Working Document

Food Wastage Footprint

Impacts on natural resources

Technical Report

About this document

The Food Wastage Footprint model (FWF) is a project of the FAO Natural Resources and Management Department, funded by Germany.

This Technical Report of the FWF model presents the results of Phase I of the FWF project, as related to the impacts of food loss and waste on climate, water, and biodiversity. This study is based on the food wastage estimates made by a previous FAO study on global food losses and food waste (FAO 2011a), with minor data adjustments, and primarily uses FAOSTAT data and structure. This Technical Report is not edited nor formally published; however, it is made available electronically for the purpose of transparency regarding data sources and methodological choices used in the FWF model, as published in the document entitled "Food Wastage Footprint: Impacts on Natural Resources. Summary Report" (FAO, 2013).

Phase I of the FWF was implemented by BIO-Intelligence Service, France, especially with the support of BIO-IS staff members Olivier Jan, Clément Tostivint, Anne Turbé, Clémentine O'Connor and Perrine Lavelle. This project also benefited from the contributions of many FAO experts, including: Alessandro Flammini, Nadia El-Hage Scialabba, Jippe Hoogeveen, Mathilde Iweins, Francesco Tubiello, Livia Peiser and Caterina Batello.

Phase II of the FWF project is refining this study and taking further food wastage environmental accounting research.

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Executive summary

FAO estimates that each year, approximately one-third of all food produced for human consumption in the world is lost or wasted. This food wastage represents a missed opportunity to improve global food availability, but also to mitigate environmental impacts and resources use along the food chain. Although there is wide recognition of the major environmental implications of food production, no study has yet analysed the impacts of global food wastage from an environmental perspective.

This FAO study provides a global account of the environmental footprint of food wastage focusing on the impact of that wastage on climate, water, land and biodiversity. For this study, "wastage" incorporates both food loss and food waste along the food supply chain and a model has been developed to answer two key questions: What is the magnitude of food wastage impact on the environment? What are the main sources of these impacts, in terms of regions, commodities and phases of the food supply chain involved – with a view to identify "environmental hotspots" related to food wastage?

The scope of this study is global. It identifies and focuses on seven geographical regions and considers a wide range of agricultural products – representing eight major food commodity groups. Impact of food wastage has been assessed along the complete supply chain, from the field, through processing, distribution, and consumption, to disposal of food.

The global volume of food wastage in 2007 is estimated at 1.6 Gtonnes of "primary product equivalents", while the total wastage for the edible part of food is 1.3 Gtonnes. This amount can be weighed against total agricultural production for food and non-food uses, which is about 6 Gtonnes.

Without accounting for GHG emissions from land use change, the carbon footprint of food produced and not eaten is estimated at 3.3 Gtonnes of CO_2 equivalent. As such, food wastage ranks as the third top GHG emitter after USA and China. Globally, the blue water footprint of food wastage – the consumption of surface and groundwater resources – is about 250 km^3, which is equivalent to the annual water discharge of the Volga river, or three times the volume of Lake Geneva. Finally, produced but uneaten food occupies almost 1.4 billion hectares of land, representing close to 30 percent of the world's agricultural land area. While it is difficult to estimate its impact on biodiversity at global level, food wastage unduly compounds the negative impact that monocropping and agriculture expansion into wild areas have on loss of biodiversity, including mammals, birds, fish and amphibians.

The loss of land, water, and biodiversity, as well as the negative impacts of climate change represent huge costs to society that are yet to be quantified. The direct economic cost of wastage of agricultural food products (excluding fish and seafood), based on producer prices only, is about USD 750 billion, equivalent to the GDP of Switzerland.

With such figures, it becomes clear that a reduction of food wastage at global, regional, and national scales would have a substantial positive effect on natural and societal resources. Reducing food wastage would not only avoid pressure on scarce natural resources, it would mean more food is available for consumers. This, in turn, would enable re-tallying the projection that food production will need to increase by 60 percent by 2050 in order to meet demand of the increasing population.

This study highlights global environmental hotspots related to food wastage at regional and subsectoral levels, for consideration by decision-makers wishing to engage in waste reduction.

Wastage of cereals in Asia emerges as a significant problem for the environment, with major impacts on carbon, blue water, and arable land. Rice represents a significant share of these impacts, given the high carbon-intensity of rice production methods (e.g. paddies are major emitters of methane), combined with high quantities of rice wastage.

Wastage of meat, even though wastage volumes in all regions is comparatively low, generates a substantial impact on the environment in terms of land occupation and carbon footprint, especially in high income regions (that waste about 67 percent of meat) and Latin America.

Fruit wastage emerges as a blue water hotspot in Asia, Latin America, and Europe because of food wastage volumes.

Vegetables wastage in industrialized Asia, Europe, and South and South East Asia constitutes a high carbon footprint, mainly due to large wastage volumes.

By highlighting the magnitude of the environmental footprint of food wastage by regions, commodities or phases of the food supply chain, this study will enable actions to be defined and prioritized for the various actors contributing to resolving this global challenge.

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Chapter 1. Context and objectives of the study

1.1 Context

In 2010, FAO commissioned the Swedish Institute for Food and Biotechnology (SIK) to carry out a study on global food losses and food waste (FAO 2011a). This work, published in 2011, reported that each year one-third of all food produced for human consumption in the world is lost or wasted due to a variety of reasons that differ between countries. This corresponds to a volume of 1.3 billion metric tonnes of edible food being lost or wasted annually.

Food is lost or wasted throughout the supply chain, from initial agricultural production down to final household consumption. Food loss refers to the decrease in edible food mass at the early stages of the food chain such as production and postharvest handling. This occurs mostly in developing countries. Food waste refers to the discard of foodstuff at the retail and consumption levels and is typical of lifestyles observed in high-income countries.

This recent FAO study along with previous work (Lundqvist et al. 2008; T. Stuart 2009; Parfitt et al. 2010) – confirm that this is a global problem of tremendous proportions.

In addition, by 2050 food production will need to be 60% higher than in 2005/2007 to meet the increasing world population's demand (Alexandratos & Bruinsma 2012). In this context, it is rather surprising to note that not much research is ongoing in this area in spite of the fact that this food wastage obviously represents a missed opportunity to improve global food security.

To complete the picture, one can underline that this produced but uneaten food has significant environmental and economic costs. It is commonly said that food chains have major environmental impacts (UNEP 2010a; European Commission 2006). Foodstuffs we consume have embedded environmental impacts because of energy and natural resources inputs as well as associated emissions generated throughout their life cycle.

To date, no study has analysed the impacts of global food wastage from both an environmental and an economic perspectives.

1.2 Objectives

In this context, this project of FAO's Natural Resources Management and Environment Department primarily focuses on the environmental impacts of food losses and waste. The study is based on the previous FAO study on food loss and waste (FAO 2011a) – aspects such as technical definitions, grouping of the world regions and food commodity groups, slightly adjusted food wastage quantifications, etc. – and builds on it.

The aim of the project is to provide a worldwide account of the environmental footprint of food wastage along the food supply chain, focusing on impacts on climate, water, land, and biodiversity. The model that was developed for this purpose seeks to answer one key question: "Where do the impacts come from?" This implies to pinpoint the major contributors to the footprint that is to say regions, commodities, or phases of the food chain considered as "environmental hotspots".

Ultimately, the goal is to bring more precision to the debate on the environmental impacts of food waste and losses, by providing a more consistent knowledge base, which can be used to underpin future policy debate in this area.

1.3 Structure of the report and tasks of the FWF project

This report presents the outcomes of the following tasks of the FWF project:

Literature review

This project started with a literature review on food wastage and related environmental impacts. Key methodological choices are presented in Chapter 2. The screened data sources are presented in Annex I.

In addition, it should be stressed that food wastage is an issue that connects with a number of other topics. A mind map was designed with the objective to represent the various concepts related to food wastage. This mind map is presented in Annex II.

Data collection

A consistent data collection within and outside FAO with the perspective of identifying and selecting data to feed the model was performed. A summary of the data used in the FWF project is presented in Annex III. Data selected for each component are further described in dedicated sections of Chapter 3.

Development of a Food Wastage Footprint model (FWF model)

The aim of the FWF model is to quantify the environmental impacts of food wastage and potential benefits through its mitigation. The FWF model is presented in Chapter 3. Its results are presented in Chapter 4.

Levers for potential reductions of food wastage volumes/impacts

Causes of food wastage and potential levers for its reduction are presented in Chapter 5.

Limitations of the study and potential improvement

Limitations of the study and potential improvement areas for future research are discussed in Chapter 6.

Chapter 2. Methods

There are three main sections in this chapter. Firstly, the definition of food wastage retained in this study is presented. This is a key issue since the concept of food wastage is complex and has multiple meanings in the literature. Secondly, the geographical and food product's scopes are detailed. Choices made for this research are in line with the work realised for the previous FAO (2011) study and with the FAOSTAT database structure. Finally, the third section describes the general framework used for the assessment of the environmental and economic components.

2.1 Definitions

2.1.1 Food loss, food waste and food wastage

This study builds on the following definitions adapted from FAO's previous work (FAO 2011a; FAO 2012a).

Food loss

Food loss is a decrease in edible food mass at the production, post-harvest, processing and distribution stages in the food supply chain. These losses are mainly caused by inefficiencies in the food supply chains, such as poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, no access to markets. In addition, natural disasters play a role.

Food waste

Food waste refers to food appropriate for consumption being discarded, usually at the retail and consumer levels.

Food wastage

Food wastage refers to any food lost by deterioration or waste. Thus, the expression "food wastage" encompasses both food loss and food waste.

2.1.2 Food wastage accounted in this study

Food directed to human consumption

Similarly to FAO (2011), food wastage amounts presented in this study cover products that are directed to human consumption. Therefore, food that was originally grown in the perspective of human consumption but which unwittingly leaves the human food chain is considered as food loss or food waste, even if it is afterwards directed to a non-food use such as feed or bioenergy.

This approach actually distinguishes "planned" non-food uses vs. "unplanned" non-food uses, which are hereby regarded as losses.

Edible part and non-edible part of food

This study aims at assessing the environmental impacts of food wastage. Since environmental impacts relate to the entire product and not its edible part only, wasted and lost food products are taken as a whole in the footprint calculations (i.e. no "conversion factors" are applied, see section 3.1.3 for details).

Note that for informative purposes, food wastage volumes are presented in two different ways: 1/ food wastage arisings considering the full products and 2/ food wastage arisings with edible parts only (see section 4.1.1).

Moreover, it can be mentioned that some studies such as WRAP (2010) further distinguish among edible food waste the "avoidable" and "possibly avoidable" food waste (parts of e.g. fruit, bread or meat that some people eat, others not). Such distinction is not made in FAO (2011) nor in the present study.

Animal feed

Some studies such as UNEP (2009) consider that grains used for feeding livestock and fishes of aquaculture are wastage. The underlying idea is that conversion efficiency of grains to produce animal protein is low and thus represents a loss of food. This methodological choice is not retained in FAO's work on food wastage (FAO 2011a) nor in the present study. Indeed, it can lead to large discrepancies in the quantification of food wastage volumes.

The present study does not consider feed as food wastage and agricultural products given to animals are not accounted in the food wastage volumes. However, from an environmental footprint point of view, impacts of feed are indirectly accounted through the impacts of wasted / lost animal products (e.g. impacts of 1 kg of wasted beef meat bears a part of the impact of "indirectly wasted" grains used to feed the animal).

2.2 Scope

2.2.1 Grouping of world regions

The geographical scope of the study is global, the world being divided in seven world regions and 21 sub-regions as presented in Table 1. This distribution is similar to FAO (2011) and these sub-regions correspond to the available FAOSTAT's Food Balance Sheets (FBS) as shown by the FAO country codes (see Table 1).

This grouping choice is made for data treatment reasons so that food quantities and food wastage percentages taken respectively from these two latter sources can easily fit in the FWF model (see section 3.1.2), and maximise the data's and results' accuracy.

Table 1: World regions selected for the project

Region #	Region name	Region short name	Sub-region #	Sub-region name	FAO country code
Region 1	**Europe**	Europe	R1-1	Europe	5400
Region 2	**North America & Oceania**	NA&Oce	R2-1	Australia	10
			R2-2	Canada	33
			R2-3	New Zealand	156
			R2-4	USA	231
Region 3	**Industrialized Asia**	Ind. Asia	R3-1	China	351
			R3-2	Japan	110
			R3-3	Republic of Korea	117
Region 4	**Sub-Saharan Africa**	SSA	R4-1	Eastern Africa	5101
			R4-2	Middle Africa	5102
			R4-3	Southern Africa	5104
			R4-4	Western Africa	5105
Region 5	**North Africa, Western Asia & Central Asia**	NA,WA&CA	R5-1	Central Asia	5301
			R5-2	Mongolia	141
			R5-3	Northern Africa	5103
			R5-4	Western Asia	5305
Region 6	**South & Southeast Asia**	S&SE Asia	R6-1	South-Eastern Asia	5304
			R6-2	Southern Asia	5303
Region 7	**Latin America**	LA	R7-1	Caribbean	5206
			R7-2	Central America	5204
			R7-3	South America	5207

2.2.2 Commodity groups

The study covers a wide range of agricultural products. Eight food commodity groups further divided in 21 food sub-commodity groups are addressed. These groups are built from available FBS aggregated categories (see FBS category codes in Table 2) and encompass a range of products that is identical to FAO (2011). These products can be either processed or unprocessed (i.e. primary products – see Box 1).

Similarly to world regions, this grouping choice is made to allow efficient integration of existing data on food quantities and food wastage percentages.

Table 2: Agricultural commodity groups selected for the project

Commodity #	Commodity name	FBS category code	Commodity name abbreviation	Sub-commodity #	Sub-commodity name
Commodity 1	**Cereals (excluding beer*)**	2905	Cereals	C1-1	Wheat + Rye
				C1-2	Oats + Barley + Cereals, other
				C1-3	Maize
				C1-4	Rice
				C1-5	Millet + Sorghum
Commodity 2	**Starchy roots**	2907	SR	C2-1	Starchy roots
Commodity 3	**Oilcrops & Pulses**	2913&2911	O&P	C3-1	Oilcrops
				C3-2	Pulses
Commodity 4	**Fruits (excluding wine*)**	2919	Fruits	C4-1	Apples
				C4-2	Bananas
				C4-3	Citrus
				C4-4	Grapes
				C4-5	Fruits, other
Commodity 5	**Meat**	2918	Meat	C5-1	Bovine Meat
				C5-2	Mutton & Goat Meat
				C5-3	Pig Meat
				C5-4	Poultry Meat
Commodity 6	**Fish & Seafood**	2960	F&S	C6-1	Fish & Seafood
Commodity 7	**Milk (excluding butter**) & Eggs**	2948	M&E	C7-1	Milk
		2949		C7-2	Egg
Commodity 8	**Vegetables**	2918	Veg.	C8-1	Vegetables

* In the FBS, beer (and thus, the barley – or other cereal – used to produce beer) and wine (and thus, the grapes used to produce wine) are accounted for in the category "Alcoholic Beverages" (FBS code 2924). Similarly to the FAO (2011) study, this product category is not the scope of the present study.

** In the FBS, butter is accounted for in the category "Animal Fats" (FBS code 2946). Similarly to the FAO (2011) study, this product category is not in the scope of the present study.

Box 1: "Primary equivalents" for processed food

The selected commodity groups refer to primary agricultural productions. However, amounts of processed food are included in each category. A detailed list of products in each commodity/sub-commodity group is provided in Annex IV.

The choice of these food commodity groups sticks to the FBS categorisation. This categorisation includes the processed commodities in the sense that all food products are converted back to their primary equivalent, following a "**vertical standardization**" process. For example, quantities of bread are expressed in "wheat equivalent" and added to the originating commodity. Thus, amounts of wheat actually include both wheat flour and wheat flour-derived products with all quantities expressed in "wheat equivalent".

A "**horizontal standardization**" is also applied combining several types of products in a broader category in the FBS. For example, chicken meat, turkey meat and other meats of the poultry family are aggregated as poultry meat in a single line in the standardised food balance sheet.

See Annex V and FAOSTAT website[1] for additional details on FBS.

[1] http://www.fao.org/waicent/faostat/agricult/fbs-e.htm

2.2.3 System boundaries of the assessment

For all commodities, the system studied is based on a **life cycle approach**, covering the entire "food cycle" from "cradle to grave". The system thus includes the following phases:

Food Supply Chain: **Sources of food wastage**		*Food life cycle:* **Sources of environmental impacts**
1.	Agricultural production	
2.	Postharvest handling and storage	
3.	Processing	
4.	Distribution	
5.	Consumption	
6.	End of life	

Figure 1: Sources of food wastage in the food supply chain and sources of environmental impacts in the food life cycle

Regarding the sources of food wastage, the food supply chain (FSC) – i.e. from production to consumption or "farm to fork" – is segmented in five phases that are similar to FAO (2011) in order to allow efficient integration of existing data. At each of these phases, food wastage can occur due to a variety of causes such as spillage, degradation during handling or transportation, waste at distribution etc. (see section 5.1 for specific causes of wastage at each phase).

As regards the environmental impacts, it should be stressed that when food wastage occurs at a given phase of the food supply chain, three types of impacts must be considered:

- Impacts associated with the end-of-life of the waste;
- Impacts of the phase itself;
- Impacts of the previous phases so far, if any.

Indeed, each phase of the life cycle brings its own environmental impacts, therefore the impact of a unit of food wastage increases along the food supply chain. In other words, the later a product is lost along the supply chain, the higher is the "environmental cost" or impact. In fact, if food that has been processed, transported, and cooked is wasted at home, its impact per kg will be higher than unprocessed food products lost at farm. Figure 2 and Figure 3 illustrate this aspect.

Environmental impacts originate from energy and use of natural resources (input flows of the system) as well as emissions in the environment (output flows of the systems). Specific sources of environmental impacts at each life cycle phase are presented in Annex VI.

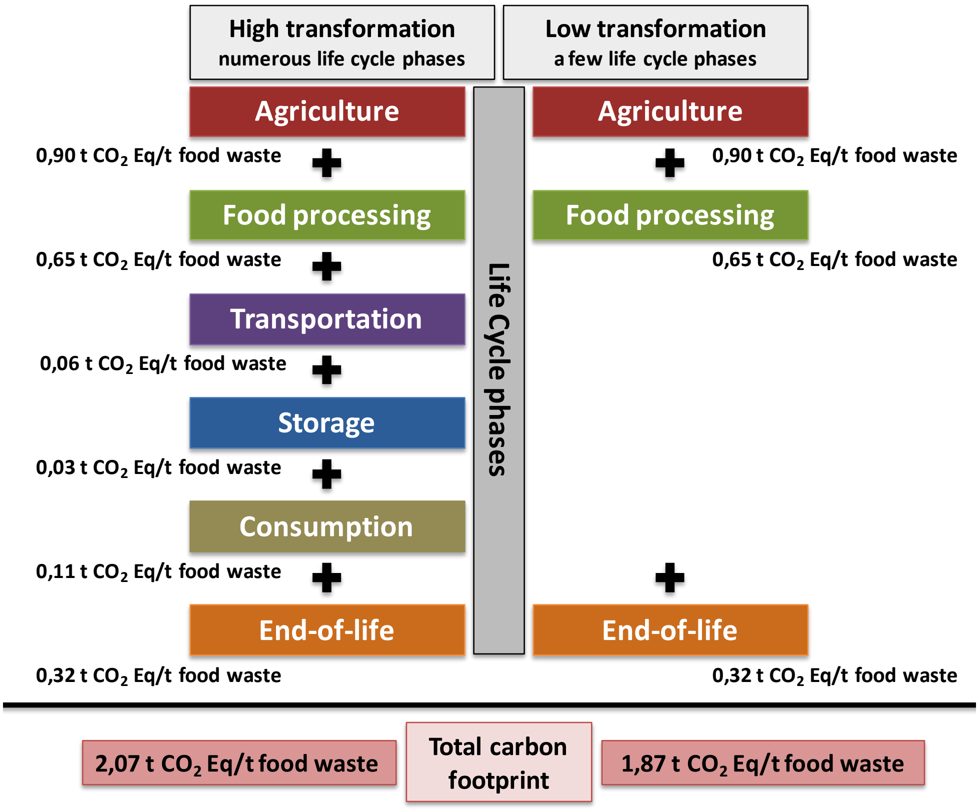

Figure 2: Example of the carbon footprints of food wastage occurring at consumption phase (left) or processing phase (right) – Source: BIO IS (2010)

Figure 3 on the next page shows in a green frame the comprehensive scope of the food wastage footprint that should ideally be covered by the FWF model for all "quantifiable" components (i.e. all components except biodiversity). However, the actual scope of the footprint is more limited for water and land components. For these latter components, the impacts of non-agricultural phases were not accounted for in the footprint calculations. Such methodological choices are justified by either 1/ data availability issues and/or 2/ results of literature research and BIO expertise showing that such phases are a negligible contributor to the overall footprint. As regards the economic component, assessment is based on producer prices. Therefore, it focuses on the economic cost associated with the agricultural production phase.

For each of the quantifiable components, the system considered in the model is presented in Chapter 3 under the sub-section "System boundaries".

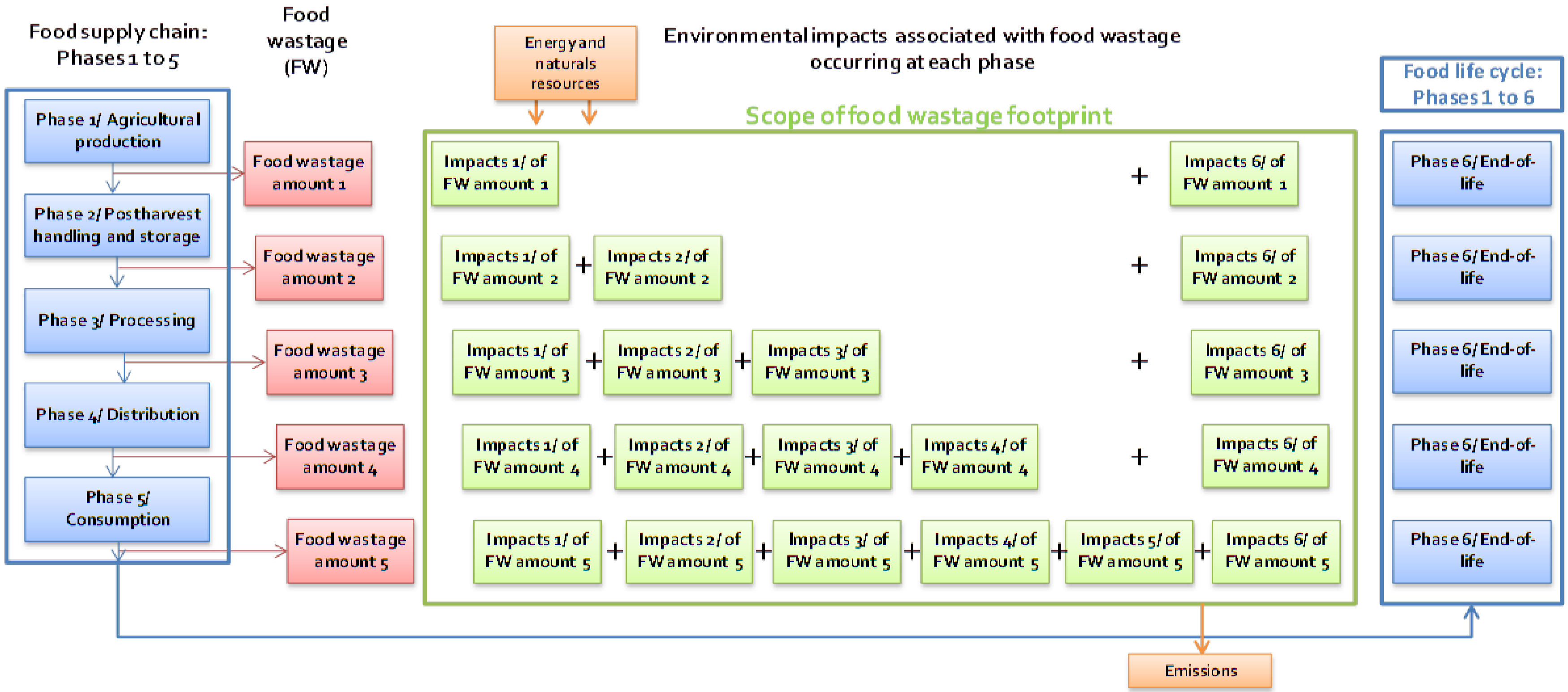

Figure 3: Food wastage and associated environmental impacts, at each phase of food supply chain.

2.3 Principles for the quantification of the components

This section describes the general framework for the evaluation of the environmental impacts of three environmental components namely, carbon, water and land for which the principles of footprint calculation are similar as well as for the economic component. These components are referred to as "quantifiable components" in contrast to the biodiversity component assessed through a combined semi-quantitative/qualitative approach (see section 3.5).

A "product-level" and "life cycle-based" approach

The approach adopted in the FWF model for quantifiable components is original in the sense that it is both **product-level** and **life cycle-based**.

It analyses 21 distinct types of food products (i.e. sub-commodities) accounting for most of the food consumed in the world, and then groups them into eight food commodities. For each of the sub-commodities, specific factors have been used (when possible) to characterise their impacts in each sub-region and each life cycle phase.

In practice, this means that factors are processed at the most disaggregated level, by sub-commodity group and by sub-region, which emphasises the differences in the practices and production methods, which in turn emphasise significant differences of impact. For example, specific factors are used to distinguish impacts of agricultural practices related to wheat produced in Europe from wheat produced in the USA. Another example is that beef meat, poultry meat and pork meat are placed in separate sub-commodities because beef meat appear much more impacting (in terms of carbon footprint) than chicken meat and pork meat.

Therefore, the FWF model can also be qualified as a **bottom-up** approach. Note that recent studies about environmental impacts of wasted crop products (Kummu et al. 2012), carbon footprint of food waste in the US (Venkat 2011), and about environmental impacts of the food cycle (BIO IS 2012) also use such a bottom-up approach (see Box 2 for additional details on bottom-up vs. top-down approaches).

A bottom-up modelling provides a degree of accuracy and rigor that may not be possible with top-down methods that intend to quantify impacts at the country level. Furthermore, the FWF model allows identifying **environmental hotspots**. Indeed, it is possible to "drill down" in the aggregated results to pinpoint the major contributors to the footprint and to answer the question "Where do the impacts come from?" and more precisely to subsequent interrogations such as:

- From which world regions or sub-regions?
- From which food commodities or sub-commodities?
- From which phases of the food life cycle?

Using impact factor for the assessment of quantifiable components

For all quantifiable components, the environmental footprint[2] (EF) of a product "i" can be expressed with the following generic equation, as a multiplication of an activity data (AD) and an impact factor (IF).

$$EF_i = AD_i * IF_i$$

This equation is valid at each phase of the life cycle.

Figure 4 illustrates the type of activity data and impact factors used in the present study. Activity data are food wastage volumes throughout the food supply chains. Impact factors are environmental impacts of food expressed by mass of food.

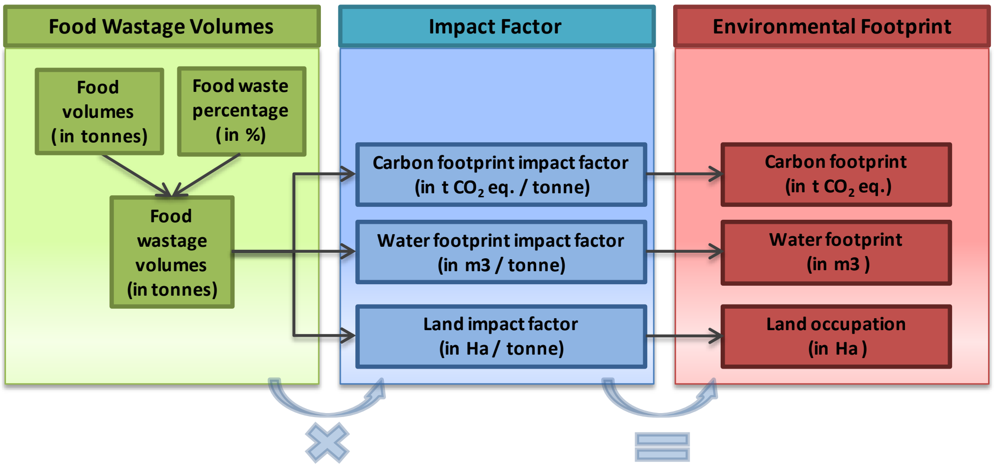

Figure 4: Activity data and impact factors used for quantifiable environmental components

The principle is similar for the economic assessment, as shown in Figure 5.

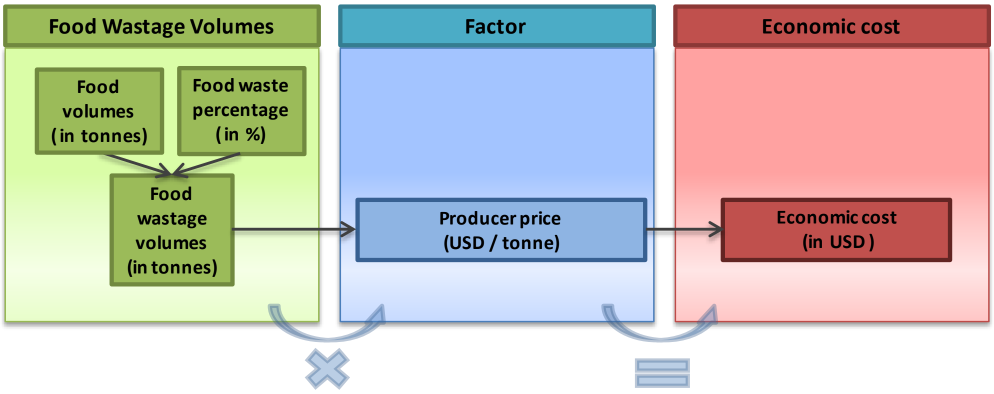

Figure 5: Activity data and factor used for economic component

Building a database

As illustrated in Table 3, the FWF model includes a database built to present activity data and impact factors for all sub-commodities (21) in all sub-regions (21) and for all FSC phases (5). Hence, for each of the quantifiable components, calculations are made at the finest level, i.e. the footprint of a quantifiable component is a potential combination of 2,205 (i.e. 21*21*5) interim values.

[2] The economic cost in the case of the economic component

Presenting the results

Ultimately, pivot tables are plugged onto the database. This allows a high flexibility in the manipulation and restitution of results, in terms of:

- Choice of aggregation level (groups or sub-groups);
- Choice of the axis of analysis (i.e. region, commodity, FSC phase);
- Combination of axis of analysis.

Data can therefore be "sliced and diced", which is crucial for hotspots' identification. The results are synthesised in custom-built tables and charts.

Table 3: Illustration of the database structure implemented in the model

Region name	Sub-region name	Commodity	Sub-commodity	Food Supply Chain Phase	Food wastage volume	Impact factor Component 2,3,4,6	Footprint of component 2,3,4,6
					AD	IF	EF = AD*IF
Sub-Saharan Africa	Middle Africa	Cereals	Maize	Phase 1			
Sub-Saharan Africa	Middle Africa	Cereals	Maize	Phase 2			
Sub-Saharan Africa	Middle Africa	Cereals	Maize	Phase 3			
Sub-Saharan Africa	Middle Africa	Cereals	Maize	Phase 4			
Sub-Saharan Africa	Middle Africa	Cereals	Maize	Phase 5			
Sub-Saharan Africa	Middle Africa	Cereals	Rice	Phase 1			
Sub-Saharan Africa	Middle Africa	Cereals	Rice	Phase 2			
Sub-Saharan Africa	Middle Africa	Cereals	Rice	Phase 3			
Sub-Saharan Africa	Middle Africa	Cereals	Rice	Phase 4			
Sub-Saharan Africa	Middle Africa	Cereals	Rice	Phase 5			
Latin America	Caribbean	Meat	Pig Meat	Phase 1			
Latin America	Caribbean	Meat	Pig Meat	Phase 2			
Latin America	Caribbean	Meat	Pig Meat	Phase 3			
Latin America	Caribbean	Meat	Pig Meat	Phase 4			
Latin America	Caribbean	Meat	Pig Meat	Phase 5			
Latin America	Caribbean	Meat	Bovine Meat	Phase 1			
Latin America	Caribbean	Meat	Bovine Meat	Phase 2			
Latin America	Caribbean	Meat	Bovine Meat	Phase 3			
Latin America	Caribbean	Meat	Bovine Meat	Phase 4			
Latin America	Caribbean	Meat	Bovine Meat	Phase 5			

Box 2: Assessing the environmental impacts of food – Top-down or bottom-up approach?

In general, there are two fundamental approaches to analyse environmental impacts of global business sectors such as food production, energy, transport, housing, etc. These two approaches are referred to as "top-down" and "bottom-up".

The top-down approach uses national-level data such as environmental accounts of economic sectors to track material flows, emissions, and waste. The EIPRO study (European Commission 2006) is an example of such a top-down approach. Although top-down approaches provide consolidated data for large geographical areas, figures are often organised by economic sectors (e.g. eating and drinking places, meat packing plants, etc.) and not for individual food products and associated supply chains (e.g. pork, milk etc.).

The bottom-up approach to environmental impacts is based on impact factors taken from Life Cycle Assessment (LCA) studies and other quantification sources. Although impact factors can provide a good, detailed picture of individual products in a specific context, there is debate on whether the impact factor from one specific product is applicable to represent the diversity and complexity of all products within a certain aggregated category (e.g. same carbon footprint for production of wheat and rye). For that very reason, commodities groups defined in the previous FAO study on food wastage (FAO 2011a) have been further divided in the present study – in particular for meat (see section 3.1.3).

Chapter 3. The food wastage footprint model

This chapter presents the methodological choices made in order to:

- Quantify food wastage volumes (component 1);
- Quantitatively assess environmental footprint for carbon, water and land (components 2, 3 and 4);
- Assess biodiversity issues (component 5) with a combined semi-quantitative/qualitative approach;
- Quantitatively assess economic cost related to agricultural production (component 6).

3.1 Component 1: Quantification of food wastage volumes

3.1.1 Objectives

The objectives of component 1 are to:

- Gather and select data on food production and food wastage percentages;
- Design an adequate structure for food wastage volumes in the perspective of further use in the FWF model. Food wastage volumes serve as an input for the footprint calculations of several components.

3.1.2 Data sources

Data on food volumes

The Food Balance Sheets (FAOSTAT 2012d) serve as the core basis to gather data on global mass flows of food for each sub-region and agricultural sub-commodity of the present study.

FBS are assembled by FAO. They display the patterns of food supply in a country/region over one year based on a combination of data on production, trade, stock change, types of utilisation of the commodities, etc. In the end, this gives a vision of the total amount of food available for human consumption in a country/region during one year.

For each food item, figures for the following elements are provided (see Annex V for definition of each element):

Supply elements

- Domestic Production (A)
- Import quantity (B)
- Stock variation (C)
- Export quantity (D)

- ➔Domestic supply quantity (E) is the outcome of the supply elements: $E = A + B \pm C - D$

Utilisation elements

- Feed (F)
- Seed (G)
- Processing (H)
- Other utilities (I)
- ➔Food available for consumption (J) is left after withdrawing utilisation elements: $J = E - F - G - H - I$

The element (J) "Food available for consumption" includes all forms of the commodity available for consumption in homes, restaurants or any catering services.

In the present study, Food Balance Sheets for the year 2007 (FAOSTAT 2012d) are used since it was the most recent data at the time the present study started (i.e. April 2012).

Note that in the FBS, domestic production data refer only to primary products while data for all other elements also include processed products derived from primary products, expressed in "primary product equivalent".

Food wastage percentages

In FAO (2011), weight percentages of food lost and wasted have been gathered based on a thorough literature search and assumptions of the authors for remaining data gaps.

For each region, tables of food wastage percentage were obtained (in % of input of each step), with in rows commodity groups and in columns life cycle phases (FAO 2011, Annex 4).

It must be underlined that FAO experts (N. Scialabba FAO NRD, personal communication, Nov. 2012) consider that food wastage percentages used in FAO (2011) for fish & seafood are questionable. Indeed, there are currently some debates on how to define fish wastage and on the way to quantify discards[3] occurring during commercial fishing, which may lead to underestimations. Therefore, food wastage volumes obtained for this commodity must be considered with caution.

3.1.3 Calculation of food wastage volumes

In general, the approach used for the quantification of food wastage volumes is similar to FAO (2011) – i.e. waste percentages of this latter source were applied to data from FAO's Food Balance Sheets. Yet, some specific adaptations are made in the present study and are presented in this section.

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[3] Discards is the proportion of fish that is not retained during commercial fishing but instead returned to the sea, often dead, dying or badly damaged.

Mass flows model used in FAO (2011)

In FAO (2011), a "Mass flows" model was used to account for food wastage in each step of the commodity's FSC. Model equations are provided in Annex 5 of FAO (2011).

Very schematically, one can summarise the calculations performed with this model as follows:

For food wastage occurring at the beginning of the FSC (agricultural production and postharvest handling and storage), figures for domestic products (element A of FBS) are slightly adapted and multiplied by specific waste percentages for each life cycle phase, food commodity group and world region.

For food wastage occurring in the rest of the FSC (such as distribution, retail, consumption, end of life), figures available for food consumption and processing (element J and H of FBS) are adapted and multiplied by specific waste percentages for each life cycle phase, food commodity group and world region.

From these calculations, food wastage volumes were obtained at region and commodity level for each commodity group. Ultimately, conversion factors were applied to determine the edible mass of the food wastage (for instance, for fruits a conversion factor of 80% was assumed for peeling. This means that in average only 80% of raw fruit is deemed edible).

Adaptations made in this study to the Mass Flows model

For the purpose of this study, two key adaptations are made to the Mass Flows model.

Breaking down of food wastage volumes at sub-region and sub-commodity level

As shown in section 2.2, this study considers 21 sub-commodities and 21-sub-regions. Therefore, food wastages volumes obtained in the Mass Flows model have been further disaggregated in order to get a specific figure for each line of the FWF database (FSC phase x sub-commodity x sub-region). List of commodities from FAO (2011) broken down for the present study needs are presented in Table 3.

Table 3-bis: Breaking down of commodities from FAO (2011)

Commodity name (FAO 2011a)	Commodity name (this study)	Sub-commodity name (this study)
Cereals (excluding beer):	1/ Cereals (excluding beer)	1-1 Wheat + Rye; 1-2 Oats + Barley + Cereals, other; 1-3 Maize; 1-4 Rice; 1-5 Millet + Sorghum
Fruit & Vegetables (including bananas):	4./ Fruits (excluding wine)	4-1 Apples; 4-2 Bananas; 4-3 Citrus; 4-4 Grapes; 4-5 Fruits, other
	8/ Vegetables	8-1 Vegetables
Meat:	5/ Meat	5-1 Bovine Meat; 5-2 Mutton & Goat Meat; 5-3 Pig Meat; 5-4 Poultry Meat

Within a food commodity group, environmental impacts of sub-commodities can vary greatly. For instance, carbon footprint factors for production of 1 kg of beef and 1 kg of chicken can show five to ten fold discrepancies. In order to properly quantify carbon footprint and allow identification of hotspots, it is necessary to calculate separate carbon footprints for these two products and thus, separated food wastage volumes are required. This is the reason of the disaggregation work performed in the present study.

Calculation of food wastage volumes with or without conversion factors

As regards carbon footprint and water footprint, products' impact factors are usually expressed in kg of food product and not by kg of edible food product. Therefore, food wastage volumes were calculated without conversion factors for the purpose of the quantification of environmental footprints. Note that food wastage volumes calculated with conversion factor are also presented in this report in order to make a comparison between the two sets of results (see section 4.1.1).

Box 3: Sub-commodities produced in a region and consumed in another: Where is the food wastage accounted for?

In the case of a food product grown in a region and consumed in another one, a question remains. Where are the wastes and losses of this product accounted for?

In the FWF model, the waste amounts are quantified at each step of the FSC. This way, losses at the production phase (and thus the impacts of the production phase) are recorded in the production region and wastes related to consumption (and thus the impacts of the consumption phase) are recorded in the consumption region.

For instance, bananas produced in Central America and exported to Europe generate:

- Losses at the production and storage phases, which are attributed to Central America's food wastage;
- Wastes at the subsequent phases in Europe, which are attributed at Europe's food wastage.

3.1.4 Assumptions

Considering that 1/ data chosen for food wastage percentage stem from FAO (2011), and 2/ the study covers 21 sub-commodity groups and 21 sub-regions for which FBS are directly available at proper format, there are no missing or incomplete data to approach with other sources or adaptations. Consequently, only minor adjustments are made:

- When breaking down the food wastage volumes for regions into corresponding sub-regions, it is assumed that the wastage are similar among the sub-regions of a given region (e.g. the same are used for Central America and South America sub-regions within the region Latin America).
- When breaking down the food wastage volumes for cereals and fruits commodities into corresponding sub-commodities, it is assumed that wastage percentages are similar among sub-commodities of a given commodity group (e.g. the same percentages are used for apples and bananas). This is however not the case for meat, as specific wastage percentages are used for each type of meat.
- It must be mentioned that in a given commodity, sub-commodities can be distinguished only if they are already stated in the FBS, as it is the case for meat. On the other hand, the commodity "vegetables" is sub-divided in "tomatoes", "onions" and a broad group called "other vegetables". Furthermore,

breaking down commodities in sub-commodities made sense for high-volumes commodities. Hence, it was not realised for the commodity "starchy roots", which present low volumes and impacts.

- It must be mentioned that FBS values for rice are provided in milled equivalents. When calculating food wastage amounts "without conversion factor", rice quantities were converted into un-milled equivalents in order to ensure homogeneity of units within the dataset (i.e. all volumes expressed in primary equivalent).
- The FWF model and the FAO results of 2011 are both based on the latest FBS values of the time i.e. for the year 2007. Therefore, slight variations might result from the use of these different datasets.

3.2 Component 2: Carbon footprint

3.2.1 Presentation of the component

The carbon footprint (CF) of a food product[4] is the total amount of greenhouse gases[5] (GHG) emitted throughout the life cycle of that product, expressed in kilograms of CO_2 equivalents[6].

This encompasses all GHG emissions of the agricultural phase – including the emissions related to the production and transport of all inputs, as well as the emissions due to on-farm energy use and non-energy related emissions (such as CH_4 and N_2O) from soils and livestock. The carbon footprint also includes the GHG emissions related to the processing of food, delivery to a point of sale or use location, and to the consumption as well as emissions from waste disposal.

Common traits of GHG emissions related to food products

Food production systems and supply chains are very diverse. Nevertheless, all foodstuffs have a common characteristic: their emissions of fossil CO_2 are less important than for most manufactured products; instead emissions of biogenic GHG such as CH_4 and N_2O are more important.

CH_4 and N_2O are very powerful GHGs, methane having a weighting factor of 25 times CO_2 and N_2O 298 (Source IPCC). For vegetable products, N_2O are often a key source of emissions (due to the use of fertilisers), as well as for production of monogastric animals such as pork or poultry (due to the use of fertilisers for feeds as well as manure management). For ruminants, CH_4 is often the dominating gas emitted because of enteric fermentation. For seafood products, correlation between energy use and climate impact is higher, especially for wild-caught fish where the climate impact is dominated by fossil CO_2 emissions from fuel use on fishing boats.

Food waste ending up in landfills also plays a role in GHG emissions; CH_4 is formed when food is degraded under anaerobic conditions in landfills.

3.2.2 Objective

The objective of the carbon component is to translate the food wastage volumes of the FWF database into tonnes of CO_2 eq. This will be done by selecting, adapting, and building up impact factors[7].

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[4] Sometimes called the carbon "foodprint" (see for instance Kling & Hough 2010).

[5] Main GHGs of anthropogenic origin are Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), fluorocarbons (e.g. CFCs and HCFCs), and others.

[6] The "CO_2 eq." unit allows comparing the different GHGs on a like-for-like basis relative to one unit of CO_2. CO_2 eq is calculated by multiplying the emissions of each of the six greenhouse gases by its 100 year global warming potential (GWP).

[7] Also called emission factors in the case of carbon footprint.

3.2.3 System boundaries of the carbon footprint assessment

In most of the carbon quantification studies, the production phase (agricultural production or fisheries) remains the most impacting over the life cycle, and accounts for up to 70% of the environmental impacts of an average food basket (Muñoz et al. 2010). Other phases of the life cycle, such as processing, tend to have less impact compared to production.

Figure 6 illustrates the system boundaries of the carbon footprint assessment.

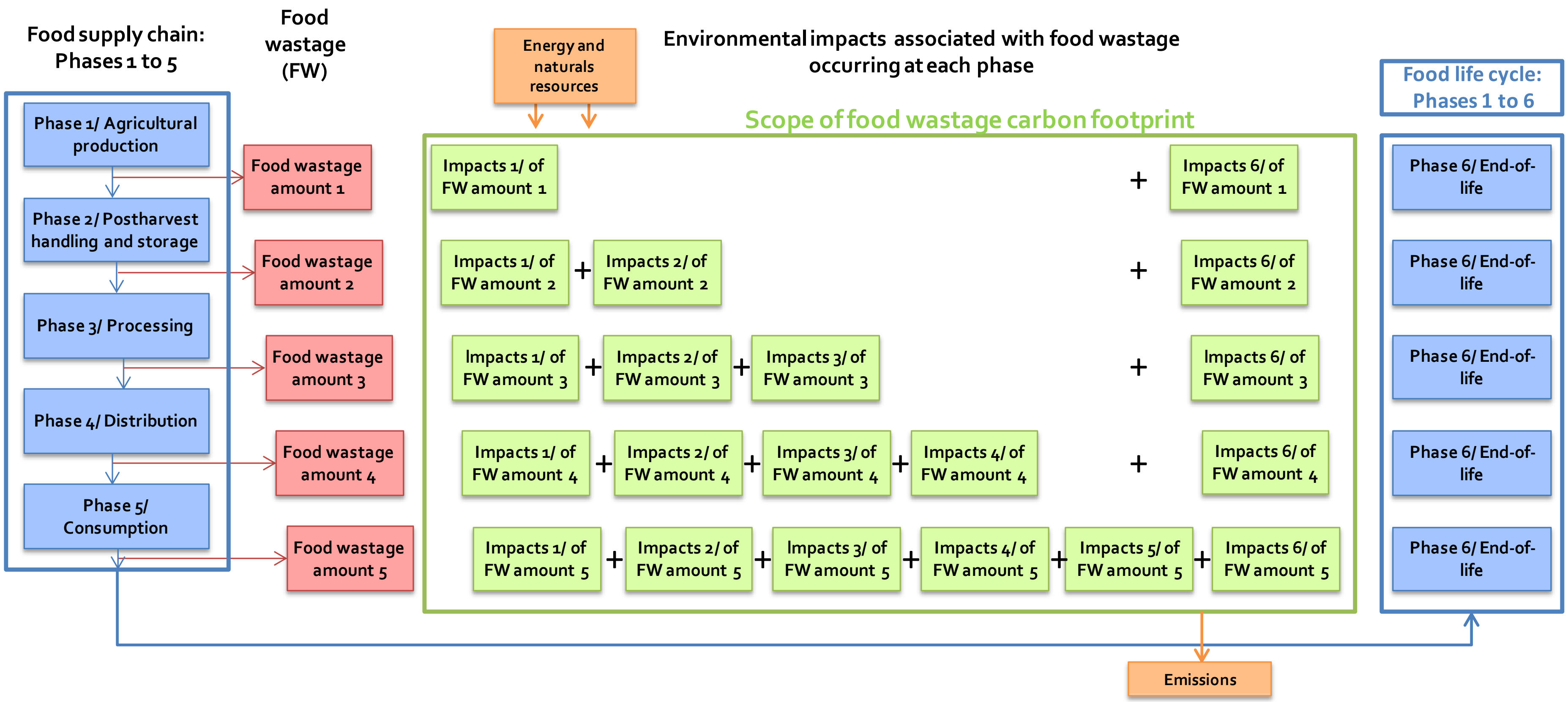


Figure 6: System boundaries of the carbon footprint assessment

3.2.4 Modelling, data sources and assumptions

The following section aims at detailing the calculation used to quantify the carbon footprint of food wastage at each phase of the life cycle of a given commodity.

The general equation for carbon footprint is common to all life cycle phases, and can be expressed as follows:

$$CF_{i,j,k} = AD_{i,j,k} * IF_{i,j,k}$$

Where:

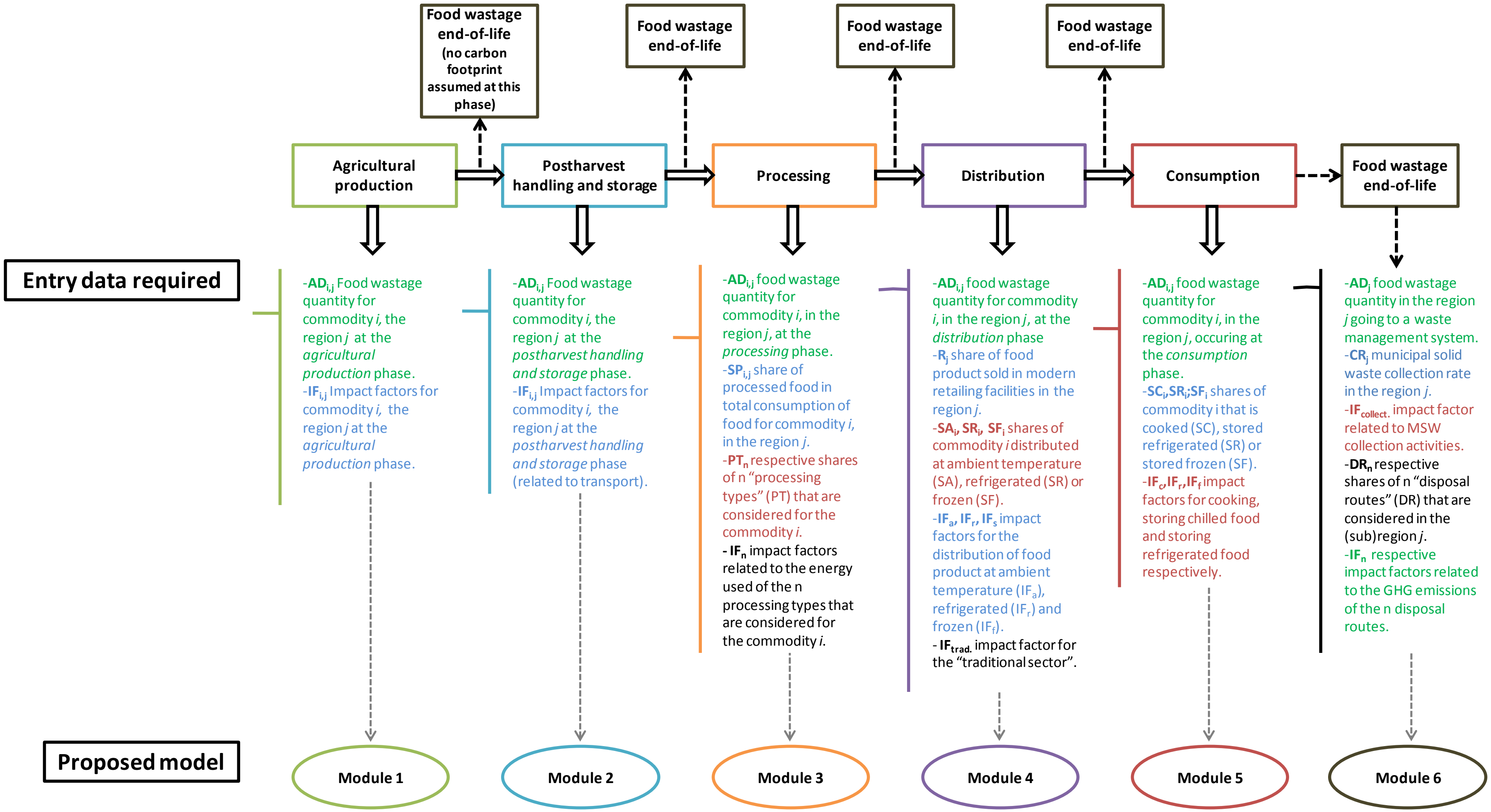
$CF_{i,j,k}$ is the carbon footprint of food wastage for the (sub)commodity i, in the (sub)region j, and occurring at the life cycle phase k, expressed in tonnes equivalent CO_2;

$AD_{i,j,k}$ is the quantity of food wastage for the (sub)commodity i, in the (sub)region j and occurring at the life cycle phase k, expressed in tonnes of food;

$IF_{i,j,k}$ is the impact factor of the (sub)commodity i, the (sub)region j and occurring at the life cycle phase k, expressed in tonnes CO_2 eq. / tonne of (sub)commodity. Impact factors are obtained from available LCA or built up using specific input data.

Each phase of the life cycle is considered as a distinct "module" of the model, with specific input data as shown in Figure 7.

Figure 7: Modules of the carbon footprint model and associated input data



Input data are used in the model to determine the impact factor of a (sub)commodity, for a given (sub)region and a specific life cycle phase. The sections hereafter detail the methods used to obtain adequate impact factors for each module.

3.2.4.1 *CARBON FOOTPRINT OF THE PRODUCTION PHASE*

Selection of impact factors

Impact factors of the production phase are gathered through an in-depth literature review of 100 published LCAs and LCI databases for the crop, livestock, aquaculture, and fishing products covered in the 21 sub-commodities. The list of the 40 publications that were selected is provided in Annex VII. Impact factors were chosen according to:

- The quality of the study (scope considered in the study, main assumptions and data used, representativeness issues etc.). Peer reviewed studies were selected in priority, but some non peer reviewed studies were also selected in order to extend the geographical coverage and the products' diversity;
- The availability of LCI data for a given product in existing public or private LCI databases (Ecoinvent, LCAFood, ESU database etc.) for the regions included in the scope of the study.
- Quality criteria used to select theses 40 studies are presented in more details in Annex VIII.

It should be underlined that at the end of 2012, FAOSTAT provided data on GHG emissions of agriculture. The FWF model was checked against these data as presented in

Box 4.

Box 4: GHG emissions of agricultural production calculated with FWF and MAGHG models

MAGHG Project presentation

In January 2011, FAO initiated the project "Monitoring and Assessment of GHG Emissions and Mitigation Potential in Agriculture" (MAGHG), funded by the governments of Germany and Norway.

The project outcome is an enhanced global knowledge base on GHG emissions, and mitigation potentials within the agriculture sector. Results are provided through a new AFOLU (Agriculture, Forestry, and Other Land Uses) global GHG database, the FAOSTAT GHG database. This database, launched in December 2012, provides a coherent time series of emission statistics over the reference period 1990-2010, at country-level, based on FAOSTAT activity data and IPCC 2006 Tier 1 methodology.

In the FAOSTAT GHG database, as in most of carbon accounting methodologies, GHG emissions from a given source (E_{GHG}) are expressed in the following generic structure, as the product of an emission factor (EF) and an activity data (AD):

$$E_{GHG} = EF * AD$$

where:

- E_{GHG} are the emissions of GHG

- EF: Emission factor from IPCC 2006 guidelines with Tier 1 approach
- AD: Activity data from the FAOSTAT database. These data (e.g., crop area, yield, livestock heads, etc.) are those collected by member countries, typically via National Agriculture Statistical Offices, and reported to FAO.

Results for agricultural sector with the FOASTAT GHG database

Emissions from agricultural sector were computed for nearly 200 countries, covering emissions of non-CO_2 gases (CH_4 and N_2O) arising from enteric fermentation, rice cultivation, manure management, synthetic fertilisers; manure applied to soils, manure left on pasture, and crop residues. The aggregate of these GHG emissions for agriculture is about 4.6 Gtonnes CO_2 eq. for the year 2010 (Tubiello et al. 2013).

Results for agricultural sector with FWF model

The FWF approach takes into account the same type of emissions as those computed by FAOSTAT i.e. GHG emissions sources from agricultural activities, but also adds the emissions that are typically quantified through LCA of products. So for instance, FWF considers additional GHG emissions from farm machinery, transport, refrigeration, etc. In this sense, the FWF approach can be referred to as life-cycle based, while the FAOSTAT GHG is more relevant for IPCC-type analyses. It is to be expected that emissions from a LCA approach, including more source categories than an IPCC approach, would be higher than the latter. However, some comparisons can nonetheless be made, in order to highlight consistencies and potential problems.

Similarly to the FAOSTAT GHG data, emissions are calculated through the multiplication of an emission factor and an activity data.

For the purpose of the comparison with FAOSTAT GHG database, activity data are agricultural production volumes coming from FAOSTAT /FBS for each commodity (except fish & seafood). Note that unlike what is done in the rest of the FWF study, activity data used in this comparison are overall agricultural production volumes and not food wastage volumes.

Regarding emission factors, values for a wide variety of products were selected from an in-depth literature research (130 references reviewed). Values relate to the agricultural production phase only (i.e. at "farm gate" LCAs). Total GHG emissions for agriculture obtained with the FWF Model are 7.3 Gtonnes CO2 eq.

Sources of discrepancies between the two models

FWF model value is 1.6 times higher than in FAOSTAT GHG database. The two values are of the same order of magnitude. Note that another ~0.7 Gtonnes CO2 eq. from prescribed burning of savannahs is not included into the FAOSTAT GHG database.

There are a number of reasons to explain the observed difference, which is due to the scope of the assessments (see Figure 8).

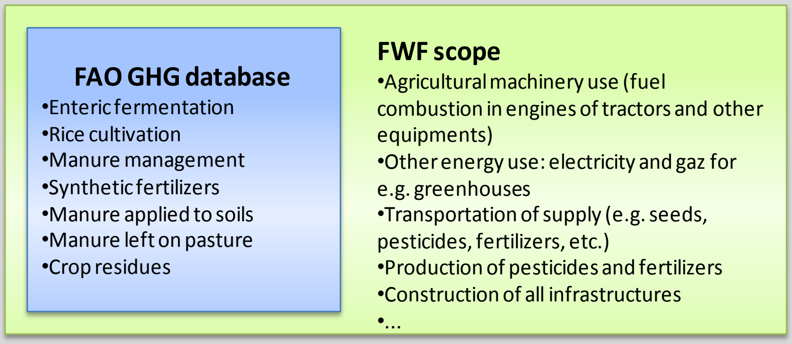


Figure 8: FAO GHG database and FWF scope

As discussed, the FAOSTAT GHG database follows the items of the UNFCCC[8]/IPCC reporting framework[9] for agricultural emissions. The emissions accounted for under the agriculture section encompass a limited number of emissions sources occurring at field/farm level; other (direct and indirect) emissions related to the agricultural processes are not taken into account. This to avoid double counting in global inventories: indeed, these emissions are reported under UNFCCC rules, but under sectors other than AFOLU, such as energy, transport, industry, etc. An example of sources dealt with in the FWF model in addition to typical IPCC reporting categories for AFOLU is the combustion of fuel used in agricultural machinery. Even if this aspect is generally not the major source of emissions of agricultural products, its overall contribution to the carbon footprint of a product can be significant in some cases. Fuel combustions are not accounted in the FAOSTAT GHG database. In the UNFCCC/IPCC framework, such emissions fall under the section "Energy/Other sectors/ Agriculture, forestry, fisheries".

Emissions factors implemented in the FWF have been calculated at product level by LCA practitioners. These factors encompass a broader range of aspects. Examples of supplementary sources of emissions are:

- Agricultural machinery use (fuel combustion in engines of tractors and other equipments)
- Other energy use: electricity and gas for e.g. greenhouses
- Transportation of supply (e.g. seeds, pesticides, fertilisers, etc.)
- Production of pesticides and fertilisers
- Construction of all infrastructures
- Etc.

Although, it remains difficult to evaluate the exact share of the difference that is due to the above-mentioned sources of discrepancies, it seems rather logical that the figure obtained with FWF model is higher since emissions factors used take into account more emissions sources.

Assumptions

Assumptions for each commodity are presented hereafter. An important methodological point on the GHG emissions related to land use change for agricultural product is discussed in Box 5.

Commodity 1 – Cereals

The sub-commodity "Wheat + Rye" is assessed with available impact factors for wheat only, as the production of wheat represents 97% of the world production for this sub-commodity (FAOSTAT 2012d).

The sub-commodity "Oats + Barley + cereals, other" is assessed with available impact factors for barley as barley represents 70% of the world production for this sub-commodity (FAOSTAT 2012d).

The sub-commodity "Millet+Sorghum" is assessed with available impact factors for barley, as there were no available values for millet and sorghum productions, which represent only 4% of the world production of cereals (FAOSTAT 2012d).

For (sub)regions with very few values for the major sub-commodities (such as Sub-Saharan Africa; South & Southeast Asia; North Africa; Western Asia and Central Asia; and Latin

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[8] United Nations Framework Convention on Climate Change

[9] http://unfccc.int/

America), the values of Nemecek et al. (2011a) were used in order to guarantee the best geographical coverage for the sub-commodities.

Commodity 2 – Starchy roots

This commodity is assessed with existing values for potatoes, given that potatoes and sweet potatoes taken as a whole represent 60% of the commodity starchy roots (FAOSTAT 2012d). The selected values are representative of the region or sub-region that they cover (e.g. the region Sub-Saharan Africa is addressed through potatoes impact factors for Eastern Africa, Western Africa, and Southern Africa).

Commodity 3 – Oilcrops & Pulses

The sub-commodity oilcrops is mostly addressed through impact factors for the production of three crops, namely soya beans, cottonseeds, and rapeseeds, which altogether represent 65% of oilcrops world production (FAOSTAT 2012d). An aggregated impact factor for the sub-commodity oilcrops in each region is obtained by weighing the production volumes taken from FAOSTAT (2012f) for these three crops.

For some regions (namely Europe; North Africa; Western Asia and Central Asia; and Sub-Saharan Africa), impact factors for olives and sunflowers were also used, as these productions represent a significant share of the oilcrops production in these regions (FAOSTAT 2012d).

The pulses sub-commodity is assessed with available data for green beans.

Commodity 4 – Fruits

The sub-commodities apples, bananas, and grapes are assessed with factors specifically representative of these products. Citrus are assessed with factors representative of oranges since oranges represent almost 60% of the world production of citrus (FAOSTAT 2012f). Note that most of the impact factors for apples, bananas and oranges are taken from Nemecek et al. (2011).

The sub-commodity "Fruits, other" includes a wide range of product (see Table 13 in Annex IV). Most of these products represent a minor share of the "Fruits, other" group. Therefore, the assessment is based on impact factors for peach, pear, strawberry and mango, as these elements represent more than 40% of the world production for this sub-commodity (FAOSTAT 2012f) and reliable factors were available. These values are weighted by the respective share of the elements in each region, coming from FAOSTAT (2012f), in order to obtain an aggregated impact factor for the sub-commodity "Fruits, other" for each region.

