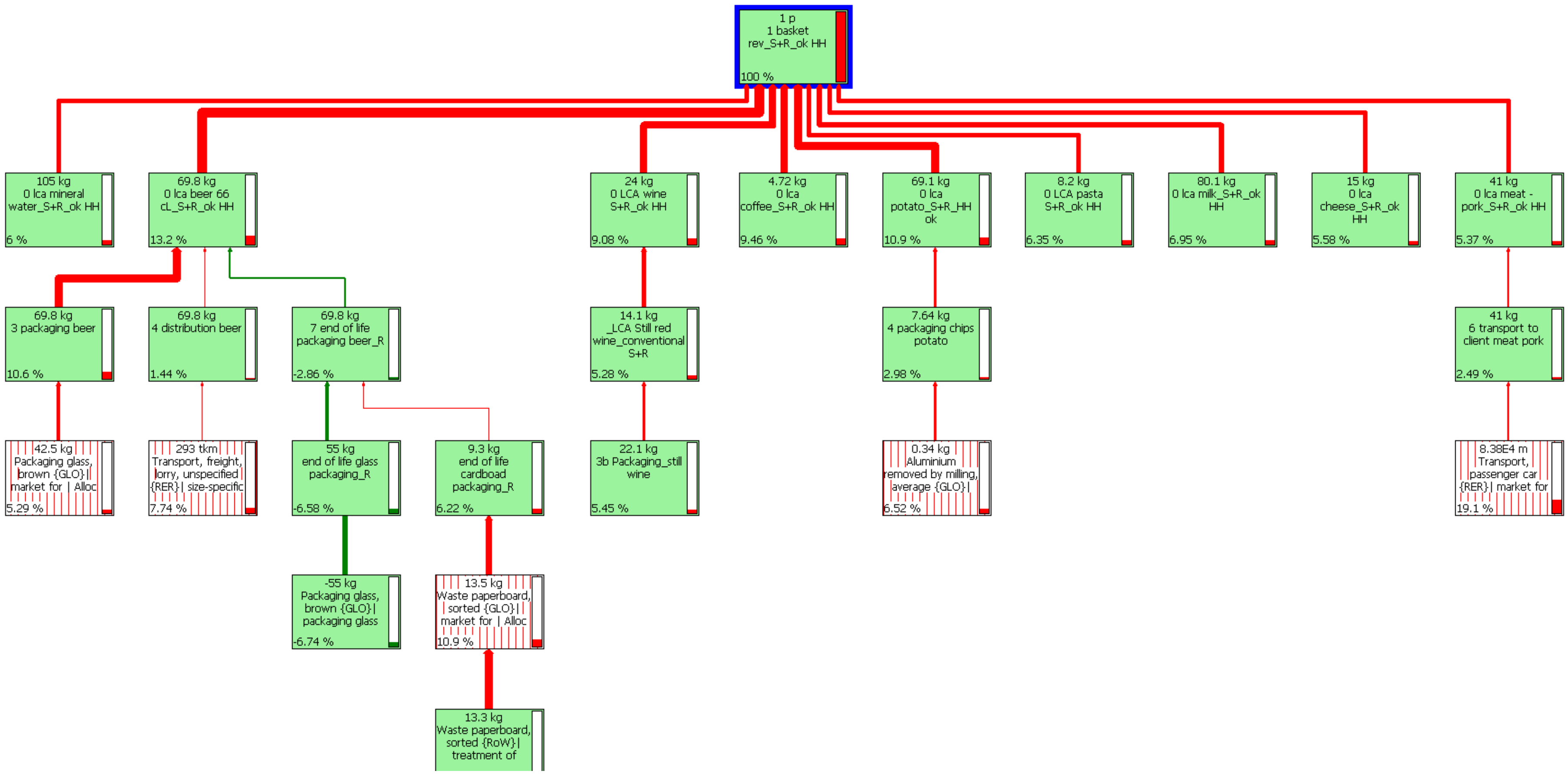
Indium (contributing to 69.3% of resource depletion)



The relevance of Indium, associated to zinc production is due to the economic allocation of the inventory related to mining. For this reason, we evaluated also the distribution of Cadmiun, second in the relevance list for Mineral resources, within the inventory of BoP food.