Commodity 5 – Meat

Every sub-commodity is assessed with impact factors representative of the different livestock production systems in each region (i.e. pasture land; mixed livestock production systems; and landless livestock production systems). The study of Seré et al. (1995) is used to set the respective share of these three production systems in each region.

Commodity 6 – Fish & Seafood

Every sub-commodity is assessed with impact factors representative of the major species from capture and aquaculture in the different regions. FishstatJ software (FAOSTAT 2012a) is used to set the respective share of production from aquaculture and capture, as well as the major species from aquaculture and capture in each region.

Commodity 7 – Milk & Eggs

The two sub-commodities "Milk", and "Eggs" are assessed with impact factors representative of the regions of Europe, and North America & Oceania, as specific values covering the other regions were missing.

Commodity 8 – Vegetables

Impact factors for this commodity are built up with values for three distinct elements, namely tomatoes, onions and "vegetables, other" (containing impact factors for carrot, cauliflower, lettuce, cucumber, spinach and broccoli production). The disaggregation in these three elements is in accordance with (FAOSTAT 2012d) categories. The selected values for these three elements are then weighted with their respective production shares in each region (FAOSTAT 2012d) in order to obtain an aggregated impact factor for the whole commodity vegetables, for each region.

Impact factor for tomatoes is built up considering the relative share of greenhouse tomato production versus field grown tomato production. Note that very scarce and fragmented information on tomatoes greenhouse production has been gathered. When possible, the type of greenhouse (i.e. heated or not) has also been taken into account.

- For the regions of Europe, and North America & Oceania, based on the few data found (Zbeetnoff Agro-environmental Consulting 2006; Interfel n.d.), the average percentage for greenhouse grown tomato production is assumed by BIO IS to be about 50%.
- It can be pointed out that the greatest expanse of protected cropping occurs in Asia, especially in China, South Korea and Japan (ISHS 2012). For China, the average percentage for all vegetables appears to be about 40% (Guo 2012) and was considered similar in South Korea and Japan.
- In addition, the ISHS (2012) indicates that Asia accounts for about 70% of the estimated area of protected crops in the world (with the vast majority of the protected areas in Asia being under plastic). In this context, it was considered as a reasonably conservative assumption to use the same value of 40% for South & Southeast Asia.
- Based on figures found for Turkey (Bayramoglu et al. 2010), percentage for greenhouse grown tomato production is assumed to be 20% for the region of Africa, Western Asia, and Central Asia.

Impact factor for "Vegetables, other" is built up considering the relative share of greenhouse vegetable production versus field grown vegetable production. Relative shares retained for tomatoes (see previous bullet point) were also used for "Vegetables, other".

Box 5: Land use change and Carbon footprint

What is land use change?

Land use change (LUC) is defined in the PAS 2050 (BSI 2011) as "a change in the purpose for which land is used by humans". Change in the use of land at the location of production of the product being assessed is referred to as **direct** land use change whereas change in the use of land elsewhere is referred to as **indirect** land use change. In other words, indirect land use change occurs "when the demand for a specific land use induces a change on other lands" as mentioned in the GHG protocol (WRI & WBCSD 2011).

Climatic impacts of land-use change

Land use change can result in large emissions of GHGs and is thus a contributor to climate change (WRI & WBCSD 2011). Indeed, land use change may lead to a change in land cover. Several categories are used by the IPCC to describe land cover (e.g. forest land, grassland, cropland, wetlands, etc.)[10]. Land conversion from a higher to a lower carbon-storing cover type will contribute to net carbon emissions. Therefore, emissions of GHGs due to changes in land use mainly come from the cutting down of forests for agriculture or built-up areas, urbanisation, roads etc.

Major areas of concerns as regards GHG emissions due to land use change include the expansion of the production of biofuels which is identified as a likely cause of tropical deforestation (indirect LUC)[11] or the growing demand for certain food products such as beef meat or soya feedstuff with direct LUC (e.g., from forestland to grassland) (IPCC 2007a).

Changes in demand for agricultural products (and co- and by-products) can also lead – through market-mediated effects – to changes in land management practices in addition to the changes in crops grown and land cover. Specifically, increased prices will lead to intensification, meaning not only yield increases (which to an extent mitigate the extensification caused by increased demand) but often higher GHG emission intensities due to increased use of inputs such as fertiliser (J. Reeves FAO NRC, personal communication, Feb. 2013).

Extent of LUC emissions and methodological issues

Land use change resulting from expansion of agricultural land significantly contributes to CO_2 emission (IPCC 2007b). According to Friedlingstein et al. (2010), the contribution of land use and land-cover change to anthropogenic carbon emissions were about 12.5% of total emissions over 2000 to 2009. LUC is indeed assumed to be one of the major contributors to global CO2 emissions, contributing 23% to the increase in atmospheric CO_2 concentration during the last 250 years. Unless they account for relevant emissions occurring from LUC and LU, studies which quantify emissions from the production of food and feedstuffs or bio-energy will underestimate the increase of the CO_2 concentration in the atmosphere by more than 20% on average (Hörtenhuber et al. 2012).

Despite the great impact on global greenhouse gas (GHG) emissions and thus on global warming, LUC is hardly incorporated into estimations of the global warming potential (GWP) in life cycle assessments or

[10] A change from grassland to cropland is a land use change, while a change from one crop (such as maize) to another (such as rapeseed) is not.

[11] If more cropland is dedicated to producing biofuel feedstocks, then forestland or wetlands somewhere else in the world might then be converted to cropland.

carbon footprints dealing with the production of food (Hörtenhuber et al. 2012). Major reasons for this are because 1/the causal link between the use of land and deforestation is not well described and 2/ there is a missing consensus on how to establish this link (J. H. Schmidt et al. 2012).

Currently, several methodologies for the calculation of greenhouse gas emissions resulting from a land use change exist, but there is no full international agreement on the method of how to account for land use changes. Existing methodologies produce results with considerable variations, because, for example, their emission boundaries differ (Pulkkinen et al. 2012; Leinonen et al. 2012). Methodological problems include the knowledge of land use before conversion, estimates of changes in above ground as well as below ground carbon content, both immediately and after initiation of cultivation and choice of depreciation time (Dalgaard et al. 2007).

LUC takes place as a result of several drivers, which are not trivial to identify. It can be very difficult to decide on the cause of indirect land-use change. When a forest is converted into cropland or grazing land, is this because, somewhere else in the world, someone else is using cropland to produce biofuel feedstock? Or is it because there is a greater demand for food due to population expansion? Or is it because, as people in emerging countries get higher living standard, they are demanding more meat?

However, it can be underlined that land-use change induced by policies affecting demand for agricultural products and the resultant GHG emissions can be and have been estimated through a variety of modelling approaches. Although these estimates depend on a range of assumptions and model characteristics, such modelling, aided by inter-model comparison, has been used to support the development of biofuels policy and legislation in the EU and the USA (J. Reeves FAO NRC, personal communication, Feb. 2013).

LUC in the FWF model

Emissions due to Land Use Change are not accounted for in the FWF model. To date, LUC cannot be included in the FWF model since land use changes issues are taken into account in only a fraction of the LCA data sources, and that such calculations are heterogeneous and continuously challenged. It can be considered that with LUC taken into account in the FWF model, the estimation for global GHG emissions would be at least 20% higher (Hörtenhuber et al. 2012) and could potentially be 40% higher (Tubiello et al. 2013).

3.2.4.2 CARBON FOOTPRINT OF POSTHARVEST HANDLING AND STORAGE

Due to a strong lack of data regarding GHG emissions related to this phase, the modelling therefore focuses on emissions due to the transportation between the farm and the processing/storage facilities for the following commodities:

- Meat – transportation from farm to slaughterhouse;
- Milk – transportation for farm to dairy plant;
- Cereals – transportation from farm to storage silo.

For other commodities, all transportations are covered in the distribution phase.

This module of the FWF model uses the following equation:

$$CF_{i,j,postharv.} = AD_{i,j,postharv} * D_i * IF_{transp.}$$

Where:

$CF_{i,j,postharv.}$ is the carbon footprint of the food wastage of (sub)commodity i, in the (sub)region j, occurring at the postharvest handling and storage phase, expressed in tonnes CO_2 eq.;

$AD_{i,j,postharv.}$ is the food wastage quantity for commodity i, in the (sub)region j, occurring at the postharvest handling and storage phase;

D_i is the transportation distance for the commodity i;

$IF_{transp.}$ is the impact factor related to the transportation of food from farm to the processing/storage facilities.

Assumptions

Potential impacts related to this phase could be:

- Energy used for manipulation and storage of food products before processing and/or distribution phase;
- Transportation to processing facilities.
- Since no studies dealing specifically with the energy consumption of postharvest storage facilities were found, this aspect was neglected (see Box 6 for details).

As regards transportation, only a few European figures were found to estimate the distances between the farm and the processing/storage facilities. Distance from farm to slaughterhouse was assumed to be 100 km in all regions which seems to be a conservative assumption based on figures for Ireland and Sweden (Cullinane et al. 2012; Hakansson et al. 2012). This distance was also applied for milk.

For cereals, distance was assumed to be 50 km in all regions based on Busato et al. (2008). Similarly to meat and milk, this value can be seen as a rather conservative assumption.

The impact factor employed is representative of an average European truck and is taken from Ecoinvent database.

Box 6: Energy used at the postharvest handling and storage phase

Firstly, it can be assumed that the vast majority of the impacts of the postharvest handling and storage phase come from energy use for the functioning of buildings and equipments used at this phase. Indeed, as commonly seen in LCA, the impacts related to the construction and end-of-life of such infrastructures will tend to be negligible when compared to the volume of products crossing them over their life cycle.

In addition, it must be underlined that the impact factors used for the agricultural production phase come from "at farm gate" LCAs, which means that postharvest handling and storage activities occurring on the farm are included in the scope of these factors. Regarding energy for storage facilities after the farm, it must be stressed that to a certain extent, these aspects are included in distribution impact factors, which include climate impacts related to cold chains.

In definitive, the major aspects that could not be taken into account relate mostly to storage of grain and fruits/vegetables outside the farm before the processing/distribution phase.

Grains are relatively less perishable than other crops, but still require care in storage, as they are not inert material but living seeds. The water content of the seeds must be reduced to a level that is safe for storage. Drying requires energy to be delivered through engineered infrastructure, particularly in the form of electricity or fossil fuels such as oil or gas. Once dried and placed in storage, the condition of the stored commodity must be maintained (e.g. controlled temperature), which is a further demand on energy supplies (IME 2013).

Storage facilities for fruit and vegetables require a much higher standard of engineering and management than grain crops. For example, in the case of fruit, systems that incorporate controlled atmosphere conditions as well as temperature and humidity management are required. Often freshly harvested crops are hot from the sun and so must be cooled before they can be stored (IME 2013).

Nevertheless, it appears that in most low-income countries postharvest storage of commodities is done in very rudimentary conditions (World bank 2011) which is, as a matter of fact, a cause of wastage. It is therefore likely that there is in this case little or no related energy consumption.

In the end, although postharvest storage can be energy consuming, given that the storage facilities can contain very large amounts of commodities, we can reasonably assume that the energy consumption brought back to one kg of product will represent a minor share of the total impacts compared to other aspects of the life cycle, most notably agricultural production.

3.2.4.3 *CARBON FOOTPRINT OF THE PROCESSING PHASE*

As regards the processing phase, energy use is often one of the major sources of environmental impacts – see for instance DEFRA (2006) who presents main processing impacts for a variety of food groups. The modelling therefore focuses on energy consumptions issues. The equation used in the processing phase's module of the FWF model is the following:

$$CF_{i,j,process.} = AD_{i,j,process.} * \left(\sum_n PT_{i,n} * IF_{i,n} \right)$$

Where:

$CF_{i,j,process.}$ is the carbon footprint of the food wastage of (sub)commodity i, in the (sub)region j, occurring at the processing phase, expressed in tonnes CO_2 eq.;

$AD_{i,j,process.}$ is the food wastage quantity for commodity i, in the (sub)region j, occurring at the processing phase;

$PT_{i,n}$ are the respective shares of n "processing types" (PT) that are considered for the (sub)commodity i – e.g. share of processed fruits that are canned, share of processed fruits that are pressed for juice, etc.;

$IF_{i,n}$ are the respective impact factors related to the energy used of the n processing types that are considered for the commodity i. Each impact factors may include emissions related to different sources of energy such as electricity, fuel, steam.

Assumptions

Shares of processed food are taken mostly from FAO (2011) and complemented with other sources (see Annex IX for details). Note that FAO (2011) used data from Food Balance Sheets[12].

Eurostat data as well as BIO IS (2012) and data from USDA give patchy information on the nature of processes applied to several commodities. Overall, for most of the regions and commodities, PT_n values must be considered as rough assumptions.

Energy consumptions for food processing are taken from Carlsson-Kanyama & Boström-Carlsson (2001).

Impact factor related to energy consumption are taken from Ecoinvent database for fuel and steam. As regards electricity, it is noteworthy to mention that impact factors depend on the electricity production mixes that are different in all countries. Impact factors for various world regions as well as world average impact factor are taken from ESU-Services (2012).

For meat, no distinction is made between "processed" or "unprocessed" meat. All meat quantities are considered to be either chilled or frozen. Carbon footprint calculations are made with emissions factors related to energy consumption for chilling or freezing.

3.2.4.4 CARBON FOOTPRINT OF THE DISTRIBUTION PHASE

Food retailing encompasses a large diversity of systems characterised by a low or high degree of complexity. However, a simplified description of the food retail sector can be proposed:

- The "modern retailing sector", including hypermarkets, supermarkets, superettes and convenient store chains[13];
- The "traditional retail sector" including small stores, local markets or other short distribution channels.

Thus, a simplified modelling can be proposed in order to quantify the impact factors related to the distribution phase. Two distinct equations are considered in distribution phase's module of the FWF model.

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[12] FBS provide data about the quantity of a given commodity that is processed but there are no details on the type of processing employed or the amounts by type of processed products that are obtained.

[13] For a matter of simplicity, the term « supermarket » is used in this document to indicate all modern convenience formats.

Modern retailing sector

For the food sold through supermarkets, the equation used is the following:

$$CF_{i,j,distrib.} = AD_{i,j,distrib.} * R_j * (SA_i * IF_a + SR_i * IF_r + SF_i * IF_f)$$

Where:

$CF_{i,j,distrib.}$ is the carbon footprint of the food wastage of (sub)commodity i, in the (sub)region j, occurring at the distribution phase, expressed in tonnes CO_2 eq.;

$AD_{i,j,distrib.}$ is the food wastage quantity for (sub)commodity i, in the (sub)region j, occurring at the distribution phase;

R_j is the share of food product sold in modern retailing facilities (supermarket, etc…) in the (sub)region j;

SA_i; SR_i; SF_i are the shares of commodity i distributed at ambient temperature (SA), refrigerated (SR) or frozen (SF).

IF_a; IF_r; IF_f are impact factors for the distribution of 1 tonne of food product at ambient temperature (IF_a), refrigerated (IF_r) and frozen (IF_f).

Traditional retail sector

For the food sold through the "traditional retail sector", it is assumed that the main contributor to GHG emissions is the transportation of goods from the production to the point of sale, without distinction between products distributed at room temperature, refrigerated, or frozen. The equation used is the following:

$$CF_{i,j,distrib.} = AD_{i,j,distrib.} * (1 - R_j) * IF_{trad.\ ,j}$$

Where:

$CF_{i,j,distrib.}$ is the carbon footprint of food wastage for the (sub)commodity i, in the (sub)region j occurring at the distribution phase, expressed in tonnes CO_2 eq.

$AD_{i,j,distrib.}$ is the food wastage quantity for (sub)commodity i, in the (sub)region j, occurring at the distribution phase;

R_j is the share of food product sold in modern retailing facilities (supermarket, etc…) in the (sub)region j;

$IF_{trad.\ ,j}$ is the impact factor for the "traditional sector" i.e. for transportation of 1 tonne of food product in the (sub)region j.

Assumptions

Data on the share of food products sold in supermarket (R_j) are mostly taken from (Thomas Reardon 2003; Thomas Reardon et al. 2004; Traill 2006) and were adapted and completed with other sources (see Annex X for details).

SA_i; SR_i; SF_i were calculated or estimated by BIO IS (see Annex X for details).

Impact factors (IF_a; IF_r; IF_f) are calculated by BIO IS (BIO IS 2009) and include the main contributors to GHG emissions:

- Energy consumed (electricity, gas) in supermarket for lighting, heating and cooling systems,
- Energy consumed (electricity) by freezers and refrigeration appliances,
- Refrigerants consumed, including refrigerant leakage,
- Transportation of the products from warehouses to supermarkets. For imported commodities, an additional distance covered by tanker has been taken into account.

As regards impact factor for the traditional sector ($IF_{trad.\ ,j}$), a transportation distance of 500 km is assumed in high-income regions (regions 1, 2 and 3). A shorter transportation distance of 100 km is assumed for low-income regions (other regions). Note that these distances are considered to be within the country of consumption. International transportations were not considered because of the tremendous amount of data that should be processed to deal with import and exports of all commodities at a global level (see Box 7 for a discussion on this aspect).

Box 7: Global estimate of GHG emissions related to international transportation of food

The increasing globalisation of agricultural systems leads to a rise in distances and quantities of food we transport. This issue has been widely debated in recent years (Savy et al. 2010; Kemp et al. 2010; Coley et al. 2009), especially with regards to air-freighted agricultural products imported from developing countries (Soil Association 2007). A large literature has focused on the emissions associated with production of goods. However, emissions associated with international transportation have received much less attention (Cristea et al. 2011).

The core issue is data. Indeed, International trade makes use of a wide range of transportation modes (ships, planes, truck, rail, all of different size and types), with very different characteristics in terms of greenhouse gas emissions, per quantity shipped.

According to the International Transport Forum (ITF), transport in a broad sense[14] accounts for 14.5% of global greenhouse gas emissions[15] (International Transport Forum 2010). Other figures cited by ITF indicate that sea and air international transportation accounts for 2% and 1.4% of the CO_2 emissions from fuel combustion. These data were obtained through cross-sector country-level assessments based on data on fuel consumption from the International Energy Agency. They illustrate the role of transport in GHG emissions, but do not allow to link the GHG emissions to the nature of goods being transported (e.g. manufactured goods, primary agricultural products, etc.).

US Researchers of the National Bureau of Economic Research (NBER), recently published a study entitled "Trade and the Greenhouse Gas Emission from international Freight Transport" (Cristea et al. 2011) based on innovative approach in this field. Using a "bottom-up" scheme, they calculated emissions related to origin-destination-product trade flows worldwide for the year 2004. Their calculations are based on detailed data from national and international sources. Results obtained show that 1/ international

[14] The term "Transport" covers here the transport of freight and passengers and all transportation means (i.e. road, aviation, maritime, rail and other types of transport).

[15] This figure is an estimate given the uncertainties in the absolute amount of GHGs emissions, especially from griculture, forestry, and biomass decay.

transportation of traded goods accounts for about 1 200 Mt CO2 eq. and 2/ transportation of agricultural products[16] accounted for 10% of transported volumes (expressed in tonne km) and 3/ 91% of the tkm of agricultural products are made with shipping, which is the transportation mode with the smallest impact per tkm (see Figure 9).

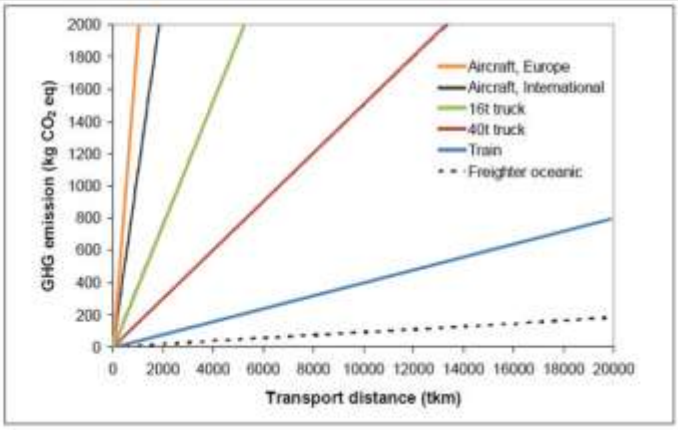

Figure 9: Greenhouse gas (GHG) emissions from food transport as affected by transport mode and distance (Ecoinvent Centre, 2007)

Given that the modal shares (for tkm by sea, air, rail and road) are rather similar between world average and agricultural products, we can reasonably consider that GHG emissions of international transportation of agricultural goods are about 120 Mtonnes CO_2 eq. Assuming a conservative 30% of food wastage on this figure we obtain about 36 Mtonnes CO_2 eq.

A comparison of this latter number to the global emissions obtained with the FWF model, which are 3.3 Gtonnes of CO_2 eq. (see section 4.2) shows that international transportation of agricultural goods represents a potential minor fraction of 1% of the food wastage footprint. Finally, we can reasonably consider this aspect negligible, with respect to the other phases of the life-cycle chain.

3.2.4.5 CARBON FOOTPRINT OF THE CONSUMPTION PHASE

Regarding the consumption phase, it is considered that the GHG emissions are related to energy used to cook and/or store the food in a fridge or a freezer. Note that this choice to focus primarily on home storage and preparations aspects for the carbon footprint of consumption phase is also made in WRAP (2011).

The equation used in the consumption phase's module of the FWF model is the following:

$$CF_{i,j,cons.} = AD_{i,j,cons.} * \left(SC_i * IF_c + SR_i * IF_r + SF_i * IF_f\right)$$

Where:

$CF_{i,j,cons.}$ is the carbon footprint of the food wastage of (sub)commodity i, in the (sub)region j, occurring at the consumption phase, expressed in tonnes equivalent CO_2;

$AD_{i,j,cons.}$ is the food wastage quantity for (sub)commodity i, in the (sub)region j, occurring at the consumption phase;

SC_i; SR_i; SF_i are the shares of (sub)commodity i that is cooked (SC), stored refrigerated (SR) or stored frozen (SF)

[16] Bulk and processed agricultural products

IF_c; IF_r; IF_f are impact factors for cooking, storing chilled food and storing refrigerated food respectively. Impact factors are expressed in kg eq CO_2 per kg of cooked or stored food.

Assumptions

The food wastage volumes occurring at consumption phase are quantified based on the FBS element "Food available for consumption"[17] to which food wastage percentages collected for consumption phase are applied. It must be underlined that for regions 1 and 2 these percentages are mostly coming from studies dealing with household food wastes. For other regions, these percentages are mostly assumptions made by the authors of the FAO (2011) study.

Very rough assumptions had to be made for each commodity regarding food storage and preparation in households. Carbon footprint impacts depend on the share of food that is stored refrigerated (SR_i) or frozen (SF_i) and/or the share of food that is consumed cooked (SC_i). These assumptions are presented in Table 4.

Energy consumptions for cooking are taken from several sources (Carlsson-Kanyama & Boström-Carlsson 2001; Carlsson-Kanyama & Faist 2000).

A single type of energy source, namely electricity was considered for cooking and storing food. The potential implications of this assumption are discussed in Box 8. Electricity impact factors for various world regions as well as world average impact factor are taken from ESU-Services (2012).

[17] FBS element "Food available for consumption" includes all forms of the commodity available for consumption in homes, restaurants or any catering services (see section 3.1.2).

Table 4: BIO IS assumptions for storage and preparation in households

Com. #	Commodity name		Storage (%)			Preparation (%)		Comments
			Room Temp.*	Refrig. SR	Frozen SF	Cooking SC	No cooking*	
1	Cereals (excluding beer)	Wheat + Rye	100	0	0	50	50	Rough assumption: 50% bread (not cooked) / 50% pasta (cooked)
		Oats + Barley + Cereals, other	100	0	0	100	0	
		Maize	100	0	0	50	50	Rough assumption: 50% sweet maize (not cooked)
		Rice	100	0	0	100	0	
		Millet + Sorghum	100	0	0	100	0	
2	Starchy roots		100	0	0	66	33	Rough assumption: 33% chips (not cooked)
3	Oilcrops & Pulses	Oilcrops	100	0	0	0	100	
		Pulses	100	0	0	100	0	
4	Fruits (excluding wine)		100	0	0	0	100	
5	Meat		0	50	50	100	0	
6	Fish & Seafood		0	50	50	100	0	
7	Milk (excluding butter) & Eggs	Milk	0	100	0	0	100	
		Eggs	0	100	0	100	0	
8	Vegetables		0	50	50	100	0	

*No GHG emissions accounted in this case

Box 8: Type of energy used for food preparation

Climate impacts of energy for cooking are not straightforward to assess since they depend on the type of energy employed (e.g. electricity, oil, gas, coal, biomass) and the energy efficiency of the cooking equipments. In addition, in the case of electricity, the carbon intensity of 1 kWh is influenced by the local electricity production mix (hydroelectricity, nuclear, fossil fuels, etc.).

In addition, most of the energy consumption data for cooking food are representative of electric appliances (e.g. oven, micro-wave oven, etc.). This latter point, combined with lack of detailed information on regional distribution of energy mixes for cooking has led us to consider a single type of energy source, namely electricity for cooking food. It allows getting a first vision of the order of magnitude of the climate impacts related to the part of food being cooked and then thrown away at consumption phase.

Stating if this assumption is globally an over or an under estimation is particularly intricate. The example hereafter illustrates why.

It is estimated that in 2009, around 40% of the population (i.e. almost 2.7 billion people) relied on traditional use of biomass for cooking, with the highest shares of population observed in sub-Saharan Africa and Asian developing countries (IEA 2011). Traditional biomass is defined by FAO (FAO 2008) as wood fuels, agricultural by-products and dung burned for cooking and heating purposes. It is mostly traded informally and non-commercially. Although being a renewable energy, biomass can have carbon impacts when burnt. This is linked to the carbon accounting rules for carbon of biogenic origin. Indeed, the IPCC's convention for GHG accounting is to ignore the contribution of CO_2 emitted from biogenic materials if these materials are grown on a sustainable basis. The idea here is that during the growth of the plants, carbon has been taken-up and incorporated, and that same amount of carbon is emitted when burnt or aerobically decomposed – the carbon balance is effectively 'neutral' as opposed to fossil fuels. However, in developing countries a significant share of this biomass is harvested in an unsustainable way (FAO 2008). This depletes the carbon stored in forests and soil over time causing net carbon emissions. Overall, the climate impact of biomass cooking will thus depend on the way this biomass is produced and managed. For instance, factors for combustion will be different for agricultural residues and for charcoal produced from illegal deforestation.

3.2.4.6 *CARBON FOOTPRINT OF THE END-OF-LIFE PHASE*

Carbon footprint of wastes

It is a known fact that waste disposal all along the supply chain can add significantly to the life-cycle carbon footprint of many food products[18]. Indeed, waste management systems typically cover a suite of activities such as collection, treatment, and disposal – that generate GHG emissions.

In the majority of countries around the world, controlled and uncontrolled landfilling[19] of untreated waste is the primary disposal method. Methane (CH_4) emissions from landfill represent the largest source of GHG emissions from the waste sector, contributing around 700 Mt CO_2 eq (UNEP 2010b).

At the global level, the climate impact of incineration is minor compared to that of landfilling, contributing around 40 Mt CO_2 eq. (UNEP 2010b). Direct emissions from facilities are predominantly fossil and biogenic CO_2. There are also low emissions of CH_4 and N_2O, which are determined by a function of the type of technology and combustion conditions. The amounts of fossil and biogenic carbon in the waste input vary significantly between countries, regions, and even facilities.

Specificities of food wastes

Once organic waste is deposited in a landfill, microorganisms begin to consume the carbon it contains, which causes decomposition. Under the anaerobic conditions prevalent in landfills, methane-producing bacteria will develop. As the bacteria gradually decompose organic matter over time, methane (approximately 50%), carbon dioxide (approximately 50%), and other trace amounts of gaseous compounds (< 1%) are generated and form landfill gas.

Food waste is an organic material. This means that:

The amount of degradable organic matter within food waste is much higher than in average municipal solid waste (which only contains a fraction of organic material). In other words, in the same conditions 1 kg of food waste will generate more CH_4 than 1 kg of average municipal solid waste (MSW).

[18] http://www.cleanmetrics.com/html/food_carbon_footprints.htm

[19] Uncontrolled landfills refers to dumping areas

Carbon within food is of biogenic origin. The IPCC has set an international convention to not report CO_2 released due to the landfill decomposition or incineration of biogenic sources of carbon.

- Only methane emissions (expressed as tonnes of CO_2 eq.) are accounted for in landfill impact factor.
- Only CO_2 coming from fossil carbon is counted in GHG emissions of incineration. Food waste contains no fossil carbon and therefore no CO_2 emissions are accounted for. Less significant emission of NO_2 coming from combustion processes are however taken into account.

Equation of end-of-life module

The equation used in the end-of-life phase's module of the FWF model is the following:

$$CF_{j,eol.} = AD_{j,eol.} * \left[CR_j * IF_{collect.} + \left(\sum_n DR_{n,j} * IF_n \right) \right]$$

Where:

$CF_{j,eol.}$ is the carbon footprint of the food wastage in the (sub)region j, occurring at the end-of-life phase, expressed in tonnes equivalent CO_2;

$AD_{j,eol.}$ is the food wastage quantity in the (sub)region j going to a waste management system

CR_j is the MSW collection rate in the region j

$IF_{collect.}$ is the impact factor related to MSW collection activities (transportation of waste to treatment site)

$DR_{n,j}$ are the respective shares of n "disposal routes" (DR) that are considered in the (sub)region j. Possible disposal routes considered in the modelling are dumps, landfills, incineration, composting.

IF_n are the respective impact factors related to the GHG emissions of the n disposal routes.

Assumption

It is assumed that food wastage quantities considered to go into a waste management system are food wastage occurring at all phases of the food supply chain except agricultural phase. Indeed, food wastage occurring at agricultural phase is most of the time dealt with at the farm location through uncontrolled open burning, or simply left in the field (UNEP 2010b). Climate change impacts of such practices are deemed negligible since the CO_2 emitted by the combustion of agricultural product is of biogenic origin. In addition, agricultural products left in the field are not degraded in anaerobic conditions (producing CH_4) like in landfills.

Regarding the way food waste is managed, it was considered that food generally goes through routes that are similar to the broader MSW category. This assumption builds on the fact that in all regions food waste represents a significant share of MSW (see

Table 21 in Annex XI).

The MSW collection rates are taken from (Hoornweg & Bhada-Tata 2012) and shown in

Table 23 in Annex XI.

The impact factor for collection of waste is taken from (ADEME 2012) and refers to the operation of a garbage truck.

Respective shares for each disposal route (i.e. dumps, landfills, compost, and incineration) are taken from (Hoornweg & Bhada-Tata 2012) and shown in

Table 22 in Annex XI.

Impact factors for each disposal route (IF_n) are calculated using IPCC guidelines (IPCC 2006). It must be underlined that IPCC's approach does not make any distinction between food commodities. In other words, impact factors are calculated for 1 kg of food wastage, be it meat or fruits or any other commodity.

In order to calculate the impact factor for landfilling, data on the rate of capture of landfill gas are necessary (i.e. the amount of land fill gas that is not eventually released in the atmosphere but flared or used to produce energy). Based on data from Bahor et al. (2009) a capture rate of 40% is used for Europe; 50% for region 2 and for Japan and South Korea; 35% for other (sub) regions.

It must be underlined that waste management systems can provide indirect GHG savings due to energy generation. Indeed landfill gas or combustion energy can be used to produce electricity and/or steam. Some accounting methodologies consider that the energy generated with these systems avoids the production of energy with "traditional systems" and associated emissions thus generating GHG credits. Such potential credits are not accounted in for in the present modelling.

3.3 Component 3: Water footprint

3.3.1 Presentation of the component

A water footprint is a measure of freshwater consumption that connects water use to a certain place, time, and type of water resource. The *Global standard on water footprint assessment* developed by the Water Footprint Network (WFN) defines the water footprint of a product as the total volume of freshwater that is used directly or indirectly to produce the product. It is estimated by considering water consumption and pollution in all steps of the production chain (Hoekstra et al. 2011).

In the WFN's definition, a water footprint consists of three sub-components that measure different sorts of water appropriation: blue, green, and grey. These three sub-components are presented below.

The **blue water footprint** refers to consumption of surface and groundwater resources along the supply chain of a product. The term "consumption" refers to one of the following four cases:

- Water evaporates;
- Water is incorporated into the product;
- Water does not return to the same catchment area, for example, it is returned to another catchment area or the sea;
- Water does not return in the same period, for example, it is withdrawn in a scarce period and returned in a wet period.

The **green water footprint** is an indicator of the human use of so-called "green water". Green water refers to the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Green water is potentially available for crop growth (but not all green water can be taken up by crops, because there will always be evaporation from the soil and because not all periods of the year or areas are suitable for crop growth).

The **grey water footprint** of a process step is an indicator of the degree of freshwater pollution that can be associated with the process step. It is defined as the volume of freshwater that would be required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards.

3.3.2 Objectives

The primary objective of the water component is to calculate impact factors that will translate the food wastage volumes of the FWF database into cubic meters of water. A second objective is to give an overview of the level of water scarcity in the world regions where lost/wasted food was produced.

3.3.3 System boundaries of the water footprint assessment

Recent studies on global water footprint of world and countries demonstrate the major role played by agriculture. It appears that consumption of agricultural products contributes to 92% of the water footprint of humanity (Hoekstra & Mekonnen 2012).

Besides, the *Water Footprint Assessment Manual* underlines that for product with ingredients originating from agriculture, it is relevant to particularly look into the water footprint of the related agricultural processes since they often are the major contributors to the overall water footprint of the product (Hoekstra et al. 2011). This is typically the case of foodstuffs. For that reason, the modelling work is focused on the agricultural production phase. Other phases are not accounted for in the FWF model, although food processing for example also requires water to a certain extent (see Box 9 for a discussion on this aspect).

Blue water footprint of agricultural products comes from irrigation water withdrawn from ground- or surface water that is evapotranspirated or incorporated into the product. Green water on the other hand, is the rainwater directly used and evapotranspirated by non-irrigated agriculture, pastures and forests. Finally, grey water footprint does not reflect an actual water consumption as it measures a theoretical volume of water that is required to dilute pollutants. This latter footprint was not calculated in the present study.

Box 9: Food processing and water consumption

Water consumption and water withdrawal

It must be pointed out that water use can take two forms – consumption or withdrawal – relating to different notions. Water withdrawal refers to water diverted or withdrawn from a surface water or groundwater source. Consumptive water use, deals with water that is no longer available for the immediate water environment because for instance, it has been transpired by plants, incorporated into products or consumed by people or livestock (Vickers 2001).

It is acknowledged that agriculture is the largest human use of water (Lundqvist et al. 2008). Regarding water withdrawals, agriculture accounts for 70% of all water withdrawn by the agricultural, municipal and industrial (including energy) sectors (UNESCO 2012) as shown in Figure 10. Approximately 20% of the world's freshwater withdrawals are used by industry, although this varies between regions and countries. The percentage of a country's industrial sector water demands is generally proportional to the average income level, representing only about 5% of water withdrawals in low-income countries, compared to over 40% in some high-income countries.

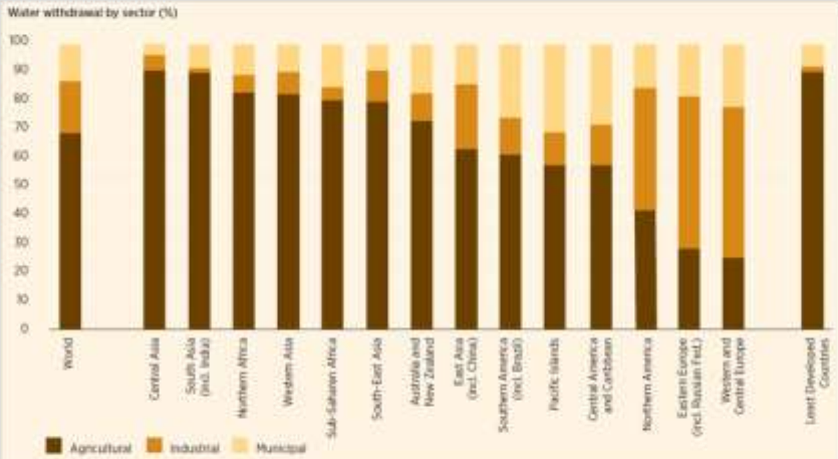

Figure 10: Water withdrawal by sector by region in 2005 (Source: UNESCO 2012)

Unlike above figure, the water footprint approach addresses the issue of water consumption. Consequently, the global repartition among sectors is modified. Indeed, agricultural production largely determines the water footprint of humanity with 92% of the total. Industrial production and domestic water contribute to 4.7% and 3.8%, respectively (Hoekstra & Mekonnen 2012).

Water and food processing

Water is a key processing medium in food processing plants. Water is used throughout the food production process, including food cleaning, sanitizing, peeling, cooking, and cooling. Water is also used mechanically as a conveyor medium to transport food materials throughout the process as well as for washing production equipment between operations (UNIDO n.d.).

Some studies provide estimates of "water use" for different processes (see Table 5). Although the methods of measurement and calculation are in general not detailed, it is most likely that these values actually refer to water withdrawals.

Table 5: Water use for different processes in the food industry

Commodity	Process	Amount of water (in m^3 / tonne of product)	Source
Fruits	canning	2.5 – 4	(World Bank 1998)
Vegetables	canning	3.5 – 6	(World Bank 1998)
Vegetables	frozen	5 - 8.5	(World Bank 1998)
Milk	processing	1.5	(INRA 2012)
Meat	processing	45 – 65	(UNIDO n.d.)
Meat (chicken)	processing	6.5	(DEFRA 2006)
Beans	processing	12- 17	(UNIDO n.d.)
Bread	processing	1.8 – 4	(UNIDO n.d.)

Overall, the above values are below the blue water impact factor of the agricultural production phase for the same products (Annex XIV). One must bear in mind that water and wastewater are common inputs and outputs of most food processing facilities. Indeed, although food processing can require large amounts of water, a large part of this waster is released afterwards (i.e. waste water). Consequently, the water consumption of food processing (and thus the water footprint) is likely to be actually much lower than the values in Table 5.

The environmental impact associated with green water use is relatively minor because it does not change the hydrological systems. Meanwhile, blue water use in irrigated agriculture has the potential for causing severe environmental problems such as water depletion, salinisation, water logging or soil degradation (Aldaya et al. 2010; Yang, H. et al. 2006 and others – see Box 10 for details). This is the reason why the present study focuses on blue water footprint.

It is important to note that in agriculture, blue and green water can substitute each other. In this case, green water can be seen as a metric to compare the vulnerability/resilience of different agricultural systems to droughts and dry spells (Dourte & Fraisse 2012). For persons interested in the complete picture, results of the green water footprint are provided in Annex XVIII.

Box 10: Blue, green and grey water footprint – A review of several reports (Hoekstra et al. 2011; Aldaya et al. 2010; Yang, H. et al. 2006; Dourte & Fraisse 2012; A. Brown & Matlock 2011).

Blue, green and/or grey water footprint?

A water footprint refers to three different sorts of freshwater use that are not comparable: (1) green water use – i.e. water from rainfall; (2) blue water use – i.e. water from groundwater or surface water; and (3) grey water use, which would be the dilution water required to reduce pollutant concentrations to acceptable values.

This distinction among green, blue, and grey water footprints recognises that the consumptive use of rainfall, groundwater, or surface water, and the water quality impacts have different economic costs and ecological impacts.

Green water use in agriculture is associated with relatively few negative environmental externalities. Its impact is considered smaller than blue water-based irrigated agricultural systems. Blue water resources are generally scarcer and have a higher opportunity cost than green water, so the present study focuses rather on the blue water sub-component in priority compared to green water.

Originally, the grey water footprint was introduced in the WFN methodology in order to express water pollution with a unit of measurement (i.e. volume) similar to blue and green footprints. Indeed, having the same unit among water footprints allows comparing (but not summing) the relative claims of water pollution and water consumption on the available water resources. Nevertheless, it is crucial to bear in mind that grey water is not a measurement of water consumption nor a measurement of volumes of water polluted. Grey water is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards.

Environmental impacts of green water use in agriculture

The environmental impact of the use of green water is relatively small because it generally does not change the distribution of water resources and the hydrological cycle. There is generally only a relatively small difference between the evapotranspiration from the cropfield and the evapotranspiration that would take place in presence of natural vegetative cover.

Although the hydrological impact is thus often small, there is a loss of natural environments. Indeed, additional green water for food production can be accessed by conversion of natural ecosystems into agricultural land. In this case, the impact is loss of natural ecosystems and habitat.

Environmental impacts of blue water use

Blue water requires facilities for storage and distribution before it can be delivered to users. The environmental impact of such water use is relevant as it changes the natural courses of water flows (e.g. surface water used for irrigation directly reduces stream flows). This can lead to insufficient environmental flows with impacts on aquatic biodiversity and ecosystems.

Moreover, excessive irrigation may also raise the water table, which in turn can lead to salinity and water logging and soil degradation, which are evident in many areas of the world.

Figure 11 illustrates the system boundaries of the water footprint assessment.

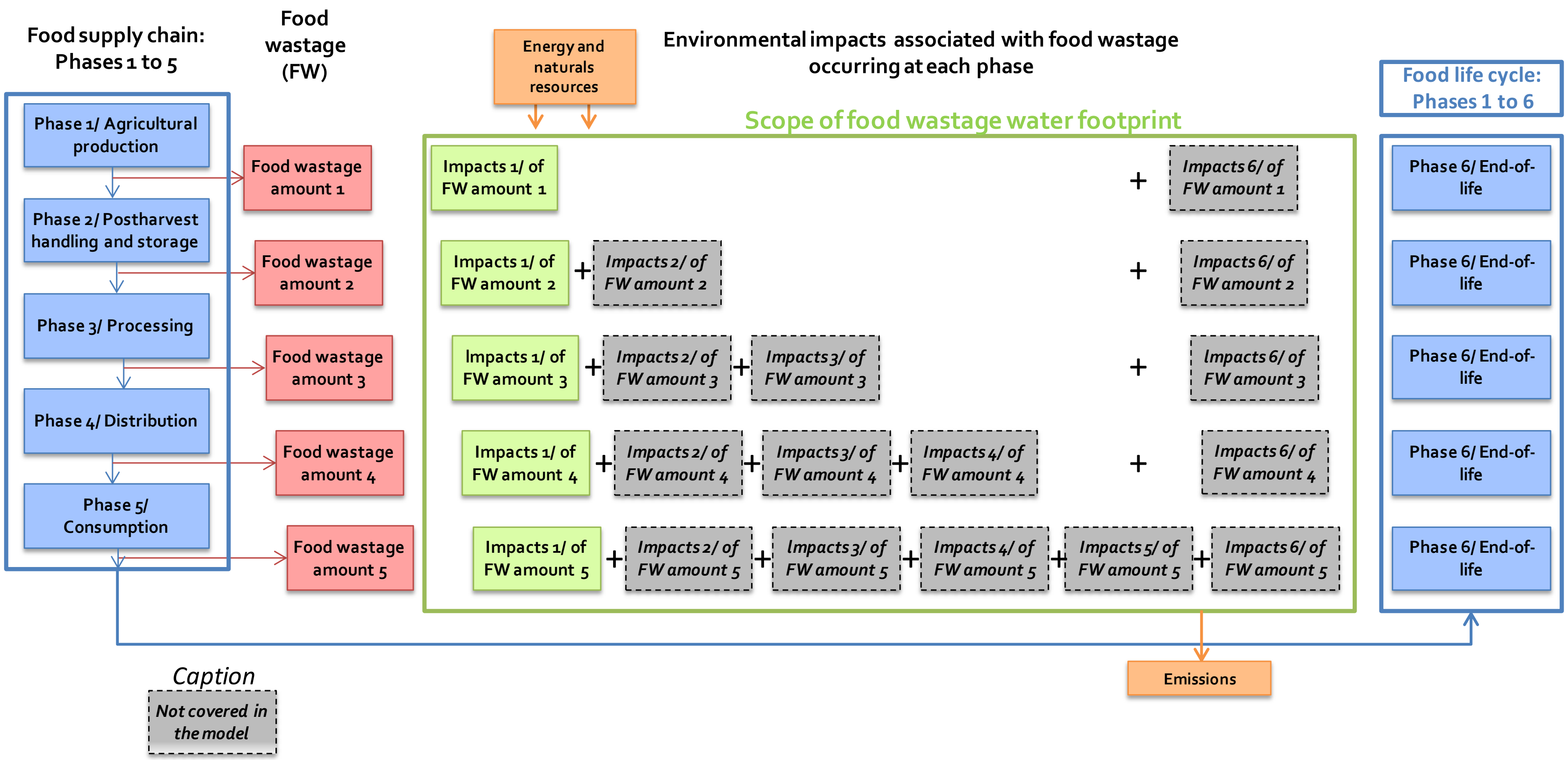

Figure 11: System boundaries of the water footprint assessment

3.3.4 Modelling, data sources and assumptions

Data sources and modelling principles are summarised in Figure 12 and further detailed in the paragraphs hereafter.

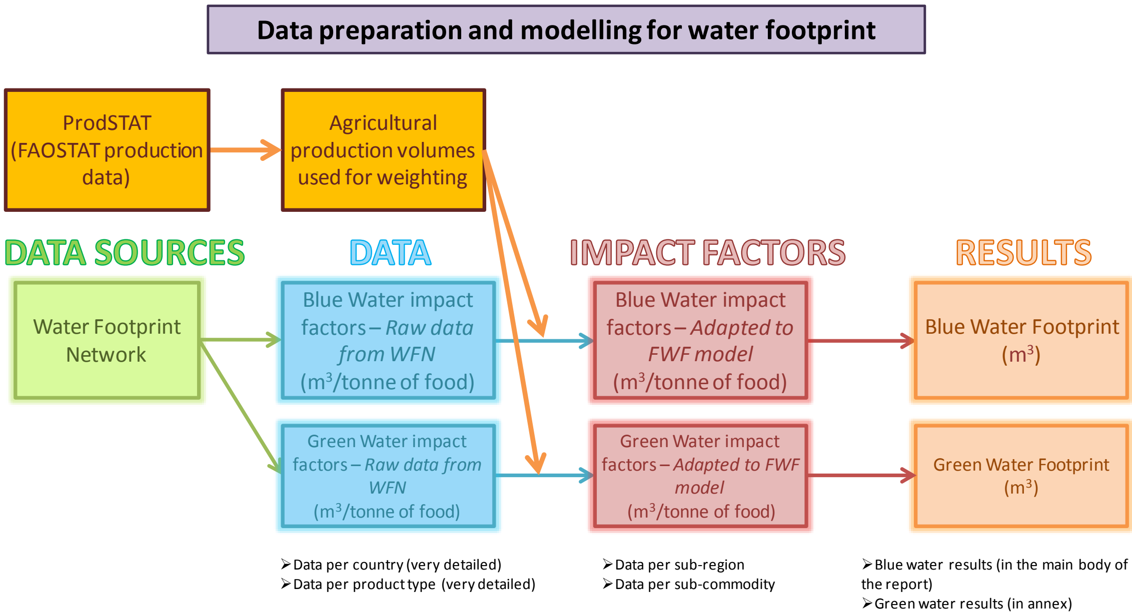

Figure 12: Data preparation and modelling for water footprint

Modelling and data sources

The water footprint module of the FWF model builds on the water impact factors provided by the Water Footprint Network (WFN) for blue water and green water. These factors databases are accessible on the WFN website[20] for crops (Mekonnen & Hoekstra 2010a) and animal products (except fish and seafood) (Mekonnen & Hoekstra 2010b). Extracts of these databases are presented in Annex XII as an illustration. Note that WFN data is partly based on FAO's data and models such as the CROPWAT model. The possibility to directly used Aquastat data was discussed during the course of the project but eventually could not be done because of data management issues (see Box 11).

Each of these databases covers about 200 hundred countries and more than 100 products. However, many data gaps in the "country * products" crossings remain but world average values for each product are also provided.

An important work of data preparation and treatment was performed to make WFN's data consistent with the FWF model structure. Practically, it requires transforming tables of 100 products * 200 countries into tables of 21 sub-commodities * 21 sub-regions, for each type of water footprint. This work was done by duplicating WFN data and using FAO's ProdSTAT data (FAOSTAT 2012f) as weighting factors to build up water footprints averaged at the sub-region and sub-commodity level.

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[20] http://www.waterfootprint.org

Here is an example:

The water footprint network provides water footprints for 1/ several categories of citrus: Oranges; tangerines, mandarins, clementines; Lemons and limes; Grapefruit (inc. pomelos); Other citrus fruit and 2/ for several countries in Europe: France, Italy, Greece, Spain, etc.

From these data, it is necessary to construct a semi-aggregated water footprint factor for the citrus sub-commodity in Europe. This is done by using production volumes in each country for each type of weighting factors in the calculation of the averaged value "citrus in Europe".

Impact factors obtained for each sub-region and sub-commodity are presented in Annex XIV.

Box 11: Link between Aquastat and WFN data

A number of recent studies on the water footprint of food wastage use the WFN database on the water (WRAP 2011; Kummu et al. 2012). Note that the impact factors from WFN are "averaged" blue water footprint of rained and irrigated systems for a given crop in a given country. To make it clearer, WFN explains that when considering the agricultural blue water footprint of rainfed crops (no irrigation) the value is always zero. Therefore, if the blue water footprint of an irrigated crop is X and the blue water footprint of a rainfed crop is zero, then the averaged blue water footprint of the crop is Y (< X) depending on the share of the production that is rainfed or irrigated in the considered region.

During the course of the project, the possibility to use data from ongoing work of Aquastat team in FAO was considered. The Aquastat team provided a dataset with amounts of water withdrawn for irrigation per tonne of products. These values are valid for irrigated crops only since they are based on irrigation requirements divided by irrigated production. Consequently, using such data in the FWF model would have implied to manipulate additional data sources to determine the share of the production that is irrigated vs. rainfed for all commodities and regions. This, compounded by incomplete data coverage for some of our commodity groups (e.g. animal products), made the use of the WFN dataset preferable, in order to ensure a better overall coherence of the results. However, efforts are on-going to use Aquastat datasets in refining the FWF model.

Assumptions

Due to unavailability of data, water footprint for fish and seafood was not taken into account. Besides, it can be pointed out that water footprint experts consider fish and seafood to be a "low or non-water consumptive" product category (Zimmer & Renault 2003).

More specifically, several authors point out that no water consumption can be associated with wild seafood and marine fisheries. It can also be considered that brackish and marine aquaculture are not water-consumptive because there is no demand or competition for marine or brackish water (Brummett 2006; Welcomme 2006). More generally, a distinction can be made between two main types of activities: fishing and aquaculture). As long as fishing remains a gathering activity (as opposed to aquaculture), it can be assumed there is no water allocated to a production process and, therefore, no water consumption. At the individual level, natural fish production in water bodies (natural or man-made), without any specific intervention may, therefore, be regarded as non-water consumptive (Lemoalle 2008).

As regards freshwater aquaculture, it can consume small quantities of water through water evaporation of natural streams and bodies, and sometimes through the agricultural primary products used to feed the fish. The topic of water consumption related to aquaculture is further discussed in Box 12.

An underlying assumption made in the quantification of water footprint is that the production sub-region is similar to the consumption sub-region. For instance, water footprint of beef meat wasted in USA is calculated with the water impact factor of 1 kg of meat produced in the USA. This is based on a macro analysis of FBS. In addition, if this beef was fed with e.g. irrigated soya from Brazil the water footprint of soya is embedded in the water footprint of beef and accounted for where the meat is consumed.

The FBS's macro analysis shows that for most commodities, imports are only limited share of total domestic food supply except for fruits (and fish & seafood). For that reason, fruits water footprint used in the model are world averages and not regionalised figures.

Whenever data was missing for a given set of country * product, the footprint value was replaced by the world average footprint value.

Box 12: Freshwater aquaculture and water consumption

Causes of water consumption in freshwater aquaculture

Water consumption by aquaculture can be divided into direct (i.e.net water harvesting arising from water content of fish) and indirect (i.e. water required to produce aquaculture feeds and to maintain pond water levels, compensating for water lost through evaporation, seepage and intentional discharge) consumption. Indirect losses are several orders of magnitude greater than direct losses (Beveridge & Brummett 2012).

Water for freshwater pond fish farming may come from rainwater harvesting (i.e. the interception and storage of water before it reaches the aquifer) or from diversion or abstraction of water from rivers or canals. Rather than loss per se, evaporation and seepage from ponds accelerate the transfer of water to the atmosphere (evaporation) and groundwater (seepage). The withdrawal of water from river channels or diversion to fish ponds can affect the flow regimes needed to sustain fish (Brummett et al. 2012).

Water loss by seepage occurs through pond dykes (infiltration) and bottoms (percolation), losses being typically three times higher through the former than the latter. Seepage rates are primarily determined by soil characteristics, clay soils generally providing much higher water retention than silt and sand soils. Infiltration is also to some extent governed by the slope of the dykes and by pond water height while percolation is influenced by the height of the water table. Seepage losses tend to decrease over time as bottom sediments accumulate (Verdegem & Bosma 2009).

Water is also needed to produce the food required to sustain fish production. Feed-associated water use is mainly determined by the types and amounts of plant ingredients in the feed (Verdegem & Bosma 2009). On average, Verdegem & Bosma (2009) estimate that food associated water consumption accounts for around 9% of total water use per unit aquatic animal production, the remainder being system-related losses (i.e. evaporation, seepage and intentional discharge). The figure, however, increases with reliance on feeds.

Cage aquaculture derives production and regulating aquatic ecosystem services from the lake or reservoir in which the cages are situated. The issue of water use in lakes is thus arguably irrelevant. In reservoirs, however, the requirements to maintain sufficient water depths for cage aquaculture can be significant. Such requirements can result in compromises with drawdown for power and irrigation (K. Lorenzen et al. 2007).

Link with the FWF model

Although the FAO (2011) food wastage data for Fish & Seafood may be more questionable than for other commodities (see section 3.1.2), it appears that this commodity accounts for about 2% of the global food wastage. This means that, compared to the other commodities, Fish & Seafood is apparently responsible for the smallest share of the global food wastage. In addition at global level, aquaculture represents about 40-50% of the world production of fish & seafood (FAOSTAT 2012a). Finally, freshwater aquaculture is a share of this 40-50%. For this reason, it can reasonably be considered that the blue water footprint of wasted/lost fish & seafood – which would be largely attributable to freshwater aquaculture – is very limited compared to other commodities.

Lastly, it can be underlined that aside from water consumption, aquaculture has other environmental impacts – most notably water pollution due to different types of wastes released (treated or un treated) in the breeding environment such as uneaten food, faeces and metabolic wastes and chemicals (including medicines) (Beveridge & Brummett 2012).

3.3.5 Taking water scarcity into consideration

3.3.5.1 *PRESENTATION OF GAEZ AND SOLAW*

The International Institute for Applied Systems Analysis (IIASA) and the FAO have been developing over the past 30 years the Agro-Ecological Zones (AEZ) methodology for assessing agricultural resources and potential. The new GAEZ v3.0 portal (FAO & IIASA 2012), gives public access to data and maps covering several thematic areas such as soil resources, agro-climatic resources, agricultural suitability and potential yields, etc.

In particular, within the land resources thematic, GAEZ provides a framework for establishing a spatial inventory of water resources. It includes datasets on water scarcity by major watersheds which are developed for the FAO SOLAW Report[21] (FAO 2011b).

Water scarcity is indeed a relevant issue to focus on. Water resources are very unevenly distributed both at geographical and temporal scale. Water scarcity has three dimensions: physical (when the demand is higher than the available supply), infrastructural (when the water demand cannot be satisfied because of ineffective infrastructures) and institutional (when secure and equitable supply of water to users is not ensured by public authorities).

In terms of physical water scarcity, it is estimated that on average a withdrawal rate above 20 percent of renewable water resources represents substantial pressure on water resources – and more than 40 percent is 'critical'. Figure 13 shows the global distribution of water scarcity by major river basin, based on consumptive use of water in irrigation.

[21] This report mostly focuses on the issue of land and water for crops. It examines the kinds of production responses needed to meet demand. It also assesses the potential of the world's land and water resources to support these desired increases in output and productivity.

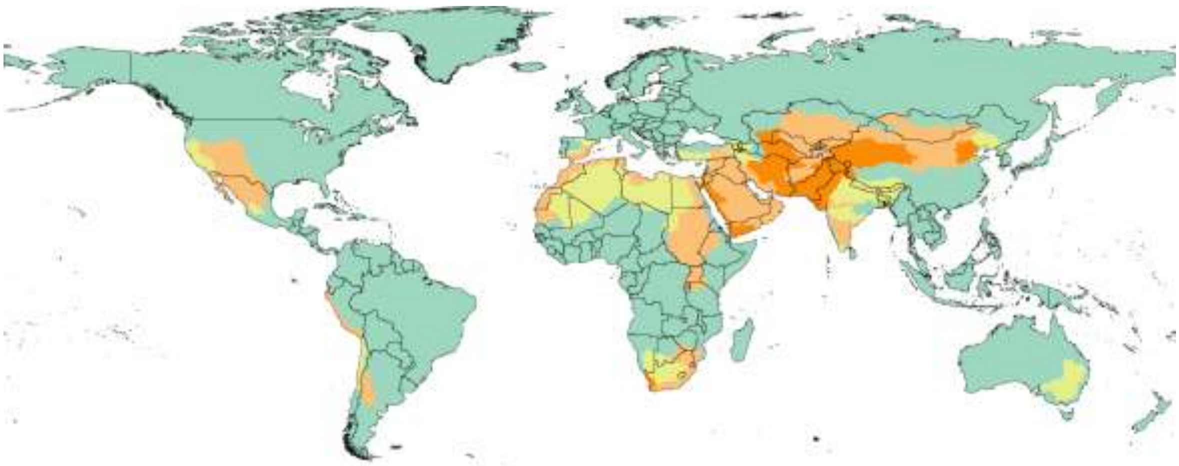


Figure 13: Global distribution of physical water scarcity by major river basin (FAO 2011b)

Figure 13 provides a representation of the levels of water scarcity by major river basin, expressed as the ratio between the irrigation water consumed by plants through evapo-transpiration and the renewable fresh water resources. Some countries are already withdrawing in excess of critical thresholds, particularly in the Middle East, Northern Africa and Central Asia.

3.3.5.2 FAO FWF WATER COMPONENT: INTEGRATING GAEZ DATA ON WATER SCARCITY

Data available on the GAEZ v3.0 portal were adapted to the FWF model in order to complement water footprint figures with a view on water scarcity aspects.

GAEZ provides for each country of the world the areas of land that have a low, moderate, high or very high water scarcity. These areas were summed up in order to derive from them figures at the regional level.

This allows getting a view on the regions that have the largest share of land areas with high or very high water scarcity. The resulting profile can be presented along with food wastage generation by region in order to see if some trends or similarities exist between the two profiles.

It should be noted that this analysis has a low resolution, thus results should be taken with caution. Outcomes of GAEZ are normally maps that have a lower spatial scale than countries or world regions as shown in Figure 13.

3.4 Component 4: Land occupation and degradation

3.4.1 Presentation of the component

The continuous growth of the human population reinforces the competition on land between forestry, agriculture, infrastructure, and natural ecosystems. Indeed, land is increasingly seen as a limited resource in particular as regards the supply of productive agricultural land. From an environmental point of view, land is a key aspect in many issues such as climate change, biodiversity, and ecosystem services. Due to these different land-related issues, *land use*[22] has diverse meanings. The present report builds on the following definitions adapted from Mattila et al. (2011) and FAO LADA (2011).

Land cover refers to the physical material on earth's surface that is to say the observed (bio)physical cover such as forest, infrastructures, etc.;

Land use per se refers to the functional dimension of land and describes how the area is used for urban, agricultural, forestry and other purposes;

Land use change refers to the change from one land use category to another, which may lead to a change in land cover; for example, planting forest on land previously used for agriculture.

Land occupation refers to the "physical" surfaces – e.g. areas of land expressed in ha for example [23]. In terms of environmental impacts, it can be seen as an indicator of the "resource depletion" category – i.e. competition for limited land area.

The land occupation component is further divided in this study in two sub-components: **arable land occupation** (ha of cropland for human consumption or for livestock feed) and **non-arable land occupation** (ha of pastures or meadows).

Land degradation as defined by FAO's LADA[24] programme is the reduction in the capacity of the land to provide ecosystem functions over a period of time for its beneficiaries (FAO LADA 2011).

Choice of the relevant land indicator

To date, there is no established and globally applicable practice on how to assess *land use* in LCA (European Commission 2010). Consequently, *land use* aspects are not assessed in most of the LCA studies even in cases in which *land use* aspects are found to be extremely important such as biofuels (Cherubini & Strømman 2011). In Mattila et al. (2011), nine different indicators are selected to represent three different impact categories of land use, namely resource depletion, soil quality, and biodiversity. Although authors pointed out that none of the tested indicators

[22] The term "land use" *in italic* is employed in a broad sense to encompass land cover, land occupation, land use per se and land use change.

[23] The usual unit is m^2 or sometimes m^2.year, which means that it is considered equivalent to occupy e.g. one m^2 during 10 years or 10 m^2 during one year. In the present study only m^2 are assessed. The duration aspect is not taken into account.

[24] Land Degradation Assessment in Drylands

describes the full range of environmental impacts caused by land use, one of the indicators they recommend eventually is land occupation.

The land occupation indicator has some advantages since it has a relatively low uncertainty and is expressed in a surface area unit (e.g. ha) which is easy to understand (Mattila et al. 2011). In addition, land (and particularly agricultural land) can be seen as a limited natural resource with a number of competing uses (e.g. agriculture, buildings, roads). Assessing land occupation provides a view on the depletion of this resource. In the present study, land occupation addresses the surface of agricultural land necessary to produce foodstuff, i.e. fields for crops and grasslands areas.

However, this single indicator is not sufficient to describe all the land-related environmental impacts. Indeed, it does not address the issue of land use change (impacts of deforestation, urbanisation, soil sealing, etc). In addition, it does not indicate if the land occupation is actually beneficial or negative for the environment, in particularly regarding impacts on soil quality. Indeed, occupation of land for e.g. agricultural use can lead to a temporary or permanent lowering of the productive capacity of land. This phenomenon is called land degradation and is recognised by the United Nations as a global development and environment issue. In this context, the land occupation figures calculated in the present study have been complemented with data from FAO LADA (2011) model in order to give a first tentative view of the linkage between land occupation of food wastage and land degradation aspects.

3.4.2 Objective

As regards the land component, the overall objective of the study is to assess land-related environmental impacts coming from food that is produced but not eaten because of wastage.

The primary objective of the land component is to quantify the amount of agricultural surfaces occupied to produce lost/wasted food. A second objective is to give an overview of the level of degradation of the land on which lost/wasted food was produced.

3.4.3 System boundaries of the land occupation assessment

As regards food products, it is known from BIO IS expertise that land occupation is primarily due to agricultural surfaces per se. This is also confirmed by other authors, e.g. in Mattila et al. (2011), raw material cultivation was identified as being responsible for the majority of land occupation in the case of both beer and wine production.

Other phases of the life cycle do not use noteworthy surfaces. For instance, infrastructures such as buildings and road surfaces are ignored, providing their surfaces are negligible compared with the volume of products crossing them. For example, the food diet of an average European requires the occupation of hectares of fields but only a few square meters of food storage including the fridge and closets. This methodological choice is commonly made in LCA studies.

Figure 14 illustrates the system boundaries of the land occupation assessment.

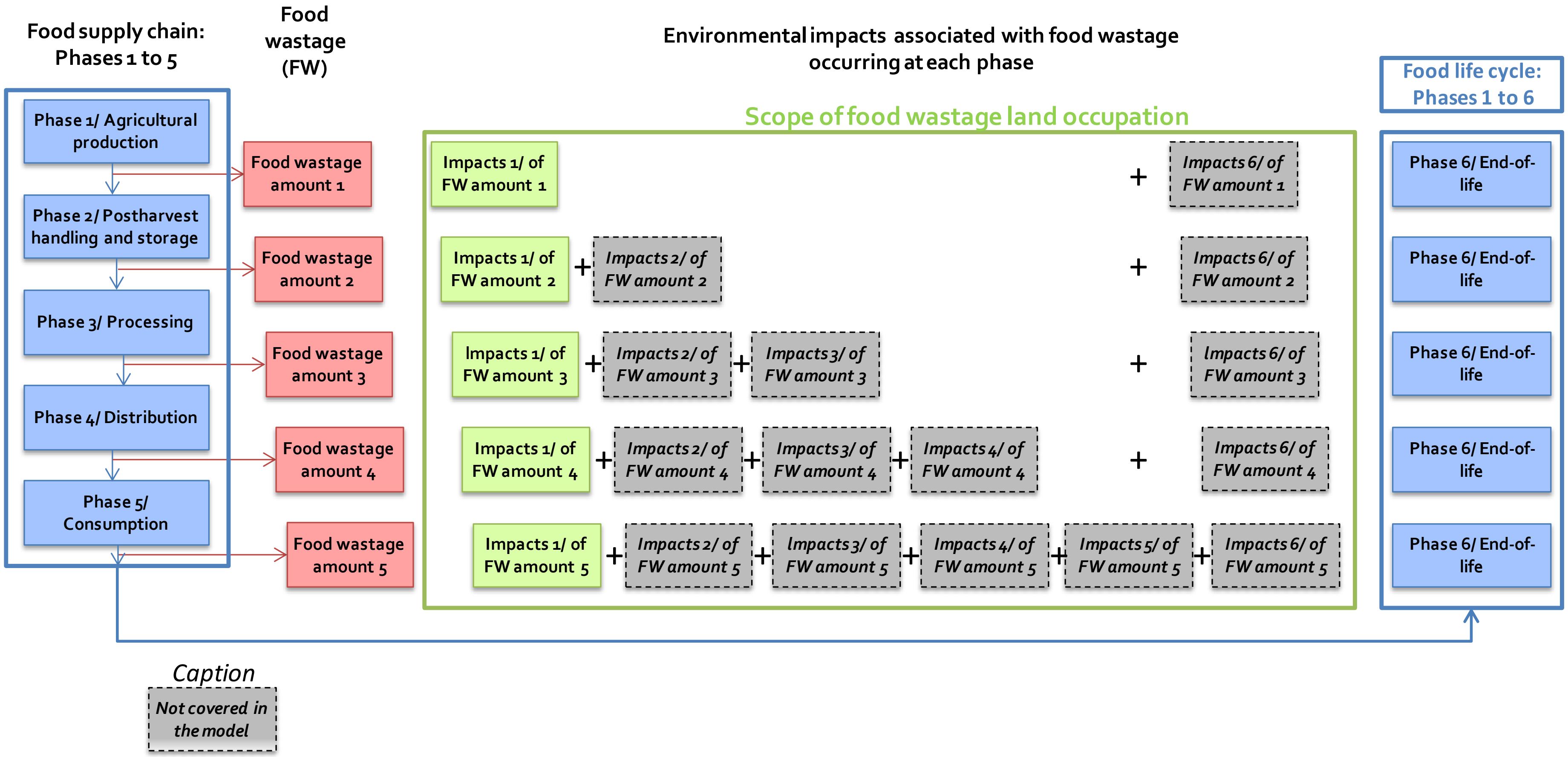


Figure 14: System boundaries of the land occupation assessment

3.4.4 Modelling, data sources and assumptions

Data sources and modelling principles are summarised in Figure 15 and further detailed in the paragraphs hereafter.

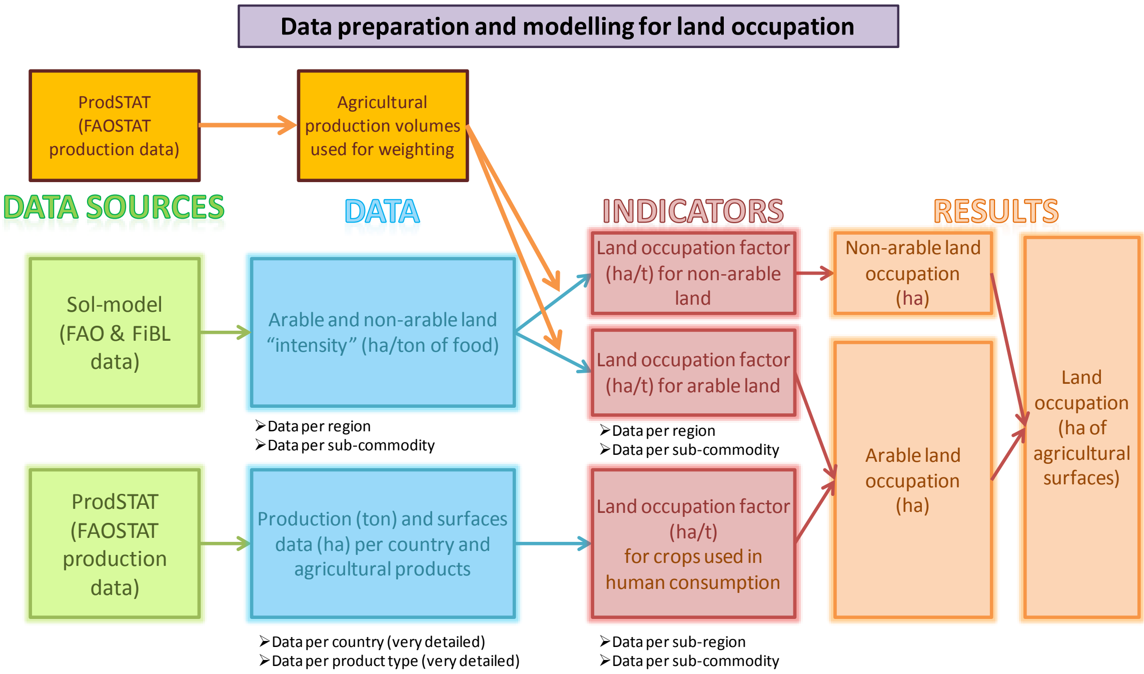


Figure 15: Data preparation and modelling for land occupation

Modelling and data sources for land occupation related to commodity groups 1,2,3,4 and 8 (i.e. crops for human consumption)

Production volumes and agricultural surfaces were extracted from ProdStat (FAOSTAT 2012f) this data was prepared to fit the sub-commodities and sub-regions of the FWF model. A land occupation factor expressed in hectares per tonne was obtained for each "sub-commodity * sub-region" pairs.

Modelling and data sources for land occupation related to commodity groups 5 and 7 (livestock products)

As regards livestock productions, land occupation assessment requires specific accountings of the agricultural surfaces occupied to produce animal feed and surfaces used for grazing, per tonne of animal product. Land occupation factors used in this study were provided by the team working on the SOL-m project (see FAO, 2012b for details on this project). Calculations of factors were based on the feeding module within SOL-m. Factors for the seven regions used in the FWF study were obtained. Note that SOL-m is an ongoing project and that the factors provided – although the best available at the time of our study – are preliminary figures.

Finally, data preparation and treatment was performed to make data for each animal product fit the model structure. In practical terms, SOL-m provided impact factors for 16 relevant animal products and they were adapted to fit in the six corresponding sub-commodities (see Table 6). This work was performed using FAO's ProdSTAT data (FAOSTAT, 2012f) as weighting factors to build up factors averaged at sub-commodity level.

Table 6: Aggregating commodities from FAO (2012b)

Item name	Sub-commodity name (this study)
Cattle meat	5-1 Bovine Meat;
Buffalo meat	
Sheep meat	5-2 Mutton & Goat Meat
Goat meat	
Pig Meat	5-3 Pig Meat
Chicken meat	5-4 Poultry Meat
Duck meat	
Turkey meat	
Goose and guinea fowl meat	
Goat milk, whole, fresh	7-1 Milk
Buffalo milk, whole, fresh	
Camel milk, whole, fresh	
Cow milk, whole, fresh	
Sheep milk, whole, fresh	
Hen eggs, in shell	7-2 Egg
Other bird eggs, in shell	

Impact factors obtained for each sub-region and sub-commodity are presented in Annex XV.

General assumptions

Land use factor for marine fish from capture and seafood is not accounted for. It is clear that because of their very nature, such products do not require agricultural land.

Regarding aquaculture (both marine and inland), it should be pointed out that in some productions systems fish can be fed with feeds coming from agricultural products. However, no detailed data could be found on land occupation factor for aquaculture. This issue is further discussed in Box 13.

An underlying assumption made in the quantification of land occupation is that products consumed in a sub-region are produced in the same region. This leads to a differentiation of the production systems and to different land occupation component values. For instance, land occupation related to wheat wasted in Europe was calculated with the land impact factor of 1 kg of wheat produced in Europe.

The FBS's macro analysis shows that for most commodities, imports are only limited share of total domestic food supply except for fruits and fish & seafood. For that reason, fruits land occupation factors used in the model are world averages and not regionalised figures.

Box 13: Freshwater aquaculture and land occupation

Causes of land occupation in freshwater aquaculture

It is clear that as aquaculture grows, more land will be required to produce the food that aquaculture uses. For instance, more than 50% of land use in carp farming and 40% of land use associated with tilapia and catfish farming is attributable to production of crop-based aquaculture feedstuffs (Hall et al. 2011).

It is acknowledged that there are currently no reliable estimates of global land use by freshwater aquaculture. Rough estimations can however be made: assuming 40 million tonnes production and a global average productivity figure of 3 t h-1, the area of land used by aquaculture is about 130,000 km^2 (i.e. approximately the size of Greece or Nicaragua). A further 25% or so should be added to account for feed production (Beveridge & Brummett 2012). While the figure is negligible in the context of agriculture, which occupies about one third of the land surface of the planet (FAOSTAT 2012b), at the local scale pond aquaculture sometimes accounts for the majority of local land use, as in some parts of the Mekong Delta. Freshwater pond aquaculture generally occupies low-lying agricultural land that is difficult to drain areas and with little alternative economic value, although such land can have potentially high biodiversity value (Beveridge & Brummett 2012).

Link with FWF model

Calculations made with the FWF model give a value of 14 million km^2 for land occupation related to food wastage in 2007 (excluding fish & seafood). This figure can be compared to the estimated area of 160,000 km^2 of land occupied by aquaculture: it appears that even if it was assumed that 100% of the production made on this surface of 160,000 km^2, it would only represent about 1% of total land occupation of food wastage. Thus, we can reasonably consider that the land occupation of wasted/lost fish & seafood is very limited compared to other commodities.

Specific assumptions for the SOL-m impact factors

The feeding module within SOL-m calculates the metabolisable energy and protein demand per livestock type. For cattle and pigs, country specific herd structures were statistically estimated.

Data are mainly based on FAO data, when possible FiBL used an average of data from 2005-2009. Data for grassland yields and areas stem from Erb et al. (2007). Further assumptions on energy contents in different fodder types were taken from numerous references in literature and expert judgments.

Fodder is distinguished between grass, forage maize, and concentrates. For grass and forage maize, the land use figures are based on country-specific yields. For concentrates, however, a fully globalized market is assumed.

For by-products (e.g. brans from wheat flour production), no land use was assumed, as the land-use was already allocated to the corresponding amount of wheat flour. By-products are however relevant for feed (e.g. brans). It was assumed that feed calories that stem from by-products from processing for human consumption do not lead to increased land use for the corresponding animal production.

It must be underlined that meat and milk are tightly linked production systems. Allocating land use to meat or milk exclusively, for example, overestimates the land use, as in this case milk can be seen as a by-product of meat or vice-versa. FiBL indicated that for correct land use calculations, the amount of milk that can be produced in a system that produces a certain quantity of meat, to which all land use is allocated, does not lead to additional land use. This means that the commodity 5 “Meat” and sub-commodity 7-1 “milk” were combined in all land use calculations made in the FWF model.

3.4.5 Taking land degradation into consideration

3.4.5.1 PRESENTATION OF LADA AND GLADIS

Global assessments of soil and land degradation have started more than 30 years ago, but had until now not achieved a clear answer on where the degradation takes place, and what impact it has on population and environment (FAO LADA 2011). In 2006, FAO started a program named the Land Degradation Assessment in Dry lands (LADA), in order to provide some qualitative and quantitative answers to land degradation questions, at a global scale. LADA aims at informing decision makers on all aspects of land degradation and relies on a set of various databases that constitute the Global Land Degradation Information System (GLADIS). GLADIS outputs are a series of global maps on the status and trends of the main ecosystems services.

Land degradation is defined by LADA as the reduction in the capacity of the land to provide ecosystem goods and services over a period of time for its beneficiaries. These goods (food, water, construction material, etc.) and services (e.g. maintaining hydrological cycles, regulating climate, cleansing water and air, etc.) are transferred in tangible and measurable entities (four biophysical parameters and two socio-economic parameters). These six parameters are as follows: biomass, soil health, water quantity, biodiversity, economics, social.

Degradation or decline in ecosystem services corresponds with a change in state of these services due to pressures and resulting in various degradation **processes**. However, before being able to quantify these changes, the baseline of the actual **status** of each ecosystem needs to be determined.

The **status** of an ecosystem is described with the above-mentioned six parameters. The status is inherent to the actual use, management, and natural conditions, and is an assessment of the baseline. Partly inherited, partly natural and partly human induced; the combination of these six parameters corresponds with the actual **status of degradation**.

In a similar way as described for the status, the **trends** (or **processes**) of the six main ecosystem services can be calculated or estimated to characterise the **degradation processes**. These processes are the result of external pressures exerted upon the ecosystem.

The set of values obtained for each of the four biophysical parameters for both status and trend allows calculating two aggregated indexes:

The Biophysical Status Index (BSI): aggregated land status index

The Biophysical Land Degradation Index (BLDI): aggregated land trend index

World distribution of BSI and BLDI indexes are presented on maps in FAO’s LADA report (FAO LADA 2011), as shown in Figure 17 and Figure 18.

These two indexes can be further combined in **classes of land degradation** (see Figure 16) which give an overall view of the land status and trends in a given location.

		Status			
		<=25 bad	25-49.99	50-75	>75 good
Process	>0.7 high LD process	Low status; Medium to Strong degradation	Low status; Medium to Strong degradation	High status; Medium to Strong degradation	High status; Medium to Strong degradation
	0.5-0.7	Low status; Medium to Strong degradation	Low status; Medium to Strong degradation	High status; Medium to Strong degradation	High status; Medium to Strong degradation
	0.5-0.55	Low status; Weak degradation	Low status; Weak degradation	High status; Stable to improving	High status; Stable to improving
	<= 0.5 low LD process	Low status; Improving	Low status; Improving	High status; Stable to improving	High status; Stable to improving

Figure 16: Classes of land degradation (FAO LADA 2011)

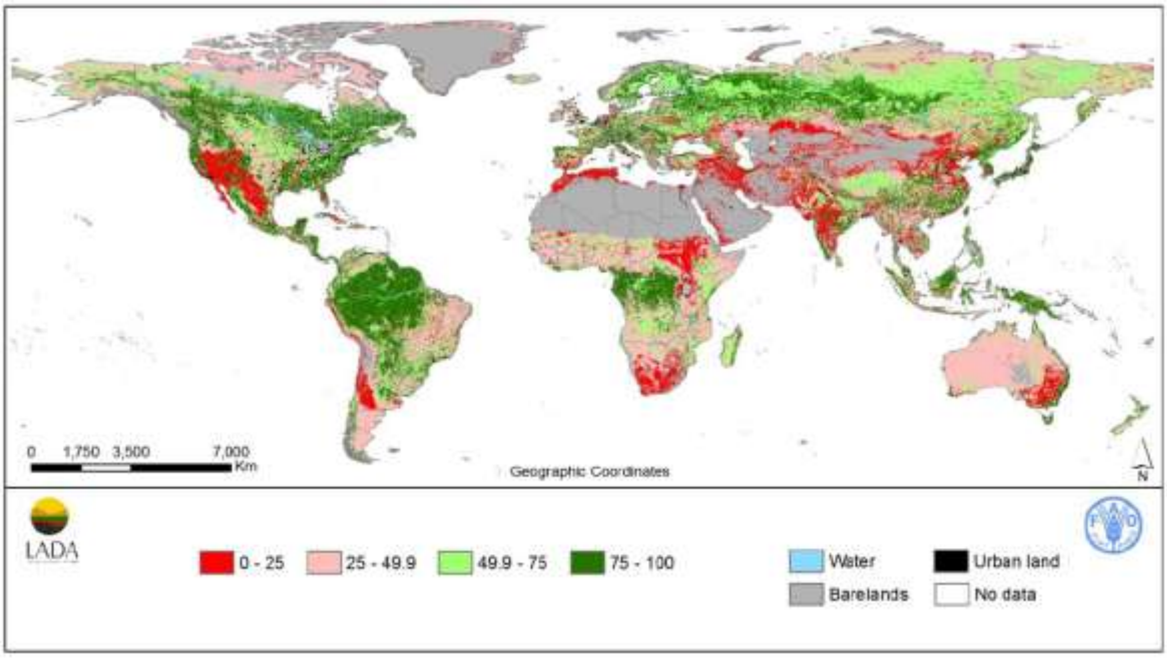


Figure 17: Biophysical status of land (FAO LADA 2011)

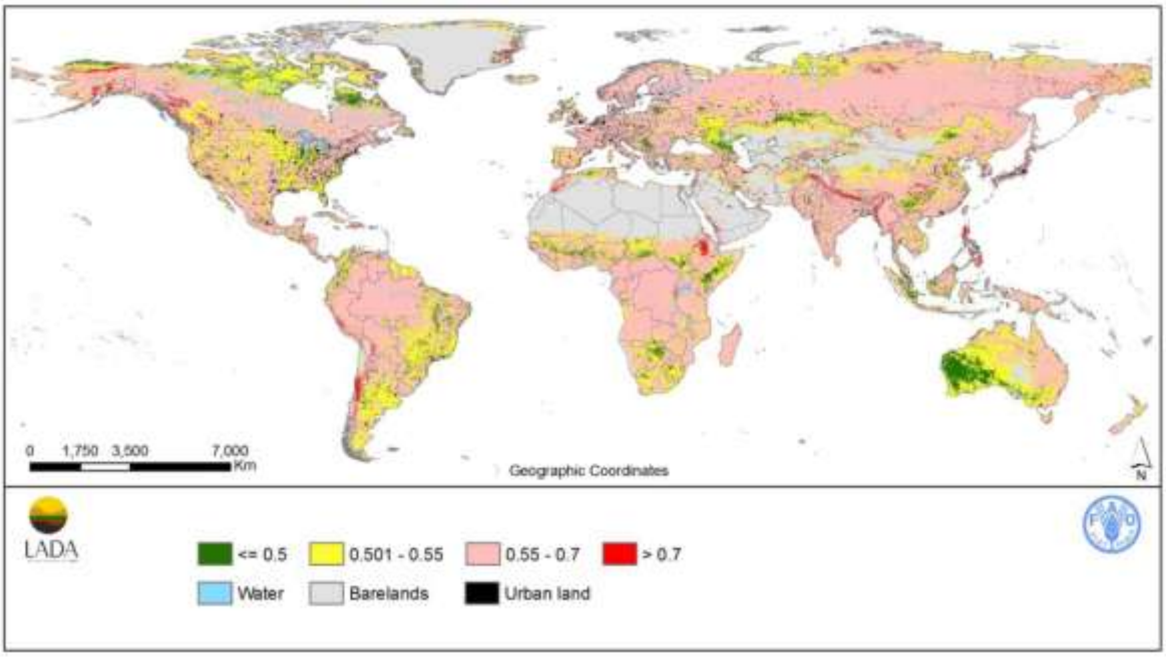


Figure 18: Biophysical land degradation process (FAO LADA 2011)

BSI and BLDI indexes are also available at country level in Annex 7A of FAO's LADA report (FAO LADA 2011), as shown in Figure 19.

Annex 7A. GLADIS statistics

Annex 7 Table 1 National statistics by axis and indexes

Country	Greenes & deforestation trend / Axis 1 Process	Carbon above ground / Axis 1 status	Trend in Soil Health / Axis 2 Process	Soil constraints / Axis 2 status	Trend in water stress / Axis 3 process	Water / Axis 3 status	Biodiversity risk resilience / Axis 4 process	Biodiversity / Axis 4 status	Trend in productivity value / Axis 5 process	Economic value / Axis 5 status	Trend in social & cultural provisions / Axis 6 process	Social and cultural goods & services / Axis 6 status	Biophysical land degradation process	Biophysical status of land
Afghanistan	52.44	10.09	39.59	89.15	32.51	8.55	43.84	42.75	69.88	17.73	50.00	40.68	0.57	0.28
Albania	51.47	21.21	35.88	61.15	51.37	94.04	22.03	21.73	62.71	71.35	50.00	75.72	0.59	0.50
Algeria	50.64	2.41	49.03	95.66	44.73	19.95	41.69	37.56	80.55	23.08	50.00	48.60	0.55	0.22
Angola	47.90	43.46	43.76	92.37	50.43	100.00	36.53	55.04	62.75	14.19	50.00	52.39	0.56	0.52
Argentina	48.18	26.41	43.75	82.08	50.52	85.71	31.63	33.73	66.14	29.29	50.00	70.02	0.56	0.45
Armenia	52.83	20.24	35.71	45.78	40.80	38.20	32.33	20.20	53.85	68.76	50.00	89.62	0.60	0.29
Australia	51.64	23.33	43.76	79.92	49.36	89.86	44.02	36.60	54.05	12.85	50.00	45.86	0.53	0.40
Austria	51.28	57.45	25.87	90.69	49.82	98.05	35.01	40.46	59.48	56.32	50.00	96.35	0.59	0.76
Azerbaijan	49.53	16.34	40.57	61.02	40.41	38.72	39.95	23.97	51.92	67.64	50.00	92.23	0.57	0.34
Bahrain	50.00	3.08	49.45	95.83	25.45	8.77	45.00	13.33	78.57	50.00	50.00	100.00	0.57	0.42
Bangladesh	50.00	10.66	40.69	34.36	46.26	63.95	32.59	27.60	71.61	58.75	50.00	84.24	0.57	0.31
Belarus	54.42	38.95	42.09	68.53	50.07	98.87	32.33	34.74	46.00	35.72	50.00	76.05	0.56	0.59
Belgium	50.25	20.62	40.96	71.74	49.63	98.05	32.33	18.45	56.46	92.01	50.00	99.77	0.61	0.54
Belize	50.11	78.42	49.60	86.21	50.86	100.00	38.78	64.96	55.85	27.01	50.00	90.90	0.54	0.76
Benin	45.60	20.12	44.27	72.84	49.96	99.22	36.26	41.32	79.51	27.20	50.00	78.35	0.57	0.42
Bhutan	50.94	59.43	14.67	90.01	46.01	58.60	34.87	55.79	54.22	31.73	50.00	61.70	0.62	0.62
Bolivia	47.74	60.25	41.11	90.34	50.13	99.43	33.23	59.72	59.22	14.61	50.00	58.76	0.59	0.71
Bosnia and Herzegovina	50.54	36.30	39.06	75.00	50.20	96.99	31.28	30.45	46.94	56.97	50.00	90.68	0.58	0.66
Botswana	55.32	20.47	45.54	85.75	48.31	74.16	35.09	50.51	47.64	7.91	50.00	74.87	0.53	0.37

Figure 19: Extract of data used for classes of land degradation assessment (FAO LADA 2011)

3.4.5.2 FAO FWF LAND COMPONENT: INTEGRATING LADA-GLADIS DATA ON LAND DEGRADATION

Data provided in FAO LADA (2011) were adapted to the FWF model in order to complement land occupation figures with a view on land degradation aspects.

Annex 7A of FAO's LADA report provides the two indexes (BSI and BLDI) necessary to calculate the class of land degradation of each country. Based on this, country-level BSIs and BLDIs were used in order to derive from them values at the sub-regional level, which is the finest geographical level employed in the FWF study (see 2.2.1).

Sub-regional level values were calculated from country level values weighted by country's agricultural surface. Thus, three sets of 21 sub-regional values for BSI, BLDI, and class of land degradation of each sub-region were obtained. This allows getting a view on:

The land degradation class/status/trend of the surfaces occupied to grow uneaten food in each sub-region,

The volumes of food lost/wasted with a low /medium / high class (or status, or trend) of land degradation in each sub-regions.

It should be pointed out that national indexes are already aggregated figures with a low resolution, thus the results of such indexes at a higher regional level should be taken with caution. Outcomes of LADA-GLADIS are mostly maps that have a lower spatial scale than countries or world regions as shown in Figure 17 and Figure 18.

3.5 Component 5: Biodiversity

3.5.1 Presentation of the component

Biodiversity comprises the diversity of life on Earth across genes, species, and ecosystems. According to the Convention on Biological Diversity, biodiversity is "the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". This biodiversity is essential in sustaining human life, as ecological systems provide a number of goods and services that benefit people. Food production is maybe the most important one, as no human activity has altered the surface of the planet more than agriculture (Tilman et al. 2001; Foley et al. 2005). Although some species can benefit from agriculture (Wright et al. 2012), habitat loss resulting from its expansion is one of the greatest threats to global biodiversity (Donald 2004; Green et al. 2005).

The challenge for biodiversity conservation is that impacts on biodiversity are multifaceted and highly location dependent. They differ in particular depending on the type of land use and its intensity and according to the biodiversity potential of the landscape. As such, biodiversity cannot be monitored by a single metric or indicator.

Food production is one of the main contributors to the continued and rapid decline in global biodiversity as production is often outsourced in areas that are important for conserving biodiversity ("hotspots of biodiversity"[25]) or already under environmental stress (BIO IS & TNO 2011). Commodities will thus have very different impacts on biodiversity according to their origin: for example, the same products, originating from different places may be linked to very different impacts, both qualitatively and quantitatively. Soybeans or coffee beans from Latin America can be linked to deforestation dynamics and associated biodiversity loss (Fearnside 2001; Philpott et al. 2008), whereas soy grown in Germany may lead to intensification of the production of other crops, or to their displacement, sometimes in a third country, through a process known as indirect land use change (iLUC). In this context, pressures on biodiversity may thus be exported abroad as e.g. agricultural production needs to be relocated or intensified to make space for other resource uses (BIO IS n.d., see Box 14).

[25] Hotspots of biodiversity hold especially high numbers of endemic species, yet their combined area of remaining habitat covers only 2.3% of the Earth's land surface. Each hotspot faces threats from human activities and has already lost at least 70% of its natural vegetation. (Myers et al. 2000)

Box 14: The biodiversity footprint of consumption: indirect land use change

Large areas of land are required to meet the growing demand for food but also bioenergy production. In order to meet these new demands, bioenergy cultivation for instance may replace prior land uses, such as cultivation of food, feed, or fibre. These commodities are likely to be displaced elsewhere along a chain of conversions or to be produced through the intensification of cultivation, unless competing demands decrease. This phenomenon is called indirect land use change (iLUC). Through conversion and/or intensification (Bertzky et al. 2008; Renewable Fuels Agency 2008; Prins et al. 2010), iLUC can impact biodiversity potentially to much greater extent than it does directly (Phalan et al. 2013) and biodiversity impacts can be distributed worldwide.

For example, the EU is a net importer of food and non-food commodities from third countries that are causing threats to species elsewhere. Five EU member states (DE, FR, UK, IT, ES) are among the top ten worse contributors to global biodiversity loss through the goods they import, and responsible for over 250 species threats each on average.

3.5.2 Objective

The objective is to assess the impacts of global food wastage on biodiversity, through both a qualitative evidence-base and quantitatively through carefully selected indicators.

3.5.3 System boundaries of the biodiversity assessment

Food wastage may impact biodiversity either through the disposal of unused and sometimes useful parts of the food to waste, or through the damage caused to natural habitats for producing this food. Clearly, the damages caused to natural habitats during the production phase are considerably greater than biodiversity impacts due to the disposal of unused parts. Food waste may typically be left on field or disposed of to landfills or through incineration. Both of these solutions may in fact have some positive impacts on biodiversity, if appropriate management practices are used. For instance, restored landfill sites can provide important habitats for common and threatened bird populations (Rahman et al. 2011). Similarly, crop residues left on field may provide a source of organic matter stimulating soil biodiversity (Turbé et al. 2010). In contrast, the collateral impacts of food production (agricultural production, fisheries and aquaculture) on natural ecosystems have much more critical consequences for biodiversity. They typically lead to land use change and over-exploitation, as well as increased chemical use and spread of invasive species, all of which are main drivers of biodiversity loss. For example, the conversion of natural areas to agriculture results in habitat loss for wild animals, and may lead the extinction of some populations or species. The assessment is thus focused on the food production phase.

Globally, one of the major pressures on biodiversity remains the transformation of natural habitats to agriculture, especially through forest clearance (Jenkins 2003). However, there are great differences between developed and developing world. In the developed world, the transformation of natural habitat to agriculture was largely completed several centuries ago, and this process is now starting to reverse, owing mostly to land abandonment or habitat restorations. In contrast, new croplands in recent decades have largely come at the expense of natural habitats in developing countries, particularly tropical forests (Gibbs et al. 2010). A large part of this crop expansion seems to come at the expense of intact forests, but disturbed forests and other degraded land are also sources for new permanent agriculture. This largely results from the export of the food demand from developed countries to these developing countries (see see Box 14 for an illustration). But more pervasive is that those developing countries that have been experiencing a forest transition in recent years towards reforestation, have usually simply shifted the forest clearings abroad, in other developing countries (Meyfroidt et al. 2010). These aspects of food wastage responsibility related to international trade are not covered in this report.

The type of farming and the intensity of production is a second cause of biodiversity loss. Agricultural yields have risen dramatically over the last 40 years (Green et al. 2005), through intensification of production systems and selection of high-yield varieties. This process is often associated with a simplification of agricultural landscapes, and reductions in diversity of crops at regional level. The switch to increasingly intensive land uses, or land use cascade, is often associated with detrimental impacts on wild species (see Figure 20). For instance, intensive management practices such as use of fertilisers and pesticides are established causes of biodiversity decline. However, on a landscape scale, it is not clear whether land-sparing or land-sharing strategies are better for biodiversity (Phalan, Balmford, et al. 2011, Box 15). Indeed, hardly any studies appropriately measure crop yields, compared with appropriate control systems and using meaningful biodiversity metrics.

It is beyond the scope of this study to consider the relative impacts of different farming production systems, as well as the impacts due to ILUC. As yet, there are no globally available spatially explicit datasets reflecting land use intensities. While FAO data on crop production could be used to reconstruct historical trends in agricultural yields, research would be needed to investigate whether increased yields are associated with increased biodiversity threats (see Chapter 6), while accounting for confounding variables (e.g. type of crop, human population, etc.). However, evidence of the impacts that different production systems may have on biodiversity is reviewed in section 3.5.4.2.

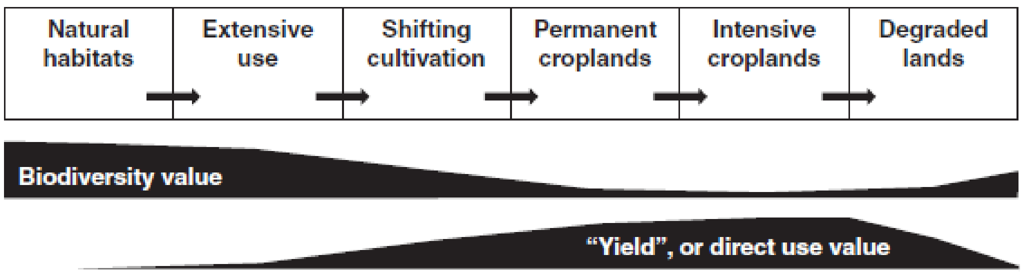


Figure 20: Simplified diagram of the land-use cascade (Phalan, Balmford, et al. 2011)

Intensification of land uses generates increased yields while reducing populations of many wild species and ecosystem services. As land becomes degraded, it may be abandoned and progressively revert to some natural state, while other land is being moved down the land use cascade to keep the food production levels.

Box 15: Global food production, intensification of production and biodiversity impacts: the land-sparing, land-sharing debate

The increase in human demand for food has two consequences in terms of land use: the conversion of natural habitats to agricultural land uses and the intensification of use of already modified lands. From a biodiversity perspective, the key question is how to best allocate land uses for a given level of agricultural production, to allow the maximum level of biodiversity to persist? (Phalan, Balmford, et al. 2011). The switch to increasingly intensive land uses, or land use cascade, is often associated with detrimental impacts on wild species. However, on a landscape scale, it is not clear whether land sparing or land sharing strategies are better for biodiversity (Phalan, Balmford, et al. 2011).

Many conservation biologists argue that the global application of wildlife-friendly farming methods would reduce the impact of agriculture on biodiversity. Wildlife-friendly farming involves integrating biodiversity conservation and food production on the same land, emphasizing heterogeneity, resilience, and ecological interactions between farmed and unfarmed areas. Typical examples are the agricultural subsidies in Europe to encourage farming practices that minimise the negative effects of fertilisers or pesticides or that include the retention of patches of natural habitats. However, there is considerable evidence suggesting that such wildlife-friendly farming is associated with reductions in yields, and thus to produce the same of amount of food, requires more land than high-yield farming, leaving less land available for natural habitats.

Another possibility is that increase in crop yield can enable land-sparing: a reduction in the amount of new cropland areas that would otherwise be needed to meet the growing food demand, allowing a greater area of intact habitat to be spared for conservation (Phalan, Balmford, et al. 2011). Agricultural yields have risen dramatically over the last 40 years (Green et al. 2005), giving rise to the idea that growing food demands could be met while at no further expansion of agricultural land. Recent evidence shows that although cropland area has expanded in recent times (Green et al. 2005) and is likely to expand further by 2050 (Balmford et al. 2005), land-sparing may have contributed to the maintenance of natural vegetation cover in the past. In a landmark study, (Phalan, Onial, et al. 2011) showed empirical evidence across gradients of agricultural intensity that land-sparing proved to be a more promising strategy for minimising the negative impacts of food production on biodiversity.

3.5.4Data sources and indicators

3.5.4.1 ***BIODIVERSITY INDICATORS***

The broadness of the biodiversity concept and the different interpretations imply that many indicators have been used to measure biodiversity. While some indicators focus on species richness or vulnerability, others focus on the extent of natural ecosystems and others still on drivers of biodiversity loss. However, most indicators have been developed for small well-known ecosystems and cannot easily be applied at the global level (PBL 2010). At this level, indicators need aggregation over large areas, different systems and usually suffer from data gaps. The main indicators used in global assessments are discussed below to describe their strengths and weaknesses, in particular for measuring the impacts of potential avoided food production. The description is structured according to the five categories proposed by the CBD to represent the state and change in state of biodiversity:

- Extent of ecosystems;
- Abundance and distribution of species;

- Status of threatened species;
- Genetic diversity;
- Coverage of protected areas.

3.5.4.1.1 *Indicators of extent of selected biomes or ecosystems*

Habitat degradation and bad land use management are probably the main drivers of biodiversity loss. For example, clearance for cropland or permanent pastures has already reduced natural areas by more than 50% and much of the rest is altered by temporary grazing (Green et al. 2005; FAOSTAT). The extent of remaining, relatively undisturbed areas is thus a straightforward indicator. The extent of specific ecosystems such as forests, or coral reefs has been used in several assessments (SCBD 2011; MEA 2005). However, these indicators measure only losses in area, not in quality. Furthermore, there are difficulties in accurately measuring changes in land uses, in particular when intercropping or multiple crops occur on the same land in the same year, or because of reporting differences between countries. Since forests represent most of the natural areas that are converted to agriculture, the extent of deforestation can be a useful indicator of the impacts of food production on biodiversity.

3.5.4.1.2 *Trends in abundance and distribution of selected species*

Human activity generally leads to the decline in abundance of many native species, and to the increase of few opportunistic species, in a process known as biotic homogenisation. This decrease in species abundance may lead to local extinctions of sub-populations and eventually to global extinction. Trends in species abundance are thus a sensitive indicator, but currently this indicator focuses mostly on a limited number of species groups (Stuart H.M. Butchart et al. 2010).

Three indicators have been developed that differ mainly in their baseline. The Living Planet Index (LPI) measures trends in populations of vertebrate species living in terrestrial, freshwater, and marine ecosystems all over the globe. It is calculated using time series of population data (J. Loh et al. 2005). The changes in the population of each species are aggregated and shown as an index relative to 1970, which is given a value of 1. A decrease in the LPI represents an overall reduction of species populations, meaning more species have declined than increased in abundance, indicative of biodiversity loss. The two main drawbacks of this indicator are its limited taxonomic coverage (vertebrates) and the patchiness of data available for most of the world. No online database is currently available to use this index.

The Natural Capital Index (NCI) is similar to the LPI but sets pre-industrial state as its baseline. It is the average abundance of the original species compared to their abundance in the natural or hardly affected (pre-industrial) state. The NCI also suffers from data availability issues.

To by-pass issues of data availability, the Mean Species Abundance (MSA) index has been developed at global level using relations between pressures and impacts on species abundance. It is defined as the mean abundance of original species relative to their abundance in undisturbed ecosystems. An area with an MSA of 100% means a biodiversity that is similar to the natural situation. An MSA of 0% means a completely destructed ecosystem, with no original species remaining.

3.5.4.1.3 *Change in status of threatened species and species richness*

Indicators of species richness are often used at the local level. However, they are relatively data-intensive and signal only the disappearance of a species, without regards to the status of the population. Related indexes have been developed to overcome some of these difficulties. Such indexes can be applied at wider spatial scales. These include indexes combining data on abundance and species richness (e.g. the common species index) or indexes of remaining suitable area for a species (Jetz et al. 2007).

An established index, the Red List Index from the International Union for Conservation of Nature (IUCN) summarises threats to species, and combines this with species sensitivities to these threats, including risk of extinction. These lists are based on a combination of expert knowledge and monitoring of species trends and include ca. 65,000 species (out of the ca. 10 million species identified). Using information from the threat causes, we can monitor species threatened by agricultural production, and even associate a given agricultural threat with implicated commodities in certain regions of the world. For example, *Ateles geoffroyi* (spider monkey) is endangered and threatened by habitat loss linked to coffee and cocoa plantations in Mexico and Central America.

3.5.4.1.4 *Trends in genetic diversity of selected species*

As agricultural production systems are becoming increasingly intensive, native breeds of crops or livestock are being replaced by a fewer highly productive breeds, introduced for this purpose. These sub-components of global biodiversity are of considerable human importance, with implications both in terms of global biodiversity conservation and of food security (see Box 16). The headline indicator livestock diversity aims to measures trends in the proportion of native breeds and their risk of extinction (FAO 2010a). Unfortunately this indicator, along with other sub-indicators such as the ex situ crop collections indicators (BIO-IS for EAA 2011) is not yet developed at global level. Furthermore, trends in genetic diversity of crops or livestock only have limited interest for monitoring the biodiversity impacts of food wastage, as they are not directly linked to food production, but rather to food security.

Box 16: Agro-biodiversity: food production vs. food security

The success of modern agriculture relies on the dominance of a few high-yield species within the agricultural system, and the creation of optimal conditions for these. However, this process has led to a genetic erosion, which could have considerable impacts on food security at global level.

Trends in crops genetic diversity

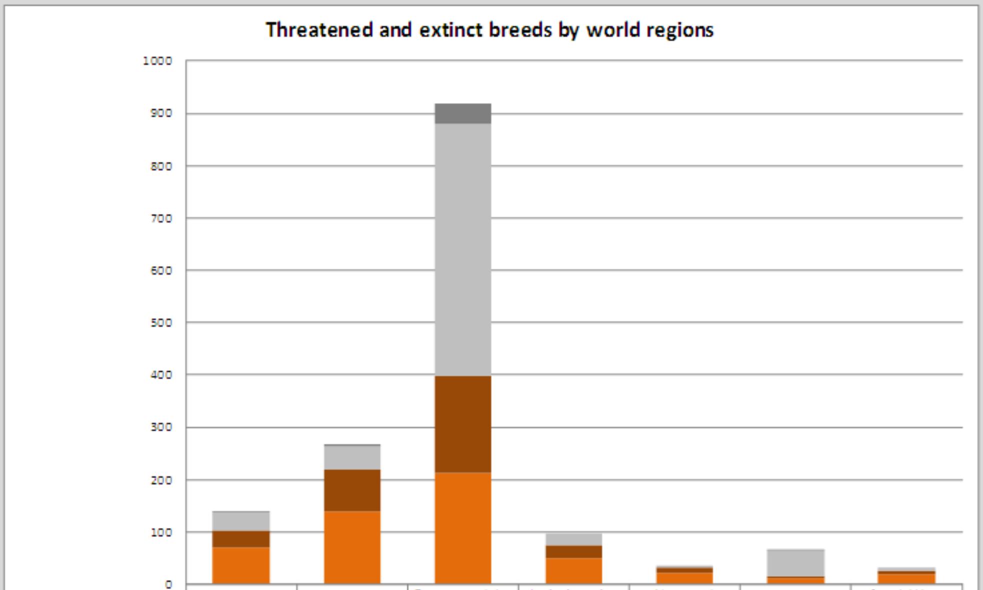
Only 30 of the 7000 cultivated crops are considered to be crops that 'feed the world', and nine species supply 75% of the world's energy needs (rice, wheat, maize, sorghum, millet, potato, sweet potato, soybean, sugar cane, and sugar beet). Over the last century, scientific plant breeding has led to the selection of varieties with higher yields, .which have contributed to the major increases in productivity witnessed over the same period of time. However, concern has been raised that this is reducing crop genetic biodiversity.

The loss of variation of crops due to the modernisation of agriculture, otherwise known as genetic erosion, may occur either through the initial replacement of landraces by modern cultivars and the associated simplification of agricultural landscapes, of by further trends in diversity reductions as a result of modern breeding practices. While the initial introduction of (exotic) cultivars led to an increase in regional crop diversity, regional declines in diversity have been observed as a result of specialisation in production. Many traditional varieties (or landraces) have been replaced by modern cultivars, resulting in homogenisation of the landscapes and reduced richness of crops assemblages. However, this varies considerably between regions of the world and crops. No comprehensive summary exists, but trends indicate that in the developed world, this replacement was practically completed by the 70s, whereas in the developing world very large areas are still planted with local varieties (Van de Wouw et al. 2009). As a result, at a global level, there is no evidence of reduced richness, especially as changes in demand are promoting the expansion of crop species once threatened with extinction – e.g. quinoa, maca – (Van de Wouw et al. 2009).

Genetic erosion could also occur if the cultivars grown by farmers are increasingly similar and fewer diversity of cultivars is being used. However, a recent meta-analysis suggests that no substantial reduction in crop genetic diversity has taken place after the transition to modern cultivars (Van de Wouw et al. 2010).

Trends in livestock genetic diversity

Thousands of years of animal husbandry and controlled breeding have given rise to genetic diversity among the world's livestock populations (i.e. breeds). Today, high-output animals co-exist with multi-purpose breeds kept by small-scale farmers. Around 20% of the 8 054 breeds are at risk, while 631 breeds are extinct (FAO 2010b). Moreover, within breed genetic erosion is also occurring as a few sires dominate breeding (FAO 2007). Increased demand for meat has led to highly specialised livestock industries, and production by a small number of breeds only. The increasing marginalisation of traditional production systems and associated local breeds is resulting in an erosion of locally adapted breeds (Ehrenfeld 2005).



	Africa	Asia	Europe and the Caucasus	Latin America and Caribbean	Near and middle East	North America	South West Pacific
extinct avian	2	5	39	0	0	1	0
extinct mammals	35	45	481	21	5	49	6
threatened avian	33,12	77,76	184,86	25,02	9,54	5,04	5,94
threatened mammals	70,51	140,25	213,18	50,38	22,11	10,89	19,14

Figure 21: Threatened and extinct breeds per world regions

Relationship between crop or livestock genetic diversity and food production

Genetic erosion of crops of livestock breeds represents a significant threat to food security. Indeed, genetic uniformity, for a long time or over large areas, makes agro-ecosystems more liable to infestation by diseases and pests. Well-known examples include the potato blight epidemic in Ireland in the 1840s and corn leaf blight which devastated maize production in the USA in the 1970s. In contrast, genetic diversity of cultivated varieties have been shown to stabilise production (Kiaer et al. 2009) and provide greater resistance to pests and diseases

(Zhu et al. 2000) than monocultures, but also to have positive effects on farmland biodiversity (Chateil et al. 2010).

In addition, decline in diversity leads to lower adaptability. Pastoralists and small-holders are the guardians of much of the world's livestock diversity. As local breeds are being lost, so is their potential of adaptation to local conditions and pests, putting at risk the local livelihoods of the farmers but also global food production given the context of global change.

3.5.4.1.5 *Coverage of protected areas*

Coverage of protected areas is a response indicator of the effectiveness of biodiversity conservation. Several indicators can be used that measure the level of protection, for example by looking at extent of protected areas, the degree of coverage of key ecosystems (protection of biodiversity hotspots or endemic bird areas), or the degree of 'naturalness' of ecosystems (e.g. wilderness areas, N. Myers et al. 2000). These indicators are rather descriptive and on their own are of limited value for understanding to food production process.

3.5.4.1.6 *Other indicators*

Other indicators have also been proposed to measure threats or pressures to biodiversity, these include indicators of sustainable use, threats to biodiversity and ecosystem integrity:

The Ecological footprint (EcF): the EcF evaluates the impact of human activities on the environment (WWF 2010) and is unique in that it directly compares human demand for biological resources with the biosphere's capacity. The EcF is defined as the amount of land that is used to meet human demands, and it is measured in global hectares of the biological land needed to renew resources used by humans and to absorb wastes and anthropogenic CO_2 emissions (Global Footprint Network 2009). The focus of EcF is thus on bioproductivity, but this may also lead to increased pressures on biodiversity, which are not accounted for by the EcF. For example, the conversion of woodlands to monoculture forests will increase bioproductivity but lead to drastic biodiversity decline. In contrast, the conversion of agricultural lands to organic practices will have lower ecological footprints.

The Ecological footprint (EcF): the EcF evaluates the impact of human activities on the environment (WWF 2010) and is unique in that it directly compares human demand for biological resources with the biosphere's capacity. The EcF is defined as the amount of land that is used to meet human demands, and it is measured in global hectares of the biological land needed to renew resources used by humans and to absorb wastes and anthropogenic CO_2 emissions (Global Footprint Network 2009). The focus of EcF is thus on bioproductivity, but it does not explicitly account for impacts on biodiversity (Vackar 2012). For example, the conversion of woodlands to monoculture forests will increase bioproductivity but lead to drastic biodiversity decline. In contrast, the conversion of agricultural lands to organic practices will lead to lower ecological footprints.

Aside from not being clearly linked to biodiversity, the EcF has important drawbacks. It does not take into account production intensity nor land use degradation. Furthermore, while EcF calculations have been carried out for almost all countries of the world, EcF for products are currently under development and there are still methodological issues to overcome.

The Biodiversity Footprint (BF) was recently developed to complement the EcF. While the EcF represents a measure of impacts on the bioproductivity of the environment, the BF aims to account for the potential biodiversity loss resulting from increasing pressures on the environment. It has been quantified at product level using the Mean Species Abundance statistics (Hanafiah et al. 2012) However, it is not yet a recognised indicator and no suitable dataset is available.

Biodiversity remains difficult to assess via traditional impact factors and life-cycle approaches. The main difficulties stem from the methodological framework of LCA, which assumes impacts are generic in space, summed across time horizons, independent (Curran et al. 2011). While developments are underway to overcome these issues, current methods are biased in terms of biodiversity attributes, taxonomic and geographic coverage. Further, they do not address overexploitation, one of the main drivers of biodiversity loss linked to food production. In addition to these methodological drawbacks, there are currently no available inventories that could be used to monitor the impacts of food waste on biodiversity at global level.

Trends in invasive species: invasive alien species are a major threat to biodiversity, and food production is responsible for the introduction of many non-native crops and livestock breeds. The number of alien species can be used to monitor trends in invasive alien species (OECD 2012). However this indicator is currently only developed at European level, and since the causes of introduction are multiple, it is difficult to attribute this indicator to food production in particular.

Trends in Mean Trophic Level: it is now well established that overfishing has fundamentally altered marine ecosystems resulting in depletion of large predators and upsetting of the food webs towards small-bodied species. This is of concern because it may have a cascading impact on ecosystem functioning and in the end on ecosystem resilience. The Marine Trophic Index (MTI), using mean trophic levels, has been developed to measure the decline in abundance and diversity of fish high in the food chain. This index communicates a measure of species replacement induced by fisheries and can be used at the global level. Since it is an index, trends in MTI are more informative than the specific MTI values.

3.5.4.1.7 *Key indicators used in this study*

All indicators reviewed are applicable on a global scale. Given the scope of this report, which is to monitor the impacts of (avoided) food production on global biodiversity, we selected two biodiversity indicators which satisfied the following criteria (Table 7):

- Based on sound scientific principles;
- Meaningful in terms of food production;
- Available data.

Four indicators were eligible (Table 7), among which we chose two terrestrial one and a marine one. Among the terrestrial indicators, we chose one at ecosystem level, and the other at species level, so as to represent different components of biodiversity. At species level, we chose the Red List indicator, focused on species threatened by agriculture. At ecosystem level, both extent of deforestation from agriculture and extent of protected area were suitable indicators. We chose the first as deforestation is the main form of natural land conversion to agriculture. Moreover, extent of protected areas (e.g. endemic bird areas) usually reflects the biodiversity value of an area, an aspect that is already captured in the Red List indicator. Finally, we considered trends in mean trophic levels of fisheries landings to represent the impacts of fisheries on biodiversity. The three selected indicators are briefly described below.

Table 7: Biodiversity indicators and their usefulness for assessing the impacts of global food production (in bold the selected indexes)

Indicator	Sound	Meaningful	Available
Extent of natural areas (e.g. deforestation)	**Yes**	**Yes (Deforestation due to agriculture)**	**Yes (with caveats)**
Living Planet Index	Yes	Limited	No (patchy data, for 5 biogeographical realms, vertebrates only)
Natural Capital Index	Yes	Limited	No (patchy data)
Mean Species Abundance	Yes	Yes (if calculated for changes to agricultural production)	No (research needed to apply it for agriculture)
Redlist index	**Yes**	**Yes (threats due to agriculture)**	**Yes**
Livestock diversity	Yes	Limited	No
Coverage of protected areas (e.g. endemic birds areas)	**Yes**	**Yes**	**Yes**
Ecological Footprint	Yes	Limited (should be applied to food production; poor link to biodiversity)	Yes
Biodiversity Footprint	Exploratory	Limited (should be applied to food production)	No
Biodiversity in LCA	No	Yes	No
Trends in IAS	Yes	No (no direct link)	No
Trends in mean trophic levels	**Yes**	**Yes (direct impact of fishing on communities)**	**Yes**

Percentage of species threatened by agriculture

This indicator is based on the IUCN Red List data[26] and measures for each sub-region the percentage of all red-listed mammals, birds, and amphibians species that are at threat from food production. For each sub-region, we thus extracted the total number of threatened species, and all the species threatened by annual and perennial non-timber crop (threat category 2.1), pollution from agricultural and forestry effluents (threat category 9.3) and livestock farming and ranching (threat category 2.3). Two sub-indicators are then used to distinguish threats from agricultural crop production (threat categories 2.1 and 9.3) and those from livestock production (Threat category 2.3).

Forest conversion due to agricultural production

[26] http://www.iucnredlist.org/

This indicator estimates the maximum extent of deforestation due to agricultural activities (and hence food production activities). Within the scope of this study it is only possible to measure the maximum area deforested, had all deforestation been due to agricultural activities, over the period from 1990 to 2010 (based on FAOSTAT data) in each of the 21 sub-regions. Deforestation has significant biodiversity impacts, including disappearance of food and habitats, and is typically associated with lower species richness and abundance as well as simpler community structures and degradation of habitats. It thus gives an indication of the weight of agricultural production (and thus food production and food waste) on biodiversity pressure.

Trends in mean trophic levels of fisheries landings

This indicator shows the average change in MTI since 1950 for each of the world regions. The MTI describes a major aspect of the complex interaction between fisheries and marine ecosystems. It is a calculated value, which reflects the species abundance balance across a trophic range from large long living and slow growing predators to fast growing microscopic producers. It is derived by assigning a numerical trophic level to selected taxa, based on size, diet and nitrogen isotope level (Pauly & Watson 2005). The index typically ranges between 2 and 4 and is one of the CBD target indicators. It was extracted for each Large Marine Ecosystems (LMEs) from the Sea Around Us Project[27]. LMEs were chosen as they are ecologically coherent areas producing about 80% of the world's marine fisheries catch. The temporal coverage for fisheries landings is quite good and allows calculating trends from 1950 until 2006. The average change in MTI since 1950 was thus calculated for each of the 67 LMEs, following the methods used in the State of the Environment Report (EAA 2010).

3.5.4.2 *REVIEW OF EVIDENCE OF BIODIVERSITY IMPACTS PER COMMODITY*

3.5.4.2.1 *Commodity 1-3 – Cereals, Starchy roots, Oilcrops and pulses*

Crop production is known to be the major driver of biodiversity loss, along a gradient from intensive to biodiversity-friendly farming. In recent years, increases in food production have owed more to intensification of crop production than to cropland expansion. Although the rate of global crop expansion is decreasing, the impacts on biodiversity are substantial: new croplands have in recent decades come largely at the expense of natural habitats, particularly tropical forests (Gibbs et al. 2010; Phalan et al. 2013). The impacts of crop production on biodiversity are very different in the developed and developing world, and according to the type of farming (industrial vs. traditional). Today, land conversions from natural habitats to crops occur largely in the developing world, usually to make place for industrialized intensive crop production systems. In contrast, in the developed world, growing proportions of agricultural land are being converted to use some biodiversity-friendly practices (e.g. agri-biodiversity schemes promoted by the CAP in the EU) or abandoned.

The greatest threats to biodiversity posed by crop expansion are likely to come from the tropics, since they support the highest species richness and endemism, while providing the most scope for increasing global agricultural production. For this reason, Phalan et al. (2013) identified the

[27] http://www.seaaroundus.org/sponsor/cbd.aspx

crops that have expanded the most rapidly in the tropics in recent years, and assessed where they might spread in the future. They found that expansion of annual crops has been more rapid and widespread than expansion of perennial crops, and has occurred across much of South America, Africa and tropical Asia (Phalan et al. 2013).

While bioenergy crops (such as soybeans, sugar cane and oil palm) have witnessed a rapid expansion over the past ten years, food crops are still the main driver of habitat loss (Figure 22). Rice, maize and wheat are well-known drivers of biodiversity loss, and together they are the dominant crop types in the tropics, responsible for almost half of forests conversions (Figure 22). Other crops, such as sorghum, cowpeas and millet have received less attention from conservationists. This is because individually, they represent smaller areas, and tend to be traditionally grown by small-scale farmers. However, even these crops are increasingly grown in large-scale monocultures, e.g. sorghum in parts of the Caribbean and Latin America; cassava in Thailand and Brazil, which can generate larger impacts on biodiversity.

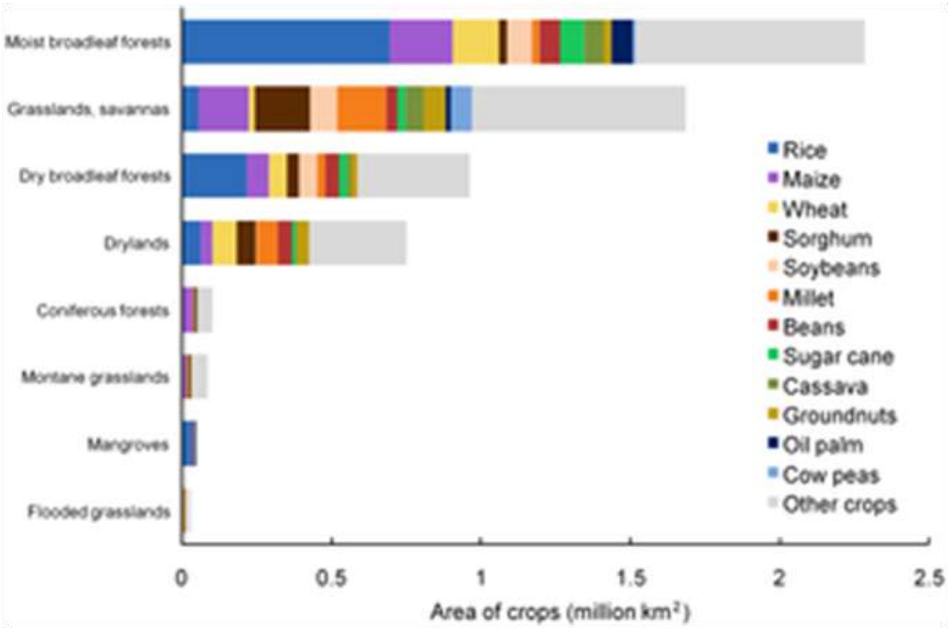


Figure 22: Total area used for the production of the top 12 commodities grown in the tropics, according to the biome (Phalan et al. 2013)

In the developed world, agricultural landscapes are changing in a different manner. Agriculture has a longer history and the changes in agricultural practices towards intensification and specialisation have had well-documented significant impacts on farmland biodiversity (Stoate et al. 2009; Wilson et al. 2009). Grassland birds and butterfly species have declined significantly in Europe over the past 20 years and are in poor conservation status. The recent ongoing trend towards agricultural abandonment is likely to lead to further declines in biodiversity. In some cases, agricultural abandonment may promote species diversity and provide opportunities for large-scale habitat restoration and connectivity. However, in many cases large-scale abandonment may in fact lead to declines in habitat heterogeneity, species diversity and result in regional extinctions. Further, it will take several decades for these habitats to regain their original biodiversity value, and they may be dominated by common or invasive species (Poláková et al. 2011).

It is likely that significant detrimental biodiversity impacts are occurring on permanent crops

Rice: the effects of rice production on biodiversity vary with production methods, which include fields managed organically or with agrochemicals and varied irrigation and planting systems. Traditional rice systems rely on fish-rice polyculture. Reductions in biodiversity are greatest along the gradient of production intensity: simplifications in irrigation systems have led to reduction in wetland diversity; replacement of traditional varieties by high-yield varieties increases the need for pesticides. Many varieties of rice are also being lost in this way. Vallan (2002) found that conversion of forest to rice fields led to an 88% decline in species richness.

Soybean: Only whole soybeans and part of the soy oil are used for human food, but an important of the production goes for animal fodder (and thus has is an indirect impact of livestock production on biodiversity, see below). Soybean is now one of the most important sources of protein, and global soybean production is mostly coming from a handful of countries (Brazil, US, China, India, Argentina). Production in these countries has soared, through both increases in cultivated areas and increase in yields. In 2004-5, Brazil produced over 50 million tonnes of soy across nearly 23 million hectares - an area roughly the size of Great Britain. Between 1999 and 2004 soy production in the Amazon region has increased by 15% per annum and soybean is one of the major cause of biodiversity loss in the Brazilian cerrado savanna. In Argentina, where 5.6 million hectares of non-agricultural land has been converted to soya production in less than ten years, forest conversion rates are three to six times the global average. In Paraguay, much of the Atlantic forest has been cut. Soybean production leads to loss of natural habitats and the infrastructure associated with its production facilitate further habitat loss (Fearnside 2001). Soybean production also generates more soil erosion than most other crops, and intensive soy cultivation is associated with massive soil nutrient depletion. For instance, large-scale soybean monocultures have rendered Amazonian soils unusable.GM soybeans are even more damaging for the environment: they are associated with monoculture expansion and thus increased risk of pest outbreaks and diseases; in turn, this leads to the increased use of pesticides, and the development of pest-resistance. Herbicides for GM soy are toxic to the mutualistic rhizobium bacteria, resulting in overall reductions in the levels of rhizobia and making soybeans dependent on chemical fertilisers.

Palm oil: Palm oil is used both as a cooking ingredient and to produce biofuels. Oil palm is one of the world's most rapidly expanding crops. It has replaced large areas of forest in Southeast Asia. More than 80% of global palm oil was produced in Indonesia and Malaysia between 1990 and 2005 and more than half of this expansion occurred in converted native forests and peatlands. Other large producer countries are Thailand, Nigeria, Columbia, Brazil, Democratic Republic of Congo, and Liberia – i.e. countries having large and old forests. Oil palm plantations support much fewer species than do forests and often also fewer than other tree crops. Oil palm production is also associated with habitat fragmentation and pollution.

Box 17: Expansion of sugarcane production for biofuels in Brazil and cascading effects on land use

Several publications demonstrated potential conflicts between meeting the demands for food and energy and safeguarding our natural capital, including biodiversity. In Brazil, long-term land use data and correlation analysis pinpoint the expansion of biofuel feedstocks as a key (although mostly indirect) driver of deforestation (Lapola et al. 2010; Andrade de Sá et al. 2013; Conservation International 2010). Quantitative estimations of corresponding deforestation remains highly uncertain. On the first hand, Marelli et al. (2011) estimated[28] that in Brazil 87,700 ha of closed forest[29] will be deforested by 2020 to meet the EU 2020 biofuel demand[30]. In particular, this would correspond to an increase in croplands of about 300 000 ha, along with the disappearance of about 32 000 ha of open forest, 50 000 ha of grasslands and 135 ha of shrubland would disappear. On the other hand, Lapola et al. (2010) suggests a substantially higher estimation for the total indirect deforestation of 121,970 km^2, i.e. 10 times higher than proposed by Marelli et al. (2011). This latter value may however be over-estimated.

As a response to the increased EU demand for bioethanol production, Brazil namely increased its sugarcane production, in particular in the Southeastern parts of the country (Lapola et al. 2010; Andrade de Sá et al. 2013; Conservation International 2010). These new cultivation patterns have been shown to cause the displacement of former cattle ranching into semi-natural and/or natural territories (Andrade de Sa et al., 2012) in Northern Brazil, within the ecotone between the Cerrado and the Amazon and/or Atlantic forests. Figure 1 illustrates the displacement of cattle production (in brown) corresponding to sugarcane expansion (in green).