Cadmium (contributing to 8.3% of resource depletion)



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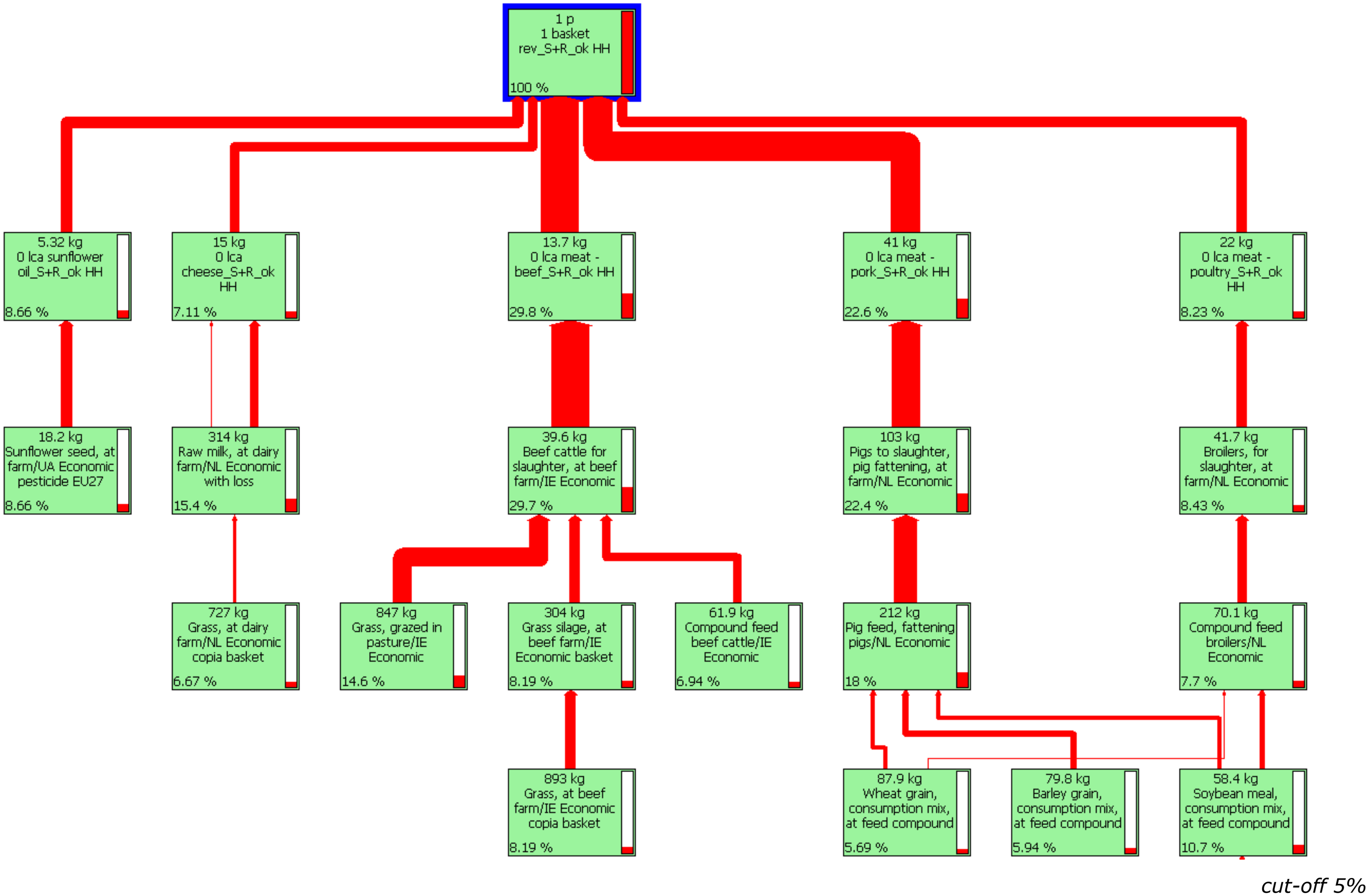
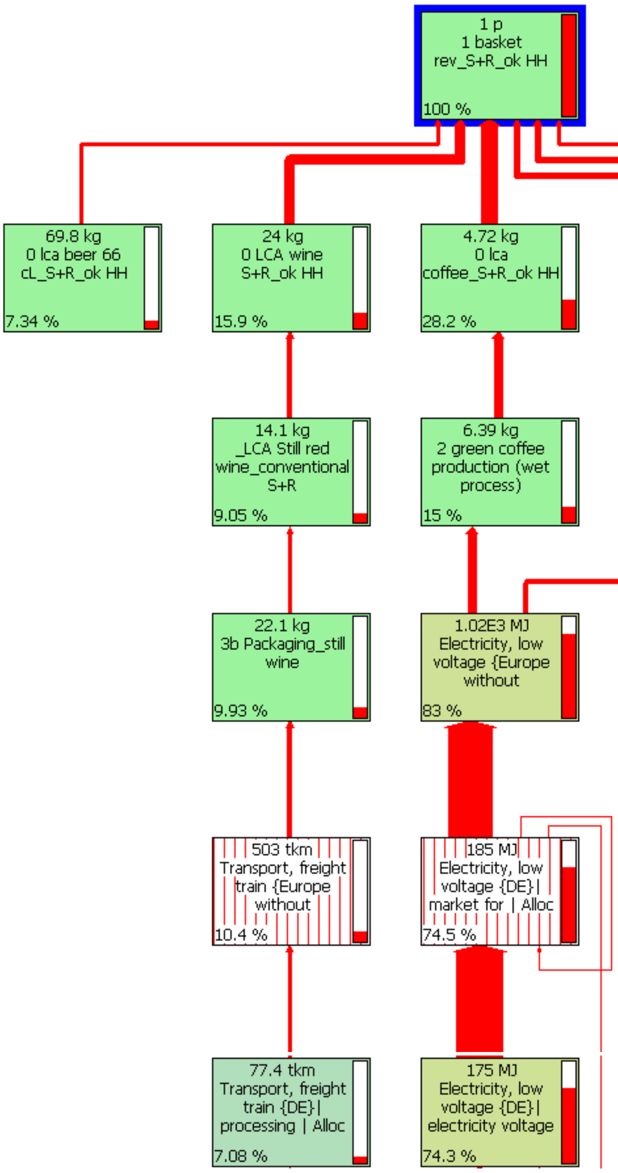
Occupation, arable (contributing to 44.6% of land use)