Both the Atlantic forest and the Cerrado belong to the 25 biodiversity hotspots identified worldwide (N. Myers et al. 2000) and the latter is widely recognised as the most diverse form of savanna in the world[31]. The Amazon forest is one of the G200 Ecoregions identified by WWF. The encroachment of rangeland into these remarkable ecologically-rich habitats threatens remarkable and endemic species (e.g. red-billed curassow, Brazilian merganser, red-tailed Amazon and red-browed Amazon) in addition to common biodiversity (Barreto et al. 2006).

In order to safeguard Brazilian biodiversity and habitats, a number of mitigation options are envisioned, such as Responsible Cultivation Areas (Conservation International 2010) and/or the integration of cattle ranching with sugarcane production.

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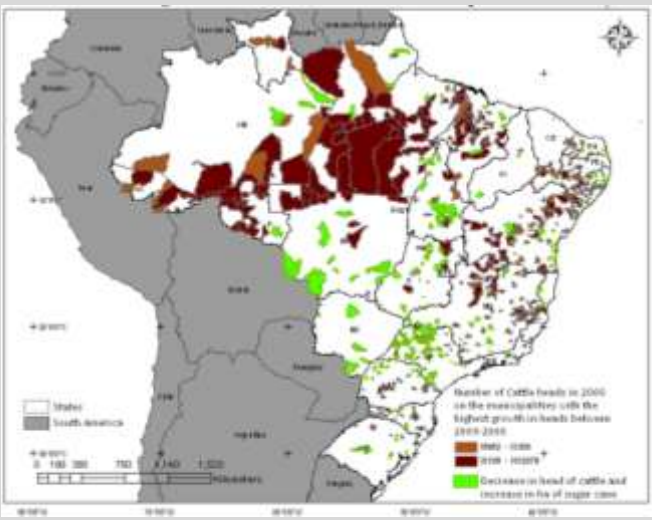
[28] Based on a spatial allocation method to translate the land use change estimates from Laborde (2011) into a more detailed spatial mapping of land use/cover changes globally in response to the EU biofuel mandate.

[29] Areas where tree cover exceeds 40 per cent (UNEP definition: www.unep.org/vitalforest/Report/VFG-01-Forest-definition-and-extent.PDF)

[30] according to the NREAPs 27.2 Mtoe biofuels in 2020

[31] cerrado.rbge.org.uk/cerrado/cerrado/flora.php



Brazilian biomes

Figure 23: Increases in cattle production, and decreases in cattle production corresponding to increases in sugarcane cultivation, in Brazilian municipalities 2003-2008[32]

3.5.4.2.2 *Commodity 5 – Meat*

Livestock has widespread impacts on biodiversity, linked to the production of forage, conversion of natural areas to pastures, grazing and the loss of genetic diversity of domestic species. These impacts vary widely according to the context. However, all in all, they are generally negative.

Livestock farming is the most widespread human activity and rangelands comprise ca. 25% of the world's land area. Overall, biodiversity in rangelands is decreasing, due to intense utilisation for livestock production and conversion into cropland (Alkemade et al. 2012). Biodiversity decreases in rangelands along a gradient of grazing intensities: rangelands with high degree of human management and very high stocking rates have the lowest biodiversity values, compared to abandoned grasslands or rangelands with moderate stocking rates. Natural rangelands have the highest biodiversity values (Alkemade et al. 2012).

Production of forage and conversion of natural areas to pastures

The rapid expansion of livestock production is predicted to continue in the future, with highest rates in developing countries. This means livestock production tends to concentrate in areas with cheap feed supply; industrialisation of production leading to a disconnection between livestock and cropping activities (spatially and functionally). The production is shifting from ruminants to monogastrics. In developing countries, livestock systems can have different types of impacts, depending on their location (Reid et al. 2010). In extensive drylands, rangelands are contracting to make way for cropping and settlements; thus maintaining grazing livestock in these areas can actually contribute to biodiversity protection. In key dryland resources, such as wetlands and riverine areas, livestock grazing is heavy, landscapes tend to be highly fragmented and may contain several alien plant species. In wetter environments, livestock production typically

[32] Conservation International – Atlantic Forest Program Brazil - Data: Municipal Cattle Research, IBGE (Brazilian Institute of Geography and Statistics). Analysis at the municipal level.

conflicts with forest systems. It may drive deforestation/reforestation dynamics, whereby the presence of pastures indicates that there has been significant biodiversity loss in the conversion from tropical forests. Livestock production can play an important role in deforestation. A recent example is the on-going conversion of over 60% of the Brazilian Cerrado largely into beef and soybeen production in Latin America where extensive cattle grazing has expanded mostly at the expense of forest cover (see Crop production is known to be the major driver of biodiversity loss, along a gradient from intensive to biodiversity-friendly farming. In recent years, increases in food production have owed more to intensification of crop production than to cropland expansion. Although the rate of global crop expansion is decreasing, the impacts on biodiversity are substantial: new croplands have in recent decades come largely at the expense of natural habitats, particularly tropical forests (Gibbs et al. 2010; Phalan et al. 2013). The impacts of crop production on biodiversity are very different in the developed and developing world, and according to the type of farming (industrial vs. traditional). Today, land conversions from natural habitats to crops occur largely in the developing world, usually to make place for industrialized intensive crop production systems. In contrast, in the developed world, growing proportions of agricultural land are being converted to use some biodiversity-friendly practices (e.g. agri-biodiversity schemes promoted by the CAP in the EU) or abandoned.

The greatest threats to biodiversity posed by crop expansion are likely to come from the tropics, since they support the highest species richness and endemism, while providing the most scope for increasing global agricultural production. For this reason, Phalan et al. (2013) identified the crops that have expanded the most rapidly in the tropics in recent years, and assessed where they might spread in the future. They found that expansion of annual crops has been more rapid and widespread than expansion of perennial crops, and has occurred across much of South America, Africa and tropical Asia (Phalan et al. 2013).

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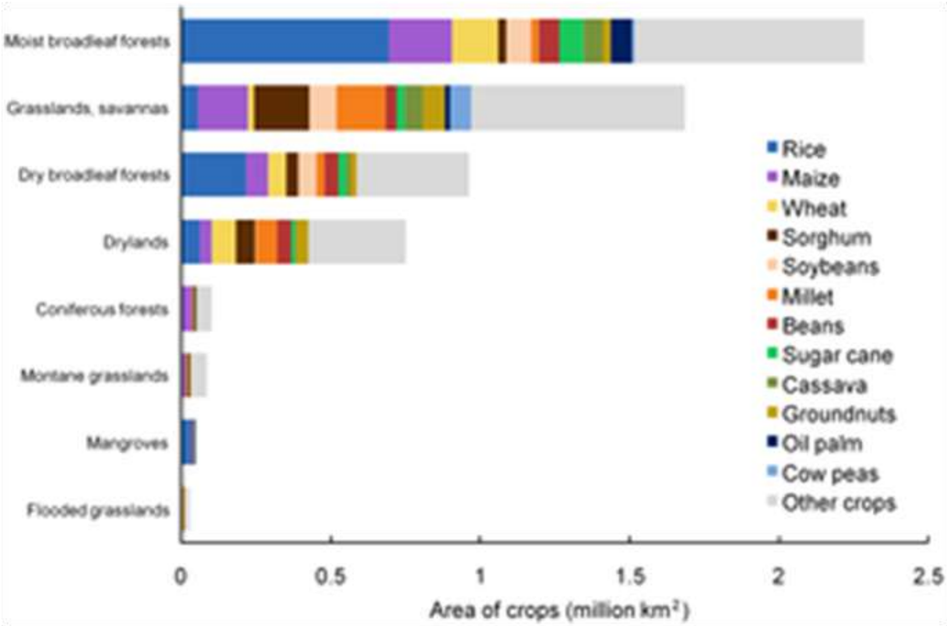

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Box 17).

In Europe, livestock farming has played a significant role in creating and maintaining many semi-natural habitats and the continuation of certain low intensity farming practices is often crucial for their survival. Some grazing, in particular, is required to maintain the structure and composition, and hence ecological value, of semi-natural grasslands, such as coastal marshes, heathlands and wood pastures. However, over the past century, most of the semi-natural grasslands with a high species and community diversity were replaced by more productive pastures with a low plant and animal diversity. In recent years, grassland areas freed from dairy production (see below) are increasingly available for other livestock, such as beef or sheep.

Grazing

Grazing affects vegetation composition and structure, and the related suite of invertebrates that rely on this vegetation for food, reproduction or shelter. In semi-natural agricultural grasslands, grazing shifts the competitive balance amongst species in the vegetation community. Livestock also have significant indirect impacts on vegetation, through nutrient enrichment and trampling, both of which may in moderation have positive impacts on diversity.

Overall, low input grazing systems have been shown to be generally effective in the maintenance of biodiversity of semi-natural grasslands (Stammel et al. 2003). Grazing can help restore biodiversity on species-poor grasslands, which may depend on the particular livestock species and on its dietary preferences.

Loss of genetic diversity

The increasing marginalisation of traditional production systems and associated local breeds is resulting in an erosion of locally adapted breeds (Ehrenfeld 2005).According to a FAO study (FAO 2007), 13% of the 20,840 livestock species referenced over the world are threatened, while 690 species are already extinct. The vast majority of threatened or extinct breeds of mammals and birds used for farming comes from Europe (see Figure 21).

3.5.4.2.3 *Commodity 6 – Fish and seafood*

Marine fishing

A host of studies have demonstrated that the fishery resource has been severely over-exploited by industrial fisheries, leading to serious conservation concerns (Pauly 1998; Watling & Norse 1998; R. A. Myers & Worm 2003). The removal of this biomass, particularly large predators, has had cascading effects, which have fundamentally altered marine ecosystems. The causes are not simply excessive fishing. Much of the issue lies in the fact that modern industrial fishing is very wasteful and causes severe collateral damage (Willison & Côté 2009). Examples include loss of nets and traps, which generate 'ghost fishing' for many years once lost at sea, bottom trawls dragged over the ocean floors, which destroy habitats in a manner akin to forest clear-cutting and the large number of by-catch species which are then thrown away as waste at sea. The amount of discarded commercially valuable fish is substantial in most fisheries, reaching 40% to 50% of total catch (Alverson et al. 1994; Leaman 1994). This is not accounting for the substantial damage done to all marine life incidentally killed by fishing, as fishing gear is being deployed on the seafloors. These impacts are made even more long-lasting in the case of deep water fisheries, as deep water fish adapted to their glacial conditions by having a slow pace of life: they tend to grow slowly, live long and reproduce late (Roberts 2002).

While large-scale fisheries are causing the greatest damage on biodiversity, small-scale artisanal fisheries are also causing damage, although on a lower scale than industrial fishing - e.g. through blast fishing.

Fisheries are concentrated into areas with some of the greatest biological significance in the deep sea (Roberts 2002). However, most of the world's oceans are concerned by these threats as very few areas are set aside for pure conservation, with no exploitation (Roberts 2002).

Aquaculture

Aquaculture has the potential to pose significant threats to biodiversity (Shiklomanov 1998). Indeed, aquatic fauna is declining at far greater rates than that of most terrestrial ecosystems (Groombridge 1992). Furthermore, the availability of naturally available habitable freshwater habitat is also very limited (0.01% of the Earth's water resources), while aquaculture is the fastest growing food industry. Yet, the net impact of aquaculture on biodiversity is difficult to estimate, as it may also have positive impacts. For example, aquaculture reduces pressure on wild fish stocks which may already be over-exploited and other destructive land use patterns may be replaced by aquaculture in ponds. The main negative effects of aquaculture on biodiversity are linked to:

Escape of alien species: aquaculture is increasingly dependent on alien species, and escapes always occur. Since farmed species tend to share the characteristics of invasive species (e.g. short generation time, rapid growth, broad environmental tolerance, high genetic variability), these are likely to outcompete native species and contribute to local extinctions.

Transmission of diseases: an effect of much intensive aquaculture is to increase the population size and density of pathogens and parasites, and transmit them to wild stock.

Genetic alterations of wild stock: hybridization of different strains can compromise the genetic integrity of the locally adapted species and the hybrids may have detrimental effects on their environment. Change in genetic diversity of natural populations due to aquaculture escapes (estimated at about three million per year) are becoming increasingly evident (De Silva et al. 2009).

Pollution: in marine waters, effluents from aquaculture may increase local biodiversity but by upsetting community structures, and potentially at the profit of invasive species; in contrast, in freshwater systems, nutrient loads lead to widespread fish kills. Some contaminants of water are mutagenic and may lead to increases in genetic diversity and/or increased mortality. Pollution may also increase the biodiversity of species pathogenic to humans. For example, eutrophication results in plankton bloom that may provide abundant hosts for viruses.

Effects of antibiotics or chemicals: the increasing use of chemical treatments and antibiotics in aquaculture is likely to lead to losses of biodiversity.

Other impacts may be linked to habitat clearance. For instance, mangroves have been cleared and saltwater brought inland to make way for shrimp ponds. Many shrimp farms have failed when they reached higher intensity, and the land could then not be restored back to its original state. However, Boyd & Clay (1998) estimate that shrimp farming is responsible for less than 10% of global mangrove loss.

The development of marine fish farming raises biodiversity concerns. At modest scales of development, biodiversity impacts may be hard to detect. But larger scale developments may damage local biodiversity due to the release of nutrients or chemical wastes directly into the environment, or the effects of escaped fish or disease transfer on wild populations (Bostock et al. 2010).

3.5.4.2.4 *Commodity 7 – Milk & eggs*

See commodity 5 – Meat; the impacts are those of bovine and poultry production. In Europe, improvement in dairy cow performance and fixed milk quotas in the recent years means that less grassland is being used for dairy production.

3.5.4.2.5 *Commodity 4 & 8 – fruits and vegetables*

Overall, fruit and vegetable production leads to similar impacts on biodiversity as cereals and starchy roots. When grown in intensive plantations, such as banana plantations in some tropical countries, fruit and vegetable production may lead to substantial environmental damages (e.g. risks of diseases, habitat and soil degradation). However, in this case the majority of production usually occurs at lower levels of intensification than for cereal crops. Moreover, the nature of these commodities may also favour biodiversity. Vegetable and fruits are usually produced over smaller areas than crops, introducing habitat heterogeneity in the landscapes. Moreover, fruit trees are permanent crops providing a permanent habitat for species. Mixed-fruit orchards for instance favour frugivores, nectarivores as well as widespread generalist species.

In developing countries, and particularly in the tropics, fruits and vegetables grown under agro-forestry practices, have the potential to conserve biodiversity in habitat remnants and provide enhanced potential for species movements between those habitat remnants. They can also reduce the pressure on formally protected forest reserves (Bhagwat et al. 2008).

In Europe, permanent crops represent important areas of conservation value and can provide habitat refuges for endangered species. This is particularly true of traditional fruit and nut orchards and olive groves. For example, olive groves provide overwintering habitats for many frugivorous and insectivorous birds, as well as foraging habitat for several other species. Extensive fruit orchards have long been part of the landscape in central Europe and are a highly diverse habitat, used by many bird and bat species as foraging habitat and nesting grounds.

3.5.5 Modelling, data sources and assumptions

Modelling and data sources

The analysis focus on two main indicators, mean annual area of deforestation and proportion of species threatened by agriculture in each sub-region. These indicators are then compared to the volumes of food waste generated in each sub-region. Furthermore, a qualitative evidence base provides complementary insights in the variability of those impacts.

Figure 24 represents the general methodology applied to this component's calculation and the kind of results obtained.

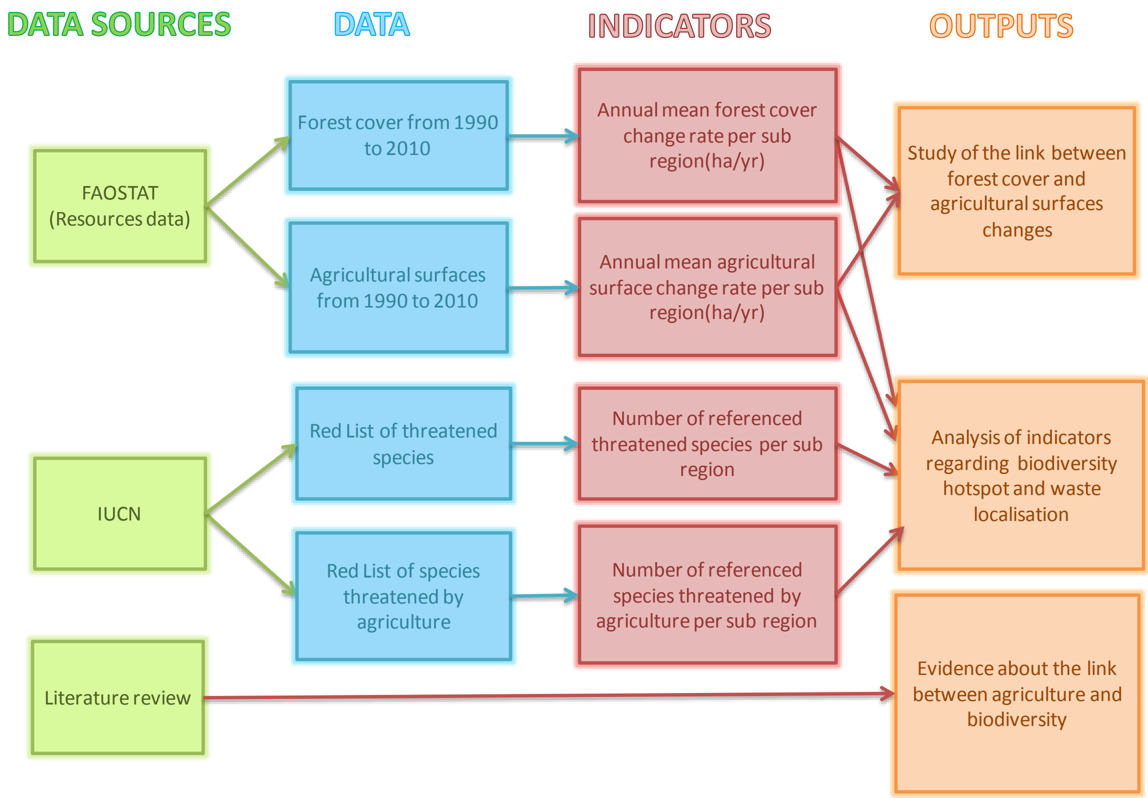

Figure 24: Calculation scheme for component 5 on biodiversity

The indicator of threatened species is based on the IUCN Redlist (IUCN 2012) for three taxa: Mammals, Amphibians and Birds, for which the most homogeneous global data exists and because together they have global significance. The analysis was performed for all threatened species (Vulnerable+Endangered+Critically Endangered) threatened by agricultural activities. We distinguished two main categories of threats: threats from agricultural crops (sub-category 2.1 Annual & perennial non-timber crops + sub-category 9.3 Agricultural and forestry effluents) and threats from livestock farming and ranching (sub-category 2.3). This means that the indicator on agricultural crop production includes both threats due to conversion of land to agriculture and to the management practices used on this land (such as use of fertilisers and pesticides). However, the direct effect of management practices on biodiversity cannot be separated. We did not include in the analysis sub-category 2.2 (Wood & pulp plantations) as it is not relevant to food production, nor sub-category 2.4 Marine & freshwater aquaculture as it is not relevant for threats to vertebrate, largely terrestrial, species. These two indicators were calculated for each of the 21 sub-regions (2.2.1. for the grouping of world regions/sub-regions).

The mean annual change in forest cover was calculated as the difference between the mean change in forest cover and the mean change in agricultural area between 1990 (or the oldest available data) and 2010 (FAOSTAT 2012c; FAOSTAT 2012f) in a given sub-region. When this difference was negative, deforestation was considered to have occurred.

The average change in MTI since 1950 was calculated for each Large Marine Ecosystem (LME). Each LME was assigned to one of the seven world regions, based on riparian countries and their importance for those countries. Some LMEs could thus be assigned to two regions, in the case of enclosed seas for instance (e.g. the Mediterranean sea was assigned both to Regions 1 and 5). Antarctica and the Arctic ocean were not assigned to any regions, thus 65 LMEs were considered for analysis. The average change in MTI was then calculated for each LME by performing a linear regression of yearly MTI values between 1950 and 2006. We tested whether this change was more likely than expected by chance (significant at the level of 5%), The slope of this regression was then multiplied by the total number of years and divided by the MTI value in 1950 to obtain the average percentage change in MTI since 1950.

Assumptions

Impacts on biodiversity were quantified only for terrestrial and marine ecosystems and for wild vertebrates. Other components of biodiversity were not considered, mostly due to lack of available data at global level. Even for those indicators, caution should be used as the underlying data are not always sufficiently detailed or accurate. For instance, reporting biases in the underlying fish landings or deforestation rates data can weaken the value of these indicators.

Within the constraints of this study, the regions where food production causes the largest impacts on biodiversity were identified. However, these biodiversity impacts could not easily be related to food wastage quantities. Moreover, they could only be quantified at sub-regional level (21 sub-regions) and not in a fully spatially explicit manner or at the commodity level. However, a qualitative evidence base is provided to help understand the impacts of some specific land use changes on biodiversity for different categories of commodities.

Similarly, the impacts on biodiversity of different agricultural and farming systems, in particular the difference between the two extremes of the continuum, traditional and intensive systems, is only discussed qualitatively for each commodity category. Most real-world farming systems are in fact somewhere along this continuum, and their biodiversity impacts can be seen as a mix between the two extremes.

The indicator on deforestation presents the maximum forest area that could have been converted to agriculture, by assuming that all deforestation is due to agricultural expansion. However, while agriculture is a major driver of deforestation, not all expansion results in the loss of intact forests: pasture, shifting cultivation fields, logged forests, degraded lands are all potential sources of new agricultural land. Therefore, the likelihood of deforestation is overestimated. Hardly any study identifies the land sources responsible for agricultural expansion, and those that do are often limited to local or regional scale (Gibbs et al. 2010). Econometric models could be used for a more robust analysis of the impacts of agriculture on forests (e.g. Angelsen & Kaimowitz 1999).

The FAO forest and land cover data are the only to offer time-series of comparable data at global level. While these data have some shortcomings (including changing definitions and variable quality data across countries) which may result in overestimates of forest loss, they remain the sole comprehensive source of national deforestation rates.

Qualitative evidence base

A brief review of the main types of impacts on biodiversity induced by conversion of natural lands to specific types of production was performed. This provides a qualitative overview of the magnitude and spatial variability of biodiversity impacts. The review is based on existing scientific evidence and distinguishes between the developing and the developed world, and where possible between different types of food commodities.

3.6 Component 6: Economic assessment

3.6.1 Objectives

The objective of the economic component is to get a first quantification, based on producer prices, of the cost of food wastage.

3.6.2 System boundaries of the economic assessment

As regards the economic component, the assessment is based on producer prices. Therefore, it focuses on the economic cost associated with the agricultural production phase.

3.6.3 Modelling, data sources and assumptions

Data sources and modelling principles are summarised in Figure 25 and further detailed in the paragraphs hereafter.

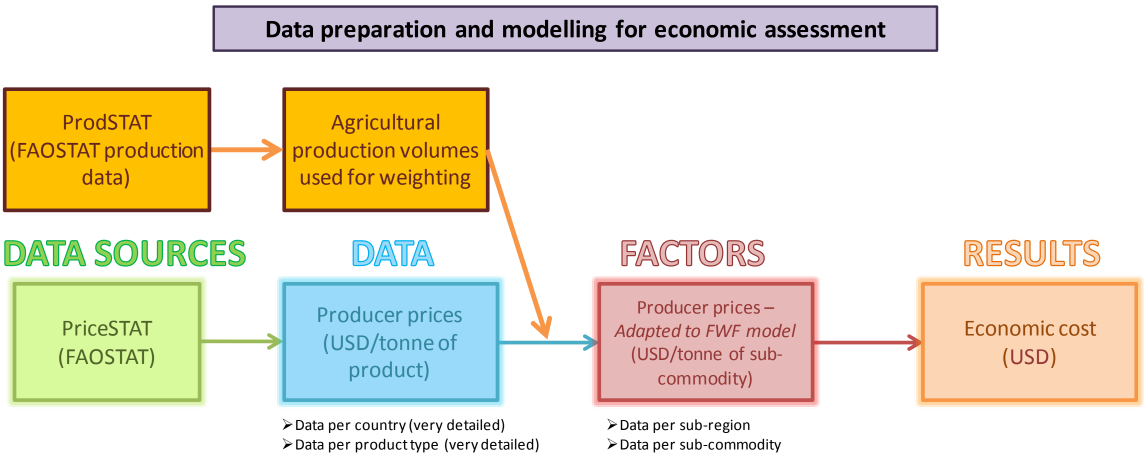

Figure 25: Data preparation and modelling for economic cost

Modelling and data sources

The economic cost of food wastage is estimated from producer prices for the year 2009 extracted from FAO's PriceSTAT database (FAOSTAT 2012e) which provides a dataset of prices for about 180 agricultural products and more than 100 countries. In practice, about 3 800 values for specific country*products prices were used[33]. This dataset provides a broad overview of producer prices distribution worldwide. The price data available are the prices at the agricultural phase (farm gate, in USD/tonne).

Note that in the context of the FAO (2011) study, two technical (unpublished) reports were produced (Gustavsson et al. 2011a; Gustavsson et al. 2011b). Compared to the public report (FAO 2011a), these reports include an additional economic cost assessment. The FWF modelling is similar in its approach to the assessment of economic costs of food production presented in these reports. However, as specified in the Appendix 5 of these two reports, the input dataset

[33] 3090 prices for crop products and 683 prices for animal products.

that was used contained 66 prices whereas a finer modelling based on 3 800 prices has been implemented in the FWF model.

An important work of data preparation and treatment was performed to make the PriceSTAT's data consistent with the FWF model structure. Practically, it requires transforming the detailed tables country*products tables into tables of 21 sub-commodities * 21 sub-regions. This work was done by using FAO's ProdSTAT data (FAOSTAT 2012f) as weighting factors to build up producer prices averaged at the sub-region and sub-commodity level.

Assumptions

Due to unavailability of data on prices, economic costs for fish and seafood were not accounted for.

The FBS's macro analysis shows that for most commodities, imports are only limited share of total domestic food supply except for fruits (and fish & seafood). For that reason, producer prices for fruits used in the model are world averages and not regionalised figures.

Chapter 4. Results of the food wastage footprint

4.1 Component 1: Food wastage volumes

This section presents the FWF model results for the quantification of food wastage volumes. Complementary results for this component are presented in Annex XVI.

4.1.1 Results overview

Unlike the previous FAO study on food wastage (FAO 2011a), the present study quantifies the food wastage volumes considering both edible and non-edible food. Indeed, since environmental impacts relate to the entire product and not its edible part only, the vast majority of studies provides impact factors for the entire product and not for its edible part only (i.e. impact per kg of "entire" product). Consequently, food wastage volumes for "edible + non-edible parts" were used in the footprint calculations. This also facilitates cross components analyses.

At world level, the total amount of food wastage in the year 2007 is about 1.6 Gtonnes of "primary product equivalents". Total food wastage for the edible part of food is 1.3 Gtonnes[34]. In order to illustrate the magnitude of these results, food wastage volumes can be compared to total agricultural production volumes (i.e. the sum of total domestic production taken from the FBS of each country). Note that this latter value, which is about 6 Gtonnes, includes agricultural production for other uses than food[35].

The amount of food wastage, the amount of food wastage for the edible part of food only, and the agricultural production are shown for each commodity in Figure 26.

[34] This value of 1.3 Gtonnes (as well as its breakdown by commodity or region) is strictly similar to the results already presented in the FAO (2011) study.

[35] This is a reason why averaged food wastage percentages cannot be directly derived from a ratio between red or green values and blue values of Figure 26.

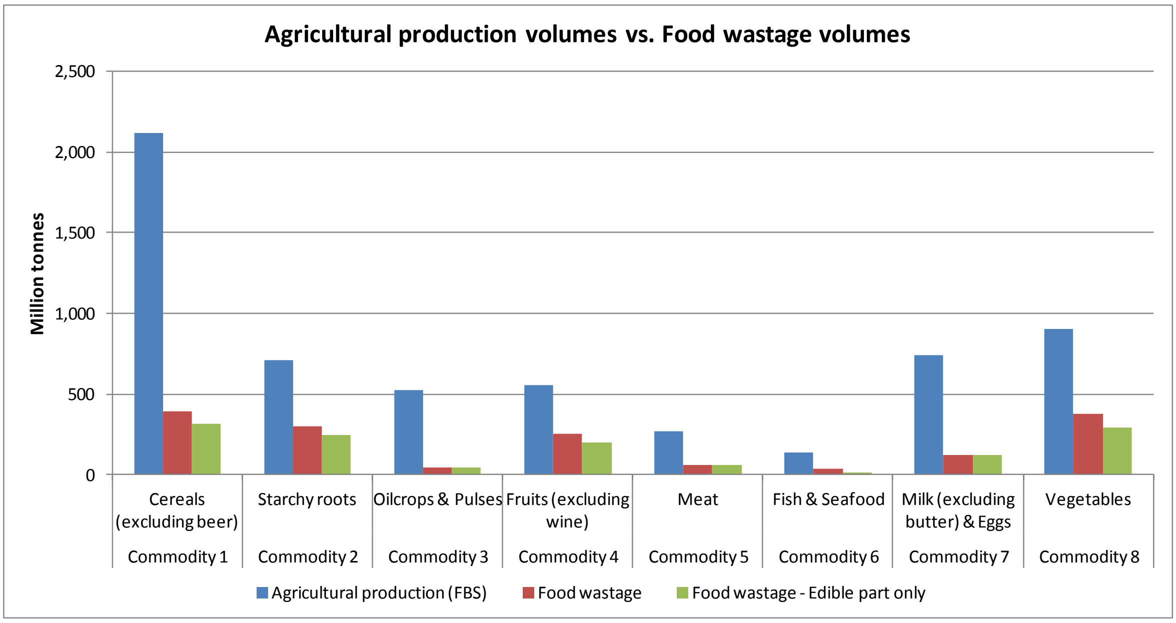

Figure 26: Total agricultural production (FBS) vs. food wastage volumes & food wastage volumes for edible part only

4.1.2 Analyses by commodity, region and phase

In the three following sections, the total amount of food wastage of 1.6 Gtonnes of "primary product equivalents" is further broken down by commodity, region, and phase of the food supply chain.

Analysis by commodity

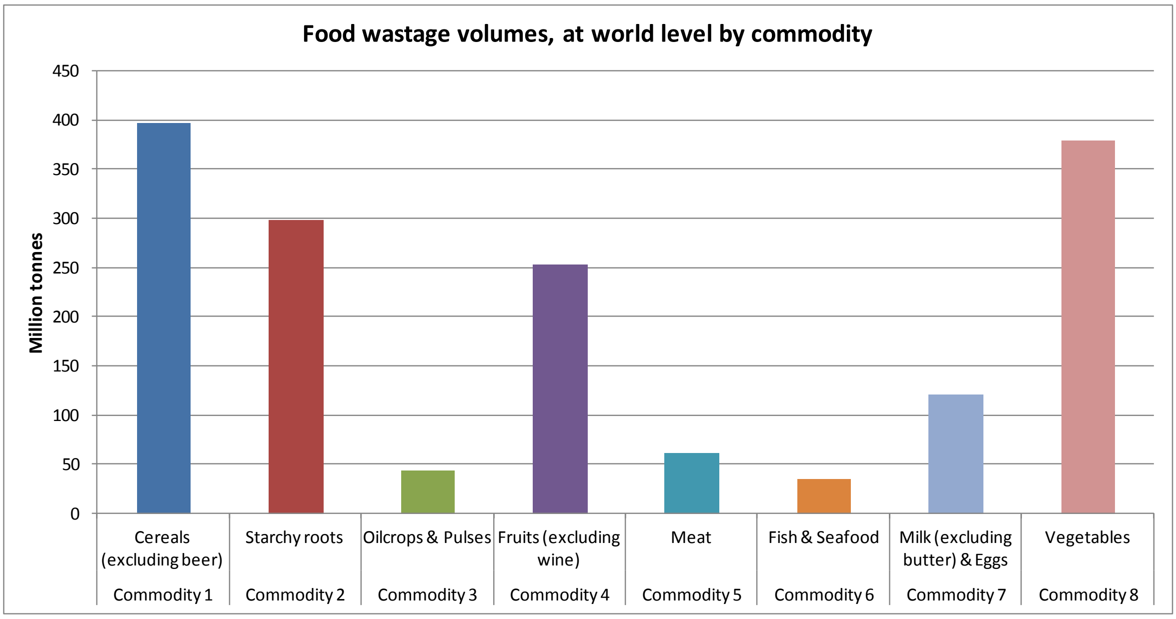

Figure 27: Food wastage volumes, at world level by commodity

Figure 27 shows that the major contributors to food wastage volumes are cereals (25% of total), vegetables (24%), starchy roots (19%), and fruits (16%). It can be noted that food crops (i.e. vegetal products) account altogether for about 85% of total food wastage volumes, and the remaining 15% are coming from products of animal origin.

Analysis by region

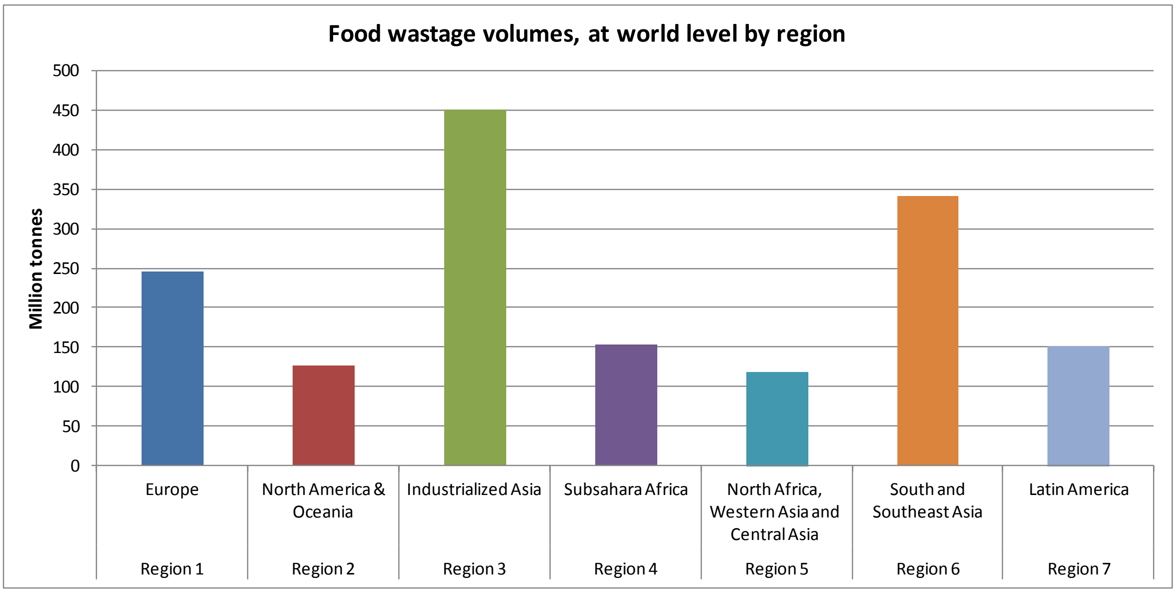

Figure 28: Food wastage volumes, at world level by region

In terms of regional distribution, Figure 28 shows that the major contributors are industrialized Asia (28% of total) and South & Southeast Asia (22%). In addition, it can be seen that medium and high-income countries (i.e. regions 1, 2 and 3) account for slightly more than half of total food wastage volumes. Note that these results, presented here in absolute terms, are further examined with a per capita analysis in section 4.1.4.

Analysis by phase

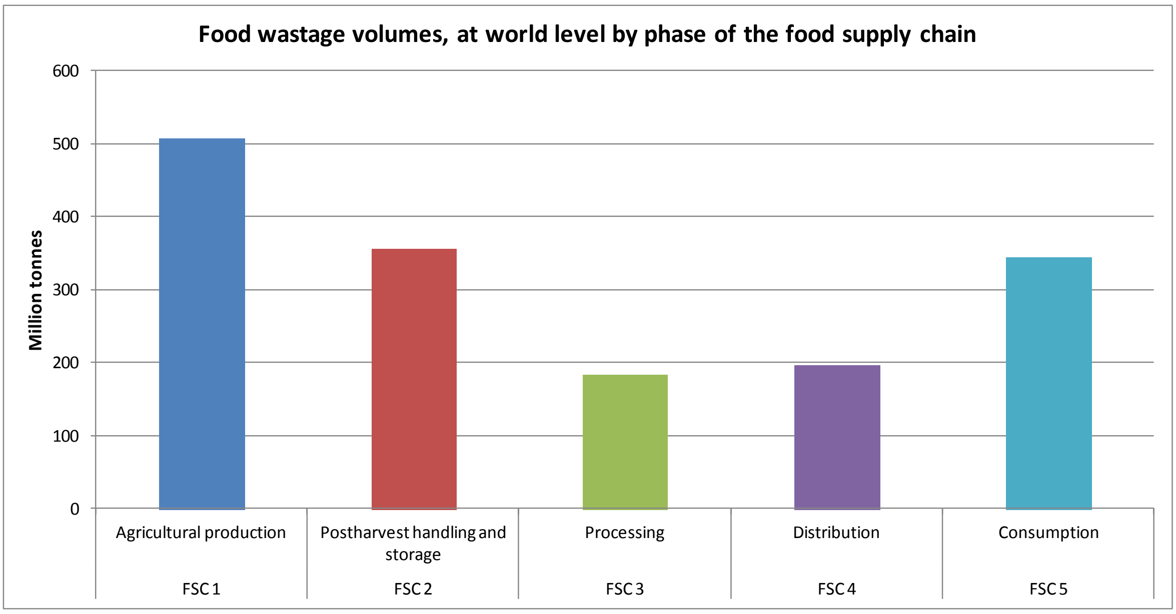

Figure 29: Food wastage volumes, at world level by phase of the food supply chain

As regards amounts of food lost or wasted along the food supply chain, Figure 29 shows that agricultural production is the main contributor with 33% of total food wastage volumes. At global level, food wastage volumes are shared between upstream phases (i.e. losses occurring before processing and/or distribution) and downstream phases (54% vs. 46%, respectively).

4.1.3 Regional profiles

In this section, the amounts of food wastage generated in each region (as shown in Figure 28) are further disaggregated using two axis of analysis: commodity groups and FSC phases. For each region, a particular profile is therefore obtained and key characteristics can be identified.

Regional profiles – Commodity groups view

Profiles presented here are built up at commodity level; profiles at sub-commodity level are presented in Annex XVI.

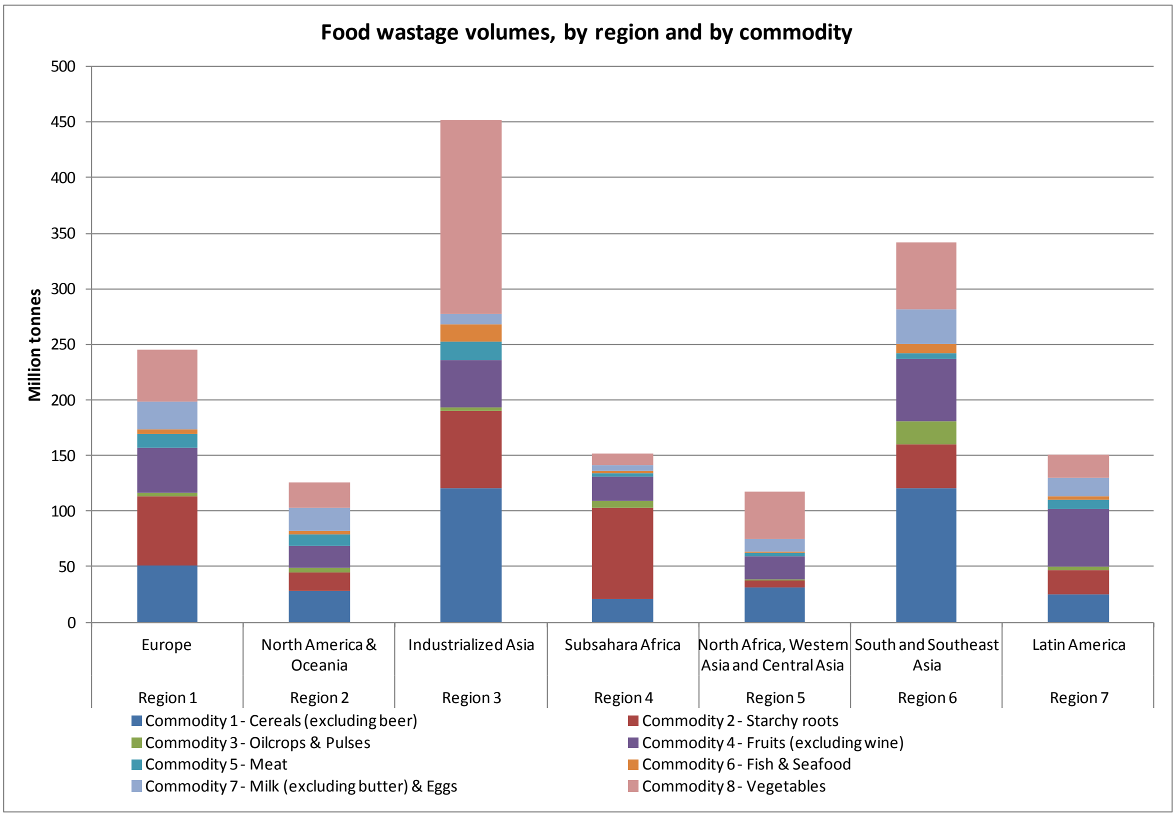

Figure 30: Food wastage volumes, by region and by commodity

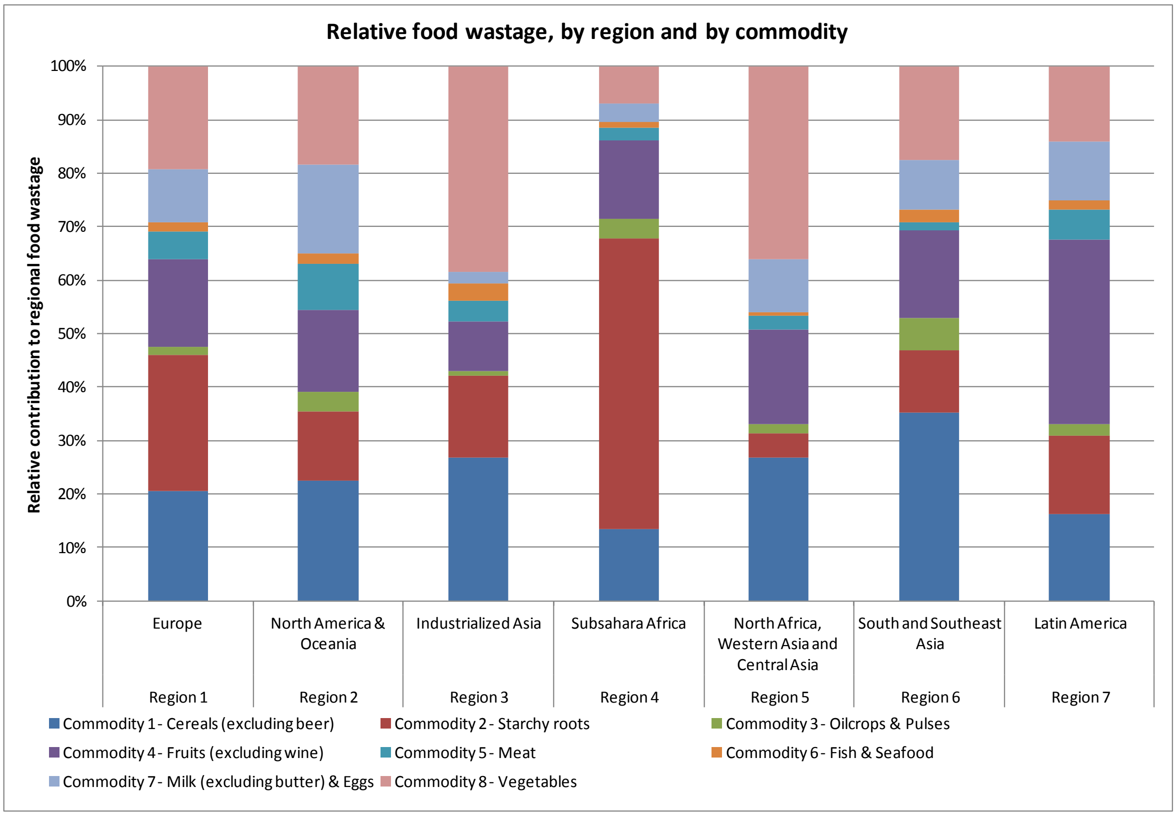

Figure 31: Relative food wastage, by region and by commodity

Looking at the regional profiles of commodities presented in an absolute (Figure 30) or relative way (Figure 31), one can see that they are quite variable from one region to another, although some common trends can be observed:

Contribution of oilcrops & pulses and fish & seafood to total food wastage is low in all regions (1 to 6% of the food wastage of the region).

- Regarding oilcrops, most of the wastage occurs at agricultural production and during postharvest handling and storage whereas there is relatively little waste in the distribution and consumption stages. This is because oilcrops are mainly consumed as vegetable oils, products that tend to be wasted less than fresh products (FAO 2011a). This can explain why the wastage for this commodity remains relatively low.
- For fish & seafood, it can be noted that the total production for this commodity is the lowest of all commodities. This means that even if 100% of fish & seafood were wasted, the contribution of this commodity to total food wastage would remain secondary. Nevertheless, for this latter commodity it should be kept in mind that available data tend to underestimate the actual food wastage (see section 3.1.2 – part on food wastage percentages).

Contribution of meat to total food wastage is also quite low in all regions (1 to 9% of the food wastage of the region). However, meat wastage is higher in medium and high-income regions (i.e. NA & Oce 8.6%; Europe 5.2%; Ind. Asia 3.8%) than in low-income regions (1.5 to 2.6%), with the exception of Latin America (5.6%).

- In medium and high-income regions, most of the wastage occurs in the end of the FSC. This can be explained by a high per capita meat consumption combined with large waste proportions by retailers and consumers, especially in Europe and the USA (FAO 2011a).
- Among the low-income regions, Latin America is the largest producer of meat and has the highest domestic supply quantity; combined with the fact that animal mortality is higher than in medium and high-income regions, this explains why contribution of meat to total food wastage is high in this region, with 30% of losses occurring at production phase.

Contribution of cereals to total food wastage is always above 20% of the food wastage of the regions except for sub-Saharan Africa and Latin America (13% and 16%, respectively).

- In all regions, important volumes of cereals are used for human consumption. For that reason, cereals contribute significantly to food wastage volumes in all regions even in low-income regions where wastage percentages of cereals remain below 12% in all phases. Contribution of cereals to total food wastage is accentuated in middle and high-income countries where wastage percentages at consumption level are high (20-27%).

Overall, vegetables, starchy roots, and fruits always contribute significantly to total food wastage in each region, but their respective shares are variable. It can be seen for instance that starchy root wastage is as high as 54% of total in sub-Saharan Africa; wastage of fruit is high in Latin America (35%) and wastage of vegetables is high in industrialized Asia (39%) and NA,WA&CA (36%).

- For fruits and for vegetables, these results can partly be explained by high wastage at agricultural production phase in all regions (27-53% of total wastage for these two commodities). A reason for this is fruit and vegetable grading, caused by quality standards set by importers and/or retailers. Losses during postharvest handling and storage and in the distribution step are also severe in low-income regions (20-24% of total wastage for these two commodities) because of the deterioration of perishable fruit and vegetables during handling and distribution in the warm and humid climate of many developing countries. Note also that in middle and high-income region, waste in the end of the FSC is significant with 15-30% of fruit and vegetables wasted by consumer households (FAO 2011a).
- For starchy roots in middle and high-income regions, the largest volumes of wastage occur during agricultural production because of crop grading related to quality standards set by retailers. In low-income countries, high wastage is also observed at early stages but similarly to fruits and vegetables, reasons are to be

found in the fact that fresh roots and tubers are perishable, making these products easily damaged during harvest and postharvest activities (FAO 2011a).

Regional profiles – FSC phases view

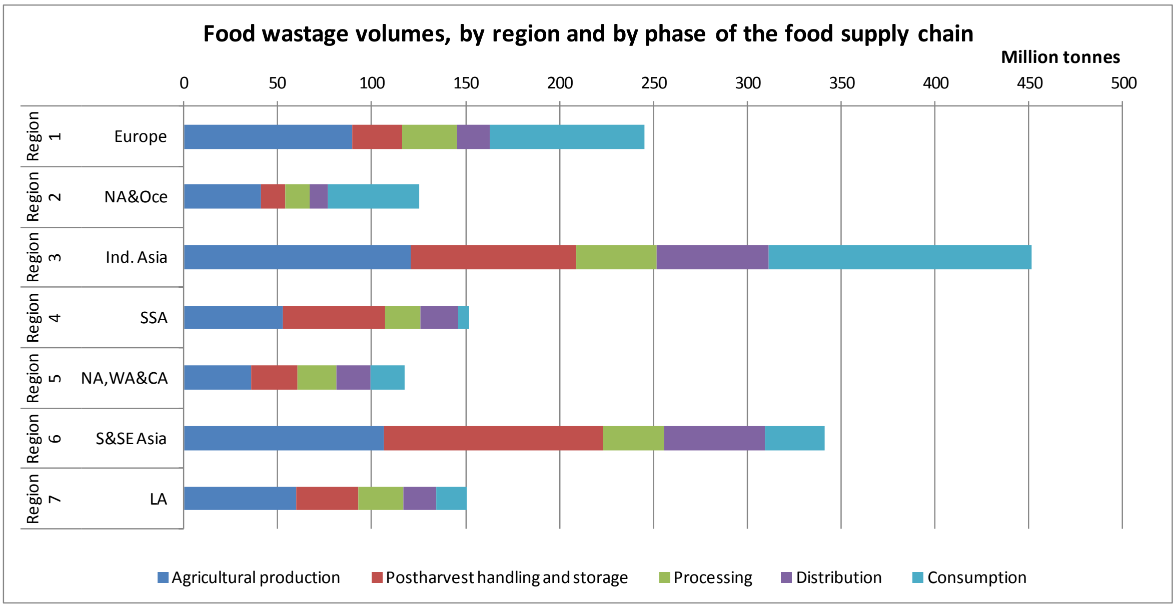

Figure 32: Food wastage volumes, by region and by phase of the food supply chain

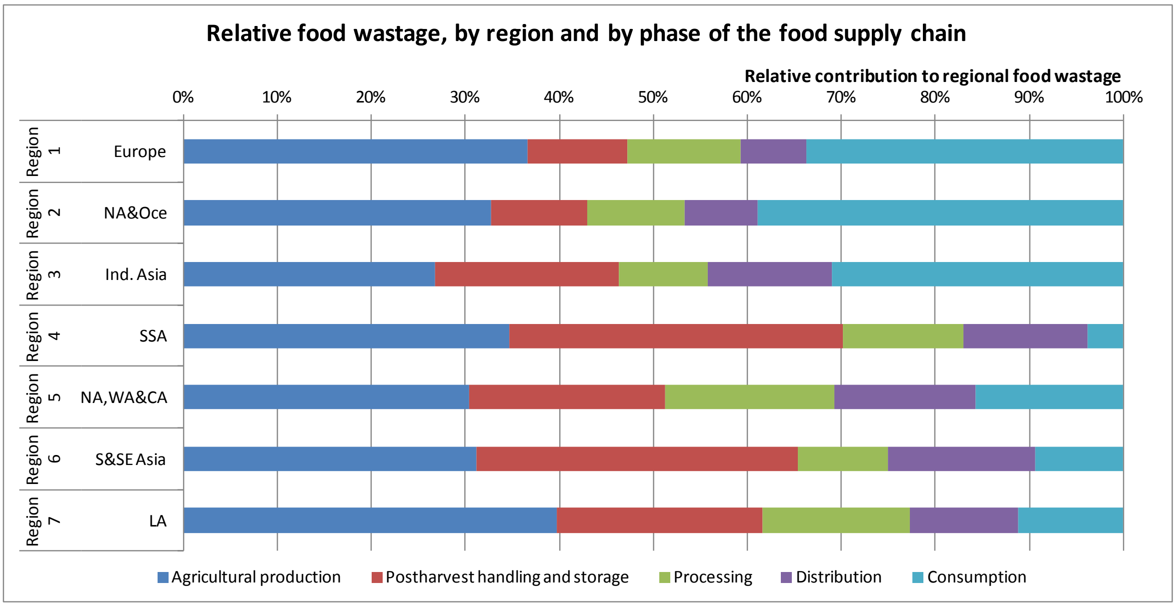

Figure 33: Relative food wastage, by region and by phase of the food supply chain

Looking at the regional profiles of FSC phases presented in an absolute (Figure 32) or relative way (Figure 31), it can be observed that:

On the upstream side, the share of wastage occurring at agricultural production appears to be rather homogenous across regions (about one third of the food wastage of a region).

On the downstream side, share of wastage occurring at consumption level can be seen as highly variable. In medium and high-income regions (i.e. regions 1, 2, and 3) wastage at this phase is high (31 to 39%) but much lower in low-income regions (4 to 16%).

This latter trend can also be seen in a more aggregated way – i.e. considering downstream FSC phases on the one hand and upstream phases on the other hand – as presented in Figure 34 and Figure 35. From these figures, one can see that in middle and high-income regions, food volumes wasted/lost are higher downstream than upstream. Conversely, in low-income regions the opposite pattern is observed.

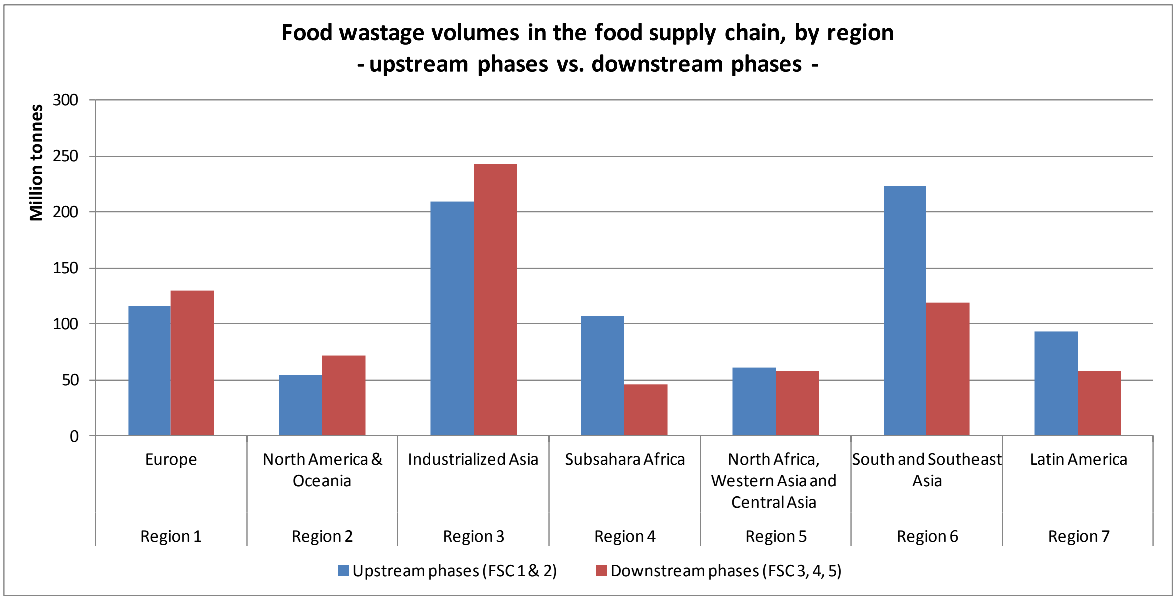

Figure 34: Food wastage volumes in the food supply chain, by region – upstream phases vs. downstream phases –

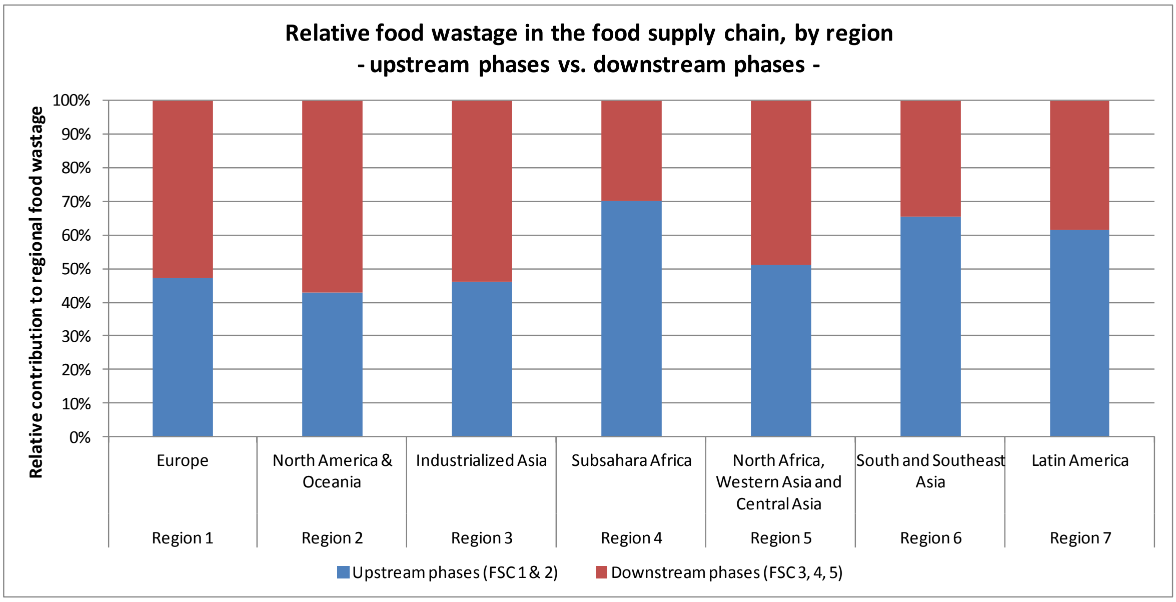

Figure 35: Relative food wastage in the food supply chain, by region – upstream phases vs. downstream phases –

Figure 34 and Figure 35 are a new illustration of what had been previously established in the FAO study on global food losses and food waste (FAO 2011a):

Major causes of food loss and waste observed in middle and high-income regions relate to consumer behaviour (e.g. insufficient purchase planning, exaggerated concern towards "best-before-dates") as well as lack of communication between different actors in the supply chain (e.g. food is wasted due to quality standards too restrictive on shape or appearance aspects).

In low-income regions, loss and waste are mostly due to financial and structural limitations in harvest technique; storage facilities; infrastructure; cooling chains; packaging and marketing systems. These limitations, along with climatic conditions favourable to food spoilage, lead to large amounts of wastage.

4.1.4 Per capita analysis

In this section, the absolute amounts of food wastage generated in each region (as shown in Figure 28) are presented per capita.

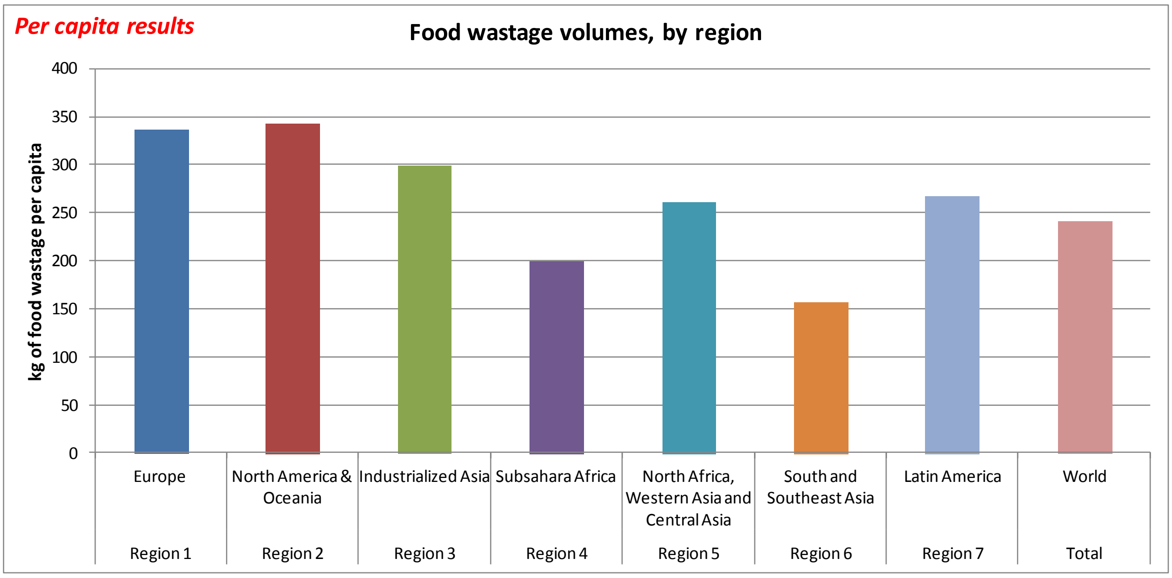

Figure 36: Food wastage volumes, by region – Per capita results

The overall pattern observed in Figure 36, is somewhat different from Figure 28. Europe, NA & Oce, and Ind. Asia stand out as the regions with the highest wastage per capita (approximately 300 to 340 kg per capita and per year). S&SE Asia, which is the region with the highest volumes of food wastage in absolute terms, is also the region with the smallest food wastage per capita (about 160 kg per cap.). Indeed, this latter region accounts for as much as one third of total population but contributes to only 22% of global food wastage

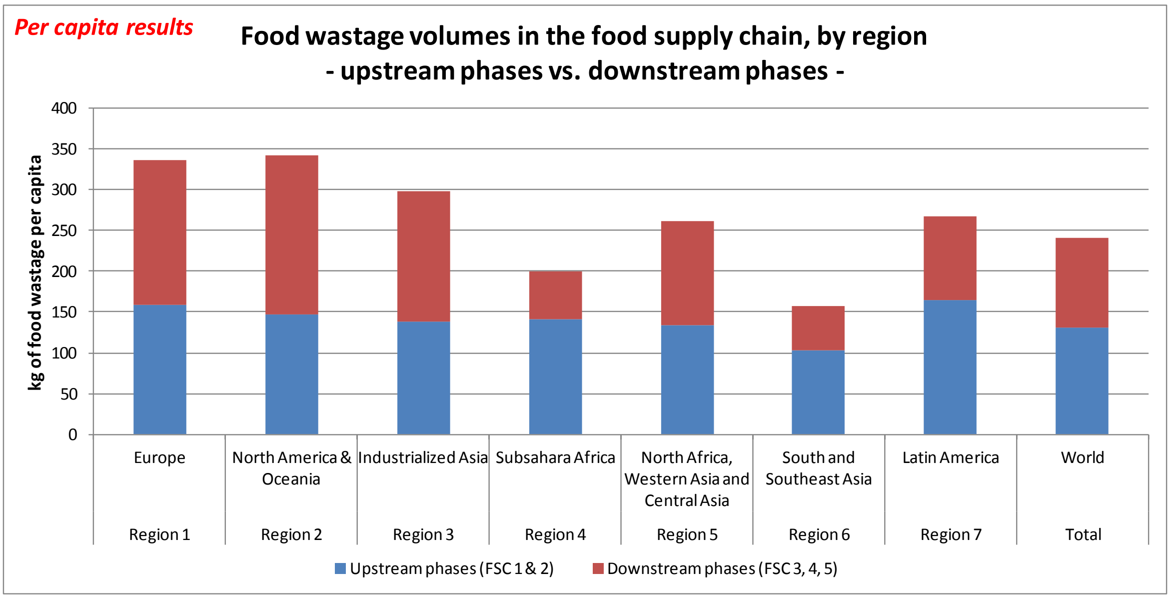

Figure 37: Food wastage volumes in the food supply chain, by region
Per capita results – upstream phases vs. downstream phases –

Figure 37 reveals that per capita wastage is more variable in downstream phases (50 to 200 kg per cap.) than in upstream phases (approx. 100 to 160 kg per cap). This means that higher per capita wastage in middle and high-income regions is due to higher wastage in downstream phases.