Water, cooling, unspecified natural origin, DE (contributing to 11.4% of water depletion)



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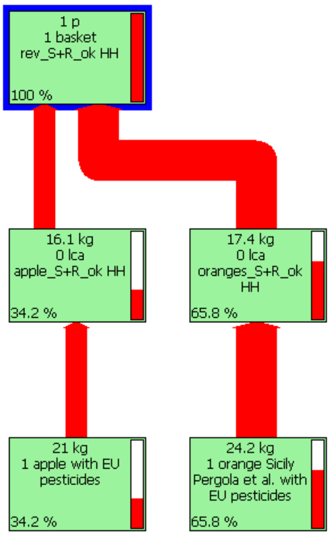
Water, unspecified natural origin, IT (contributing to 11.6% of water depletion)



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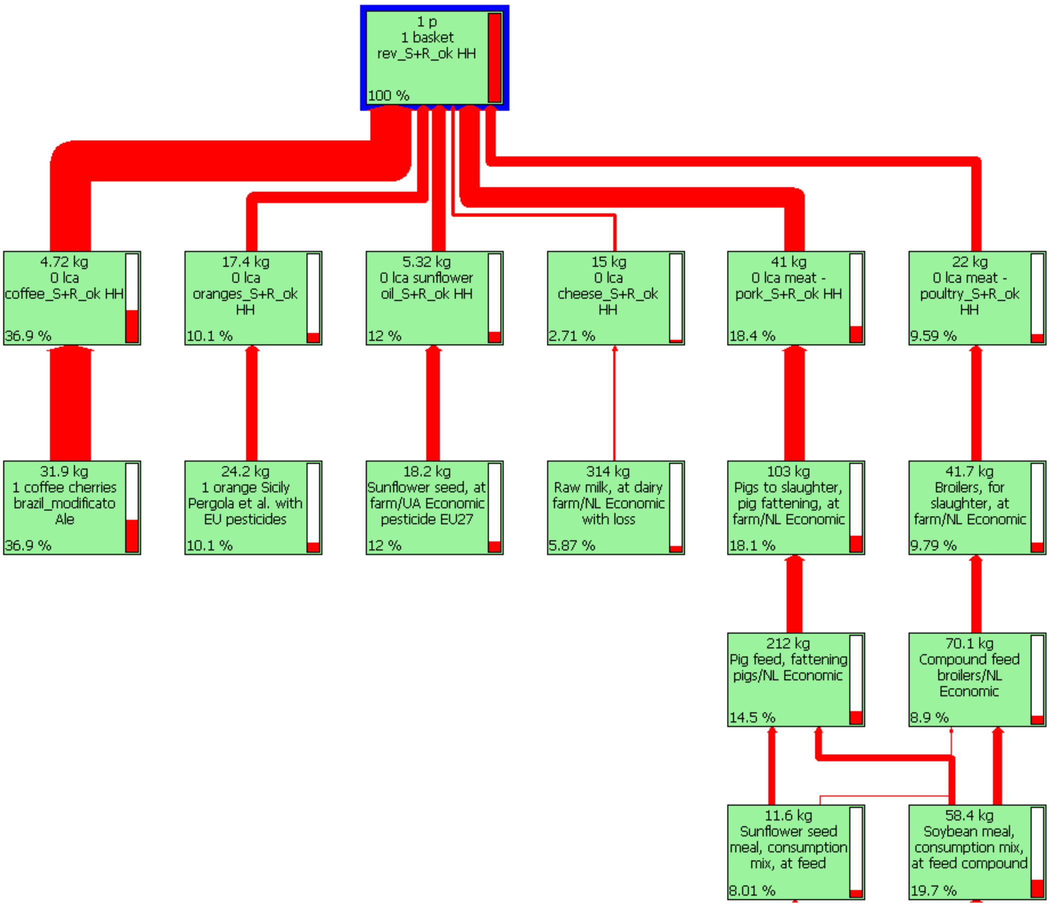
Chlorpyrifos to soil (contributing to 21.2% of freshwater ecotoxicity)