This trend can be explained by an overall higher variability, from one region to another, of food wastage percentages in downstream phases than upstream phase as well as variations in amount of food consumed per capita.

4.1.5 Identification of hotspots

Hotspots – Contribution to total food wastage

The FWF model is based on seven world regions and eight commodity groups. This leads to 56 (i.e. 7 *8) "region * commodity" pairs. The 56 pairs can be ranked according to their contributions to total food wastage and therefore enable the identification of hotspots, that is to say a limited number of region/commodity crossings that are major drivers of food wastage.

Figure 38 shows the ten "region * commodity" pairs (out of 56) with the highest contribution to food wastage volumes. Asia (i.e. Ind. Asia and S&SE Asia) appears six times in the top 10 and dominates this ranking with vegetables and cereals. SSA (because of starchy roots), Europe (because of starchy roots and cereals), and Latin America (because of fruits) are also present.

It seems quite natural to see in the top 10 on the one hand, commodities that stood out in the results overview per commodity (see Figure 27); and on the other hand, regions that stood out in the results overview per region (see Figure 28). Two regions that were not considered as major contributors to total food wastage, namely LA and SSA, do however appear in the top 10 because of fruits and starchy roots respectively. Indeed, in these two regions, the volumes consumed are important and at the same time, food wastage percentages are relatively high.

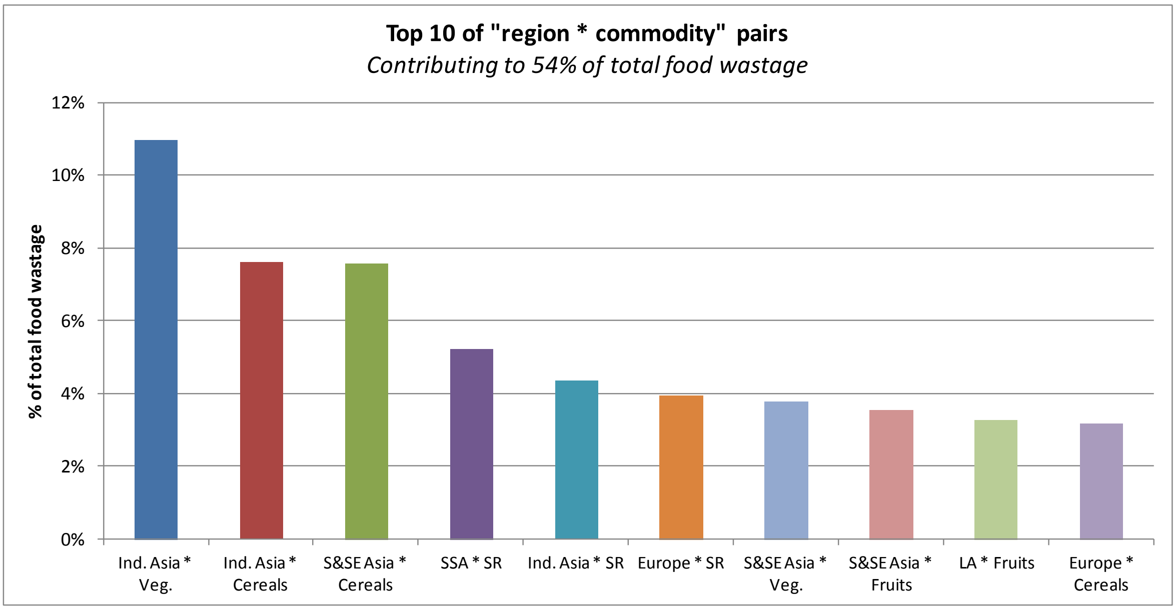

Figure 38: Top 10 of "region * commodity" pairs for food wastage

This first analysis can be refined, taking into account the FSC phase when wastage occurs. Since there are five FSC phases considered in the FWF model, this leads to 280 triplets (i.e. 7 *8*5) that can be ranked in the same way as above. The obtained top 10 is presented in Figure 39.

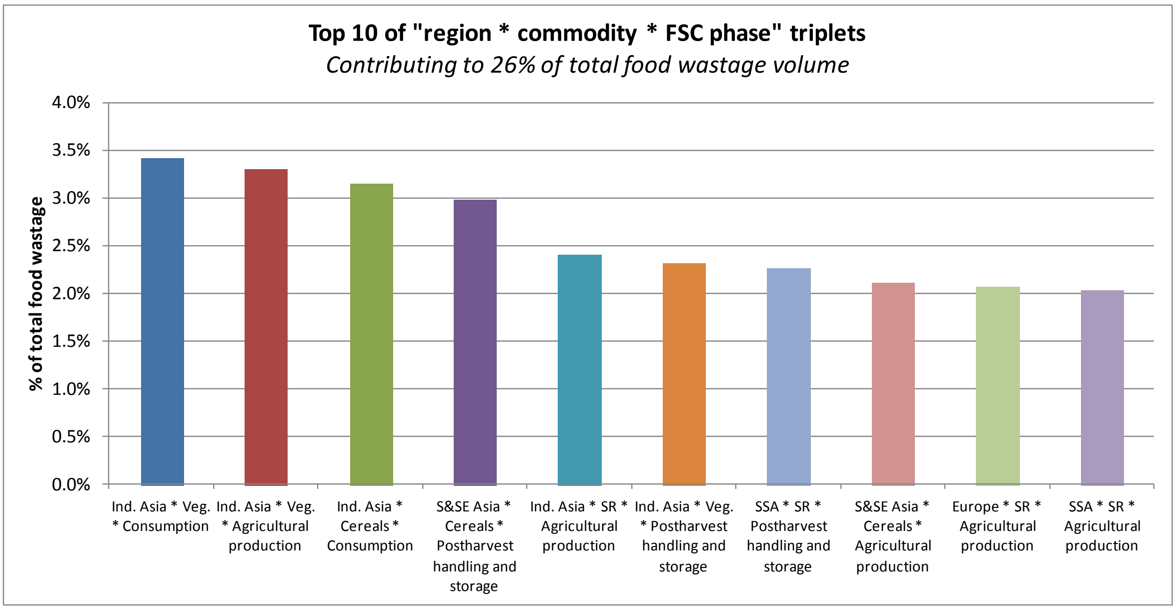

Figure 39: Top 10 of "region * commodity * FSC phase" triplets for food wastage

Except for fruits in Latin America, the same regions and commodities as in Figure 38 can be seen in this new raking. Consumption and agricultural production phases dominate the top 10 with postharvest handling and storage phase being also very noticeable.

A deeper analysis of the underlying causes of this ranking is provided hereafter:

It appears that vegetables in industrialized Asia are a key wastage hotspot both at consumption and at agricultural production phases in nearly similar quantities. To a lesser extent, postharvest phase is also a hotspot. It should be stressed that the vegetables wastage percentages for these three phases, although quite high compared to other commodities, are actually lower than in other high-income regions (FAO 2011). Thus, food wastage percentages are not the key drivers of these high food wastage volumes for vegetables. Key causes are as follows:

- Vegetable wastage is high at agricultural production and postharvest phases because industrialized Asia dominates the vegetable production with more than 50% of the global production (FAOSTAT 2012d)
- Vegetable wastage is high at consumption phase because industrialized Asia is also the world largest consumer of vegetables with more than 50% of the global domestic supply (FAOSTAT 2012d).

Regarding cereals in industrialized Asia, the consumption phase stands out as a hotspot. Key causes are as follows:

- Food wastage percentage of this step is significantly higher than the percentages of other phases.
- Industrialized Asia is an important consumer of cereals but its contribution to the global domestic supply is in the same order of magnitude as S&SE Asia (both about 20%). The reason of the difference in cereals wastage with S&SE Asia (whose wastage of cereals at consumption phase does not appears in the top 10) is that a percentage of 20% (closer to other high-income regions) has been assumed for Ind. Asia whereas 3% has been assumed for S&SE Asia (closer to other low-income regions) (FAO 2011).

Starchy roots in SSA appear twice in the top 10 with the post harvest phase and the agricultural production phase. Although SSA is not a major contributor to food wastage at global level, starchy roots are the dominant wasted commodity in this region. This is due to a combination of two factors:

- There is a high production of starchy roots in this region with about 30% of world production. Note that the dominant root in this region is cassava (FAOSTAT 2012d).
- Compared to other developing countries, the wastage percentages of these two phases are relatively high.

Europe appears once in the top 10 because of wastage of starchy roots at agricultural production phase. Considering commodity-aggregated results, it is clear that in Europe, the role of consumption phase in food wastage is high relatively to other phases (Figure 33). Nevertheless, in absolute terms, food wastage at production phase is higher in Europe than in some developing regions (Figure 32). In particular, a focus on starchy roots in Europe shows that :

- About 50% of the wastage of this commodity occurs at the agricultural production phase because of potatoes sorted out on farm due to quality standards (FAO 2011a).

- This region is a significant producer of the commodity with about 20% of global production (FAOSTAT 2012d).

Hotspots – Per capita analysis

Another way to pinpoint hotspots is to calculate per capita ratios for each of the 56 "region * commodity" pairs. That way, a new top 10 can be obtained and is presented in Figure 40. One can see that seven pairs of the first top 10 (i.e. Figure 38) are still present. However, S&SE Asia is no longer visible. This can be explained by the fact that overall, this region has the lowest food wastage volumes per capita (see Figure 36). Conversely, the NA,WA&CA region is now visible. This can be explained by the fact that cereals and vegetables are major contributors to food wastage in this region, which has in parallel a ratio of food wastage per capita higher than world average.

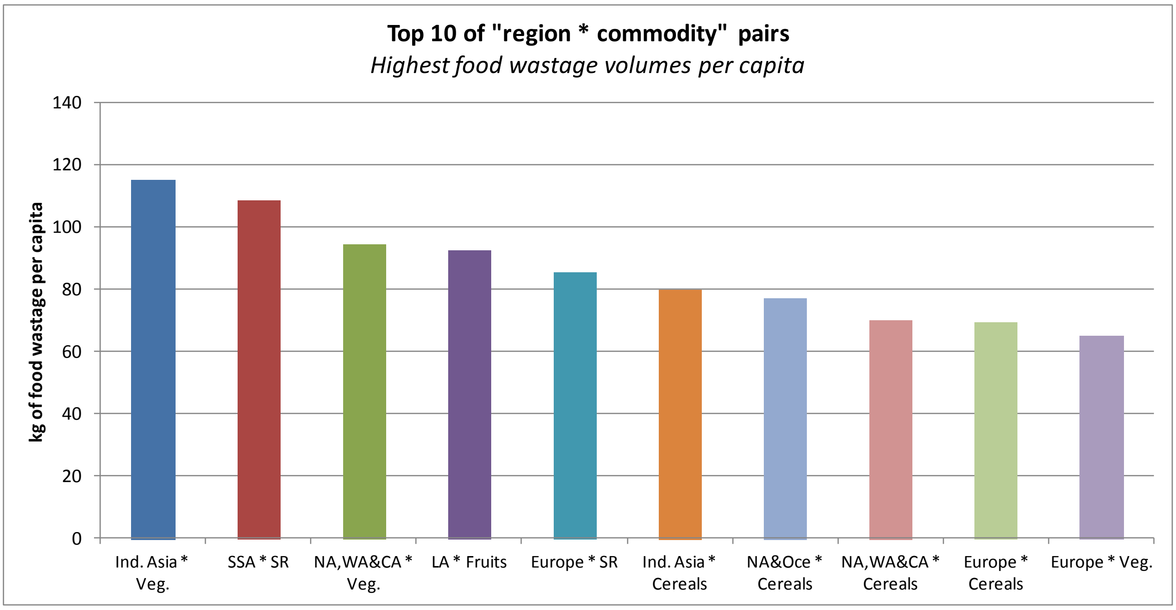

Figure 40: Top 10 of "region * commodity" pairs for food wastage volumes per capita

4.1.6 Highlights

Box 18: Highlights for component 1 – Quantification of food wastage volumes

- The total amount of food wastage in 2007 is about 1.6 Gtonnes of "primary product equivalents" whereas the total agricultural production (including non-food uses) is 6Gtonnes.
- Food crops (i.e. vegetal products) account altogether for about 85% of total food wastage volumes, and the remaining 15% are coming from products of animal origin.
- In terms of regional distribution, the major contributors are industrialized Asia (28% of total) and South & Southeast Asia (22%). In addition, medium and high-income countries account for slightly more than half of total food wastage volumes.
- At global level, food wastage volumes are shared between upstream phases (i.e. losses occurring before processing and/or distribution) and downstream phases (54% vs. 46%, respectively).
- However, when looking at the wastage at each FSC phase in each region, it can be observed

that on the upstream side, the share of wastage occurring at agricultural production is about one third of the food wastage in all regions. On the downstream side, share of wastage occurring at consumption is high in medium and high-income regions wastage (31 to 39%) and much lower in low-income regions (4 to 16%).

- Per capita, Europe, NA & Oce, and Ind. Asia stand out as the regions with the highest wastage (approximately 300 to 340 kg per capita and per year). Although S&SE Asia generates the largest volume of food wastage in absolute terms, it is also the region with the smallest food wastage per capita (about 160 kg per cap.).
- In absolute terms, hotspots for food wastage volumes are in Asia (i.e. Ind. Asia and S&SE Asia) because of vegetables and cereals. SSA (because of starchy roots), Europe (because of starchy roots and cereals), and Latin America (because of fruits) can also be seen as hotspots.

4.2 Component 2: Carbon footprint results

This section presents the FWF model results for the carbon footprint. Complementary results for this component are presented in Annex XVII.

4.2.1 Results overview

The total amount of food wastage in 2007 has generated worldwide about 3.3 Gtonnes of CO_2 equivalent. In order to perceive the scale of "1 Gtonnes of CO_2 eq.", it can be pointed out that in 2010, the total GHG emissions of road transportation in the US accounted for 1.5 Gtonnes of CO_2 eq. (and 0.9 in the EU 27)[36].

Another way to illustrate the magnitude of the GHG emissions of food wastage can be to integrate them in a country ranking of top emitters. A first comparison is made in Figure 41 based on emissions reported by Annex I parties to UNFCCC for the year 2007. Note that some major emitting countries are not Annex I parties. In order to perform a comparison with all major emitters, a dataset compiling various data sources and published by the World Resources Institute (WRI) was used. This second comparison is presented in Figure 42.

Food wastage emissions calculated with the FWF model do not take into account changes in land use (see Box 5). Therefore, country emissions presented in Figure 41 and Figure 42 are presented without LULUCF so that comparisons are made on the same grounds.

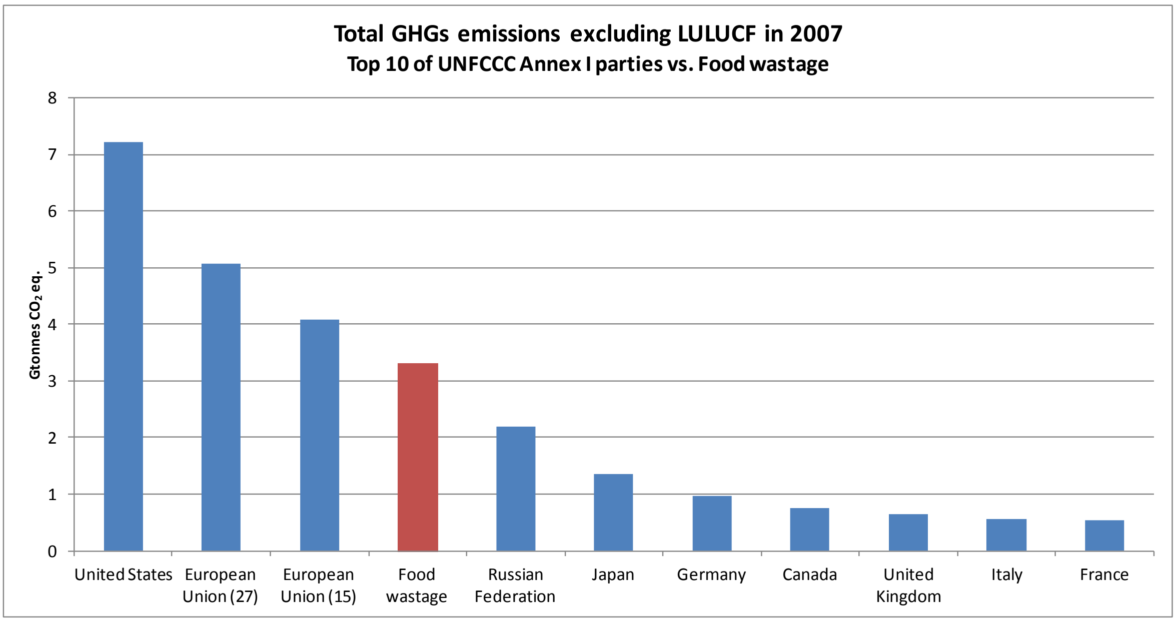

Figure 41: Top 10 of UNFCCC Annex I parties vs. Food wastage (Source UNFCCC)

[36] UNFCCC Annual GHG emissions for road transportation in 2010. Available at: http://unfccc.int

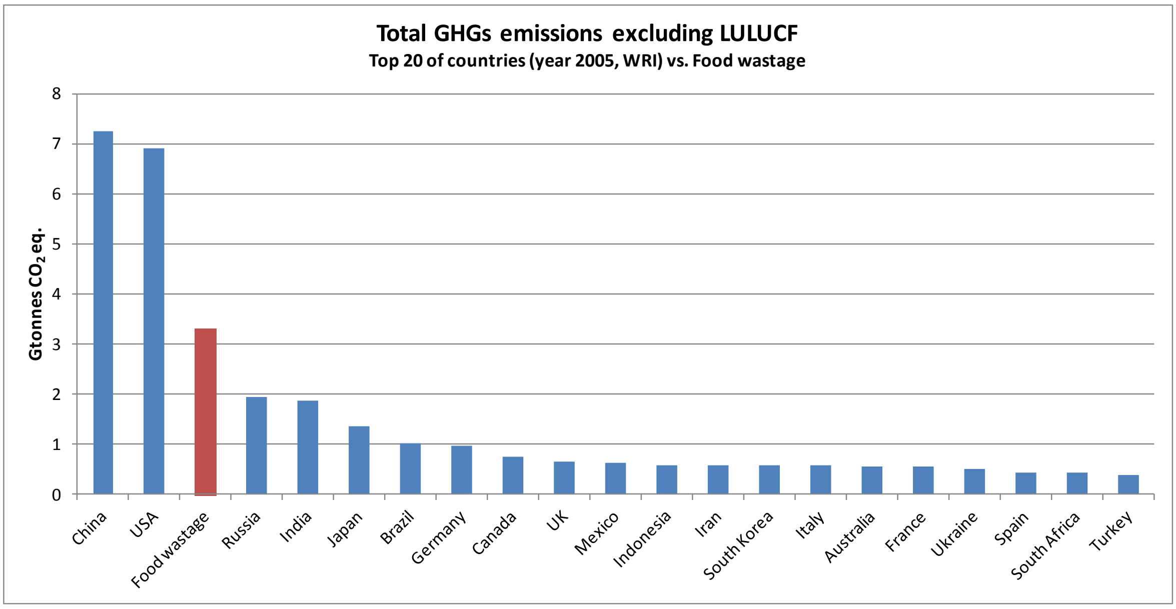

Figure 42: Top 20 of GHG emitting countries vs. Food wastage (Source WRI 2012).

4.2.2 Analyses by commodity, region and phase

In the three following sections, this amount of 3.3 Gtonnes of CO_2 eq. is further broken down by commodity, region, and phase of the food supply chain.

Analysis by commodity

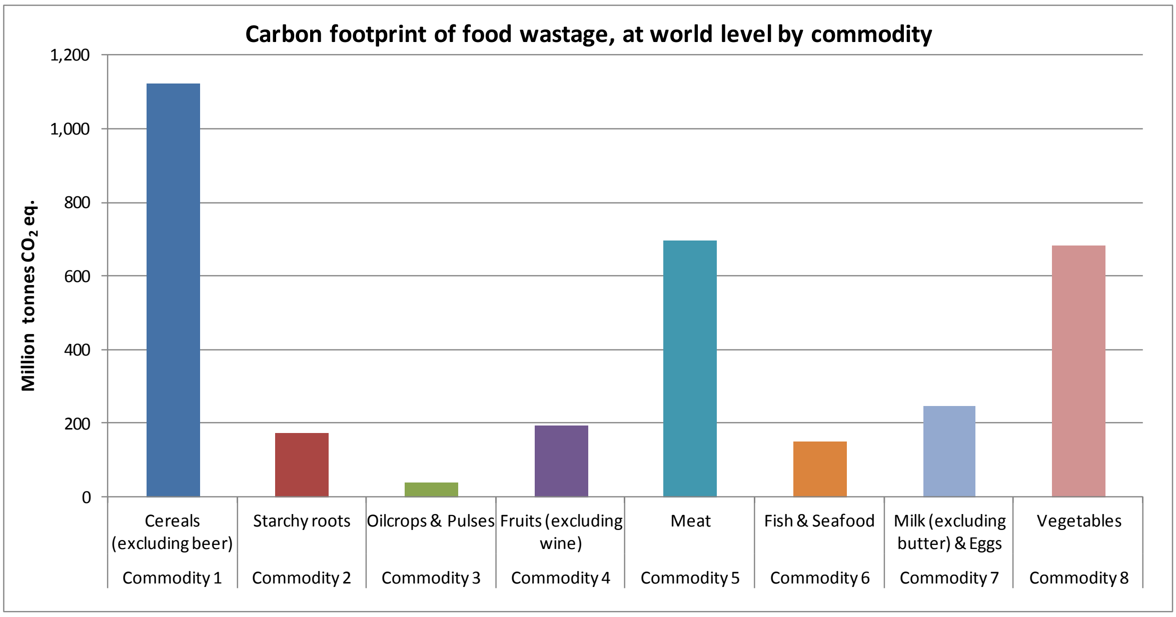

Figure 43: Carbon footprint of food wastage, at world level by commodity

Figure 43 and Figure 44 show that the major contributors to the carbon footprint of food wastage are cereals (34% of total), meat (21%) and vegetables (21%). It can be noted that products of animal origin account altogether for about 33% of total carbon footprint whereas their contribution to food wastage volumes is about 15%. Conversely, starchy roots account for 5% of total carbon footprint whereas this commodity represents 19% of total food wastage.

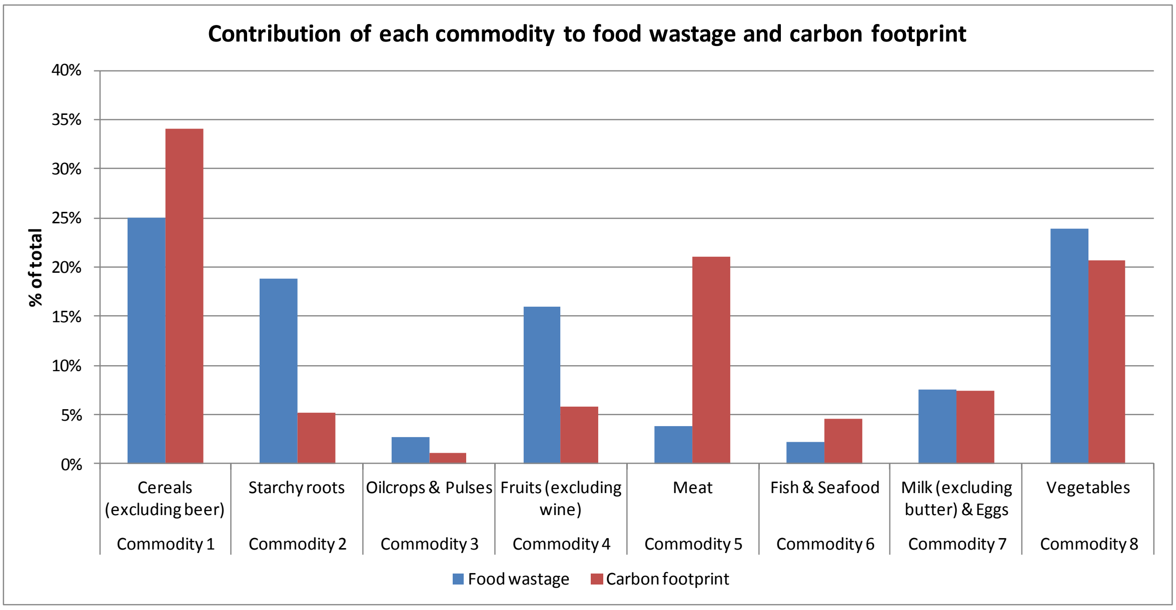

Figure 44: Contribution of each commodity to food wastage and carbon footprint

Figure 40 actually reflects the average "carbon intensity" of each commodity group (i.e. GHG emissions per kg of product – as presented in Figure 122 – Annex XVII). Below is a discussion on the GHG characteristics of the commodities in the scope of the present study. Information presented here is taken from the LCA studies that were selected for the carbon footprint calculations (see section 3.2.4.1 and Annex VII).

Cereals

For cereals, the production and application of nitrogen fertiliser is a very important contributor to the overall climate impact of these products. The production of nitrogen fertiliser generates fossil CO_2 and nitrous oxide. The application of the fertiliser generates direct emissions of nitrous oxide as well as indirect emissions because of ammonia release and leakage of nitrate. Secondly, the use of diesel for agricultural operations (ploughing, harvesting etc) and for drying the produce results in CO_2 emissions. Differences in the impact between different types of cereals mostly depend on the yield level.

It must be pointed out that one of the most important food staples is rice. Schematically, rice can be produced either in a dry ("upland") or in a wet ("paddy") system. Production of upland rice is similar to other grain crops from a climate impact perspective. The specific issue with paddy rice – which accounts for most of the rice production globally – is that methane is formed because of the anaerobic conditions encountered in the flooded fields.

Pulses

Pulses, such as peas and beans are efficient sources of protein compared to animal protein (i.e. they do not require the same amount of inputs per kg protein as compared to the inputs required to produce 1 kg of animal protein). Grain legumes' ability to fixate nitrogen from air means that only small, if any, nitrogen fertiliser is applied in the cultivation, which lowers the emission factors of these products.

Fruits, vegetables, and starchy roots

In general, the production of fruits and field-grown vegetables generates relatively low GHG emissions. As for grains, the key drivers of emissions are the use of diesel and nitrogen fertilisers, as well as yield level. Potatoes and other roots are particularly efficient in the cultivation, because of very high yield per ha. Thus, emissions of GHGs per kg of product are low.

Regarding vegetables grown in heated greenhouses, the type of heat production is the most important parameter for the product's carbon footprint. Obviously, use of fossil fuels result in high emissions of GHGs.

Meat and Dairy Products

When it comes to GHG emissions from animal products, a distinction should be made between monogastric animals and ruminants.

For monogastric animals such as pigs and poultry, the feed provision is the most important activity followed by manure management. The emissions are dominated by nitrous oxide from soil turnover of nitrogen and emissions from production of mineral fertilisers. Energy use can be of significance for some animals as chicken in order to maintain appropriate conditions in the buildings.

For ruminants such as cattle, sheep and goats, emissions of methane are often the most important. Most methane originates from the enteric fermentation (digestion of feed in the rumen); a minor share comes from manure management. The second most important source of emission is nitrous oxide related to feed provision. It includes emissions caused by production of fertilisers, soil emissions of nitrous oxides and energy used in arable farming.

Fisheries

The climate impact of fisheries is dominated by carbon dioxide emissions from onboard diesel combustion, which is directly related to the amount of fuel used. The second major factor is the leakage of refrigerants from onboard cooling equipment if the refrigerants used have a high climate impact.

Aquaculture

The production of fish farm inputs (particularly the feed) often dominates the climate impact of aquaculture products. Note that some fish (e.g. carp, tilapia) are omnivores; they can feed on crop products or residues. Other species, including popular species such as salmon, trout, and cod, are predators that require some input of marine-based feed (e.g. fishmeal and fish oil in industrialized production systems). This increases the GHG emissions of carnivorous fish.

Analysis by region

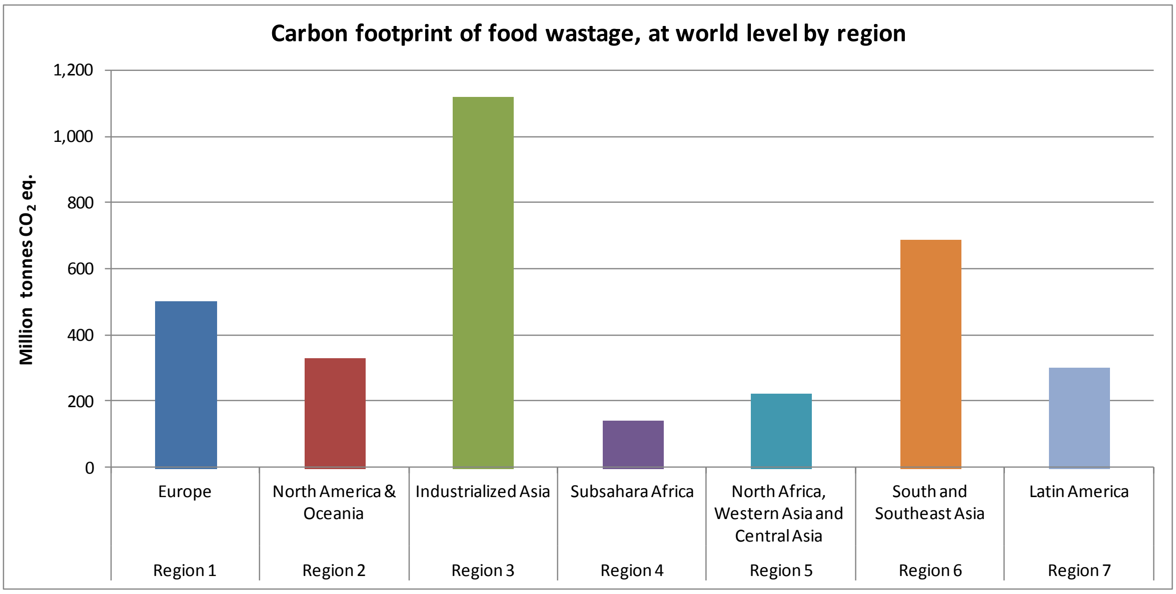

Figure 45: Carbon footprint of food wastage, at world level by region

The overall pattern presented in Figure 45, is quite similar to Figure 28. In other words, food wastage volumes and carbon footprint have relatively comparable regional distributions (as shown in Figure 46). Figure 46 shows that the major contributors to the carbon footprint are industrialized Asia (34% of total) and South & Southeast Asia (21%). In addition, it can be observed that medium and high-income regions (i.e. regions 1, 2 and 3) account for about 2/3 of total carbon footprint whereas their contribution to total food wastage is about 50%.

Note that the results presented in Figure 45 in absolute terms, are further examined with a per capita analysis in section 4.2.4.

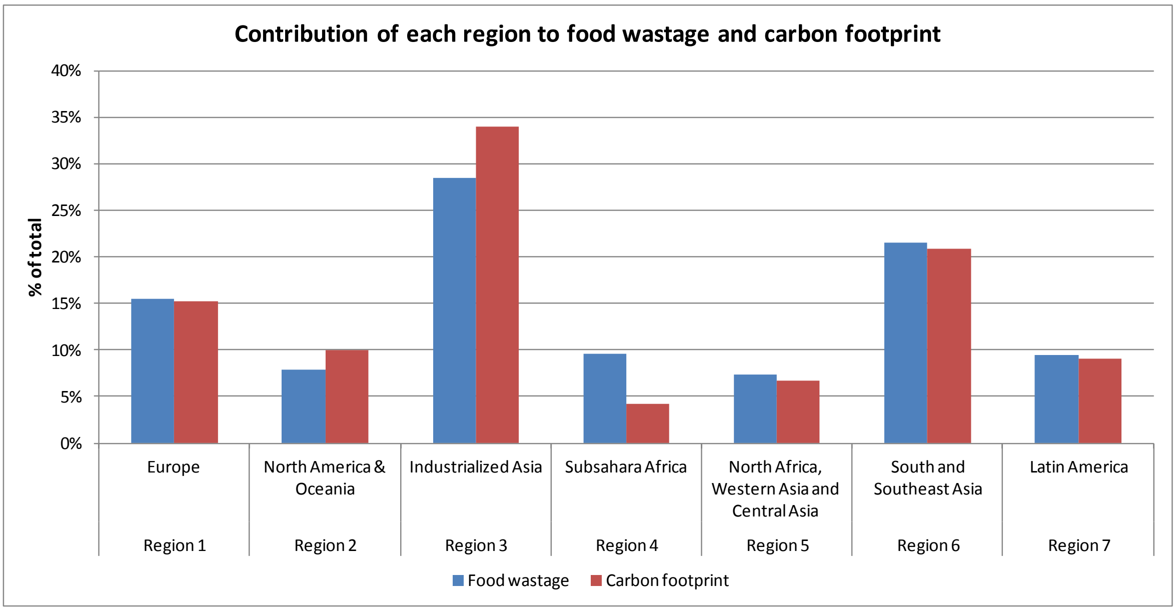

Figure 46: Contribution of each region to food wastage and carbon footprint

Figure 46 actually reflects the average "carbon intensity" of each region (i.e. GHG emissions per kg of food wastage – as presented in Figure 123 – Annex XVII). Observed variations come from the different mixes of commodities that are lost or wasted in each region (see Figure 30 and Figure 31 for commodity mixes). Here are some observed patterns noteworthy to mention:

Regional carbon intensity is higher in North America than in Europe because the share of meat in food wastage is higher (9% and 5% of regional food wastage, respectively).

Regional carbon intensity is very low in sub-Saharan because the share of starchy roots (a commodity with low carbon intensity) in the region is very high (more than 50%).

In industrialized Asia, the high carbon intensity is a result of the carbon footprint of wasted cereals and most notably rice. Rice is also an important contributor to S&SE Asia's carbon intensity.

Figure 49 and Figure 50 in next section shed more light on these aspects.

Analysis by phase

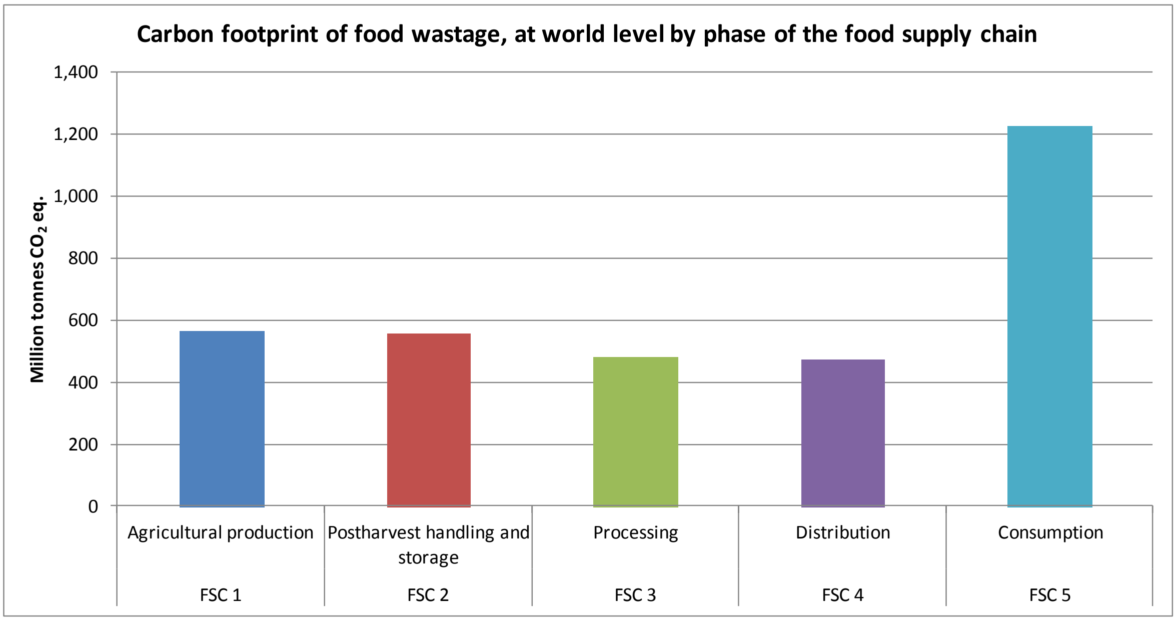

Figure 47: Carbon footprint of food wastage, at world level by phase of the food supply chain

Regarding the carbon footprint of food lost or wasted along the food supply chain, Figure 47 and Figure 48 show that wastage occurring at consumption phase is dominating the carbon footprint (37% of total) whereas this phase accounts for 22% of total food wastage. This is because the impact of a unit of food wastage increases along the food supply chain i.e. the later a product is lost along the supply chain; the higher is the impact per kg. The remaining GHG emissions are distributed evenly between other phases (14 to 17% of total).

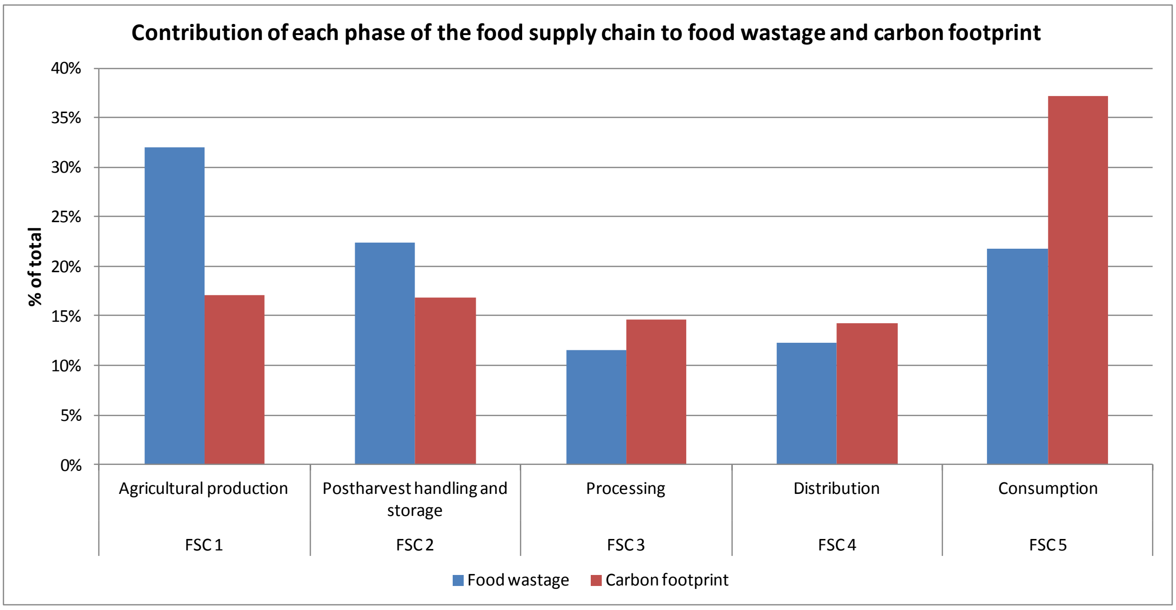

Figure 48: Contribution of each phase of the food supply chain to food wastage and carbon footprint

It should be pointed out that when food wastage occurs at a given phase of the FSC, the related carbon footprint is coming from 1/ the impacts of the phase itself 2/ the impacts associated with the end-of-life of the waste and 3/ the impacts of the previous phases, if any. This means for instance that the carbon footprint of the wastage occurring at the consumption phase comes from the cooking itself (i.e. energy for cooking) but also from the previous phases the food went through (i.e. before reaching the consumer the food was grown, stored, processed, distributed) as well as the end-of-life of this food being thrown away. More details on the linkage between phases of the FSC and impacts throughout the life cycle of food are provided in section 4.2.6.

4.2.3 Regional profiles

In this section, the GHG emissions generated in each region (as shown in Figure 45) are further disaggregated using two axis of analysis: commodity groups and FSC phases. For each region, a particular profile is obtained and key characteristics can be identified.

Regional profiles – Commodity groups view

Profiles presented here are built up at commodity level; profiles at sub-commodity level are presented in Annex XVII.

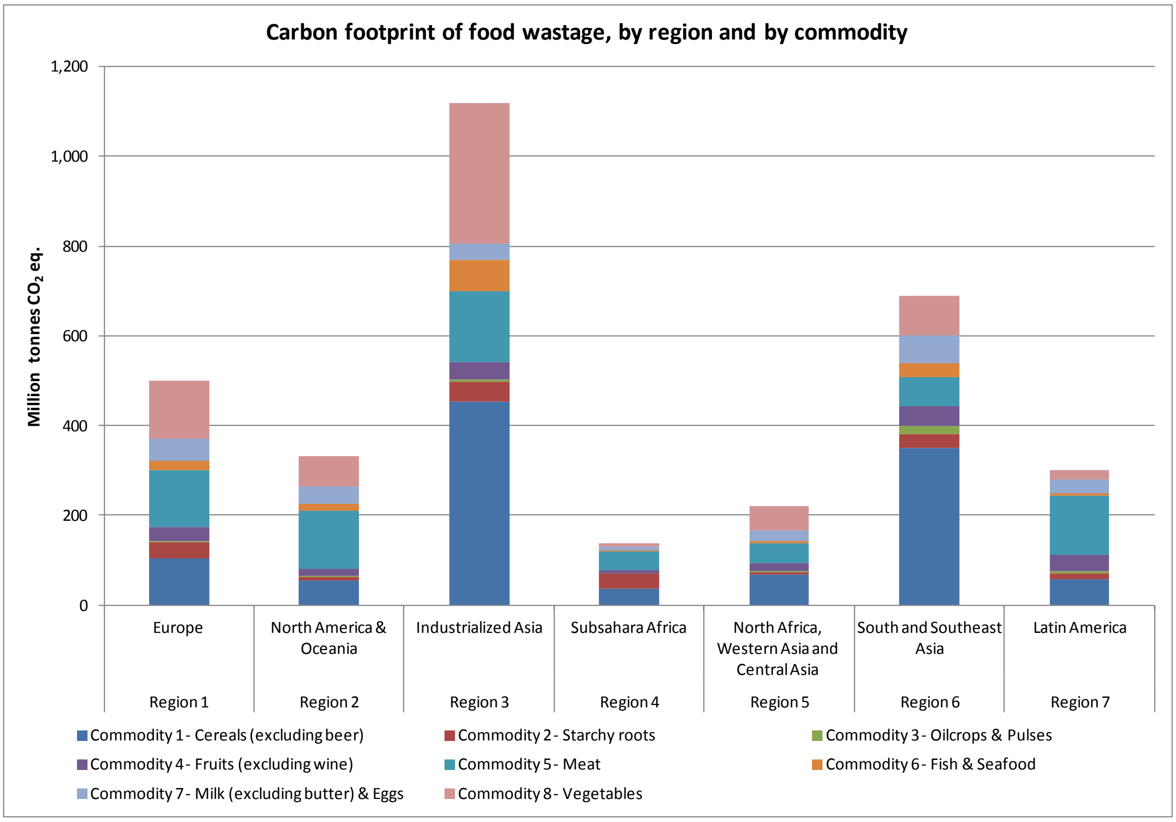

Figure 49: Carbon footprint of food wastage, by region and by commodity

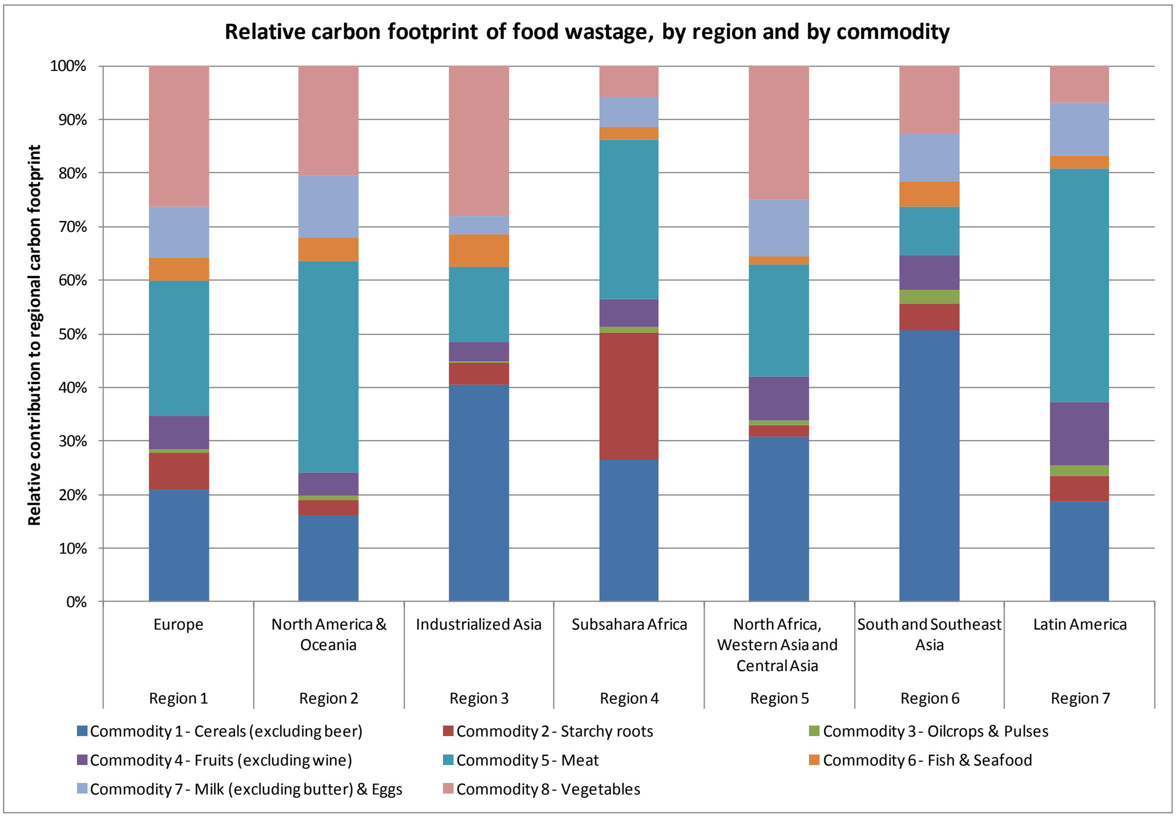

Figure 50: Relative carbon footprint, by region and by commodity

Looking at the regional profiles of commodities presented in an absolute (Figure 49) or relative way (Figure 50), one can see that they are quite variable from one region to another, although some common trends can be observed:

Contribution of lost/wasted oilcrops & pulses and fish & seafood to the carbon footprint is low in all a regions (1 to 6% of the carbon footprint of the region).

Contribution of lost/wasted starchy root to the carbon footprint is also quite low (below 7%) in all regions with the notable exception of sub-Saharan Africa (24%).

Three commodities, namely cereals, meat, and vegetables contribute significantly to carbon footprint in each region. Taken together, they account for more than 60% of the carbon footprint in every region. However, their respective shares are variable. It can be seen for instance that cereals carbon footprint is as high as 51% and 40% of total in S&SE Asia and Ind. Asia respectively. The carbon footprint of meat is high in Latin America (44%) and NA&Oce (40%).

Regional profiles – FSC view

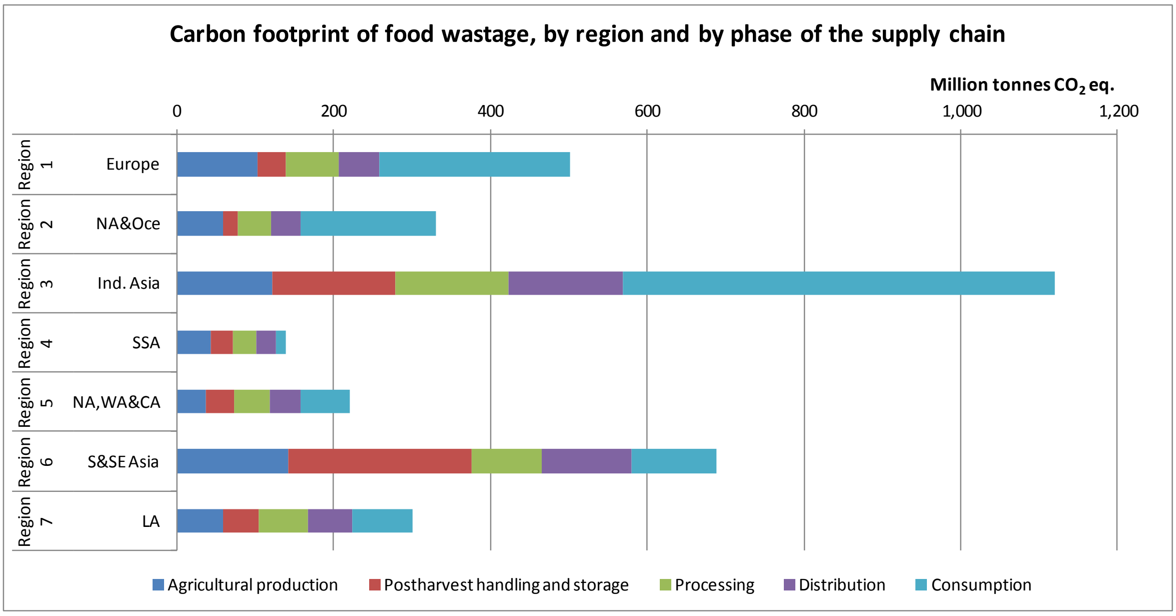

Figure 51: Carbon footprint of food wastage, by region and by phase of the food supply chain

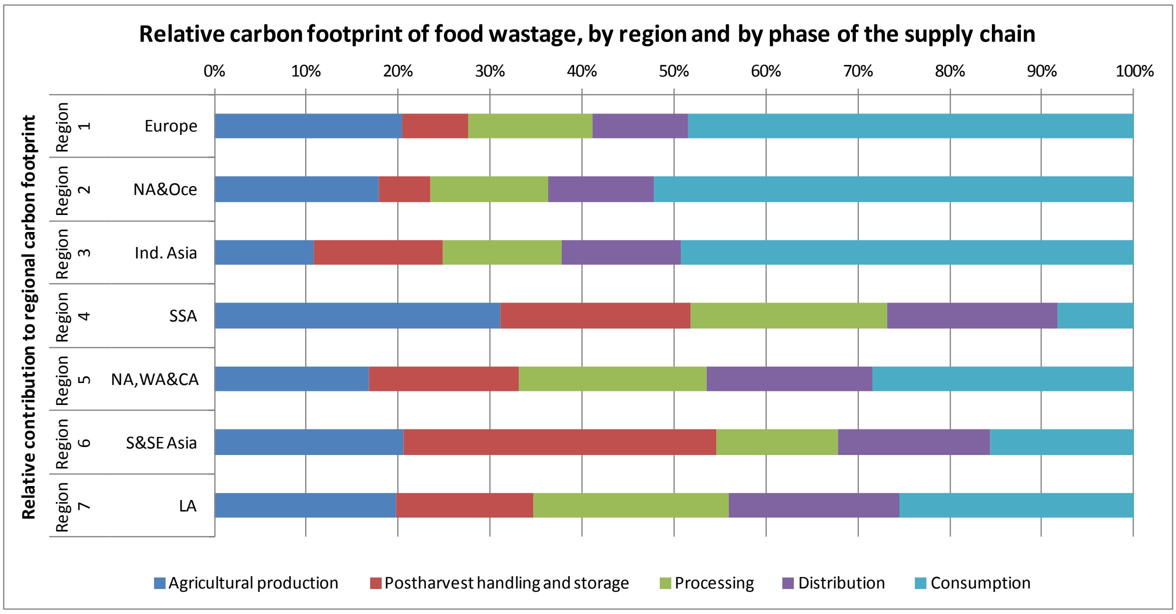

Figure 52: Relative carbon footprint of food wastage, by region and by phase of the FSC

Looking at the regional profiles of FSC phases presented in an absolute or relative way (Figure 51 and Figure 52, respectively) it can be noted that:

In all regions, the contribution of agricultural production to total food wastage which was 28-53% in terms of volumes, has decreased to 11-31% in terms of carbon footprint.

Conversely, the contribution of consumption phase to total food wastage which was 8-36% in terms of volumes, has increased to 8-52% in terms of carbon footprint. In medium and high-income regions in particular, the consumption phase is dominating the carbon footprint with about 50% of the emissions of these regions.

As mentioned previously, the reason for this pattern is that the impact of a unit of food wastage increases along the food supply chain. Trends are more complex to analyse for intermediary phases of the FSC because of the influence of the share of each commodity that is processed and the type of retail system in each region.

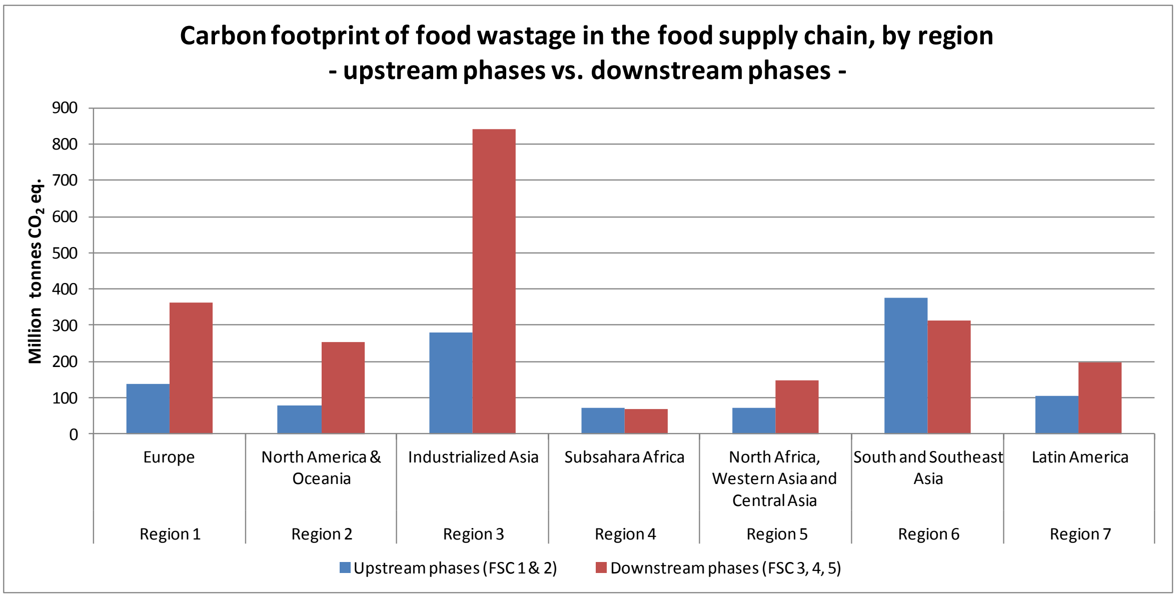

Figure 53: Carbon footprint of food wastage in the food supply chain, by region
– upstream phases vs. downstream phases –

In Figure 53, a split between upstream phases and downstream phases is made in order to perform a broader analysis. One can see that, in middle and high-income regions, carbon footprint of food wasted/lost is 2.6 to 3 times higher downstream than upstream. Conversely, in SSA and S&SE Asia carbon footprint of food wasted/lost is slightly higher upstream than downstream.

4.2.4 Per capita analysis

In this section, the GHG emissions related to food wastage in each region (as shown in Figure 45) are presented per capita.

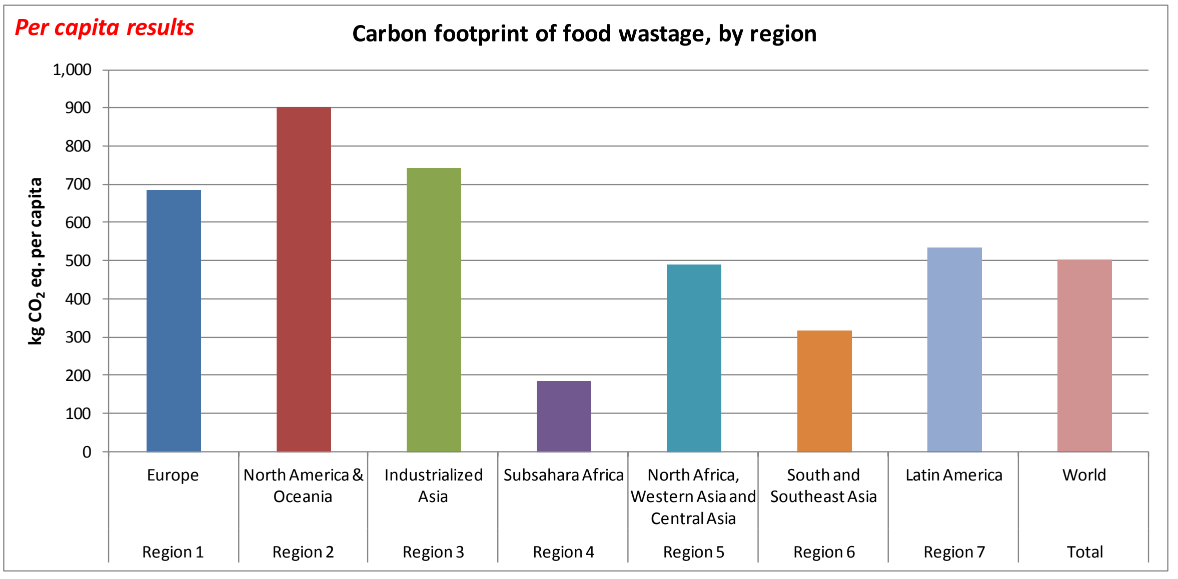

Figure 54: Carbon footprint of food wastage, by region – Per capita results

The average carbon footprint of food wastage is about 500 kg CO_2 eq. per capita and per year. Europe, NA&Oce, and Ind. Asia stand out as the regions with the highest per capita carbon footprint (approximately 700 to 900 kg CO_2 eq. per cap. and per year). Sub-Saharan Africa is the region with the smallest footprint per capita (about 180 kg CO_2 eq.).

In order to illustrate the order of magnitude of these results, it can be mentioned that in 2007, per capita carbon footprint (excluding LULUCF) was about 23 tonnes CO_2 eq. in the USA, 10.7 in Japan and 8.4 in France (Source UNFCCC).

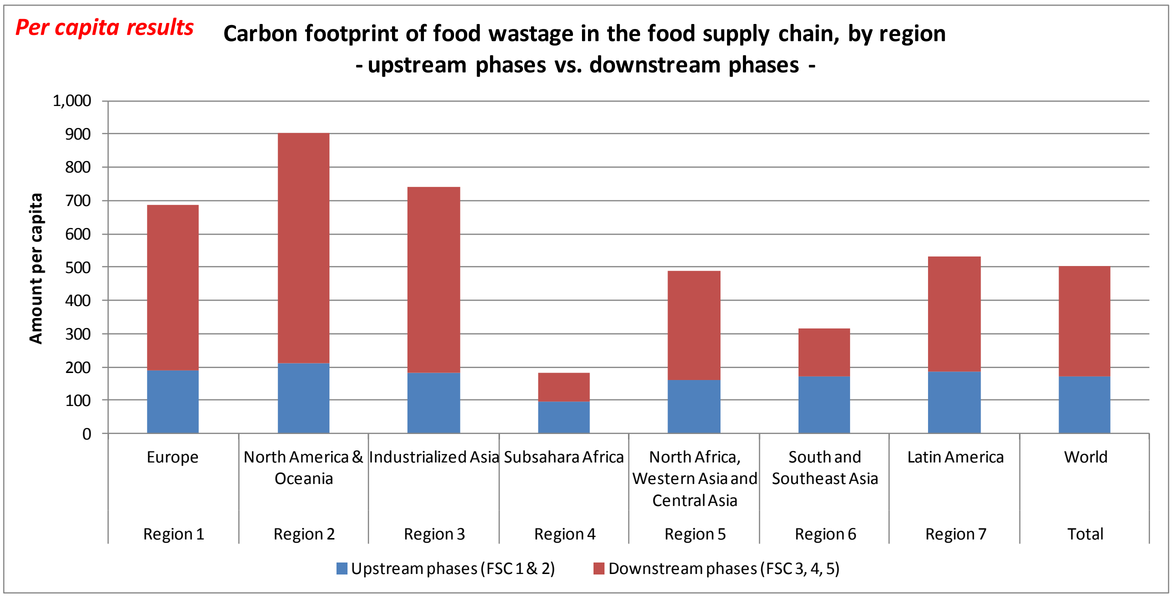

Figure 55: Carbon footprint of food wastage in the food supply chain, by region Per capita results – upstream phases vs. downstream phases –

Figure 55 reveals that per capita carbon footprint of food wastage is more variable in upstream phases (approx. 100 to 200 kg CO_2 eq. per cap) than in downstream phases (100 to 700 kg CO_2 eq. per cap.). In fact, higher per capita carbon footprint in middle and high-income regions is due to higher carbon footprint in downstream phases. These results derive from the trends already observed in Figure 37.