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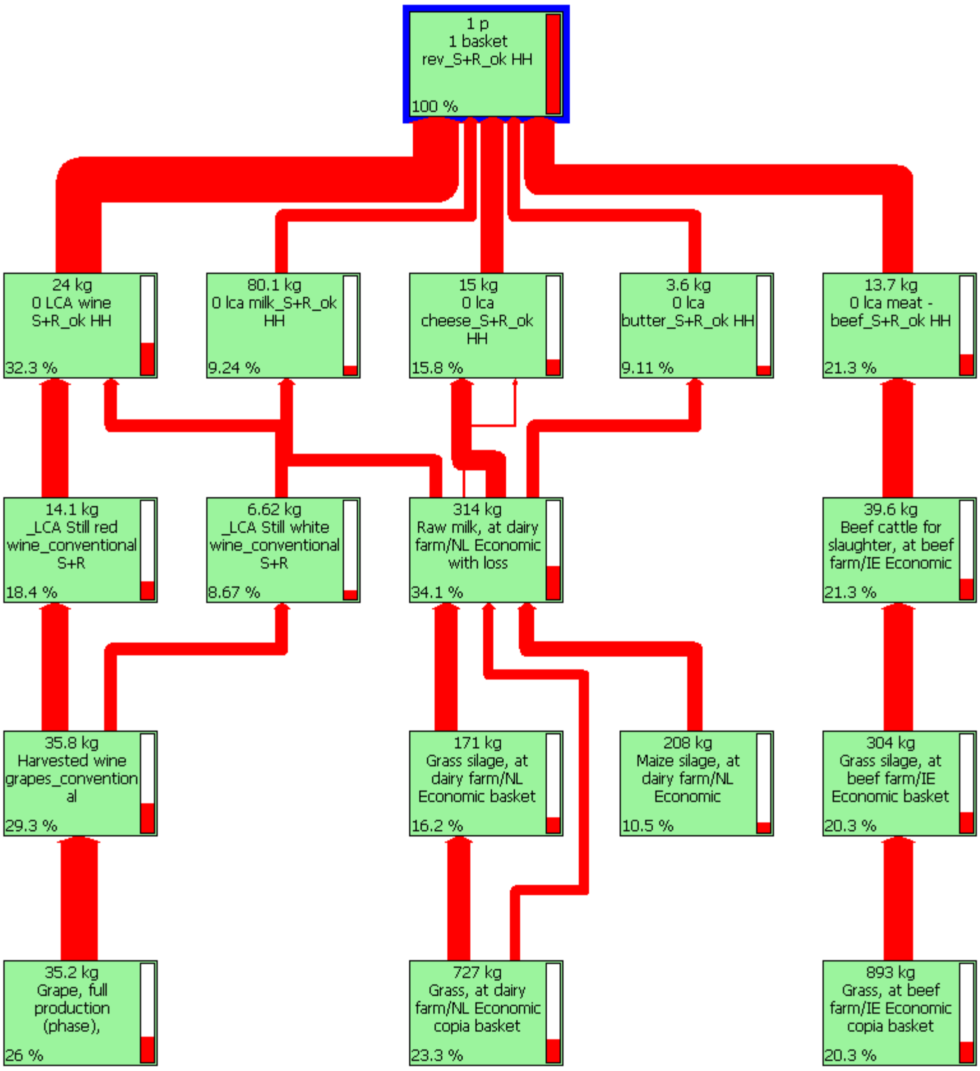
Copper, to soil (contributing to 19.6% of freshwater ecotoxicity)



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