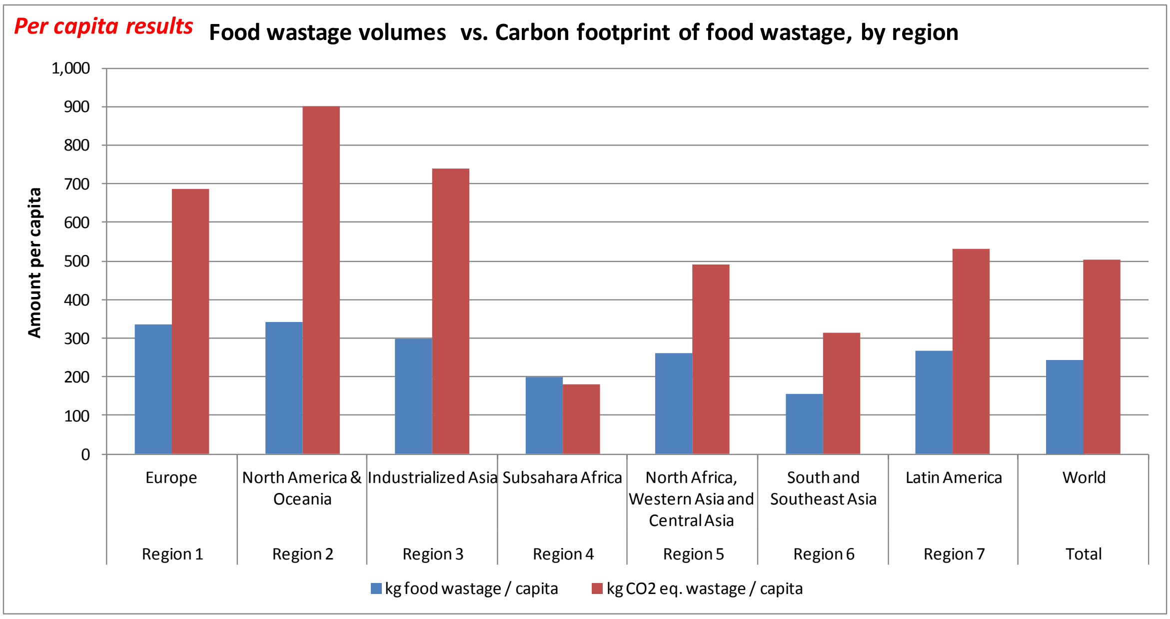

Figure 56: Food wastage volumes vs. Carbon footprint of food wastage, by region – Per capita results –

Figure 56 reveals that Europe, NA&Oce, and Ind. Asia stand out as the regions with the highest wastage per capita and the highest carbon footprint per capita.

4.2.5 Identification of hotspots

Hotspots – Contribution to total carbon footprint

Similarly to the analysis performed in section 4.1.5 for food wastage volumes, the 56 "region * commodity" can be ranked according to their contributions to total carbon footprint.

Figure 57 shows the ten "region * commodity" pairs with the highest contribution to carbon footprint. Asia (i.e. Ind. Asia and S&SE Asia) appears five times in the top 10 and dominates this ranking with vegetables and cereals. It can be noted that meat is present through four regions (i.e. Ind. Asia, Europe, NA&Oce, LA).

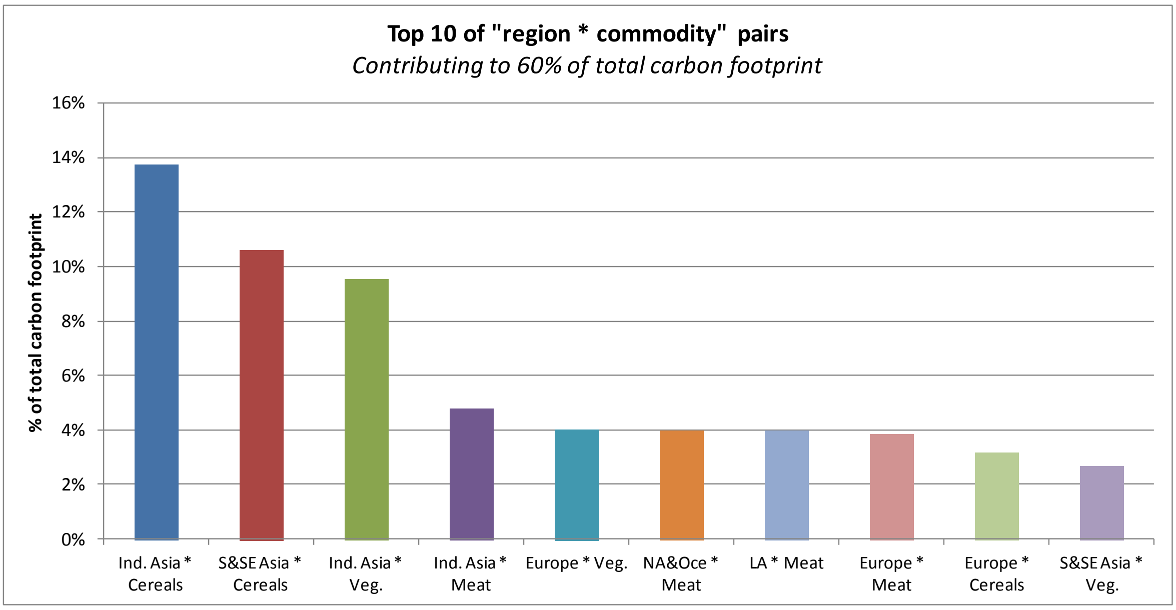

Figure 57: Top 10 of "region * commodity" pairs for carbon footprint

This first analysis can be refined, taking into account the FSC phase when wastage occurs. The obtained top 10 is presented in Figure 58.

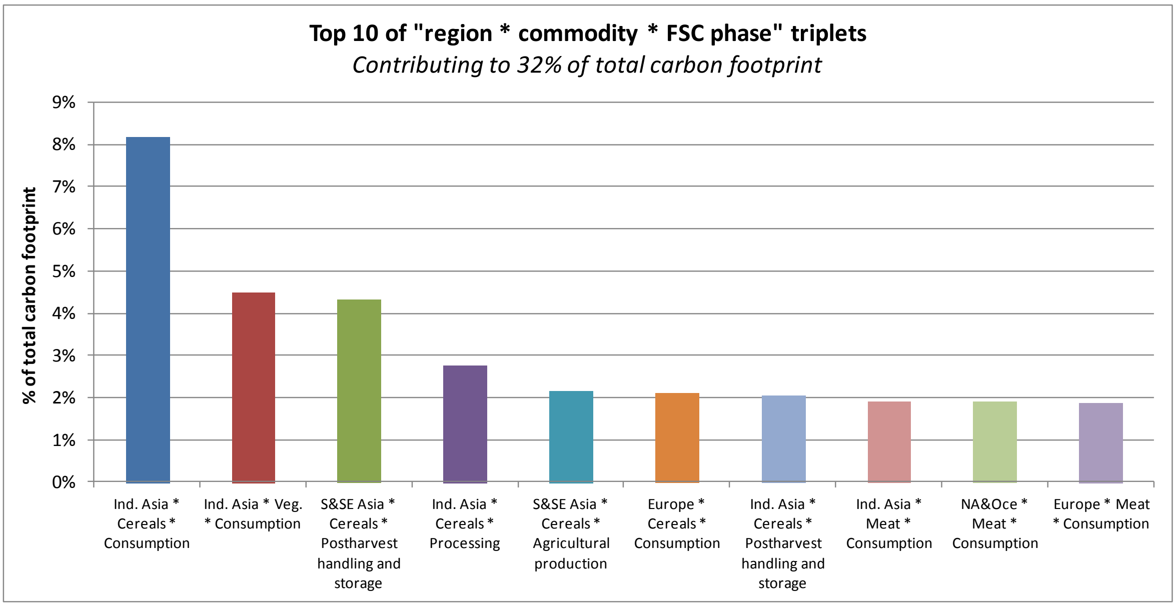

Figure 58: Top 10 of "region * commodity * FSC phase" triplets for carbon footprint

It can be observed that ranking of regions and commodities is modified but overall, the same regions and commodities (except Latin America) are found in the top 10. A key point to mention is that the consumption phase is dominating this ranking and appears six times in the top 10. This can be explained by the fact that impact factor increase along the supply chain with highest impact at the latest phase as illustrated in Figure 124 (presented in Annex XVII).

Carbon footprint is calculated as a multiplication of a food wastage amount and an impact factor. It can be interesting to determine which part of the multiplication is the main driver of the carbon footprint for the identified hotspots. Figure 59 has been built for this purpose.

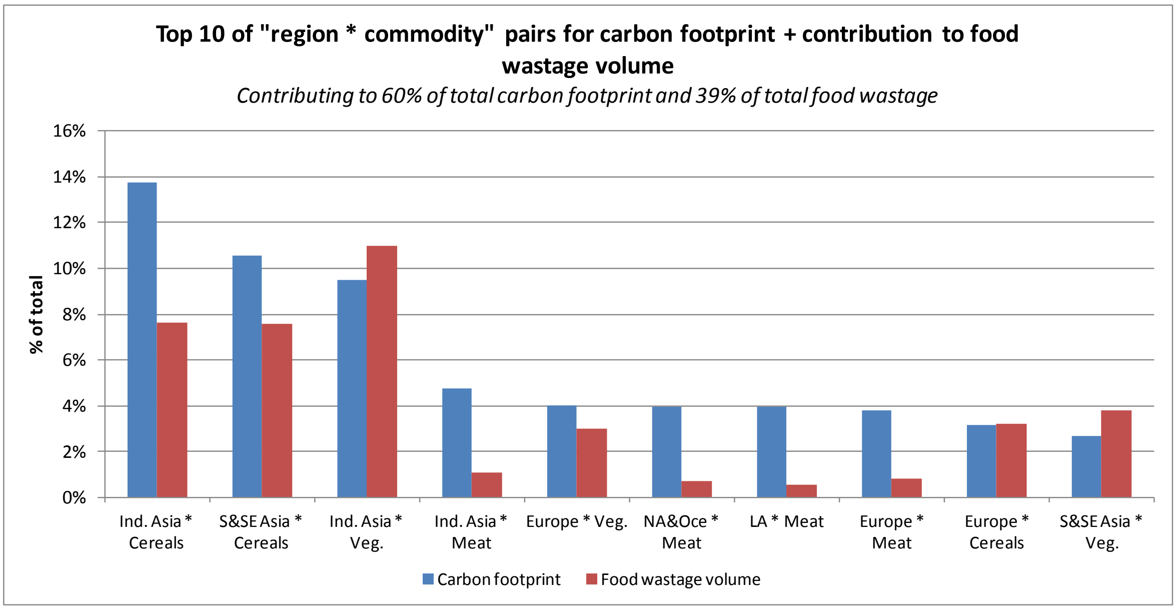

Figure 59: Top 10 of "region * commodity" pairs for carbon footprint presented along with contribution to food wastage volume

In Figure 59, the top 10 of "region * commodity" pairs for carbon footprint is presented along with their respective contribution to food wastage volume. From this figure, it can be deduced if the carbon footprint of the hotspot is mainly due to high food wastage volumes or to high impact factors. Indeed, if the contribution to total carbon footprint of a given region * commodity is high but its contribution to total food wastage volumes is low, then the driver of the carbon footprint is the "carbon intensity" of the commodity (i.e. the impact factors used in the FWF model).

Therefore, it can be noted that for vegetables the driver seems to be mostly the volume, whereas for meat the driver is the carbon intensity of the commodity. As regards cereals, both aspects play a role in the carbon footprint. Such results are in accordance with average carbon intensities of food commodity presented in Figure 122.

Looking more precisely at each hotspot, some particular patterns can be observed. Indeed, it can be seen that the two first hotspots are cereals in Ind. Asia and S&SE Asia. They account for 13.7 and 10.6% of total GHG emissions of food wastage while their contribution to food wastage volume is 7.6% each. In addition, it can be observed that cereals in Europe account for 3.2% of the total carbon footprint and 3.2% of total food wastage. Thus, it appears that wastage of cereals in Europe is less carbon-intensive. This can be explained by the fact that different cereals are primarily grown in Asia and in Europe. In Asia, rice dominates cereals wastage with 53% in Ind. Asia and 72% in S&SE Asia, whereas in Europe wheat dominates with 71% of wastage. Furthermore, average impact factors for rice in Ind. Asia and S&SE Asia are 5 and 3.4 kg CO_2 eq / kg, respectively. For wheat in Europe, the impact factor is lower: 2 kg CO_2 eq / kg. Note also that about 70% of GHG emissions of rice wastage in Ind. Asia and S&SE Asia are coming from the agricultural phase. Indeed, rice is a CH_4-emitting crop because of the decomposition of organic matter in flooded paddy fields. These higher impact factors for rice explain why wastage of cereals is more carbon-intensive in Asia.

For vegetables, an opposite pattern can be seen: the crop is more carbon-intensive in Europe than in Asia. It is likely that the carbon intensity of vegetables wastage is higher in Europe due to the fact that a higher share of vegetables are grown in heated greenhouses. Note that, due to lack of data, some assumptions had to be made regarding the share of vegetables grown in greenhouses across the various regions. Therefore, interpretations on this particular point should be made very cautiously.

Hotspots – Per capita analysis

Another way to pinpoint hotspots is to calculate per capita ratios for each of the 56 "region * commodity" pairs. That way, a new top 10 can be obtained and is presented in Figure 60. This ranking is dominated by middle and high-income regions (7 times). Cereals and vegetables are still present but meat is more visible.

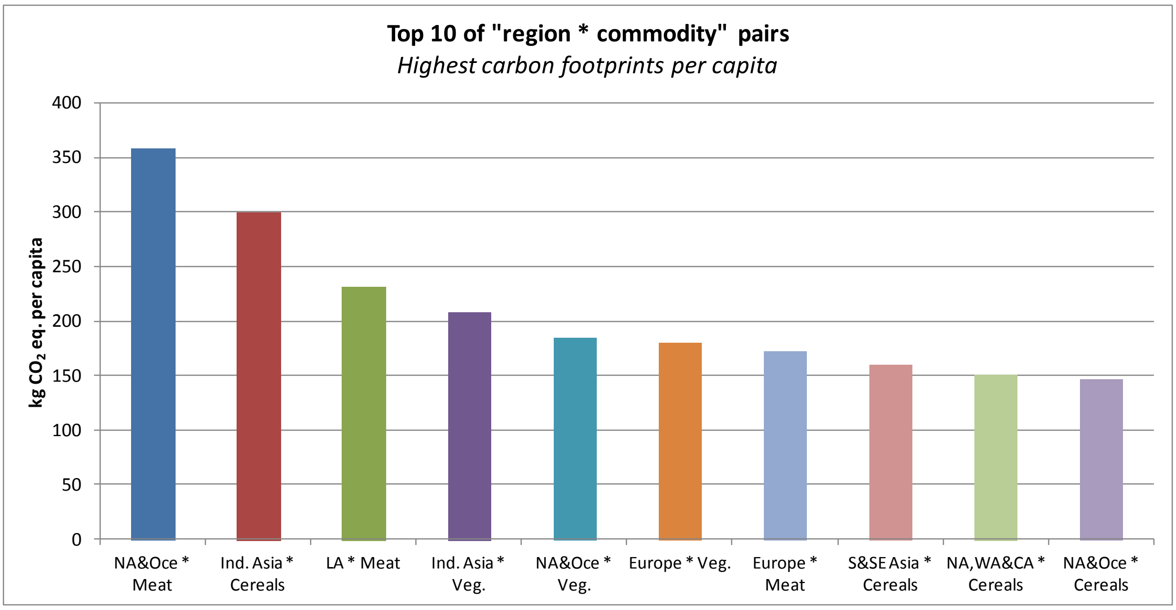

Figure 60: Top 10 of "region * commodity" pairs for carbon footprint per capita

4.2.6 Focus on food life cycle

It must be underlined that in the FWF model, there are five phases in the food supply chain where wastage can occur. Moreover, six phases of the life-cycle phases can generate GHG emissions.

When food wastage occurs at a given phase of the FSC, the related carbon footprint is coming from 1/ the impacts of the phase itself 2/ the impacts associated with the end-of-life of the waste and 3/ the impacts of the previous phases, if any. Figure 61 presents the contribution of these various aspects to the carbon footprint of each FSC phase.

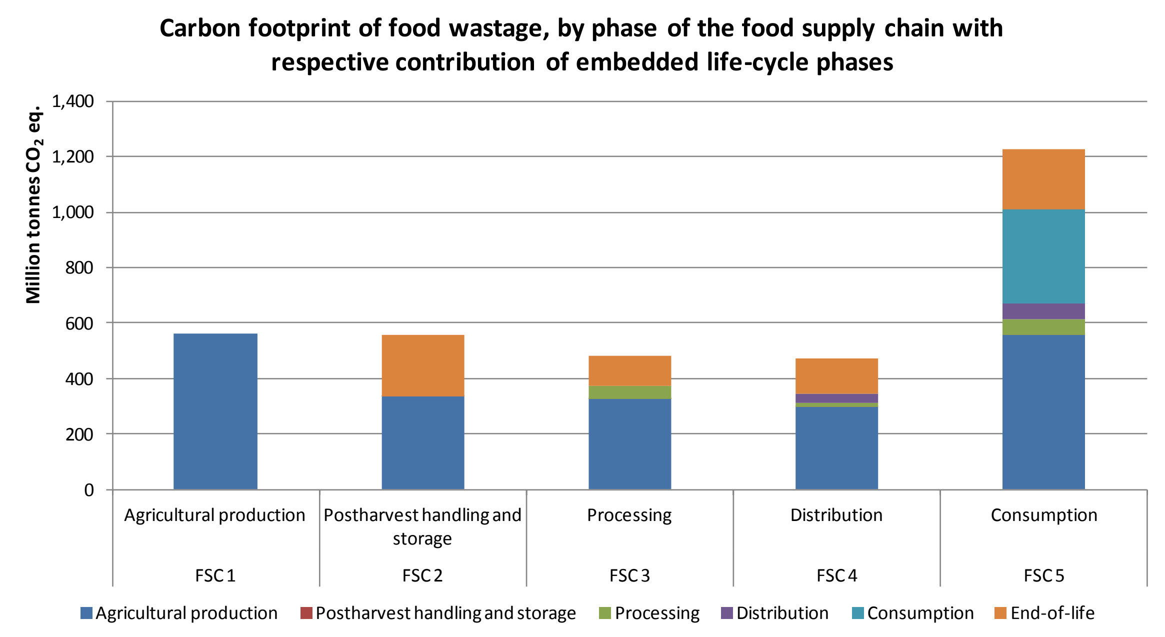

Figure 61: Carbon footprint of food wastage, by phase of the food supply chain with respective contribution of embedded life-cycle phases

It can be observed that the GHG emissions from the agricultural phase are always the major contributor. At the consumption phase, the GHG emissions coming from consumption itself (i.e. energy for cooking) play a significant role (28% of the carbon footprint of consumption). Emissions related to end-of life are noticeable for all phases except for agricultural product where it was considered that only negligible emissions occurred[37].

Finally, the total amount of 3.3 Gtonnes of CO2 equivalent can be broken down by life-cycle phases (Figure 62). This further confirms what is observed in Figure 61.

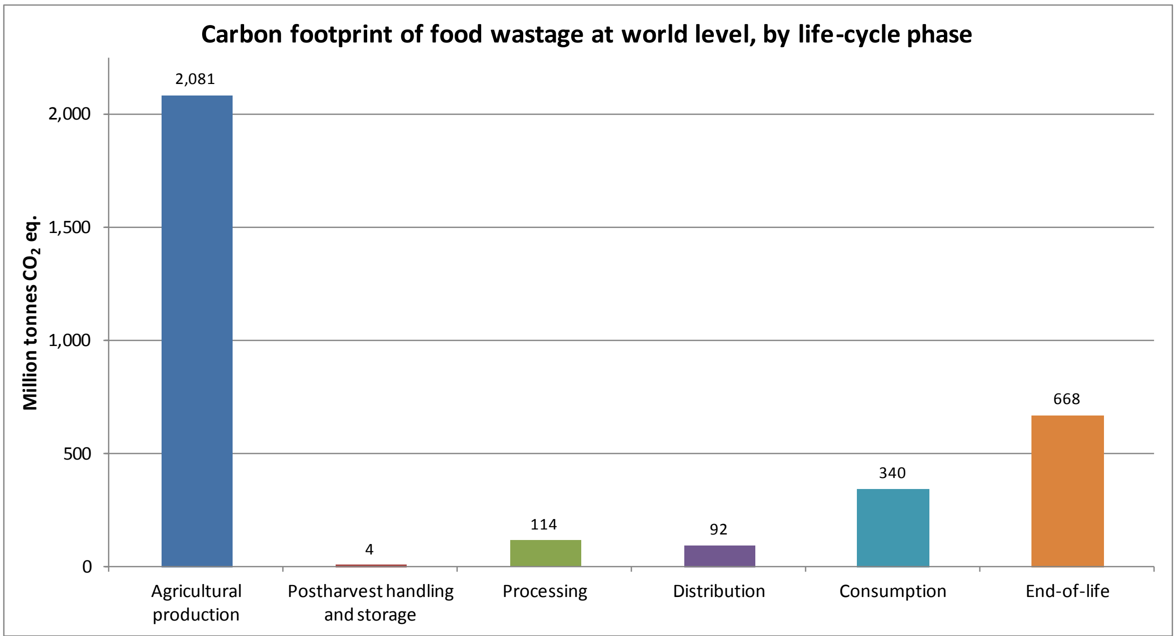

Figure 62: Carbon footprint of food wastage, by life-cycle phase

[37] Food wastage occurring at agricultural phase is most of the time dealt with at the farm location through practices whose GHGs emissions are deemed negligible (see section 0 for details).

4.2.7 Variability analysis of carbon footprint

A complementary analysis has been carried out to assess the potential range of variation of the carbon footprint of food wastage.

For each (sub)commodity, the FWF model normally uses various impact factors in order to differentiate regions. For the purpose of the variability analysis, the ranges of factors implemented in the model were screened and the highest and lowest factors for each (sub)commodity were selected. These two datasets (i.e. high and low values) were applied to all regions in order to calculate two scenarios that would constitute a lower bound and a higher bound for the model. Total GHG emissions obtained are 1.5 – 5.1 Gtonnes of CO_2.

It appears that cereals have the largest variability range because of the combination of two factors. Firstly, this is the most lost/wasted commodity. Secondly, the impact factors for cereals can vary significantly because of yields and crop management practices, most notably the level of machinery use (for sowing, harvesting, ploughing operations, fertilisation, possible mechanical weeding) and the amounts of fertiliser and pesticide applied (Nemecek et al. 2011).

Vegetables have the second largest variability range. Indeed impact factors for this commodity can differ a lot depending on the way vegetables are grown – i.e. field grown or greenhouse grown with a fossil energy source (Nemecek et al. 2011; A. G. Williams et al. 2006; Torrellas et al. 2012).

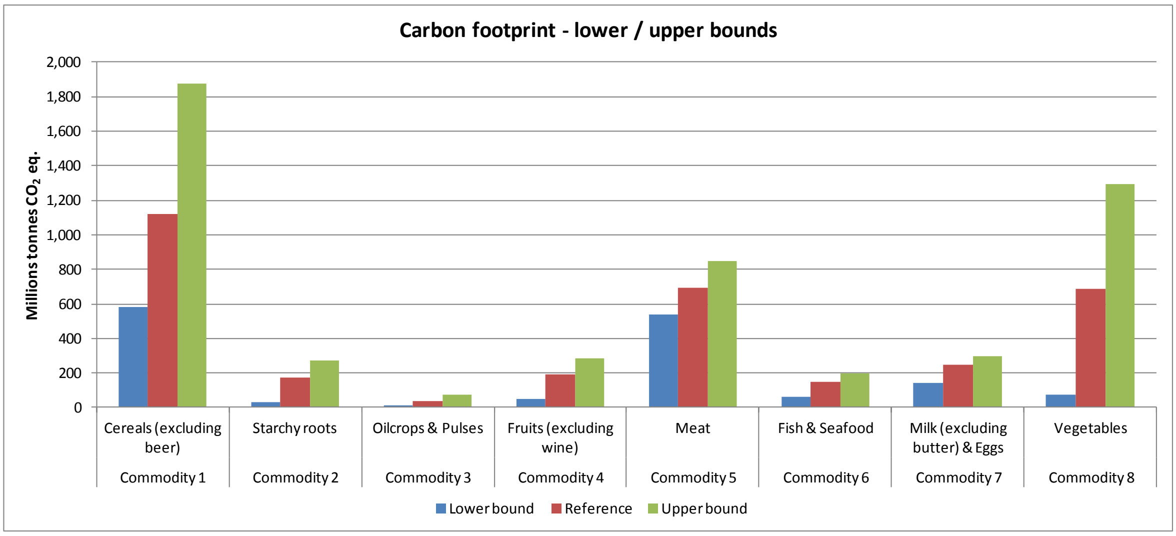

Figure 63: Variability analysis of carbon footprint

4.2.8 Highlights

Box 19: Highlights for component 2 – Carbon footprint results

- The total amount of food wastage in 2007 has generated about 3.3 Gtonnes of CO_2 equivalent. This is more than two times the GHG emissions from road transportation in the USA.
- The major contributors to the carbon footprint of food wastage are cereals (34% of total), meat (21%) and vegetables (21%). Products of animal origin account altogether for about 33% of total carbon footprint whereas their contribution to food wastage volumes is about 15%.

- In terms of regional distribution, the major contributors to the carbon footprint are industrialized Asia (34% of total) and South & Southeast Asia (21%). In these regions, cereals carbon footprint is as high as 51% and 40% of the total of the region. In addition, medium and high-income regions account for about 2/3 of total carbon footprint whereas their contribution to total food wastage is about 50%. The carbon footprint of meat is high in medium and high-income regions. More meat is produced, consumed and wasted in these regions.
- When looking at the wastage at each FSC phase, consumption phase is dominating the carbon footprint (37% of total) whereas this phase accounts for 22% of total food wastage. This is because the impact of a unit of food wastage increases along the food supply chain. The remaining GHG emissions are distributed evenly between other phases.
- In middle and high-income regions, carbon footprint of food wasted/lost is 2.6 to 3 times higher downstream than upstream. Conversely, in SSA and S&SE Asia carbon footprint of food wasted/lost is slightly higher upstream than downstream.
- The average carbon footprint of food wastage is about 500 kg CO_2 eq. per capita and per year. Europe, NA&Oce, and Ind. Asia stand out as the regions with the highest per capita carbon footprint (approximately 700 to 900 kg CO_2 eq. per cap. and per year). Sub-Saharan Africa is the region with the smallest footprint per capita (about 180 kg CO_2 eq.).
- In absolute terms, hotspots for carbon footprint are mostly in Asia (i.e. Ind. Asia and S&SE Asia) because of vegetables and cereals. From a climate perspective, wastage of meat is also clearly an issue. Indeed, Ind. Asia, Europe, NA&Oce and LA appear as carbon hotspots because of meat wastage. Globally, the driver of the carbon footprint seems to be mostly the volume for vegetables, whereas for meat the driver is the carbon intensity of the commodity. As regards cereals, both aspects play a role in the carbon footprint.
- In the FWF model, there are five phases in the food supply chain where wastage can occur and there are six phases of the life-cycle that are potential sources of GHG. Overall, no matter when the wastage occurs, the main cause of GHG emissions is due to the production of the food.

4.3 Component 3: Blue water footprint results

This section presents the FWF model results for the blue water footprint. Complementary results for blue water footprint and results for the green water footprint are presented in Annex XVIII.

4.3.1 Results overview

At world level, the blue water footprint of total food wastage in the year 2007 is about 250 km^3 (i.e. 250 Gm^3). In order to grasp the scale of this amount, it can be pointed out that it is more than 38 times the blue water footprint of US domestic water consumption or 3.6 times the blue water footprint of total US consumption[38]. In terms of volume, 250 km^3 represents the water discharge of the Volga River during a year.

Another way to illustrate the magnitude of the blue water footprint of food wastage can be to integrate it in a country ranking of largest blue water consumers. The ranking is based on the national water footprint accounts provided by the WFN (Mekonnen & Hoekstra 2011).

The blue water footprint of food wastage calculated with the FWF model focuses on the footprint of agricultural production (see section 3.3.3). Therefore, national water footprint accounts presented in Figure 64 are for the blue water footprint of the national consumption of agricultural products. It appears that the global water footprint of food wastage is higher than the national blue water footprint account of any country.

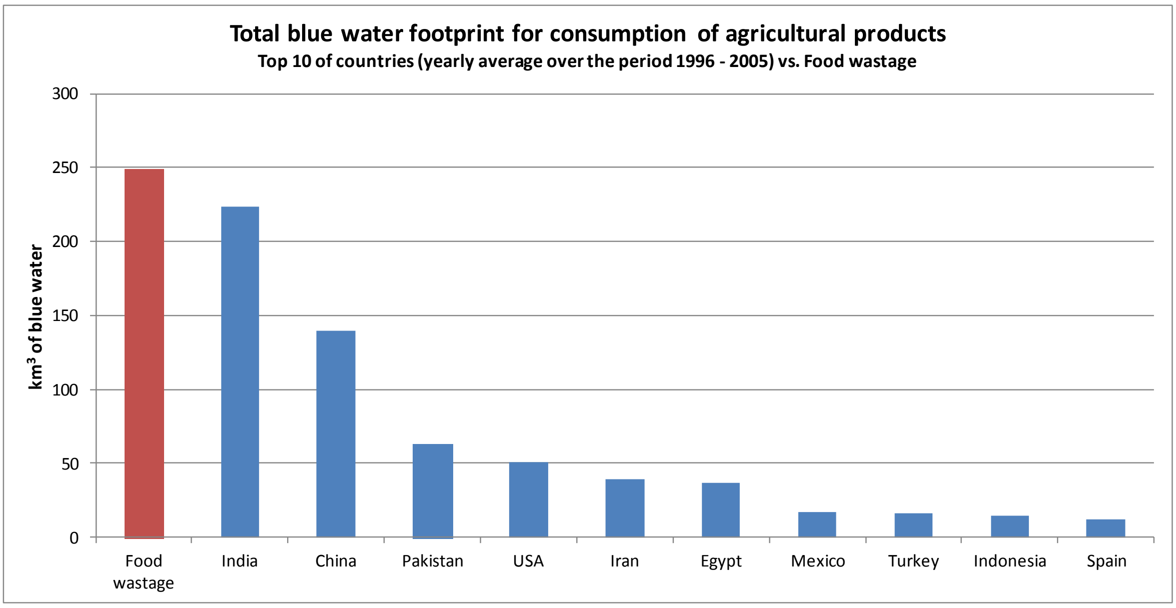

Figure 64: Top 10 of national blue water footprint accounts for consumption of agricultural products vs. Food wastage (Source WFN: Mekonnen & Hoekstra 2011)

4.3.2 Analyses by commodity and region

[38] Average over the period 1996 – 2005. The blue water footprint of total national consumption includes the blue water footprint of agricultural products, industrial products, and domestic consumption.

In the two following sections, this volume of 250 km^3 of blue water is further broken down by commodity and region.

Analysis by commodity

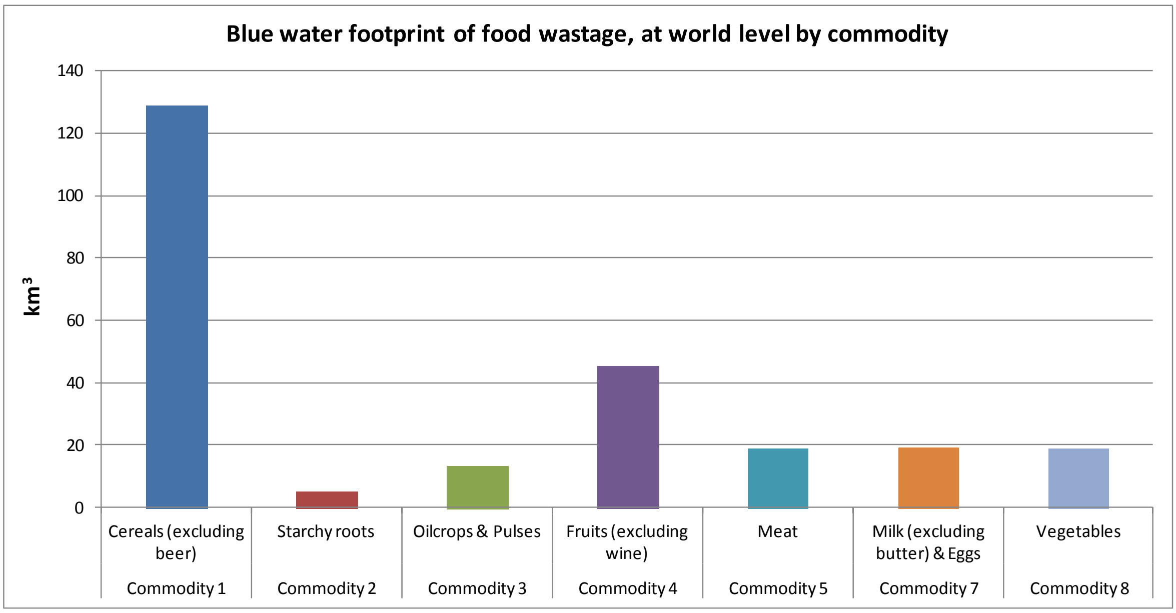

Figure 65: Blue water footprint of food wastage, at world level by commodity

Figure 65 and Figure 66 show that the major contributors to the blue water footprint of food wastage are cereals (52% of total) and fruits (18%) whereas their contribution to total food wastage[39] are 26% and 16%, respectively. Conversely, starchy roots account for 2% of the water footprint whereas this commodity represents 19% of total food wastage.

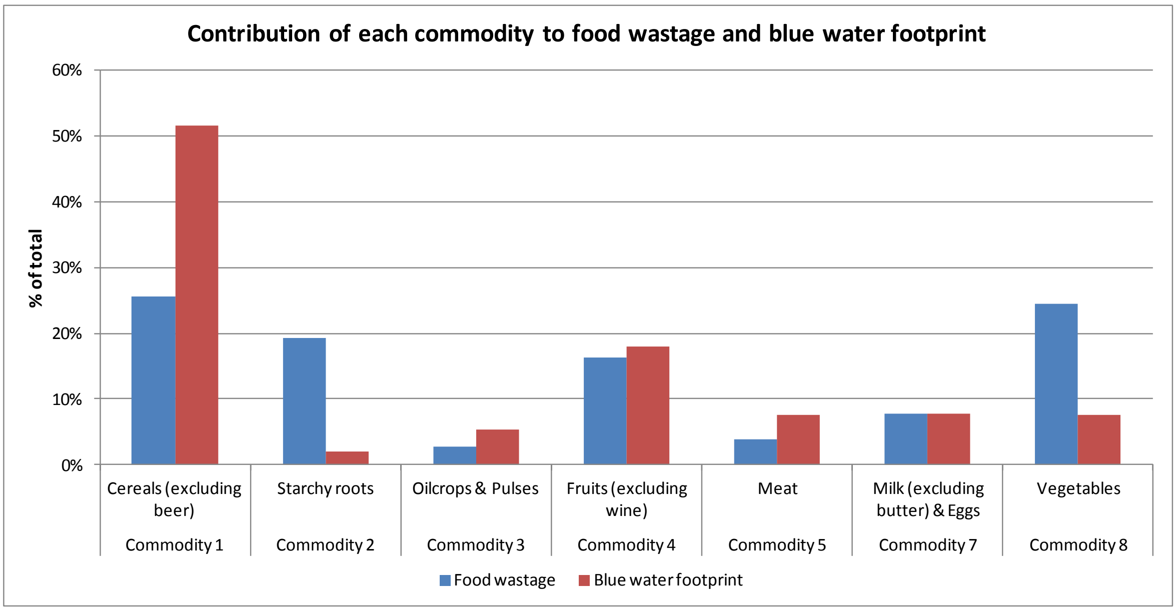

Figure 66: Contribution of each commodity to food wastage and blue water footprint

Figure 66 actually reflects the average "blue water intensity" of each commodity group (i.e. m^3 of blue water per kg of product as presented in Figure 128 – Annex XVIII). Below is a discussion on

[39] Excluding fish & seafood to allow a comparison on the same grounds

the water intensity characteristics of the commodities in the scope of the present study. Information presented here is adapted from Mekonnen & Hoekstra (2010a) and Mekonnen & Hoekstra (2010b).

Crops

Firstly, it should be pointed out that comparing the water footprint of products must be done very cautiously. Global average water footprints can be quite different from region-specific water footprints. Thus, relative performance of products may differ depending on the geographical scale.

The water footprints of a given crop vary across countries and regions. This is mainly due to differences in crop yields. For instance, relatively small water footprints per tonne of cereal crops are observed in Europe. On the other hand, the water footprints of cereal crops are quite large in most parts of Africa. This can mainly be explained by the higher average yield in Europe compared to that observed in Africa.

The average water footprint per tonne of primary crop differs significantly among crops. Crops with a high yield or large fraction of crop biomass that is harvested generally have a smaller water footprint per tonne (e.g. starchy roots, fruits or vegetables) than crops with a low yield or small fraction of crop biomass harvested (e.g. cereals, oilcrops). Note also that the water footprint can also vary significantly across products within a commodity.

Animals

In general, animal products have a larger water footprint per tonne of product than crops. It appears that from a freshwater resource perspective, it is more efficient to obtain calories, protein and fat through crop products than animal products. Most of the water footprint comes from the feed for the animals. It must be underlined that drinking water for the animals only accounts for a minor share. Three key parameters affect the water footprint of animals: feed conversion efficiency of the animal, feed composition, and origin of the feed. The nature of the production system (grazing, mixed, industrial) is important because it has an effect on all three parameters.

The feed conversion efficiency, that is to say the amount of feed required to produce one unit of animal product strongly affects the water footprint. For instance, cattle have a relatively low conversion efficiency leading to large water footprint. Feed composition is also a driver of the footprint most notably, the ratio of concentrates versus roughages and the constituents of the concentrates. In spite of favourable feed conversion efficiencies, chicken and pig have relatively large fractions of cereals and oil meal in their feed, which results in relatively large water footprints. The origin of the feed is also a factor influencing the water footprint of a specific animal product because of the differences in climate and agricultural practice in the regions from where the various feed components are obtained.

Analysis by region

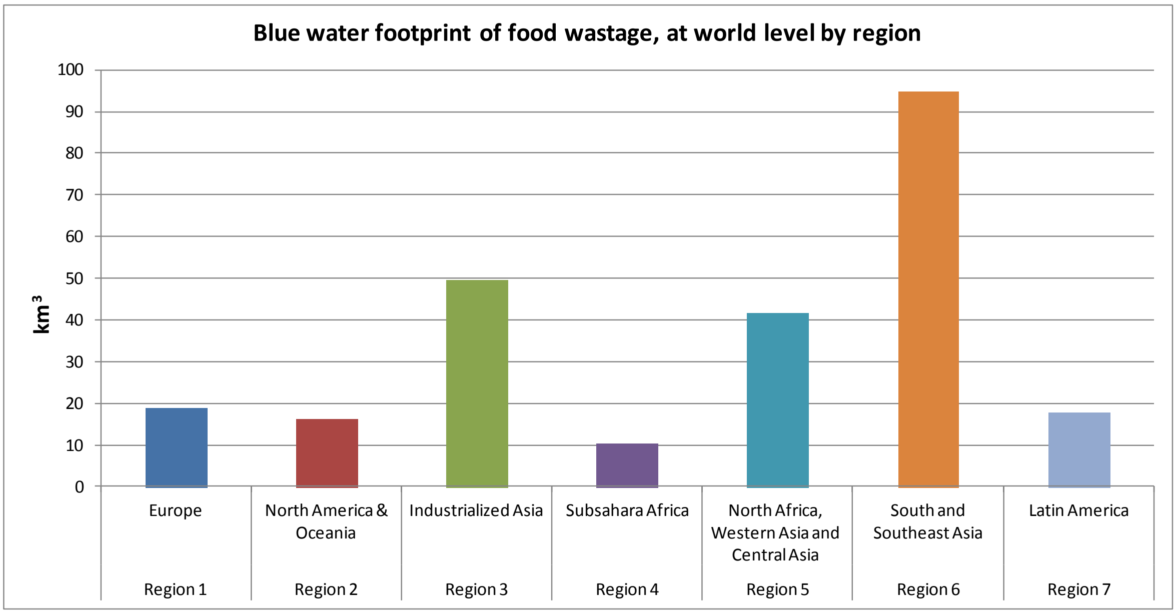

Figure 67: Blue water footprint of food wastage, at world level by region

Figure 67 and Figure 68 show that the major contributors are South & Southeast Asia (38% of total), industrialized Asia (20%) and NA,WA&CA (17%). In addition, it can be seen that low-income regions account for about 2/3 of total blue water footprint whereas their contribution to total food wastage is about 50%.

Note that the results presented in Figure 67 are further examined with a per capita analysis in section 4.3.4.

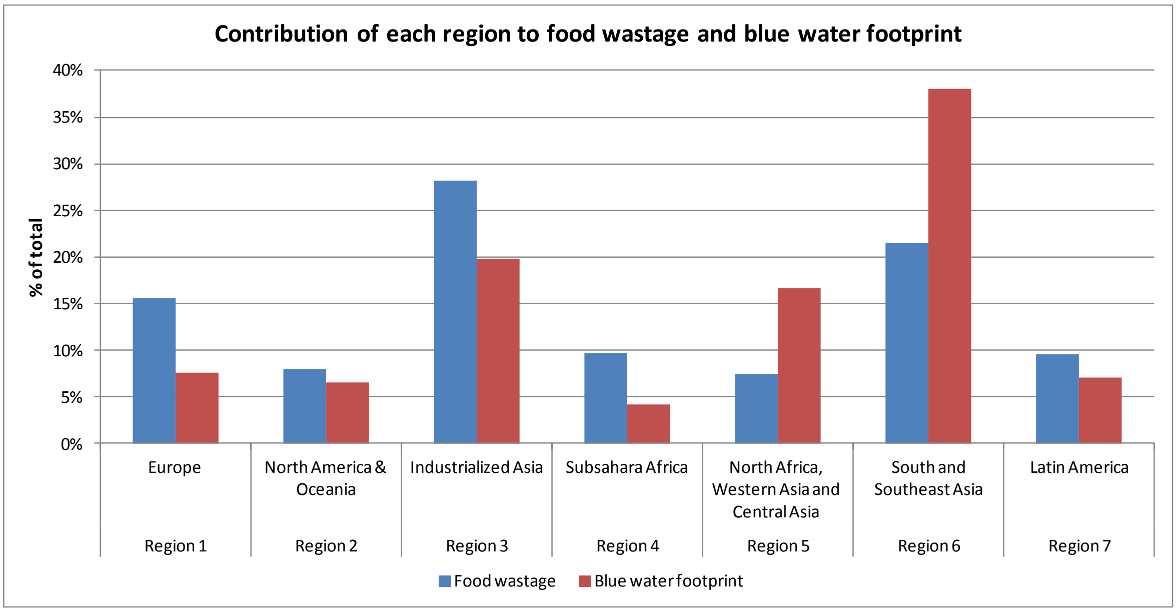

Figure 68: Contribution of each region to food wastage and blue water footprint

Figure 68 actually reflects the average "blue water intensity" of each region (i.e. m^3 of blue water per kg of product as presented in Figure 129 – Annex XVIII). Observed variations come from the different mixes of commodities that are lost or wasted in each region (see Figure 30 and Figure 31 for commodity mixes) combined with specific impact factors.

Here are some observed patterns noteworthy to mention:

Regional blue water intensity is much higher in NA,WA & CA and S&SE Asia than in other regions. In these two regions, a large share of the footprint is due to cereals (about 50 and 60%, respectively).

- In NA,WA & CA, it is mostly because of 1/ wheat and maize wastage in the "Northern Africa" sub-region and 2/ wheat and rice wastage in the "Western Asia" sub-region. Impacts factor for these products are higher than average in these sub-regions.
- In S&SE Asia, it is mostly because of wheat and rice wastage in Southeast Asia sub-region (in particular in India). Impact factor for wheat is higher than average in this sub-region.

Regional blue water intensity is very low in sub-Sahara Africa because the share of starchy roots (a commodity with low blue water intensity) in the region's food wastage is very high (more than 50%).

Figure 69 and Figure 70 in next section shed more light on these aspects.

4.3.3 Regional profiles

In this section, the blue water footprint of food wastage in each region (as shown in Figure 67) is further disaggregated by commodity groups. For each region, a particular profile is obtained and key characteristics can be identified.

Regional profiles – Commodity groups view

Profiles presented here are built up at commodity level; profiles at sub-commodity level are presented in Annex XVIII.

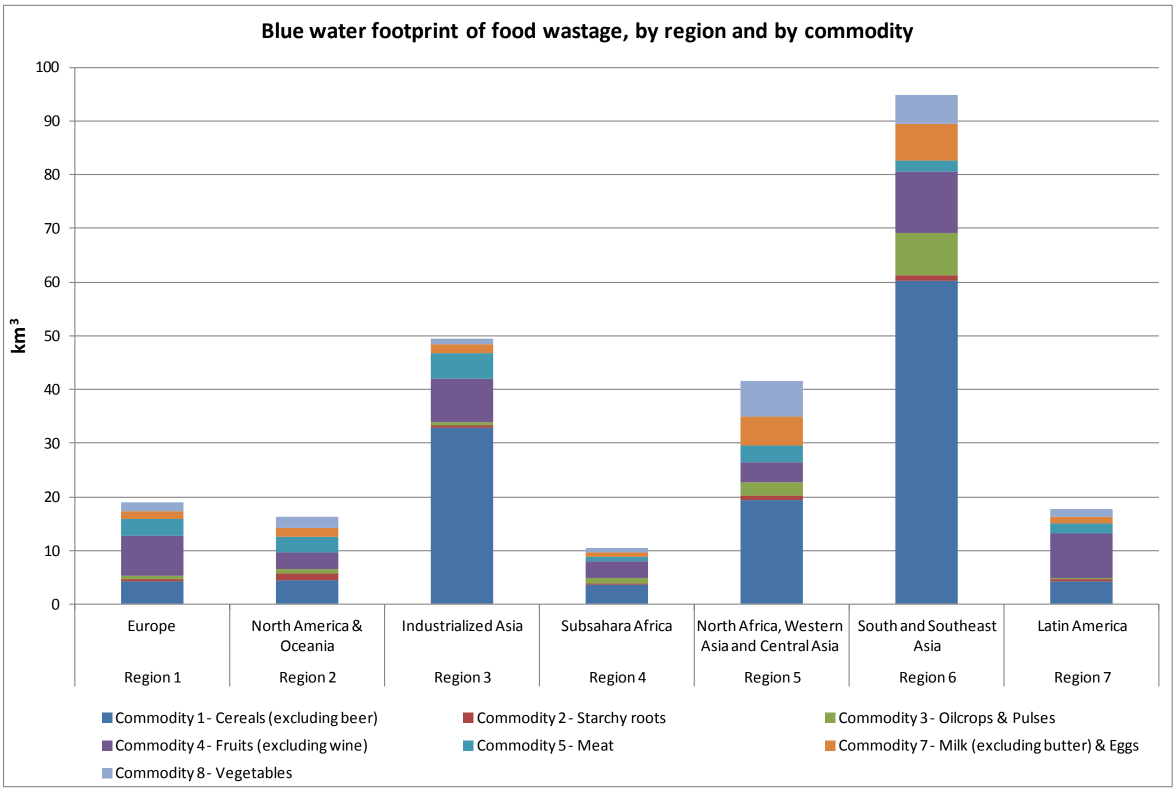

Figure 69: Blue water footprint of food wastage, by region and by commodity

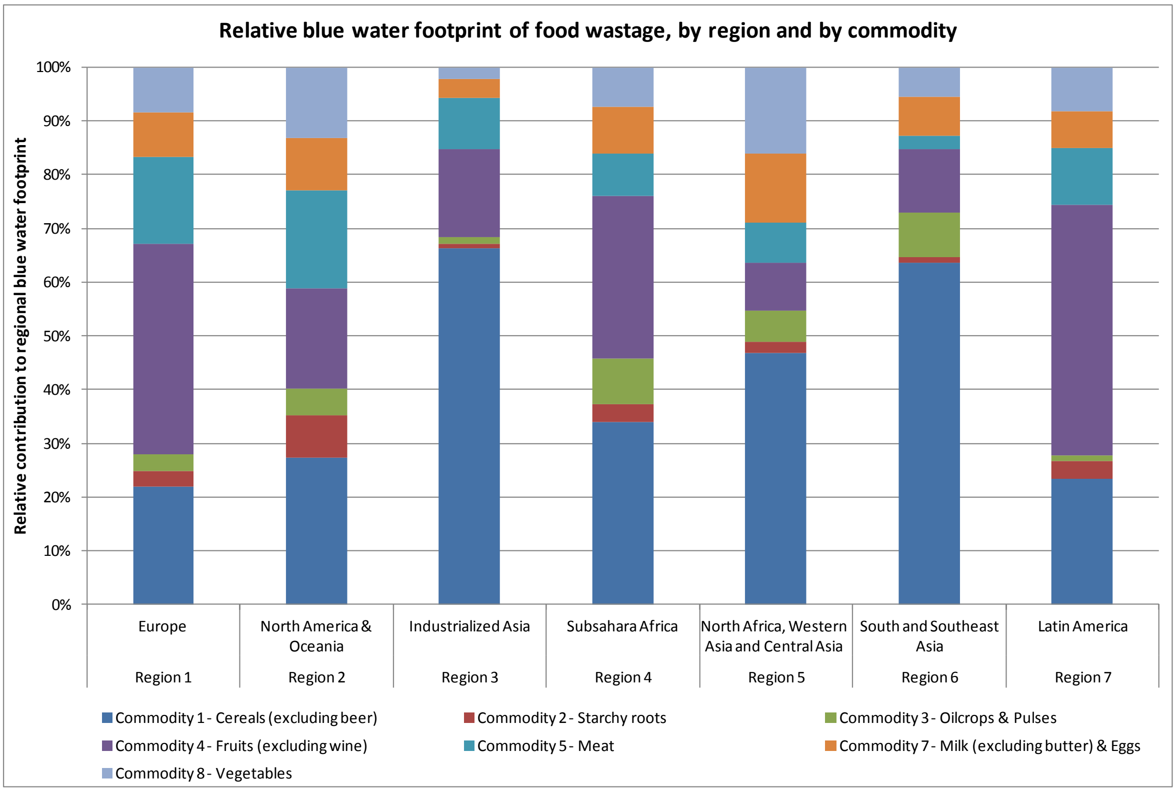

Figure 70: Relative blue water footprint of food wastage, by region and by commodity

Looking at the regional profiles of commodities presented in an absolute (Figure 69) or relative way (Figure 70), one can see that they are quite variable from one region to another.

Some common trends can however be observed:

Contribution of lost/wasted oilcrops & pulses and starchy roots to the blue water footprint is low in all a regions (1 to 9% of the blue water footprint of the region).

- For oilcrops & pulses this is mostly because of the small share of this commodity in the food wastage of all regions
- For starchy roots, it is mostly because the blue water impacts factors are low.

Contribution of cereals to the blue water footprint is above 22% in all regions and as high as 64-66% in S&SE Asia and Ind. Asia, respectively. In both regions, wheat and rice are the main contributors of the footprint of cereals because of a combination of relatively high shares in food wastage and relatively high impacts factors compared to other commodities.

Fruits, vegetables, meat, and milk also have significant contributions. It must be underlined that contribution of meat is higher in Europe and NA&Oce (16-18%) than in low-income countries (2-10%). This is primarily because the share of meat in regional food wastage is higher in these two regions.

4.3.4 Per capita analysis

In this section, the blue water footprint of food wastage in each region (as shown in Figure 67) is presented per capita.

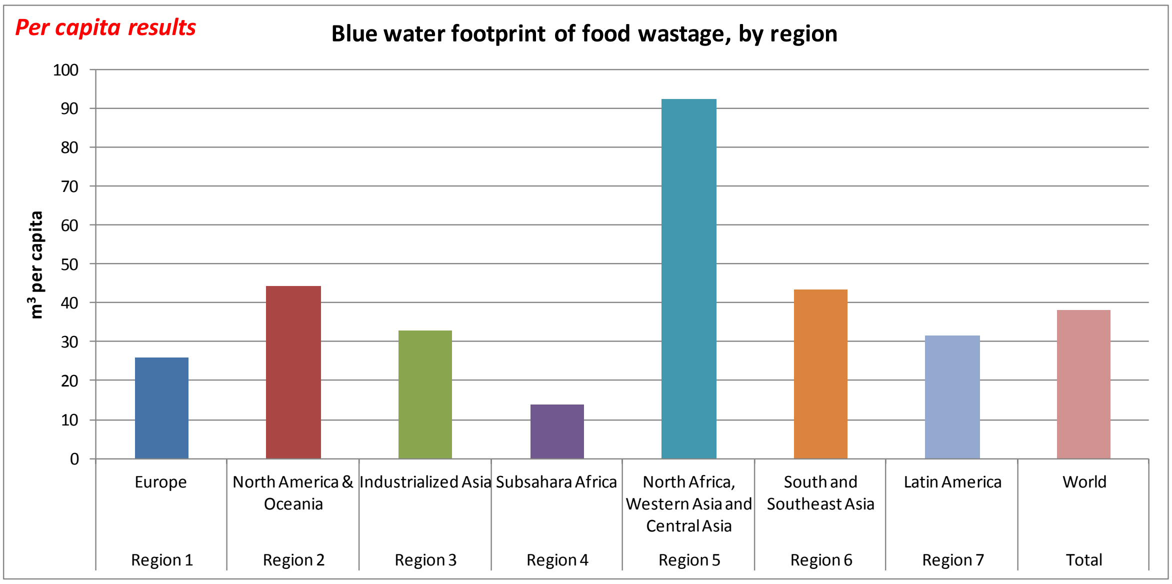

Figure 71: Blue water footprint of food wastage, by region – Per capita results

The overall pattern observed in Figure 71, is somewhat different from Figure 67. Most notably, S&SE Asia, that stood out as the region with the highest absolute water footprint is actually close to world average when looking at the per capita results. At world level, the average blue water footprint of food wastage is about 38 m^3 per capita and per year. NA,WA&CA stands out as the region with the highest per cap. footprint (more than 90 m^3 per cap. and per year). Indeed this region represents 17% of the total water footprint of food wastage but only 7% of the total population. Sub-Saharan Africa is the region with the smallest footprint per capita (14 m^3 per cap. and per year). This region represents only 4% of the total water footprint of food wastage but holds as much as 12% of the total population.

In order to illustrate the order of magnitude of these results, it can be mentioned that in 2007, the per capita blue water footprint for domestic water consumption was only about 7 m^3 per cap. and per year (world average) and the highest value was for Canada with 29 m^3 per cap. and per year (Mekonnen & Hoekstra 2011).

Note that the average blue water footprint of food wastage when considering food crops only (i.e. not taking into account animal products) is about 30 m^3 per capita and per year, a value that is close to the value reported by Kummu et al. (2012) which is 27 m^3 per capita and per year.

4.3.5 Identification of hotspots

Hotspots – Contribution to total blue water footprint

Similarly to the analysis performed in section 4.1.5 for food wastage volumes, the "region * commodity" pairs can be ranked according to their contributions to total blue water footprint.

Figure 72 shows the ten "region * commodity" pairs with the highest contribution to blue water footprint. Cereals dominate this ranking with the three first places accounting for 45% of total footprint. Fruits are also quite visible in the top 10 as they appear four times but the contribution of this commodity remains secondary (14%) compared to cereals.

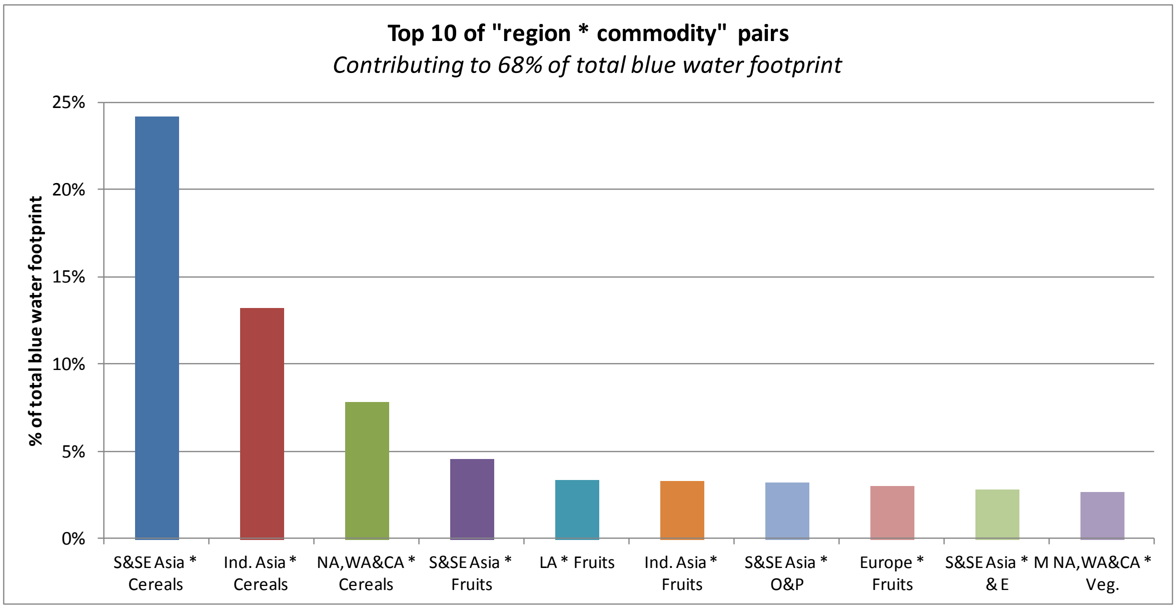

Figure 72: Top 10 of "region * commodity" pairs for blue water footprint

Blue water footprint is calculated by multiplying a food wastage amount by an impact factor. It can be interesting to determine which part of the multiplication is the main driver of the blue water footprint for the identified hotspots. Figure 73 has been built for this purpose.

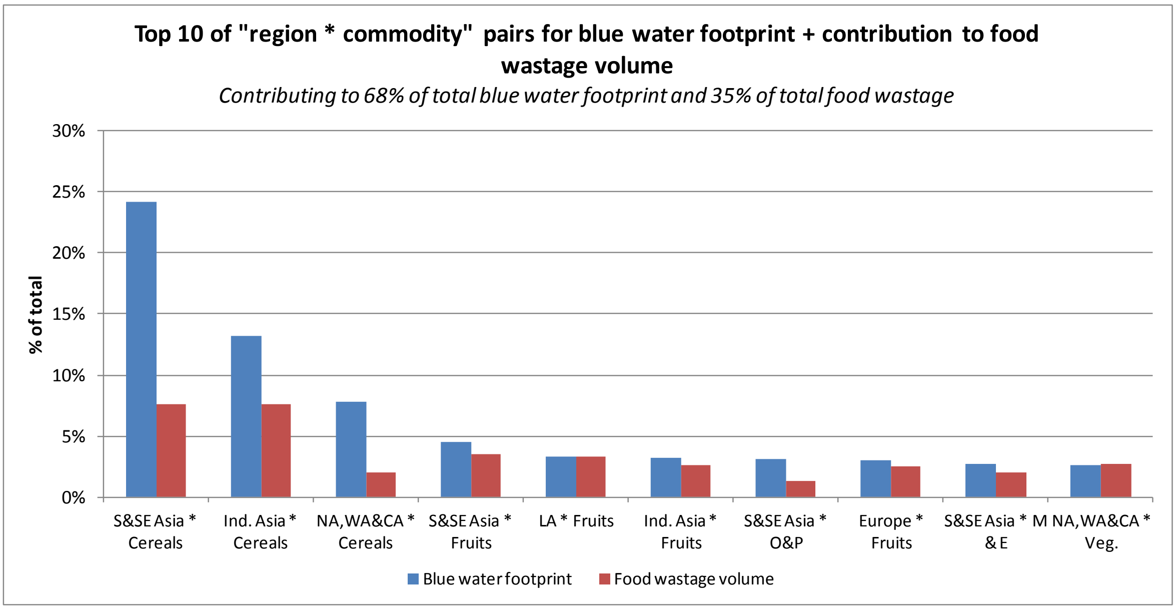

Figure 73: Top 10 of "region * commodity" pairs for blue water footprint presented along with contribution to food wastage volume

In Figure 73, the Top 10 of "region * commodity" pairs for blue water footprint is presented along with their respective contribution to food wastage volume. From this figure, it can be deduced whether the water footprint of the hotspot is mainly due to high food wastage volumes or to high impact factors.

Therefore, it can be noted that for cereals the driver seems to be mostly the water footprint intensity of the commodity, whereas for fruits it seems to be more related to the wastage volumes. Such results are in accordance with average blue water intensities of food commodity presented in Figure 66.

More specifically, in S&SE Asia the water footprint of cereals primarily comes from the sub-region Southern Asia (because of India). In Ind. Asia, it is because of China. In both sub-regions, major contributing cereals are wheat and rice. Regarding NA,WA&CA, it appears that the key sub-regions are Northern Africa and Western Asia, because of wheat and maize and wheat and rice, respectively. Concerning fruits, the estimate is considered fairly robust at global level. Nevertheless, interpretation of disaggregated results is complicated by some methodological constraints. Indeed, it appears that the main contributor to the footprint of this commodity is the "fruits, other" sub-commodity which includes a wide range of product but is not further broken down in the FBS and thus, in the FWF model.

Hotspots – Per capita analysis

Another way to pinpoint hotspots is to calculate per capita ratios for each of the "region * commodity" pairs. This way, a new top 10 can be obtained and is presented in Figure 74. One can see that the ranking is modified but six pairs of the first top 10 (i.e. Figure 72) are still present. NA,WA&CA, which is the region with the highest overall blue water footprint per capita, dominates this ranking since two new commodities from this region have appeared. It can also be mentioned that NA&Oce is now visible because of cereals and fruits. This region is not responsible for a large share of the food wastage of these two commodities (respectively 3.4% and 6.8%) but with only 5.6% of the total population, this makes a significant per capita ratio.

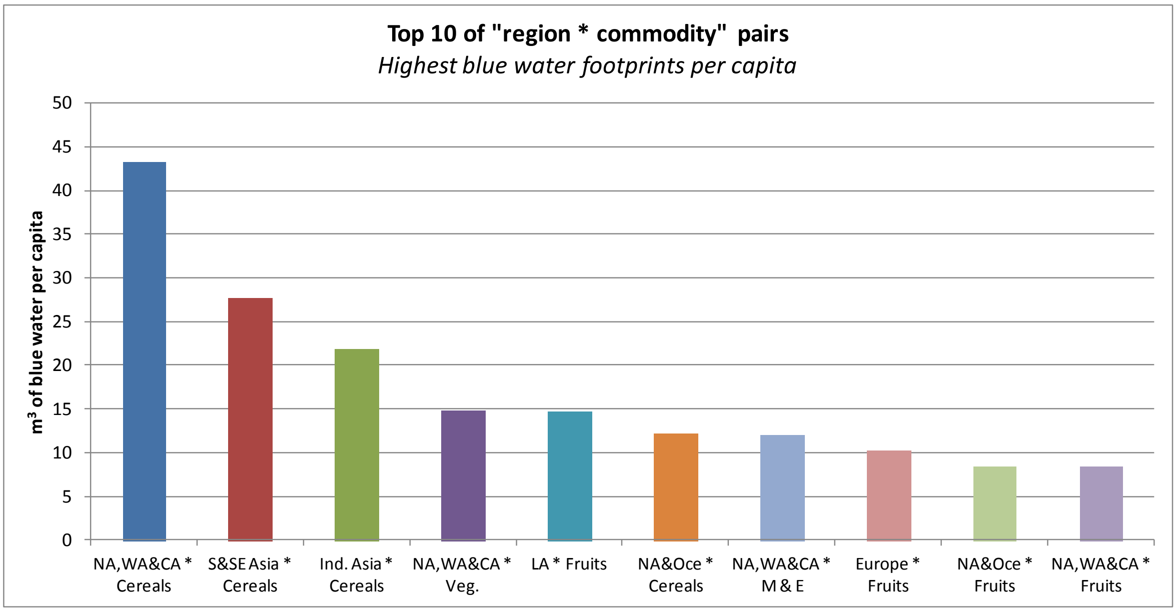

Figure 74: Top 10 of "region * commodity" pairs for blue water footprint per capita

4.3.6 Water scarcity

Based on the GAEZ data, the surfaces of water basing having a "high" or "very high" physical water scarcity were added for each region of the FWF model. This allows getting a view on the regions that have the largest share of land areas with high or very high water scarcity.

In Figure 75, the obtained water scarcity profile is placed alongside food wastage in order to reveal potential linkage between the two aspects.

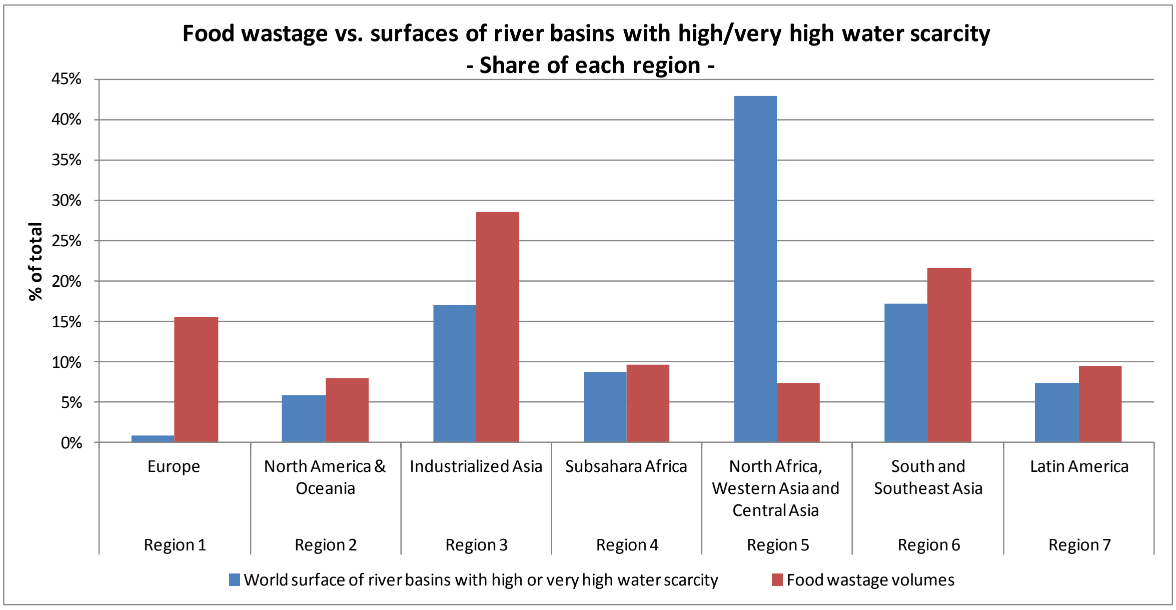

Figure 75: Food wastage vs. surfaces of river basins with high/very high water scarcity – Share of each region –

The blue bars in Figure 75 are somehow a low-resolution outline of SOLAW physical water scarcity map (see Figure 13). Knowing that agriculture is the largest water consumer, one can consider that comparing regional food wastage (red bars) and water scarcity (blue bars) somewhat provides a rough indicator of the "useless" or "ineffective" pressure put by food wastage on the water resource. In this regard, it seems that Ind. Asia and S&SE Asia constitute key issues since these regions have significant contributions to water scarcity and food wastage issues. However, making a relevant connection between water scarcity and volumes of food wastage is not obvious. Indeed, most of the land situated in NA,WA&CA experience arid or semi-arid climates and logically, this region has the largest share of water-scarce surfaces. On the other hand, NA,WA&CA accounts for a relatively minor share of food wastage compared to the issue of water scarcity but it can be questioned if this gives a fair account of the actual pressure of food wastage on the water resource in such scarce conditions ?

In order to get a better understanding of the real significance of food wastage in water-scarce regions, it may be more suitable to confront the water scarcity and the blue water footprint of food wastage, as shown in Figure 76. This figure sheds a new light on the potential food wastage-related pressure on water.

Firstly, it can be observed that even though it seems that there is a link between the two profiles, there is no direct correlation between the two as they illustrate outcomes of distinct methodologies. Indeed a number of parameters play a role in the regional water footprint of food wastage such as production and consumptions levels, commodity mixes, food wastage percentages, impact factors, etc.

Caution is required when it comes to interpretation but it can be interesting to point out that the significant contribution of the NA,WA&CA region to total blue water footprint suggests that the pressure of food wastage on water resource seems to be relatively high in this water-scarce region. This could be explained by high impact factors in this region compared to other regions. In addition, it can be underlined that for similar surfaces of water-scarce river basins, S&SE Asia has a higher water footprint compared to Ind. Asia because of higher impact factors for the Southern Asia sub-region. This could apparently lead to a higher pressure of food wastage on water in this region compared to Ind. Asia.

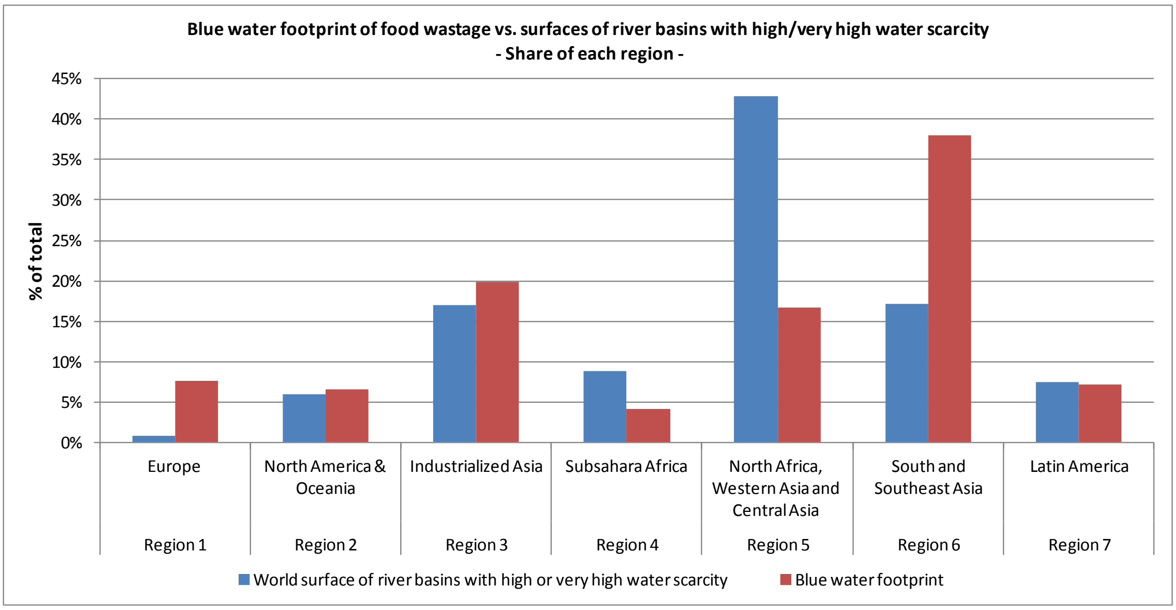

Figure 76: Blue water footprint of food wastage vs. surfaces of river basins with high/very high water scarcity – Share of each region –

4.3.7 Highlights

Box 20: Highlights for component 3 – Blue water footprint results

- At world level, the blue water footprint of total food wastage in 2007 is about 250 km3 (i.e. 250 Gm3). It is more than 38 times the blue water footprint of US domestic water consumption. In terms of volume, it represents the water discharge of the Volga River during one year.
- The major contributors to the blue water footprint of food wastage are cereals (52% of total) and fruits (18%) whereas their contribution to total food wastage are 26% and 16%, respectively.
- In terms of regional distribution, the major contributors are South & Southeast Asia (38% of total), industrialized Asia (20%) and NA,WA&CA (17%). In addition, it can be noted that low-income regions account for about 2/3 of total blue water footprint whereas their contribution to total food wastage is about 50%.
- Regional blue water intensity is much higher in NA,WA & CA and S&SE Asia than in other regions. In these two regions, a large share of the footprint is due to cereals (about 50 and 60%, respectively). Regional blue water intensity is very low in sub-Sahara Africa because the share of starchy roots (a commodity with low blue water intensity) in the region's food wastage is very high (more than 50%).
- At world level, the average blue water footprint of food wastage is about 38 m3 per capita and per year. NA,WA&CA stands out as the region with the highest per cap. footprint (more than 90 m3 per cap. and per year). Indeed this region represents 17% of the total water footprint of food wastage but only 7% of the total population.
- In absolute terms, hotspots for water footprint are due to cereals in S&SE Asia, Ind. Asia and NA,WA&CA. To a smaller extent, fruits in some regions (S&SE Asia, LA, Europe) can also be seen as hotspots but this commodity remains secondary compared to cereals. On a global scale, the driver of the water footprint seems to be mostly the water intensity for cereals, whereas for fruits it seems to be more related to the wastage volumes.

4.4 Component 4: Land results

This section presents the FWF model results for the land component. Complementary results for this component are presented in Annex XIX.

4.4.1 Results overview

The total amount of food wastage worldwide in 2007 has occupied about 1.4 billion hectares of agricultural land. This represents about 28% of the world's agricultural land area (FAOSTAT 2012b). In order to illustrate the magnitude of this result, surfaces occupied to produce uneaten food can be compared to the areas of the world's largest countries (Figure 77) and to national agricultural land areas (Figure 78). The area data presented hereafter are taken from FAOSTAT (2012b).

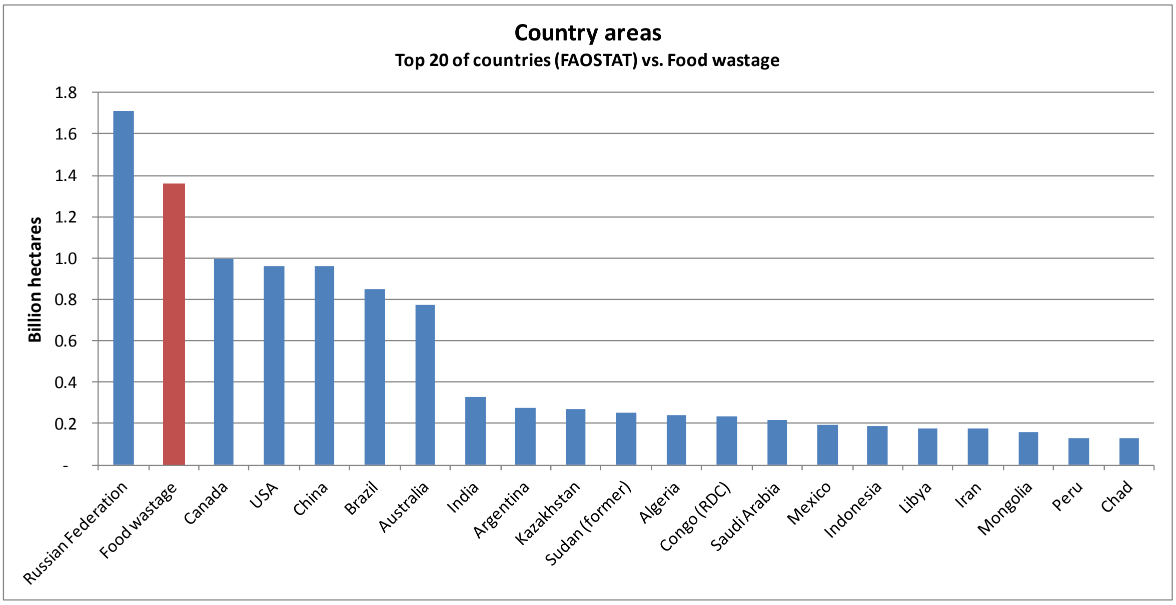

Figure 77: Top 20 of world's largest countries vs. Food wastage

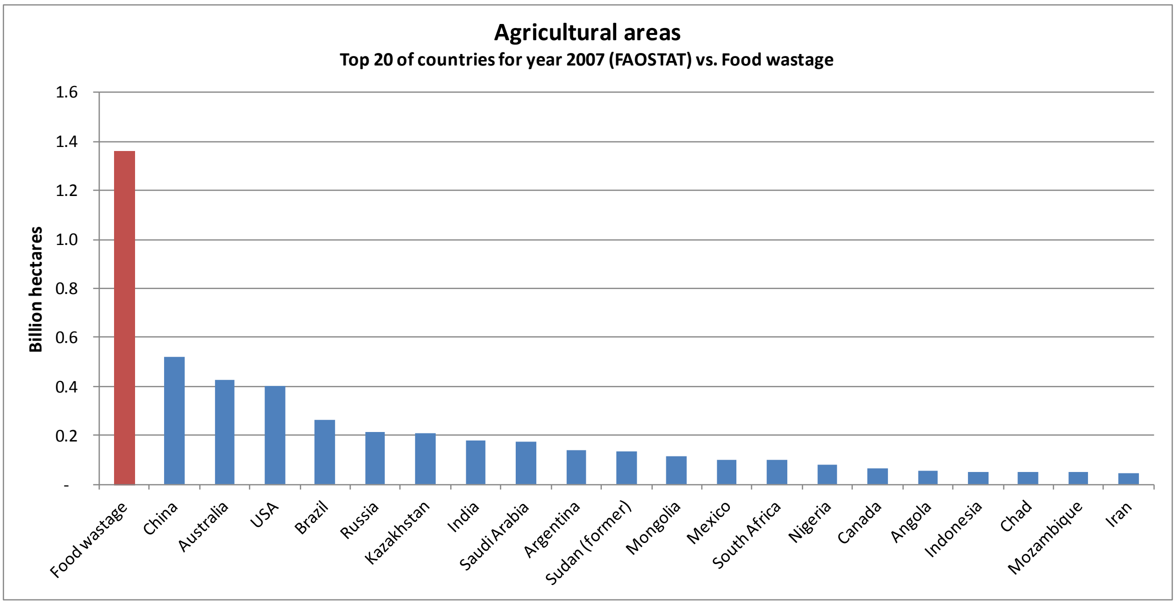

Figure 78: Top 20 of national agricultural land areas vs. Food wastage

4.4.2 Analyses by commodity and region

In the two sections below, this surface of 1.4 billion hectares of land is further broken down by commodity, by region as well as by type of land (i.e. arable or non-arable land).

Analysis by commodity

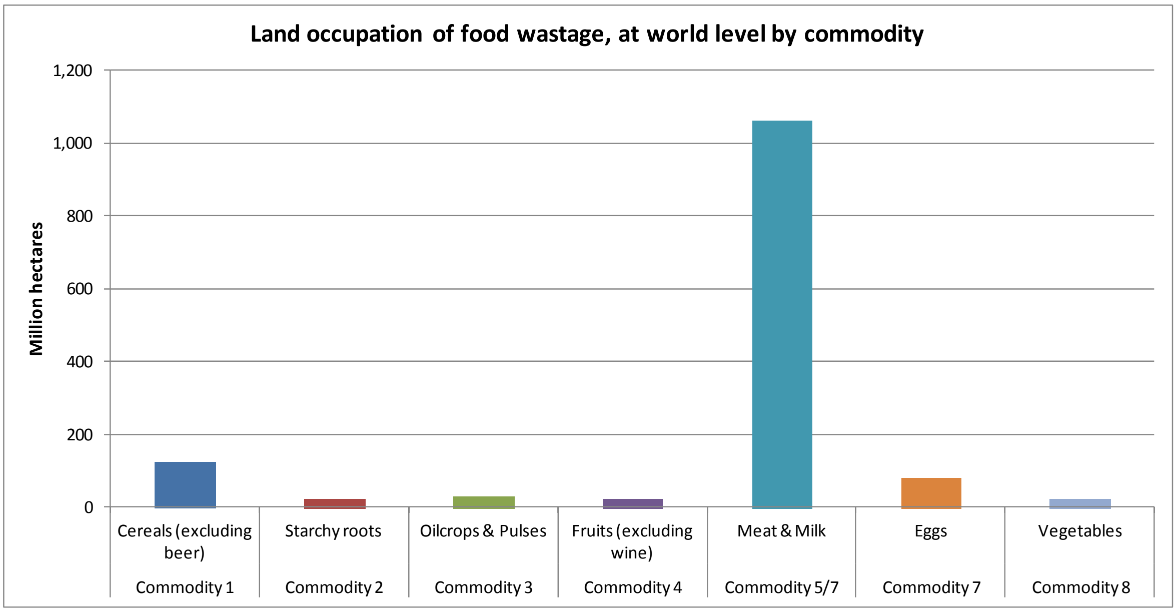

Figure 79: Land occupation, at world level by commodity

Figure 79 and Figure 80 show that the major contributors to the land occupation of food wastage are meat & milk with 78%of the total surface whereas their contribution to total food wastage is 11%[40].

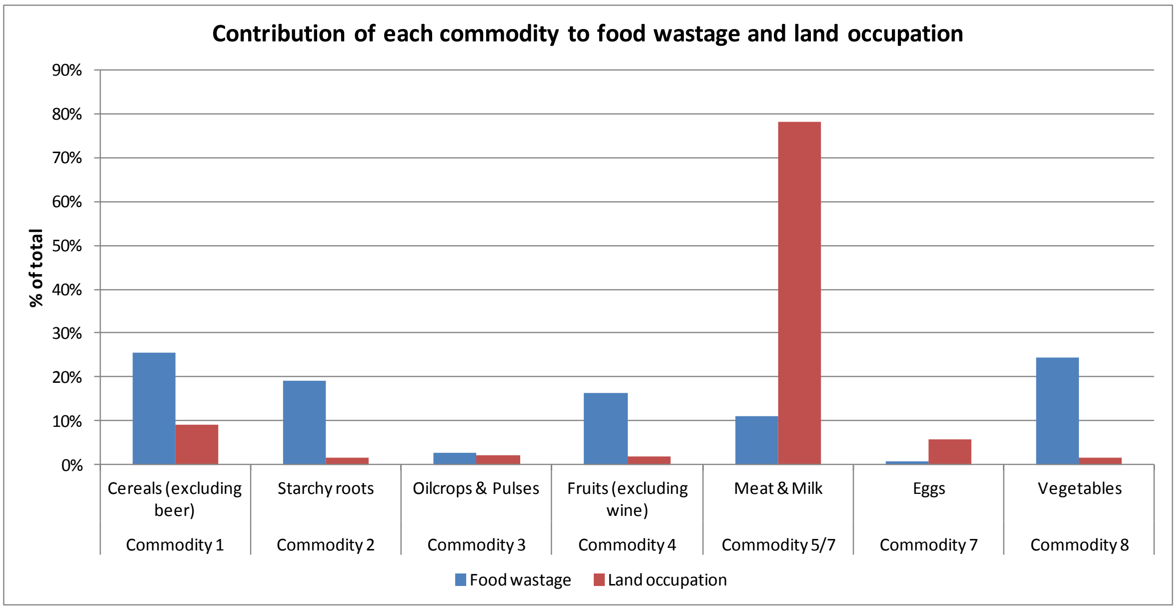

Figure 80: Contribution of each commodity to food wastage and land occupation

[40] Excluding fish & seafood to allow a comparison on the same grounds.

Figure 80 actually reflects the average "land intensity" of each commodity group (i.e. ha of land per tonne of product as presented in Figure 136 – Annex XIX). In practical terms, "land intensity" is the reciprocal of the yield (i.e. tonne of product per ha). Therefore, the land intensity is inversely proportional to the yield.

Below is a discussion on the land occupation/yield characteristics of the commodities in the scope of the present study. Information presented here is based on an analysis of the yield datasets from ProdStat (FAOSTAT 2012f) as well as personal communication with the FiBL team working on the SOL-m project.

Crops

Firstly, it should be underlined that comparing the yields of crop products must be done with caution. World average yields can be quite different from region-specific ones. Thus, a given product can have a higher yield than another one at world level but the opposite can be observed locally.

The yield of a given crop varies across countries and regions. This is mainly due to differences in agricultural practices (inputs, water and land management) and agro-climatic conditions. For instance, relatively high yields of wheat are observed in Europe and the US compared to other regions. Overall, higher yields are generally observed for commodities where a large fraction of crop biomass is harvested (e.g. starchy roots, fruits or vegetables) compared to crops where a small fraction of crop biomass is harvested (e.g. cereals, oilcrops).

Animals

As regards livestock production, land occupation assessment requires specific accountings of the agricultural surfaces occupied to produce animal feed and/or surfaces used for grazing, per tonne of animal product. The land intensity of an animal product is primarily determined by the feed conversion efficiency of the animal, the composition of the feeding ration, and the origin of the constituents of the ration.

For ruminants, the feeding ration can be composed of roughages (e.g. pasture) and/or concentrates (e.g. grains, soy-meal) and other supplements. Schematically, the share of roughages and the grassland productivity will influence the non-arable land occupation intensity. Conversely, the share of concentrated feed, its constituents such as maize or soy, and the yields in the originating regions of these crops will influence the arable-land occupation intensity.

Land occupation intensity of monogastric animals can also be divided in arable and non-arable land. Although monogastric animals do not feed on grass, the reason why they also have a non-arable land intensity lies in the fact that milk or components of milk (which require grassland) can be found in concentrates. This is implemented as a back loop in the SOL-m model.

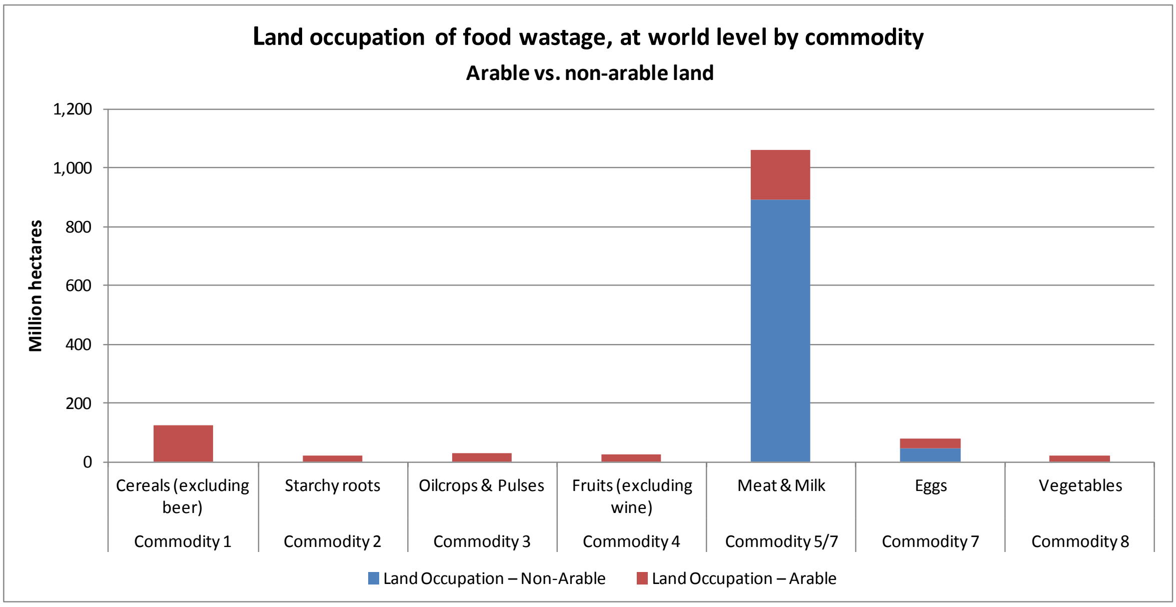

Figure 81: Land occupation of food wastage, at world level by commodity Arable land vs. non-arable land

Figure 81 reveals that the majority of the surfaces occupied to produce lost/wasted meat & milk are non-arable land (i.e. meadows and pastures). Meat & milk occupy 95% of non-arable land, the remaining 5% coming from eggs. Moreover meat & milk also occupy about 40% of total arable land (i.e. cropland) occupied by food wastage. This is because of feed crops grown on arable land that are indirectly wasted when meat or milk is wasted. Food crops taken as a whole contribute to about 20% of total land occupied by food wastage. Wasted/lost food crops only use arable land and cover 52% of total arable land occupied by food wastage.

Analysis by region

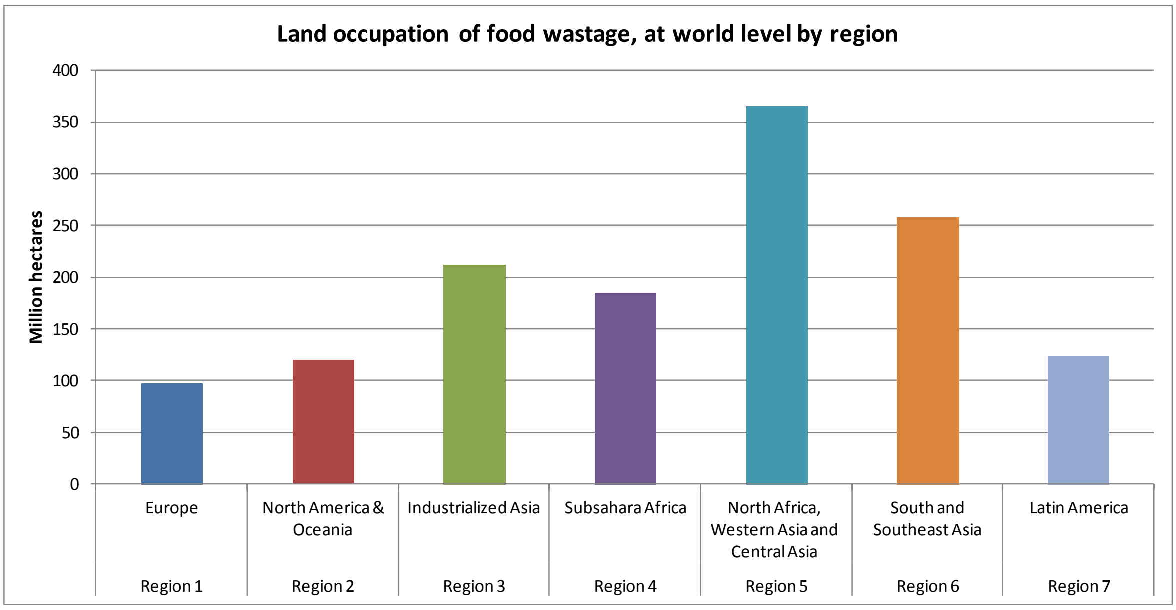

Figure 82: Land occupation, at world level by region

As regards the roles of each region in the surfaces occupied by food wastage, Figure 82 and Figure 83 show that the major contributor is NA,WA&CA with 27% of total. In addition, it can be observed that low-income regions account for about 2/3 of total land occupation whereas their contribution to total food wastage is about 50%.

Note that these results, presented in Figure 82 in absolute terms, are further examined with a per capita analysis in section 4.4.4.

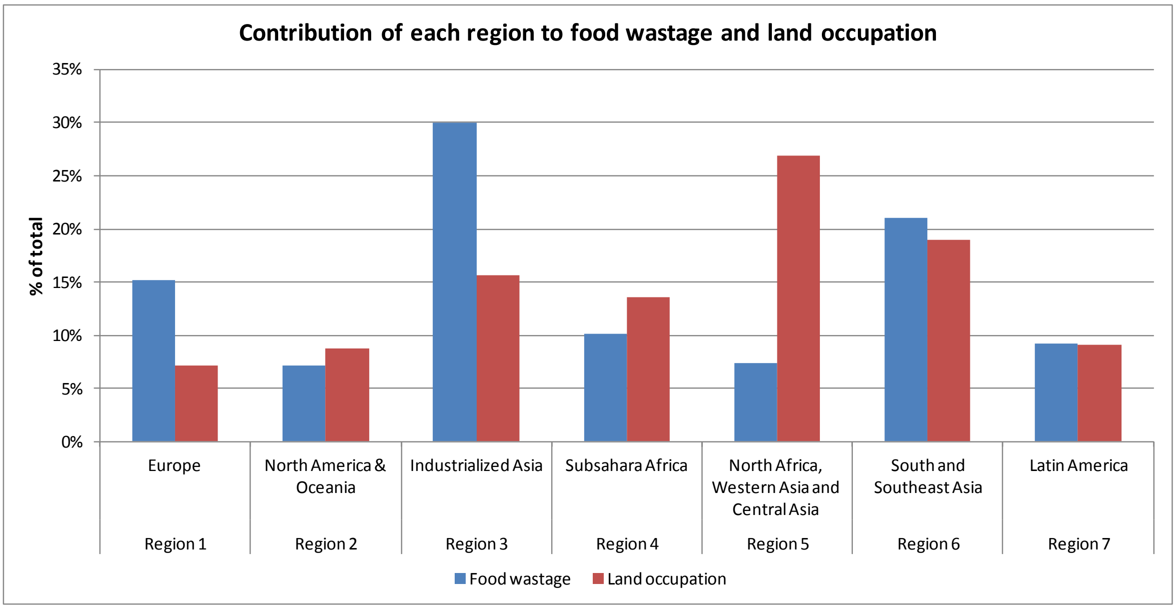

Figure 83: Contribution of each region to food wastage and land occupation

Figure 83 actually reflects the average "land occupation intensity" of each region (i.e. ha of land per tonne of product as presented in Figure 137 – Annex XIX). Observed variations come from the different mixes of commodities that are lost or wasted in each region (see Figure 30 and Figure 31 for commodity mixes) combined with specific shares of arable and non-arable land as shown in Figure 84. Here are some observed patterns noteworthy to mention:

Land occupation intensity is much higher in NA,WA&CA than in other regions. In this region, 85% of the land occupation of food wastage is non-arable land for meat & milk, in particular for bovine, ovine and caprine animals. In this region, the non-arable land impact factor is very high. This is because the productions systems mostly rely on grassland for feeding animals. In addition, these grasslands have low yields, resulting in low livestock productivity. Consequently, large areas are required to feed animals.

Europe and Ind. Asia have the lowest land occupation intensity. It can be observed that the share of non-arable land for meat & milk is still the largest contributor to land occupation but in parallel, the share of arable land for meat & milk is higher than in other regions. In these regions, the non-arable land impact factors are lower because productions systems generally rely less on grassland and because grasslands are more productive. Feeding rations includes higher shares of concentrates resulting in more arable-land occupation. In the end, this results in lower total land occupation intensity.

Note that the difference between industrialized Asia and S&SE Asia is mostly due to differences in cattle production systems with higher grassland productivity and higher share of concentrates in feeding rations in Ind. Asia, resulting in higher productivity.

Figure 85 and Figure 86 in next section shed more light on these aspects.

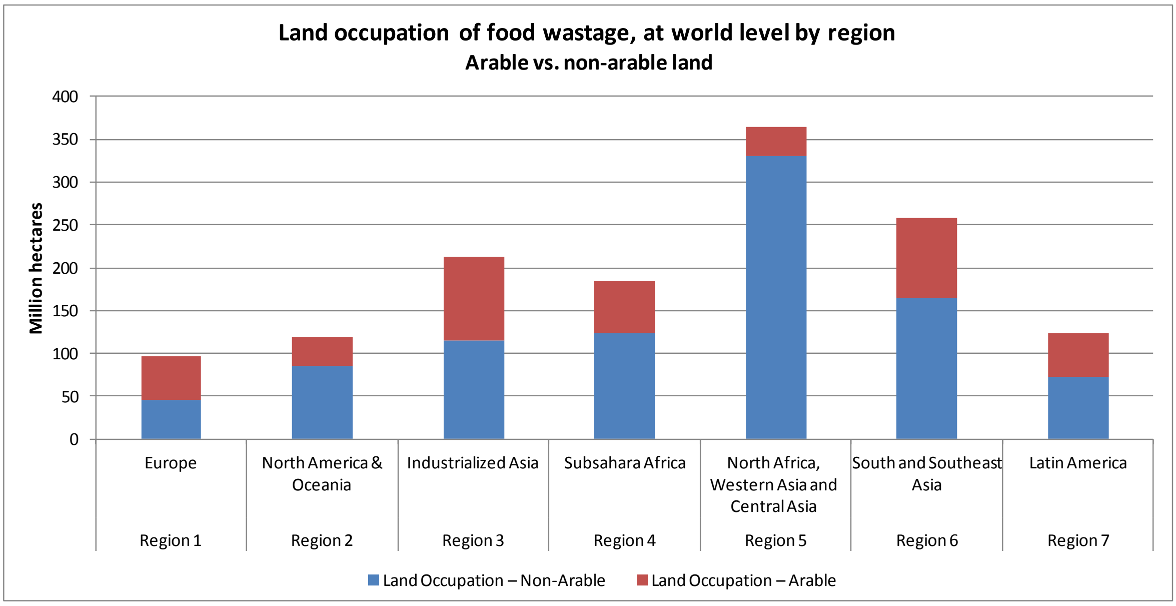

Figure 84: Land occupation of food wastage, at world level by region Arable land vs. non-arable land

Figure 84 shows that in NA,WA&CA, more than 90% of the land occupation is due to non-arable land. In other regions, the share of non-arable land fluctuates between 47% for Europe and 71% for NA&Oce. In all regions, meat & milk are the largest contributors to non-arable land occupation. These commodities are also key drivers of arable land occupation. Consequently, the share or arable and non-arable land in each region is mostly driven by the share between grass and concentrate in the feeding rations. Regions that have higher shares of arable land tend to have lower total land occupation intensity because it is generally related to systems that are more productive.

4.4.3 Regional profiles

In this section, the land occupation of food wastage in each region (as shown in Figure 82) is further disaggregated by commodity groups and at the same time by type of land (i.e. arable or non-arable). For each region, a particular profile is obtained and key characteristics can be identified.

Regional profiles – Commodity groups view

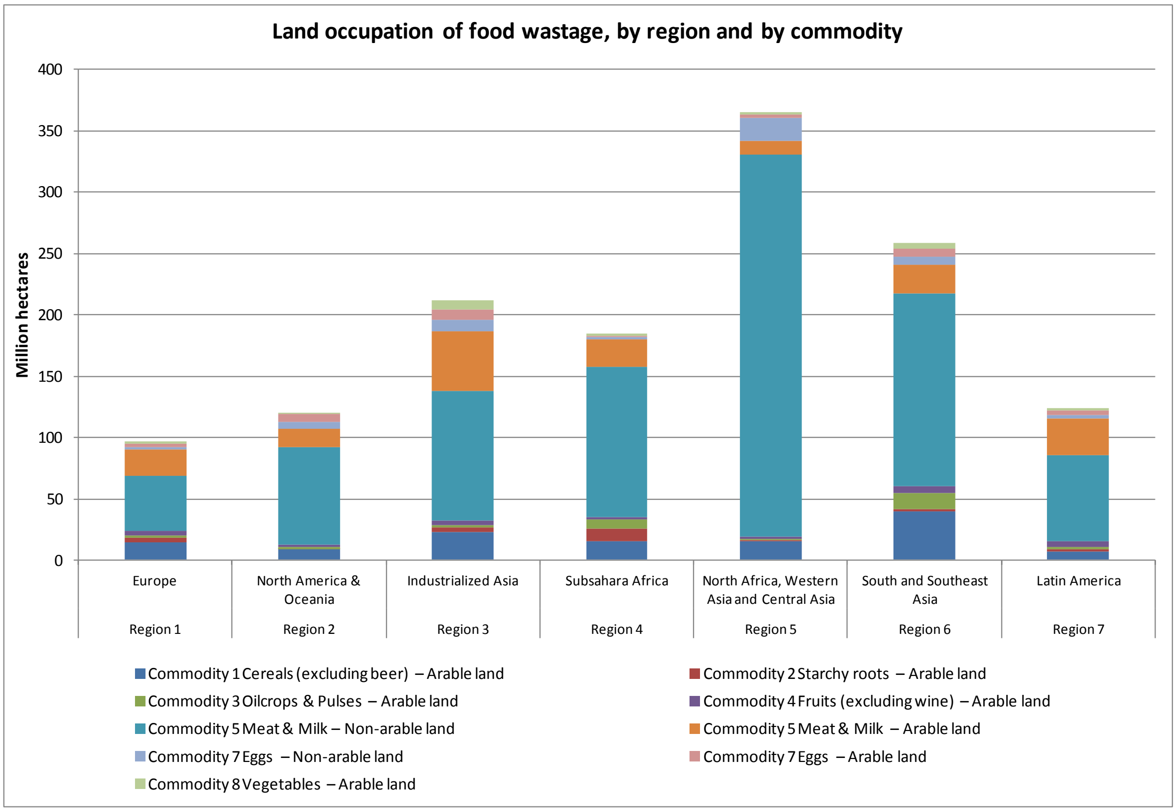

Figure 85: Land occupation of food wastage, by region and by commodity

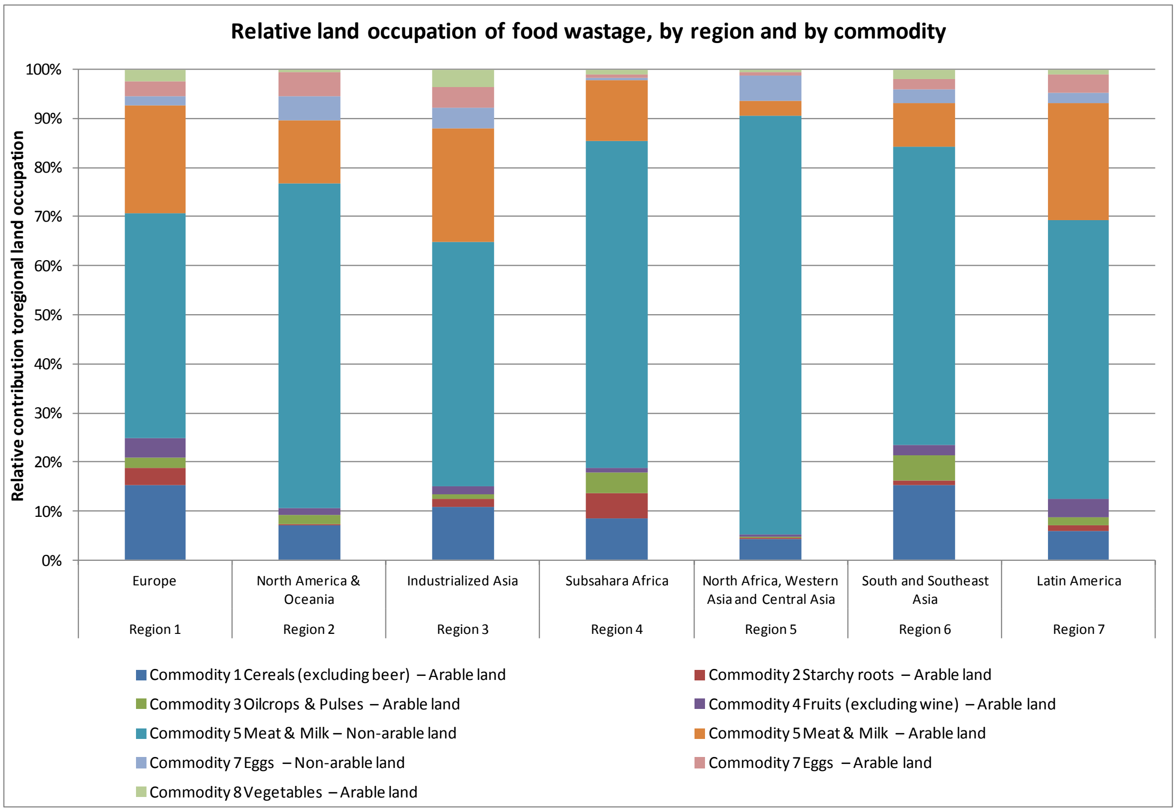

Figure 86: Relative land occupation of food wastage, by region and by commodity

The major features of the regional profiles of commodities presented in an absolute (Figure 85) or relative way (Figure 86) are as follows:

Surfaces of non-arable land occupied to produce lost/wasted milk & meat contribute to as much as 46-85% of total land occupation of food wastage in each region.

Lost/wasted milk & meat also necessitate large surfaces of arable land. Arable land used by these commodities contributes to more than 10% of total land occupation of food wastage in all regions except NA,WA&CA and S&SE Asia where production systems rely more on (low productive) grasslands.

Among food crops, the largest contributors to land occupation of food wastage are cereals. Arable land used to grow uneaten cereals contribute to 4-15% of total land occupation of food wastage in each region.

In spite of significant food wastage volumes, starchy roots, vegetables and legumes, are note very visible in the profiles because of their generally high yields.

4.4.4 Per capita analysis

In this section, the land occupation related to food wastage in each region (as shown in Figure 67) is presented per capita.

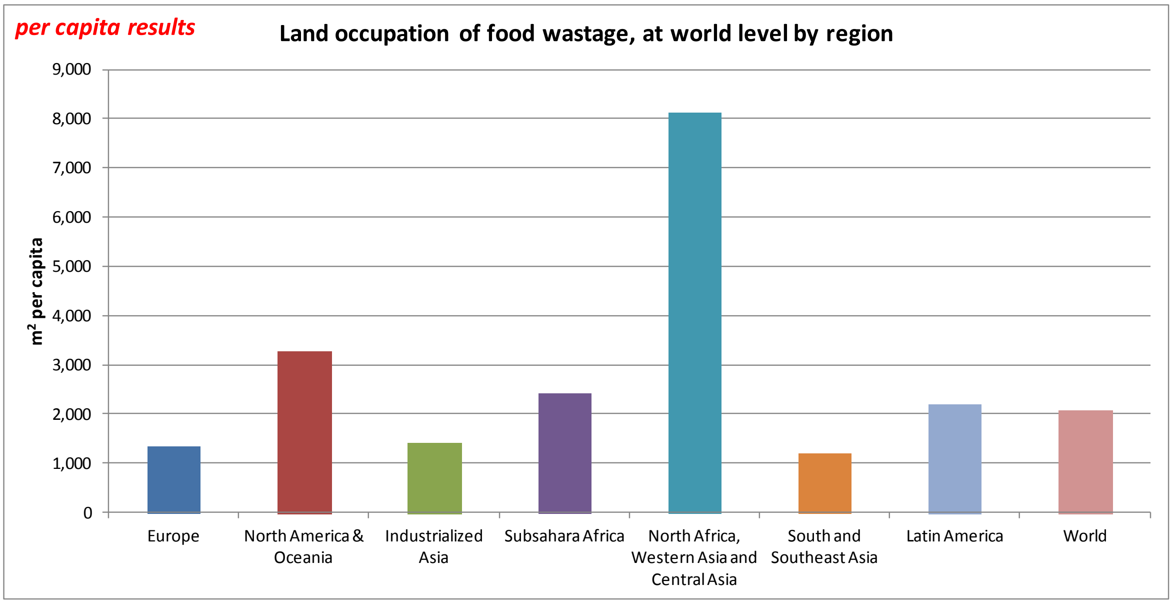

Figure 87: Land occupation of food wastage, by region – Per capita results

The average land occupation of food wastage is about 2,000 m^2 per capita and per year. NA,WA&CA stands out as the region with the highest per capita footprint (more than 8,000 m^2 per cap. and per year). Indeed, this region relies mostly on low productive grassland for animal production and thus contributes to 27% of the global land occupation of food wastage whereas its population is only 7% of total. Sub-Saharan Africa is the region with the smallest land occupation per capita (about 1,200 m^2 per cap. and per year). This region also relies on grassland for animal production but grassland productivity is relatively higher than in NA,WA&CA. Consequently, the region contributes for 13.6% of total land occupation whereas its population represent 15% of total.

Note that the average land occupation of food wastage when considering food crops only (i.e. not taking into account animal products) is about 330 m^2 per capita and per year (see Figure 88), a value that is close to the value reported by Kummu et al. (2012) which is 305 m^2 per capita and per year.

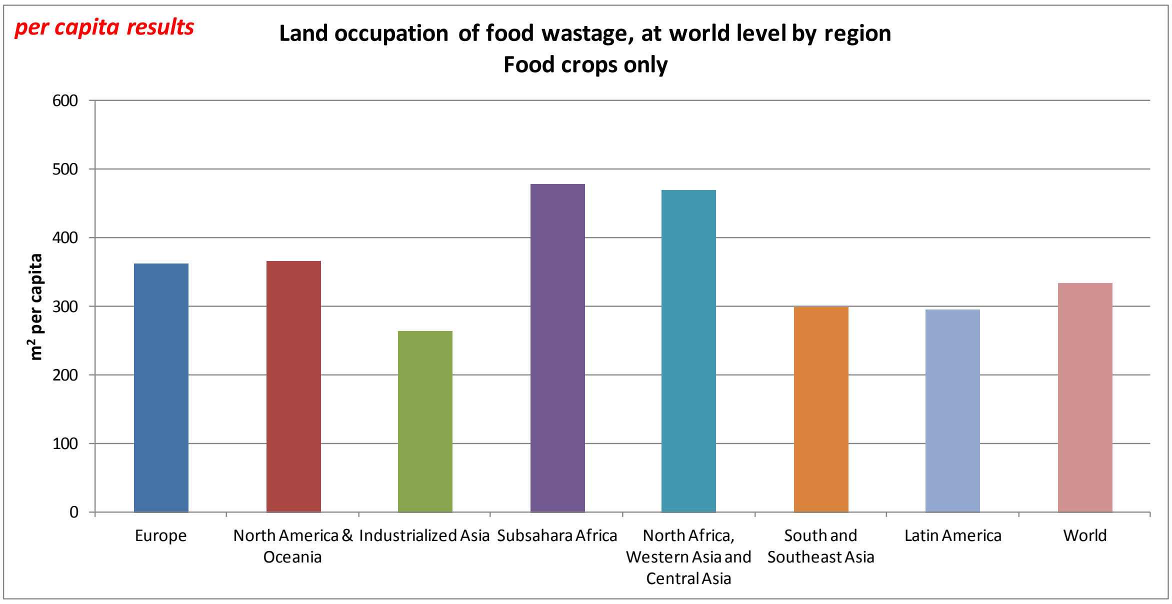

Figure 88: Land occupation of food wastage, by region – Food crops only, per capita results

4.4.5 Identification of hotspots

Hotspots – Contribution to total land occupation

Similarly to the analysis performed in section 4.1.5 for food wastage volumes, the "region * commodity" pairs can be ranked according to their contributions to land occupation. Specifically for this component, a distinction is made between hotspots related to arable land occupation and hotspots related to non-arable land occupation.

Figure 89 shows the ten "region * commodity" pairs with the highest contribution to arable land occupation. Meat & milk on the one hand and cereals on the other hand dominate this ranking.

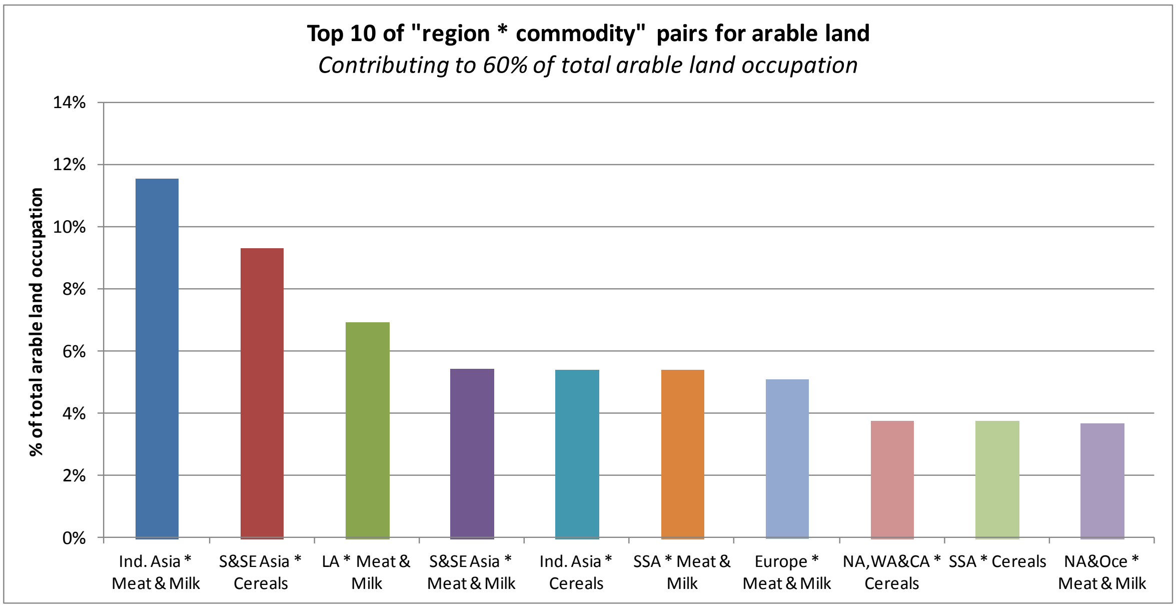

Figure 89: Top 10 of "region * commodity" pairs for arable land occupation

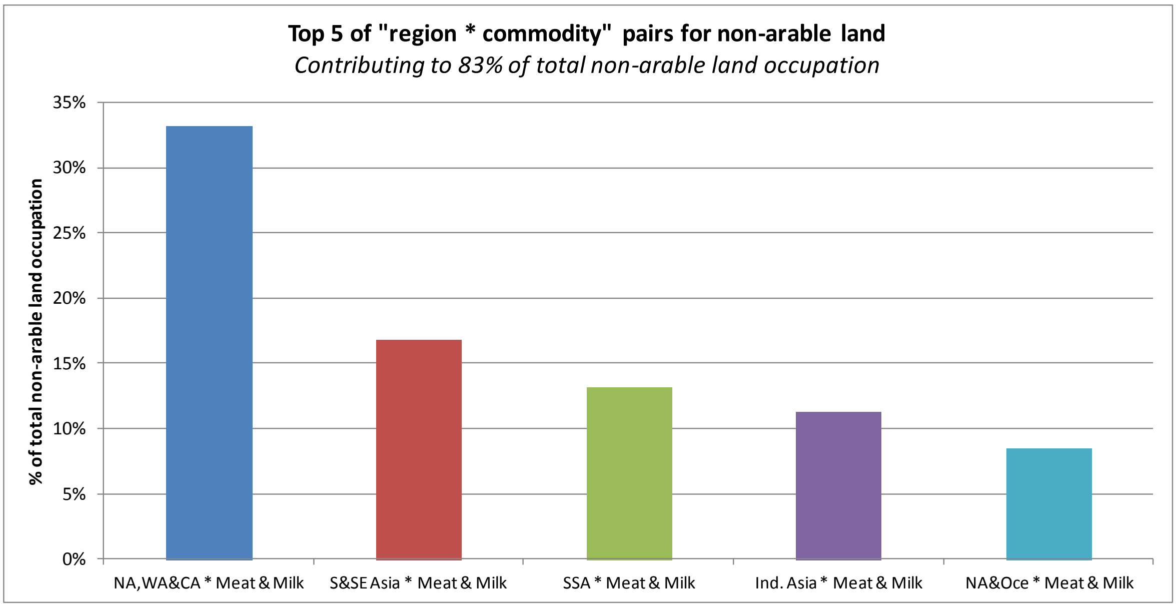

Figure 90: Top 5 of "region * commodity" pairs for non-arable land occupation

Figure 71 shows the five "region * commodity" pairs with the highest contribution to non-arable land occupation.

Land occupation is calculated as a multiplication of a food wastage amount and an impact factor. It can be interesting to determine which part of the multiplication is the main driver of land occupation for the identified hotspots. Figure 91 and Figure 92 have been made for this purpose.

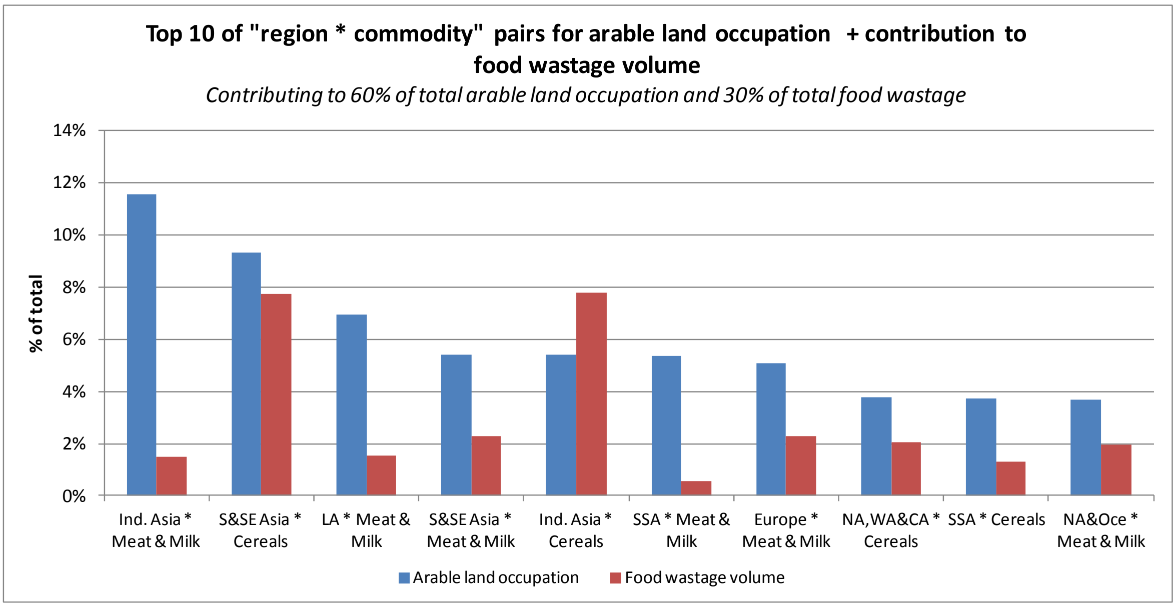

Figure 91: Top 10 of "region * commodity" pairs for arable land occupation presented along with contribution to food wastage volume

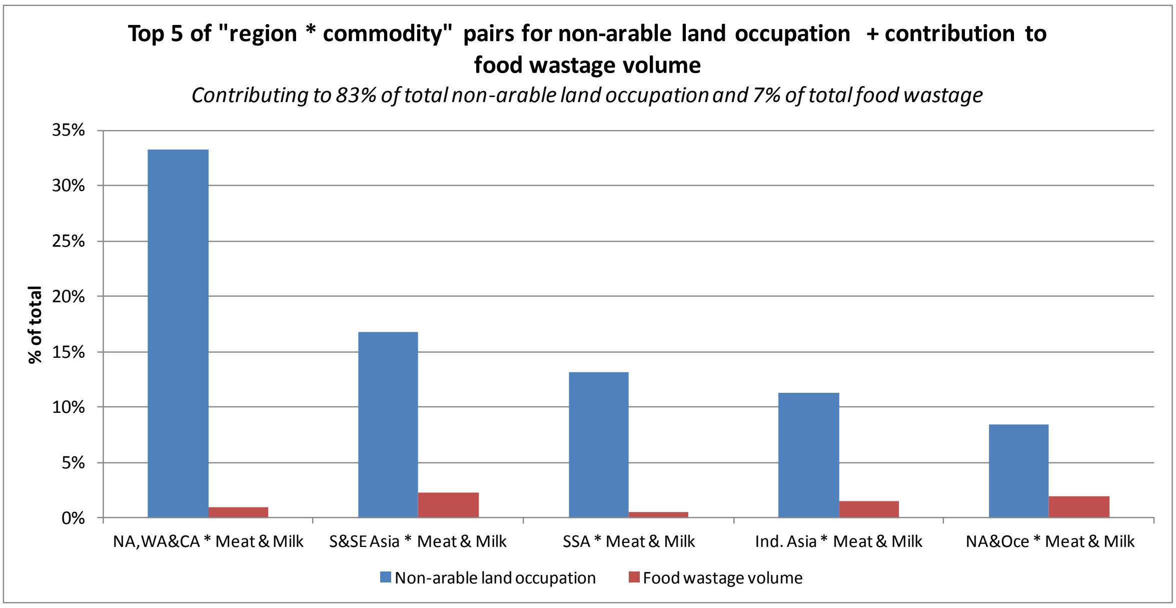

Figure 92: Top 5 of "region * commodity" pairs for non-arable land occupation presented along with contribution to food wastage volume

In the two figures above, top "region * commodity" pairs are presented along with their respective contribution to food wastage volume. From these figures, it can be deduced whether the land occupation of the hotspot is mainly due to high food wastage volumes or to high impact factors.

Therefore, it can be noted that for meat & milk, the driver seems to be mostly the land occupation intensity of the commodity, be it for arable land or non-arable land. The observed variability in the impact factors of meat & milk across regions is due to differences in production systems (composition of the feeding ration, amount of land required to produce the constituents of the ration).

For cereals, volumes do play a role in the contribution to arable land occupation but impact factors can accentuate or limit the effect of volume. For instance, cereals in S&SE Asia and Ind. Asia have the same contribution to total food wastage volumes but different contributions to arable land occupation because their impact factors are different. The main reason lies in the fact that more rice is wasted in S&SE Asia and rice yields are lower in this region than in Ind. Asia resulting in higher impact factor in S&SE Asia.

Hotspots – Per capita analysis

Another way to pinpoint hotspots is to calculate per capita ratios for each of the "region * commodity" pairs. The top 10 (for total land occupation) obtained is presented in Figure 93.

Animal products are visibly dominant in this ranking. Major per capita hotspots are located in NA,WA&CA which is the region with the highest total land occupation per capita (see Figure 87).

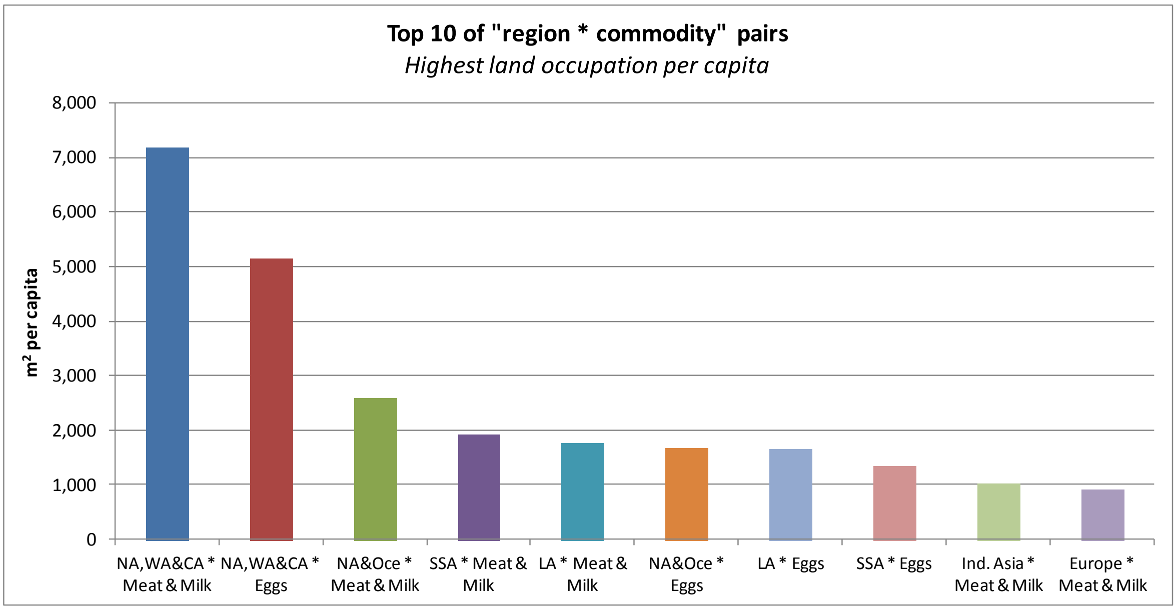

Figure 93: Top 10 of "region * commodity" pairs for land occupation per capita

4.4.6 Land degradation

BSI, BLDI and class calculated at sub-regional level

The land degradation status, trend, and class of the surfaces occupied to grow uneaten food in each sub-region are presented in Table 8.

Table 8: BSI, BLDI and class calculated at sub-regional level

Region name	Sub-region name	BSI	BLDI	Class	Description (i.e. land degradation status; land degradation trend – see Figure 16)
Europe	Europe	0.58	0.57	7	High status; Medium to strong degradation
North America & Oceania	Australia	0.40	0.53	10	Low status; Weak degradation
	Canada	0.59	0.56	7	High status; Medium to strong degradation
	New Zealand	0.55	0.58	7	High status; Medium to strong degradation
	USA	0.54	0.56	7	High status; Medium to strong degradation
Industrialized Asia	China	0.47	0.57	6	Low status; Medium to strong degradation
	Japan	0.77	0.60	8	High status; Medium to strong degradation
	Republic of Korea	0.71	0.62	7	High status; Medium to strong degradation
Sub-Saharan Africa	Eastern Africa	0.43	0.58	6	Low status; Medium to strong degradation
	Middle Africa	0.54	0.56	7	High status; Medium to strong degradation
	Southern Africa	0.32	0.55	10	Low status; Weak degradation
	Western Africa	0.42	0.56	6	Low status; Medium to strong degradation
North Africa, Western Asia and Central Asia	Central Asia	0.28	0.55	6	Low status; Medium to strong degradation
	Mongolia	0.34	0.58	6	Low status; Medium to strong degradation
	Northern Africa	0.21	0.57	5	Low status; Medium to strong degradation
	Western Asia	0.21	0.61	5	Low status; Medium to strong degradation
South and Southeast Asia	South-Eastern Asia	0.58	0.60	7	High status; Medium to strong degradation
	Southern Asia	0.36	0.60	6	Low status; Medium to strong degradation
Latin America	Caribbean	0.48	0.60	6	Low status; Medium to strong degradation
	Central America	0.51	0.58	7	High status; Medium to strong degradation
	South America	0.61	0.57	7	High status; Medium to strong degradation

Linkage with food wastage volumes

The repartition of food wastage at agricultural production phase per class of land degradation (as defined in FAO LADA 2011) is presented in the Figure 94.

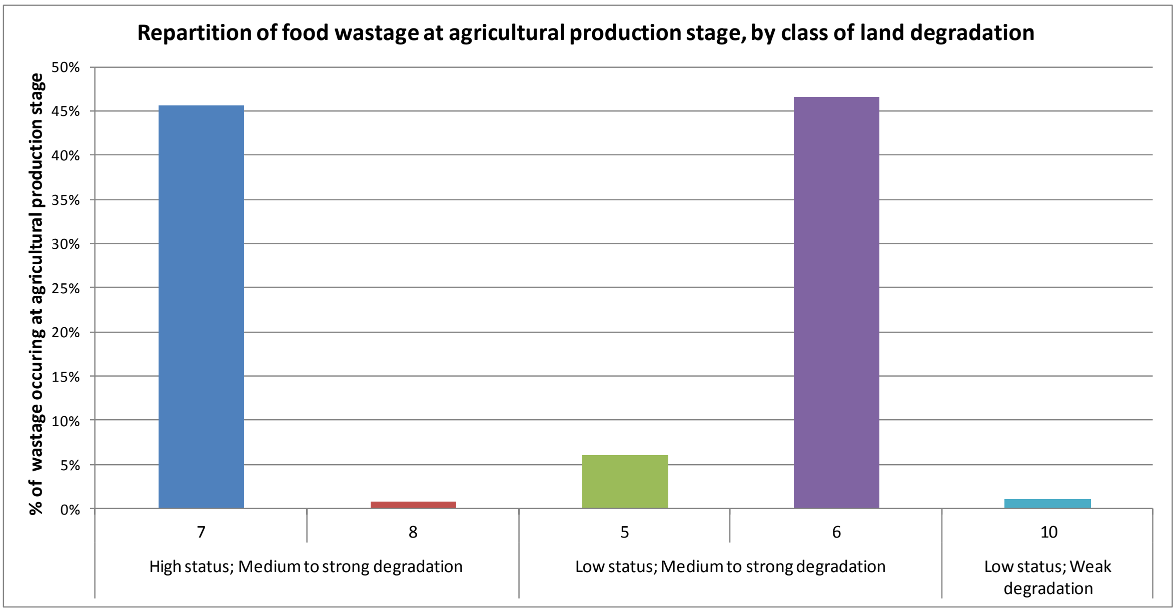

Figure 94: Repartition of food wastage at agricultural production phase, by class of land degradation

Almost 99% of food wastage at the agricultural production phase seems to be produced in regions where soils are experiencing, in average, a medium to strong land degradation.

In addition, more than 50% of food wastage at the agricultural production phase seems to be produced in regions whose soils are, on average, currently in a low status in terms of soil degradation.

4.4.7 Highlights

Box 21: Highlights for component 4 – Land results

- At the world level, the total amount of food wastage in 2007 has occupied about 1.4 billion hectares of agricultural land. This represents about 28% of the world's agricultural land area.
- The major contributors to the land occupation of food wastage are meat & milk with 78%of the total surface whereas their contribution to total food wastage is 11%.
- The majority of the surfaces occupied to produce lost/wasted meat & milk are non-arable land (i.e. meadows and pastures). Meat & milk occupy 95% of non-arable land. Moreover meat & milk also occupy about 40% of total arable land (i.e. cropland) occupied by food wastage. This is because of feed crops grown on arable land that are indirectly wasted when meat or milk is wasted. Food crops taken as a whole contribute to about 20% of total land occupied by food wastage. This land is arable land.
- In terms of regional distribution, the major contributor is NA,WA&CA with 27% of total. In this region, 85% of the land occupation of food wastage is non-arable land for meat & milk, in particular for bovine, ovine and caprine animals. In this region, the productions systems mostly rely on (low productive) grassland for feeding animals. Europe and Ind. Asia have the lowest land occupation intensity. In these regions, the non-arable land impact factors are lower because productions systems generally rely less on grassland and because grasslands are more productive. Feeding rations includes higher shares of concentrates resulting in more arable-land occupation.
- The average land occupation of food wastage is about 2,000 m^2 per capita and per year. NA,WA&CA stands out as the region with the highest per capita footprint (more than 8,000 m^2 per cap. and per year) because of its production systems.
- In absolute terms, hotspots for arable land occupation are located in several regions due to meat & milk (e.g. Ind. Asia, LA, S&SE Asia) and cereals (e.g. S&SE Asia, Ind. Asia). Hotspots for non-arable land occupation are primarily located in NA,WA&CA and S&SE Asia.
- It can be noted that for meat & milk, the driver seems to be mostly the land occupation intensity of the commodity, be it for arable land or non-arable land. The observed variability in the land occupation factors of meat & milk across regions is due to differences in production systems. For cereals, volumes do play a role in the contribution to arable land occupation but yields and thus land occupation factors can accentuate or limit the effect of volume, as it is the case with rice in S&SE Asia and Ind. Asia respectively.

4.5 Component 5: Biodiversity results

4.5.1 Regional and sub-regional profiles

Maximum area deforested by agriculture per sub-region

Our analysis indicates that forest cover exhibited a net decrease over the period from 1990 to 2010 in 11 of the 21 sub-regions (Table 9). All declines of forest cover occurred in the developing world, except for Australia. Interestingly, Western, Central and Southern Asia had net increases in forest cover, although this may simply mean that they shifted the forest clearings abroad, in other developing countries (Meyfroidt et al. 2010).

Agricultural land area has been decreasing across most of the world, except in the African continent, Western Asia, South-Eastern Asia and South America. Most of these world regions appear to have expanded their agricultural areas at the expense of forests (Figure 95; Column c, Table 9). The values are the maximum area of forests that may have been cleared for agriculture. Even though there are many caveats in this estimation (see section 3.5.5), it is in line with existing findings in the literature and expert opinions. According to Gibbs et al. (2010) across the tropics, between 1980 and 2000, more than 55% of new agricultural land came at the expense of intact forests, and another 28% came from disturbed forests. As seen from Table 9, when these rates of change are used, estimates of deforestation from agriculture are all in the same order of magnitude as the maximum estimates calculated in this study (Columns c and cGibbs, Table 9). According to ONFi expert, the link between agriculture and deforestation is close to one for one in developing countries.

Table 9: Mean changes in forest and agricultural covers between 1990 and 2010

Sub-regions	Mean annual change in forest cover (1 000 ha/yr)	Mean annual change in agricultural surfaces (1 000 ha/yr)	Maximum area deforested (1 000 ha/yr)	Proportion of agricultural land coming from forests	Maximum area deforested
	a	b	c= Min [Abs (a), abs(b)] if a<0 and b>0	Source: Gibbs et al. (2010)	cGibbs using Gibbs et al. (2010)
Europe	802.6	-1,643.3			
Australia	-225.1	-2,918.5			
New Zealand	29.3	-256.9			
Canada	0	-8.8			
USA	384.4	-1,236.7			
China	2471.4	-372.5			
Japan	1.1	-57.1			
Republic of Korea	-7.4	-17.1			
Eastern Africa	-1,528.6	1,240.8	**1,240.8**	88%	**1091.9**
Middle Africa	-793.0	102.0	**102.0**	93%	**94.86**
Southern Africa	-180.9	126.7	**126.7***	92%	**116.1**
Western Africa	-920.6	1,667.6	**920.6**	94%	**1567.5**
Central Asia	11.9	-757.0			
Mongolia	-81.9	-518.7			
Northern Africa	-323.7	971.7	**323.7***	92%	**890.8**
Western Asia	87.7	2,594.8			
South-Eastern Asia	-1,690.0	830.8	**830.8**	92%	**764.4**
Southern Asia	107.9	-772.1			
Caribbean	52.1	-13.6			
Central America	-594.4	-5.5			
Southern America	-4132.7	1,958.6	**1,958.6**	76%	**1488.6**

*values for these regions were not available from Gibbs et al. (2010). The average value for all African regions was used for both.

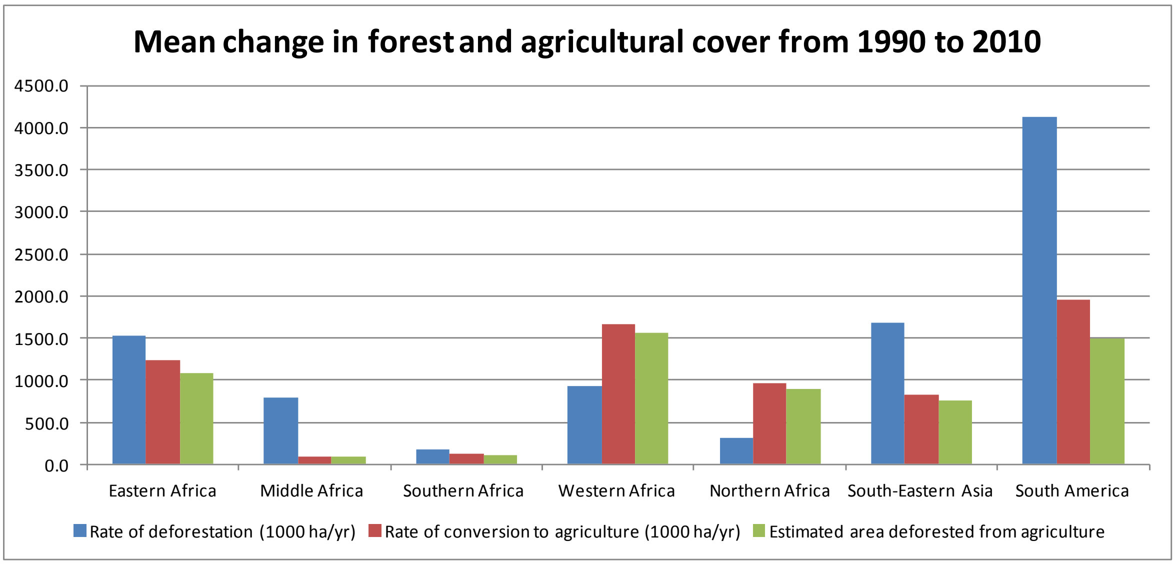

Figure 95: Maximum area of forest converted to agriculture from 1990 to 2010, in regions where deforestation occurred. Blue bars represent the total area deforested, red bars the total agricultural expansion, and green bars the difference between the two.

Percentage of species threatened by agriculture per sub-region

Figure 97 shows that farming (including land conversion and intensification) is a major threat to biodiversity worldwide. The threats are substantially more important on average from crop production than from livestock production (70% and 33% respectively, Figure 96). While this trend is expected, as grasslands are known to be more biodiversity-friendly than more intensive forms of agricultural productions (see section 3.5.4.2), the difference is striking. For both crop production and livestock production, the threats are considerably larger in developing countries (Regions 4-7) than in developed countries (Regions 1-3), as would be expected given the current rates of agricultural expansion in the developing world. Crops are responsible for 44% of species threats in developed countries, compared to 72% in developing countries, on average. The trend is less strong for livestock production, where developed countries are responsible for 21% of the threats, compared to 34% for developing countries on average. Unsurprisingly, in the developing world; the main biodiversity impacts are located around the tropics, including Middle Africa, Central and Southern Asia. Crops are causing most threats to biodiversity in Africa (Middle, Western and Eastern) and South Asia (Southern and South Eastern Asia), where on average 80% of species are threatened by agricultural production. In contrast, livestock is an important threat mostly in South America and North Africa, where on average 55% of species are threatened by livestock farming and cattle ranching. These results are in line with the evidence from the literature (see section 3.5.4.2).

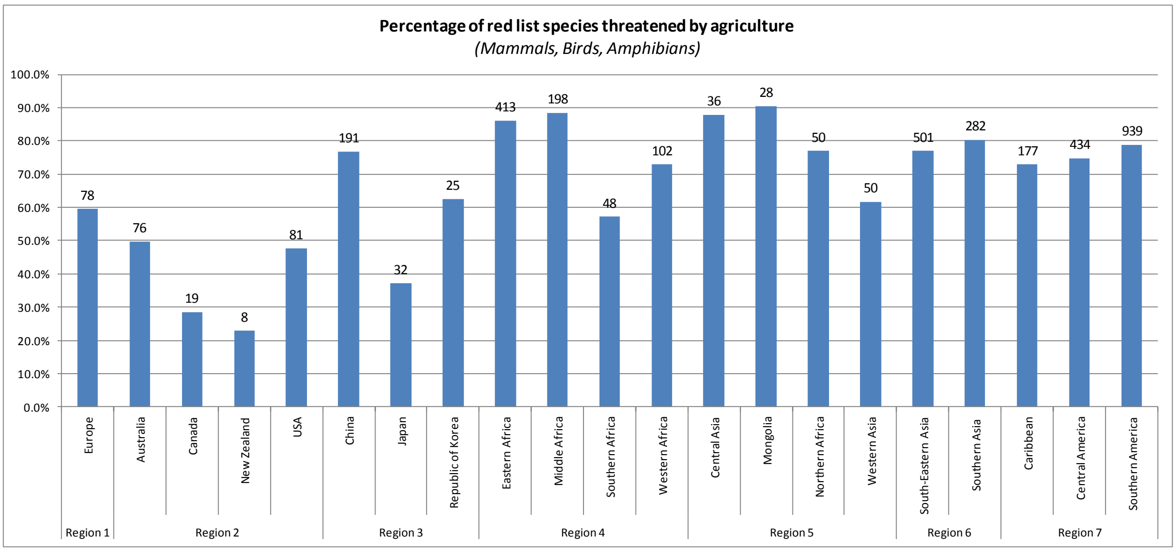

Figure 96: Percentage of Red List species of Birds, Mammals and Amphibians that are threatened by crop production and livestock farming (the number of threatened species is indicated above the bars).

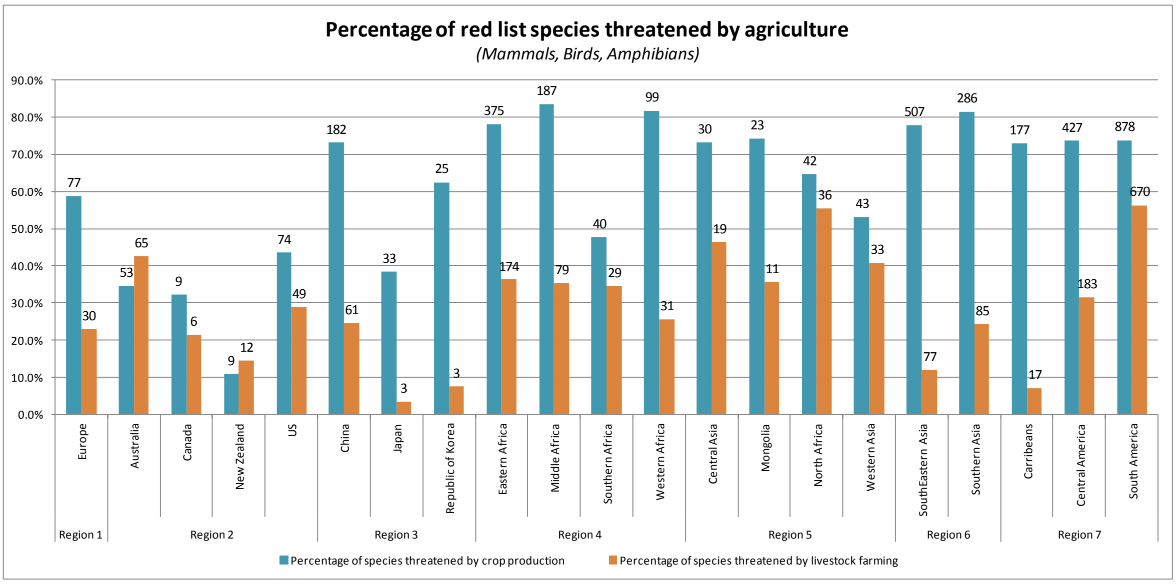

Figure 97: Percentage of Red List species of Birds, Mammals and Amphibians that are threatened by agriculture: crop production and livestock farming (the number of threatened species is indicated above the bars).

However, the different taxonomic groups show different sensitivities, in particular regarding livestock farming and ranching (see Figure 98, Figure 99, Figure 100). On average, mammals are most at threat from livestock production in Central and Western Asia, including Mongolia (58% of mammal species threatened in these regions on average; Figure 100). This could be explained by the fact that livestock ranching is still very traditional in these steppic regions, consisting mainly semi-nomadic pastoralism with low grazing intensities. The steppes still hold a variety of large mammals, including bears, camels, wild asses and predators such as wolves and snow leopards. Human-wildlife conflicts may threaten them. In the case of amphibians, the high risks from livestock farming observed in Canada, North Africa and Central Asia are artefacts of a small sample size: only a handful of amphibians were reported in the Red List in these countries, but all of these species are endangered by livestock farming. Amphibians in Australia and South

America are being endangered by livestock production more than in other countries (Figure 98), apparently as a result of habitat loss and diseases (GAA 2004). Livestock farming tends to cause greater threats to birds on average than for the other taxonomic groups (36% vs. 33%; Figure 99), largely because more bird species are at threat than the overall average in Central America (45% vs. 32%) and Southern Asia (43% vs. 24%). This may be linked to agricultural expansion, and conversion of natural forests to rangeland, especially prevalent in these two regions. Forest specialists, which are highly represented in birds (>60% of all bird species) may thus be endangered and driven to extinction. A recent study also showed that some Central American and South Asian ecoregions (Indonesia's Seram rain forests, and the moist forests of Trinidad and Tobago) were high conservation priorities for bird conservation as they experienced high rates of deforestation and have little protected areas coverage (Buchanan et al. 2011).

In terms of agricultural crop production systems, regional differences can also be observed among the three taxonomic groups. For example, almost 10% more amphibian species are threatened by agriculture in Central America than the global average (Figure 98), again as a combined result of habitat loss and diseases (GAA 2004). Birds are substantially more impacted by agricultural production in Mongolia and China than the global average (95% vs. 36.5 and 82% vs. 25% of birds threatened respectively; Figure 99). This result is surprising, and deforestation alone cannot explain it, otherwise similar trends would be observed in other regions in the developing world. The main agricultural productions in China and Mongolia are rice and wheat. It is therefore possible that birds are more at threats in these regions due to the combined loss of wetland and forest habitats, since both habitats hosting a number of specialist bird species. Mammals are generally less threatened by agriculture than the other two taxonomic groups (64% of threats vs. 70% on average; Figure 100). This may be explained by the fact that a number of mammal species are able to survive in agricultural systems, or can use these habitats for feeding but find shelter in nearby more natural remnants.

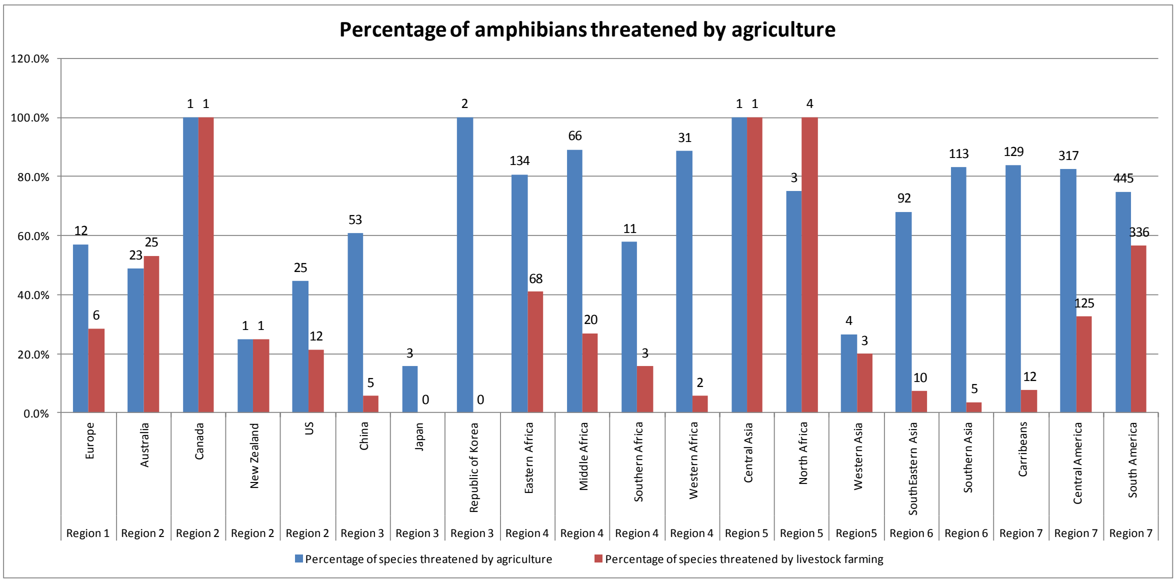

Figure 98: Percentage of Red List species of Amphibians that are threatened by agriculture: crop production and livestock farming (the number of threatened species is indicated above the bars).

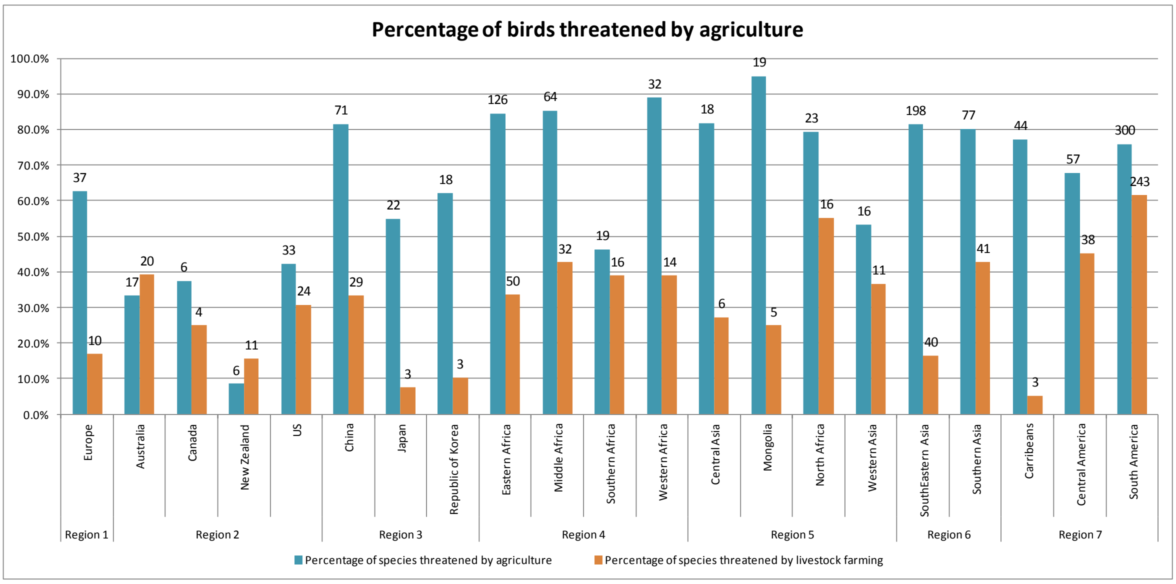

Figure 99: Percentage of Red List species of Birds that are threatened by agriculture: crop production and livestock farming (the number of threatened species is indicated above the bars).

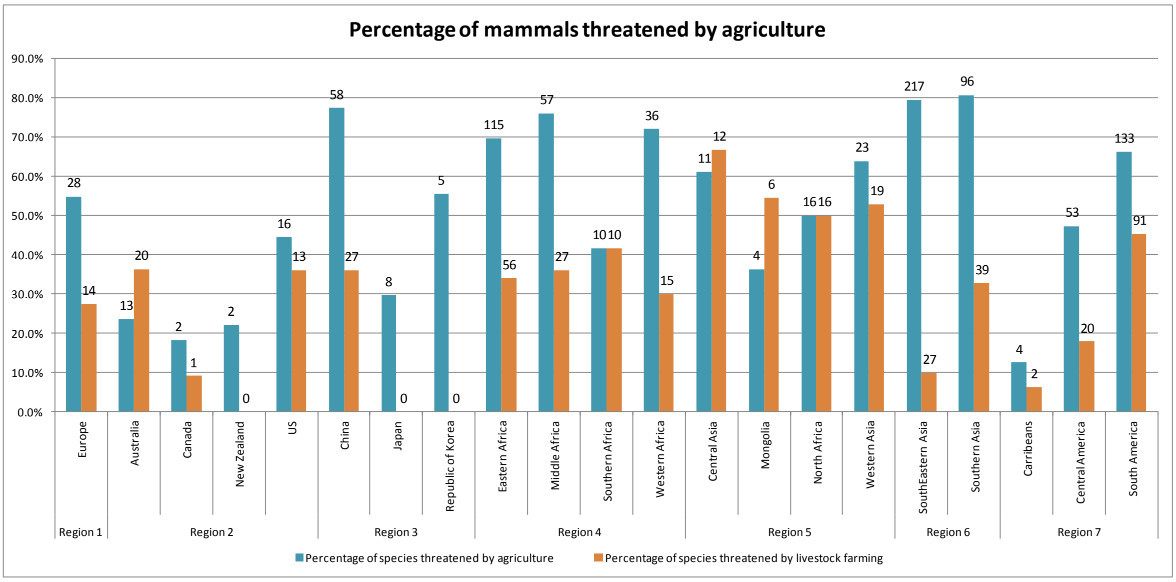

Figure 100: Percentage of Red List species of Mammals that are threatened by agriculture: crop production and livestock farming (the number of threatened species is indicated above the bars).

Average change in MTI since 1950 in each world region

The mean trophic level has been globally declining since 1950 (see Figure 101 to Figure 107). However, the decline is happening at very different rates in different seas. Forty four seas have witnessed a decline in their MTI since 1950, in most cases significant (in 40 seas). Several seas are typical examples of fishing down the foodweb (Pauly 1998). The Humboldt current is a highly productive LME which supports the world's largest fisheries. Its MTI plummeted as soon as fisheries of anchoveta (a low trophic level species) took off in the late 1950s. Similarly, since the 1990s the MTI has been declining in the Newfoundland Labrador shelf as the cod stock began to collapse. Other seas are simply not very productive and species poor in terms of fish fauna (e.g. Kara sea). Some declines are more difficult to interpret and may be due to misreporting in the underlying catch statistics (e.g. over-reporting of catches, by including catches outside the LME, as might be the case in the Yellow sea).

Some LMEs, such as the Mediterranean sea, the Gulf of California and Mexico or the Norwegian sea show more stable trends over time. For instance in the Mediterranean sea, the MTI has increased until the mid 1980s and declined since the mid-1990s, as the expansion of offshore fisheries ceased. Substantial fishing down has occurred and demersal populations are constantly overfished (Pauly 1998), however very few stocks appear to have collapsed[41].

In contrast, twenty seas have seen an increase in their MTI since 1950, although this increase was significant in only 14 of these. However, increases in MTI may mask biodiversity declines. For instance, in the Agulhas current, the sharp increase in mean trophic level since the 1970s reflects the collapse of low trophic level species, the pilchard and anchovies fisheries[41]. In the Gulf of Thailand, poor taxonomic details on the landings data are likely biasing the statistics. Other increases may highlight a shift in resource use. For instance in the New Zealand shelf the mean trophic level of reported landings has been on the rise since the mid-1970 probably due to the development of previously under-utilised high trophic fisheries resources[41]. The majority of reported landings are supplied by stocks described as "fully exploited". In the Red sea or the East Brazil Shelf the mean trophic level has increased relatively steadily in recent years. In these two LMEs, fishing occurs mainly at the subsistence or artisanal levels, although there is also commercial fishing of some species (e.g. lobster). But while in the East Brazil shelf 70% of commercially exploited stocks are over-exploited or collapsed, the fisheries of the Red Sea are still expanding and sustainability is not at stake.

At a regional level, the trends are generally similar. Most regions show significant declines in average MTI since 1950. Developing regions with few seas (Regions 4, 5 and 6) show relatively stable or positive trends in MTI, probably reflecting the fact that fishing still occurs mainly for subsistence in these areas. In contrast, more developed regions with the greatest diversity of seas (Regions 1, 2 and 3) show many declining trends in MTI, reflecting the importance of commercial fisheries and their impacts on the food webs. Some of these regions (Regions 1,2 and also Region 7) also show a number of stable or increasing trends in MTI values, that may in some cases reflect the uptake of more sustainable practices, but also mask some biodiversity declines.

[41] http://www.lme.noaa.gov

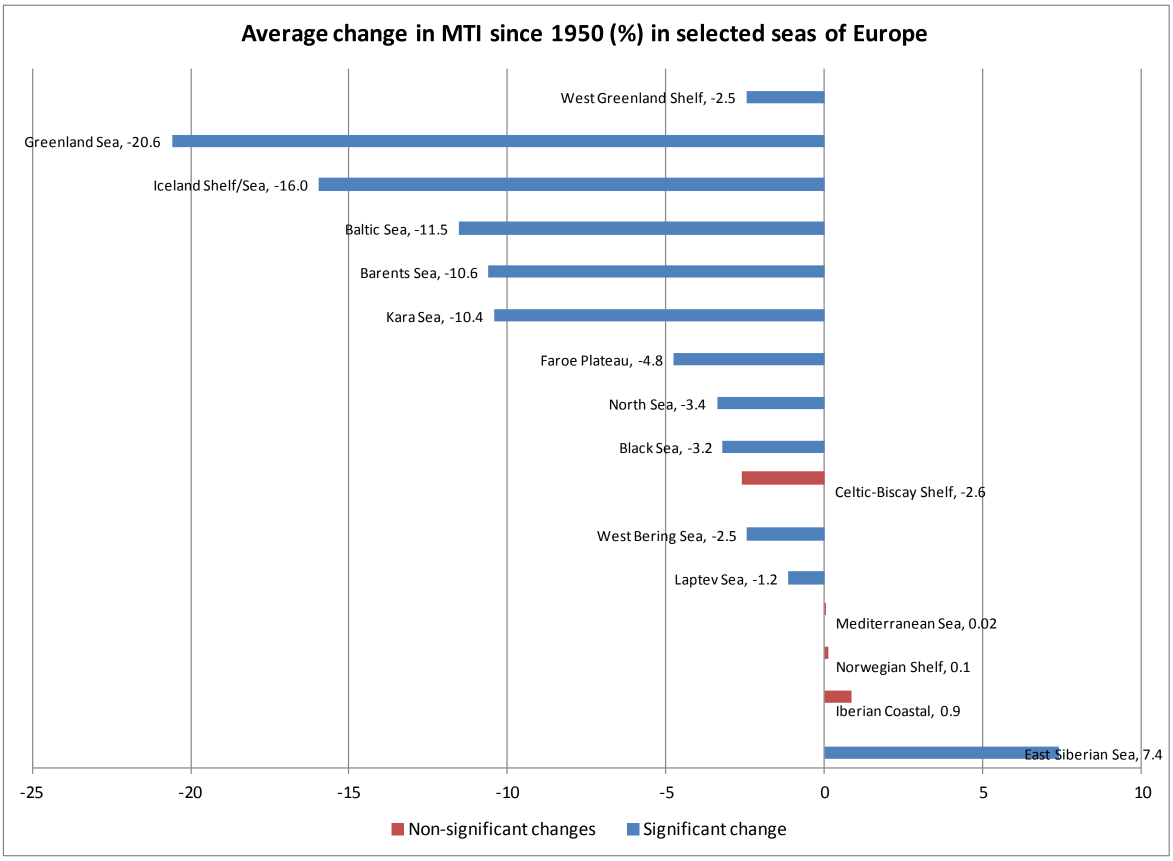

Figure 101: Average change in mean trophic level since 1950 in selected LMEs of Europe (Region 1). The percent change is indicated next to the bars, blue bars represent significant changes while red bars represent non significant changes.

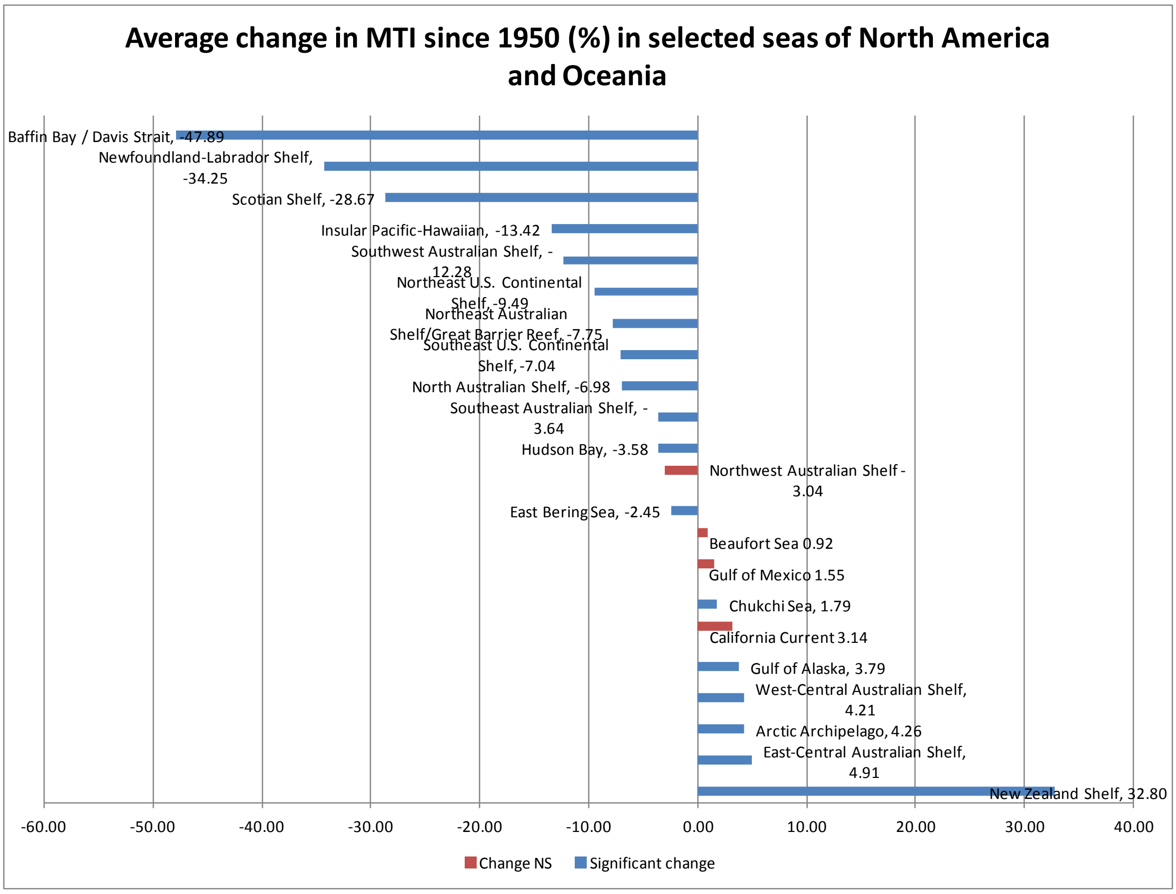

Figure 102: Average change in mean trophic level since 1950 in selected LMEs of North America & Oceania (Region 2). The percent change is indicated next to the bars, blue bars represent significant changes while red bars represent non significant changes.

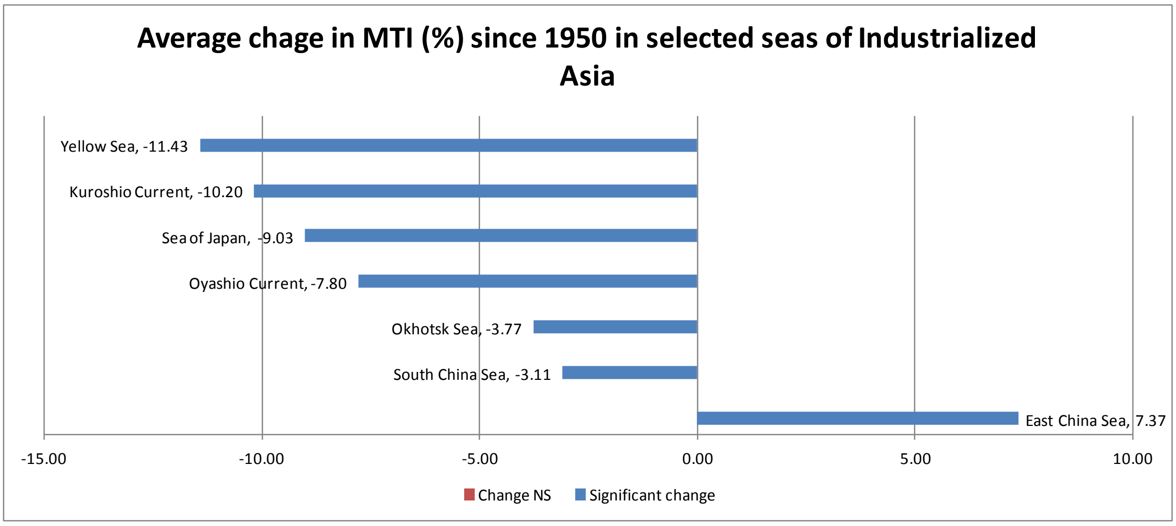

Figure 103: Average change in mean trophic level since 1950 in selected LMEs of Industrialised Asia (Region 3). The percent change is indicated next to the bars, blue bars represent significant changes while red bars represent non significant changes.

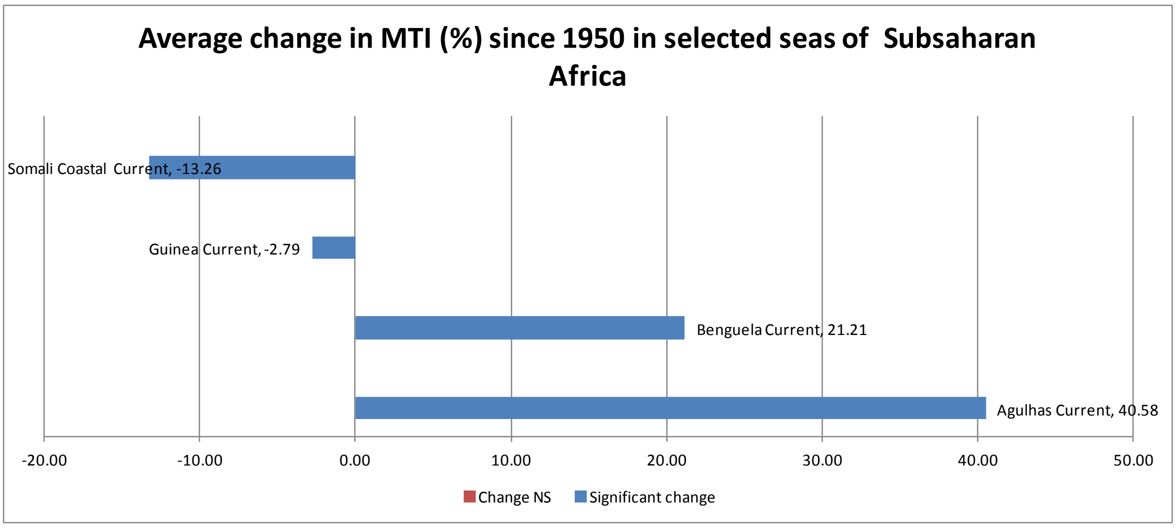

Figure 104: Average change in mean trophic level since 1950 in selected LMEs of Subsaharan Africa (Region 4). The percent change is indicated next to the bars, blue bars represent significant changes while red bars represent non significant changes.

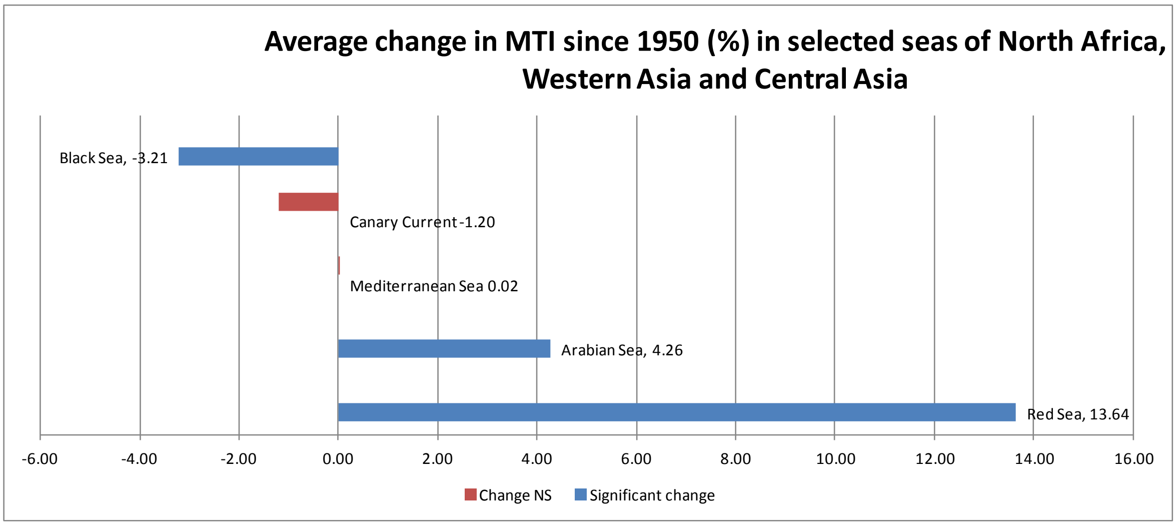

Figure 105: Average change in mean trophic level since 1950 in selected LMEs of North Africa, Western and Central Asia (Region 5). The percent change is indicated next to the bars, blue bars represent significant changes while red bars represent non significant changes.

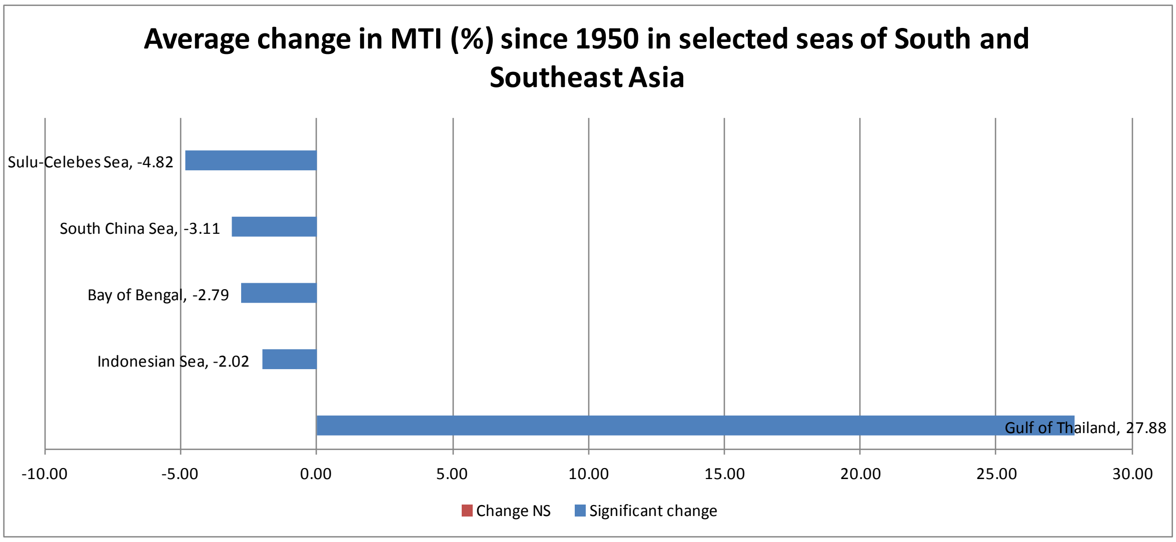

Figure 106: Average change in mean trophic level since 1950 in selected LMEs of South and Southeast Asia (Region 6). The percent change is indicated next to the bars, blue bars represent significant changes while red bars represent non significant changes.

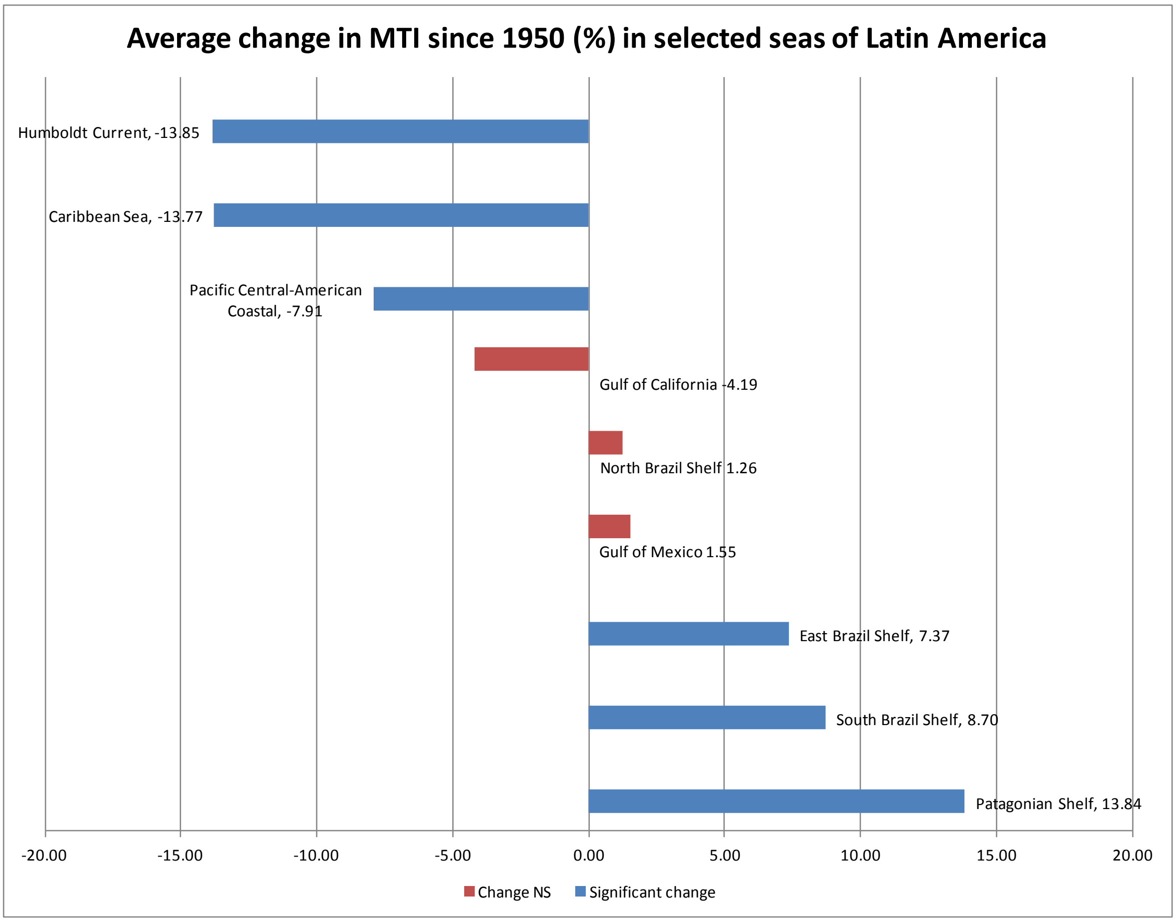

Figure 107: Average change in mean trophic level since 1950 in selected LMEs of Latin America (Region 7). The percent change is indicated next to the bars, blue bars represent significant changes while red bars represent non significant changes.

4.5.2 Highlights

4.6 Component 6: Economic assessment results

This section presents the FWF model results of the economic assessment of food wastage.

4.6.1 Results overview

At world level, the economic cost – based on the 2009 producer prices – of the total amount of food wastage in 2007 is about 750 billion USD. In order to illustrate the order of magnitude of this amount, the blue water footprint of food wastage can be compared to the GDP of most developed countries (Figure 108).

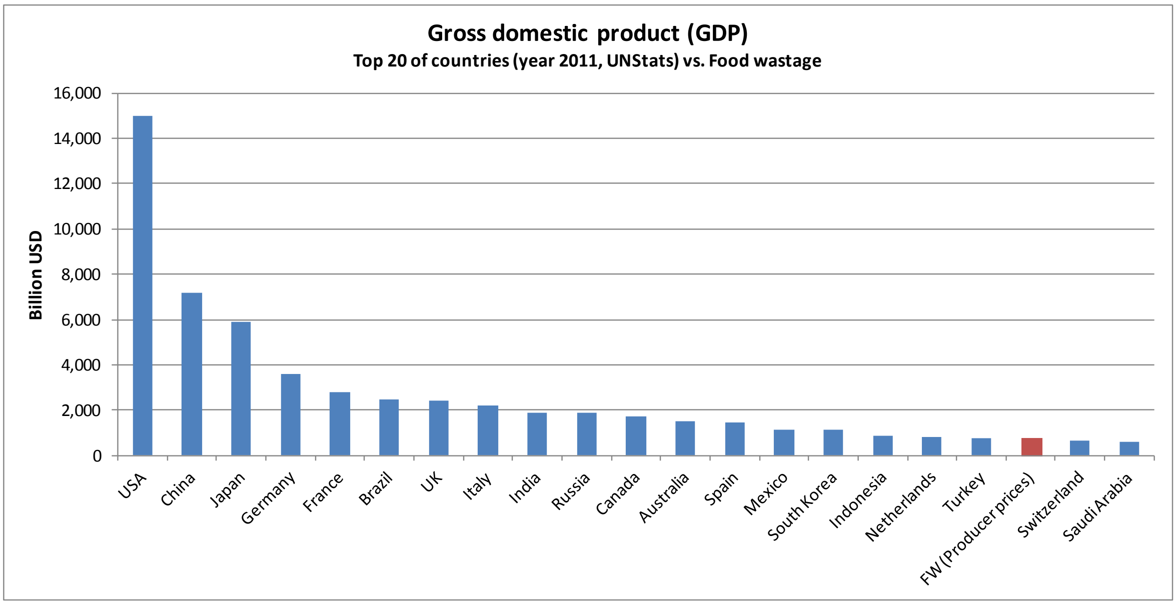

Figure 108: Top 20 of countries GDP vs. Food wastage (Source UNStats 2012)

4.6.2 Analyses by commodity and region

In the two following sections, this cost of 750 billion USD is further broken down by commodity and region.

Analysis by commodity

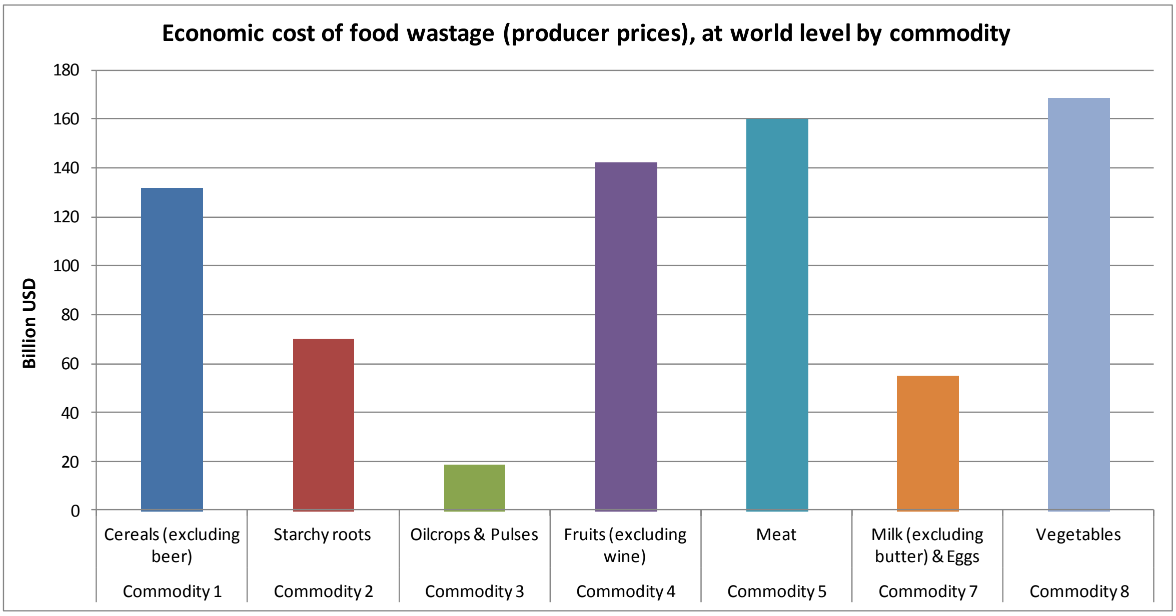

Figure 109: Economic cost of food wastage, at world level by commodity

Figure 109 and Figure 110 show that the major contributors to the economic cost of food wastage are vegetables (23% of total cost), meat (21%), fruits (19%), and cereals (18%).

As regards meat, this contribution to the total cost of food wastage is visibly driven by a high producer cost per kg of meat. Indeed meat accounts for about 4 %[42] of total food wastage but for about 20% of total economic costs of this wastage. For cereals on the other hand, the contribution to total cost is mostly driven by high food wastage volumes. For fruits and vegetables, prices and volumes have a balanced contribution but it appears that average producer prices are higher for fruits.

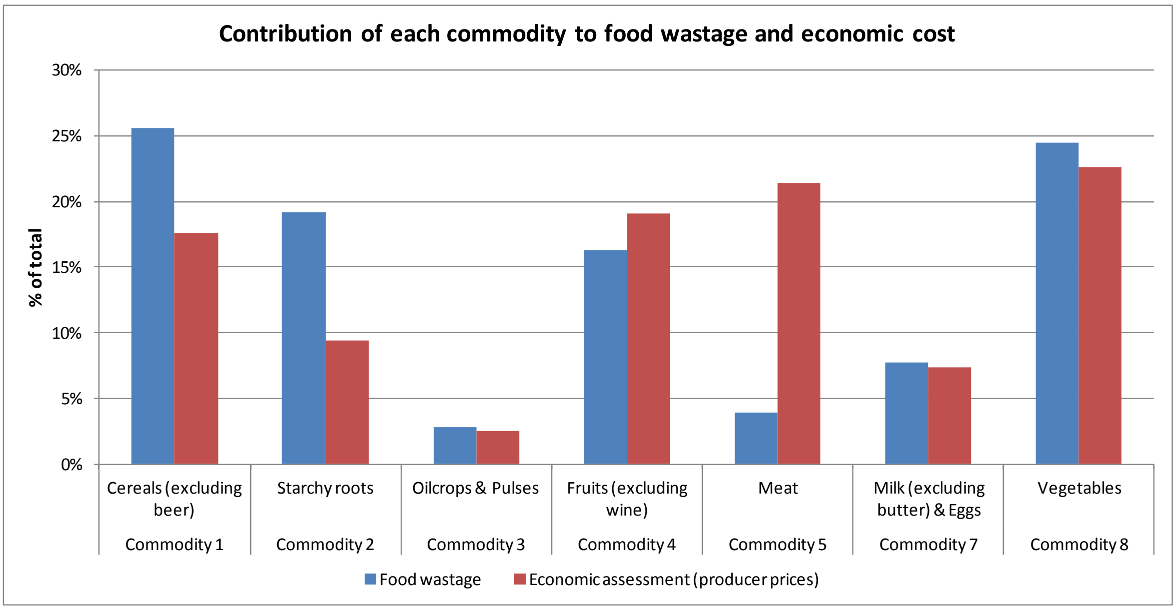

Figure 110: Contribution of each commodity to food wastage and economic cost

[42] Excluding fish & seafood to allow a comparison on the same grounds

Analysis by region

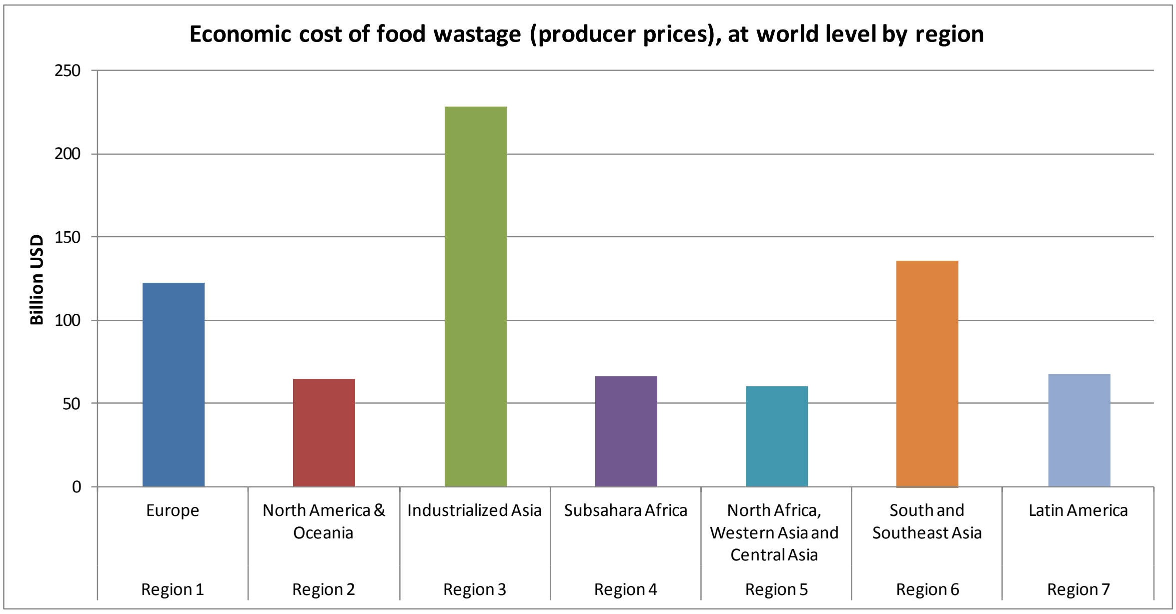

Figure 111: Economic cost of food wastage, at world level by region

The overall pattern presented in Figure 111, is quite similar to Figure 28. In other words, food wastage volumes and economic cost have relatively comparable profiles, in terms of regional distribution (as shown in Figure 112). Figure 112 shows that the major contributors are industrialized Asia (31% of total) and South and Southeast Asia (18%), two regions that are also the largest contributors to food wastage volumes.

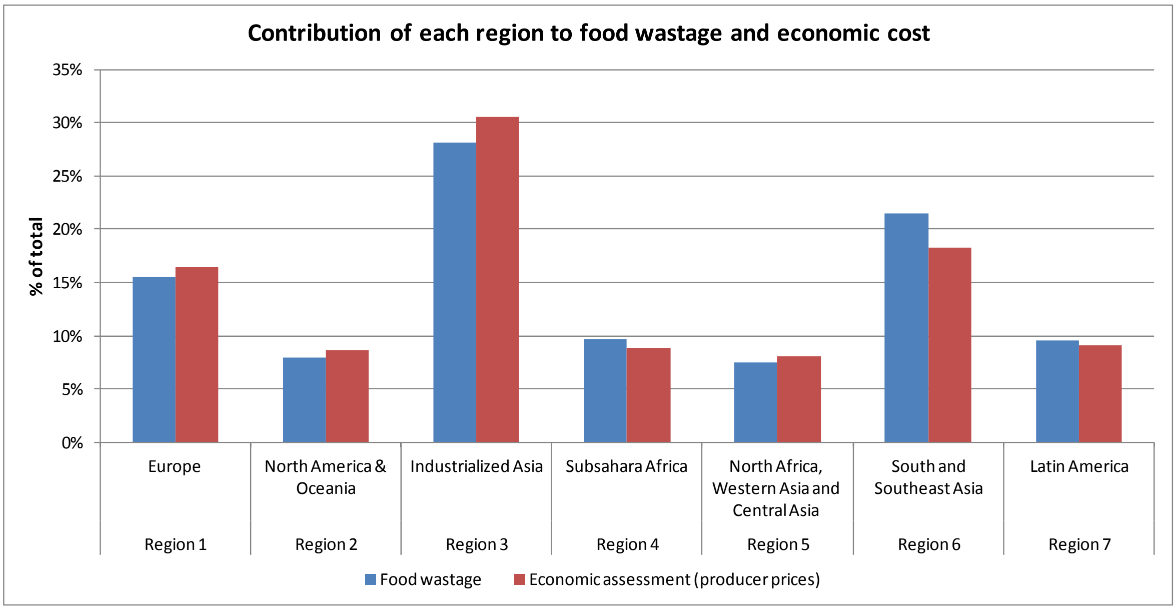

Figure 112: Contribution of each region to food wastage and economic cost

Further details can be seen in Figure 113 and Figure 114 in next section.

4.6.3 Regional profiles

In this section, the economic cost of food wastage in each region (as shown in Figure 111) is further disaggregated by commodity groups. For each region, a particular profile is obtained.

Regional profiles – Commodity groups view

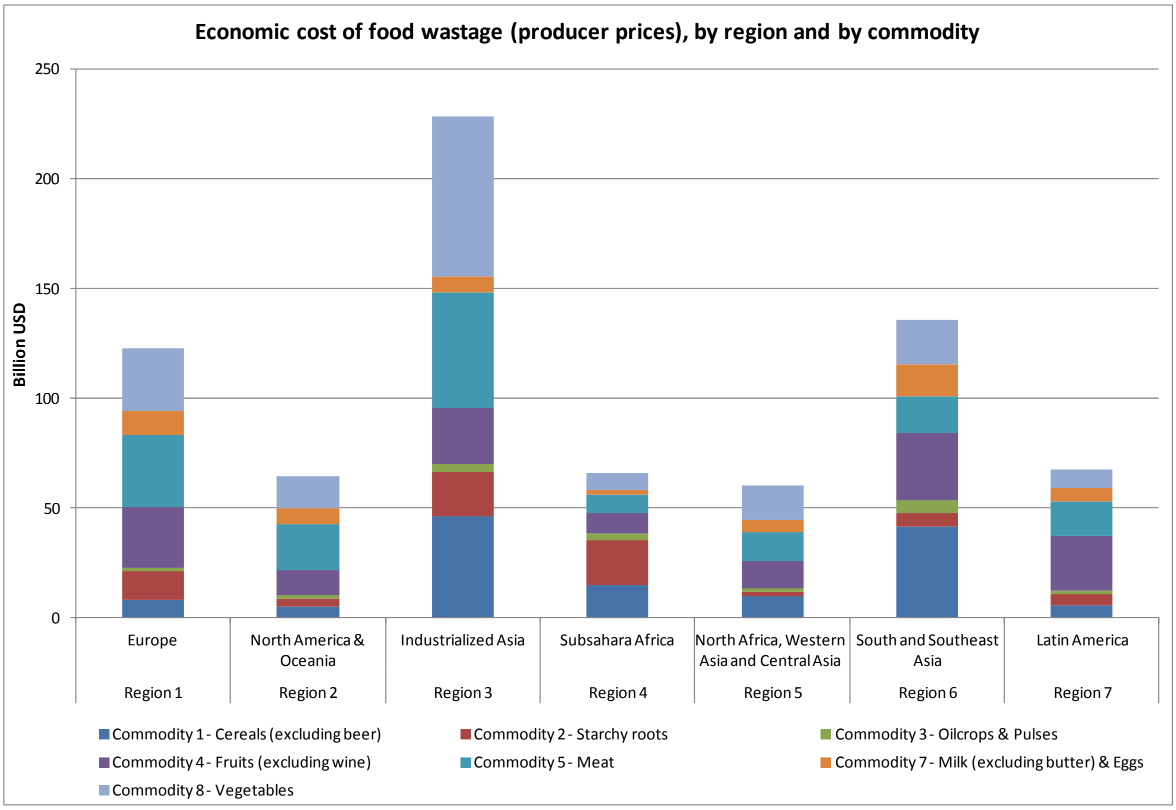

Figure 113: Economic cost of food wastage, by region and by commodity

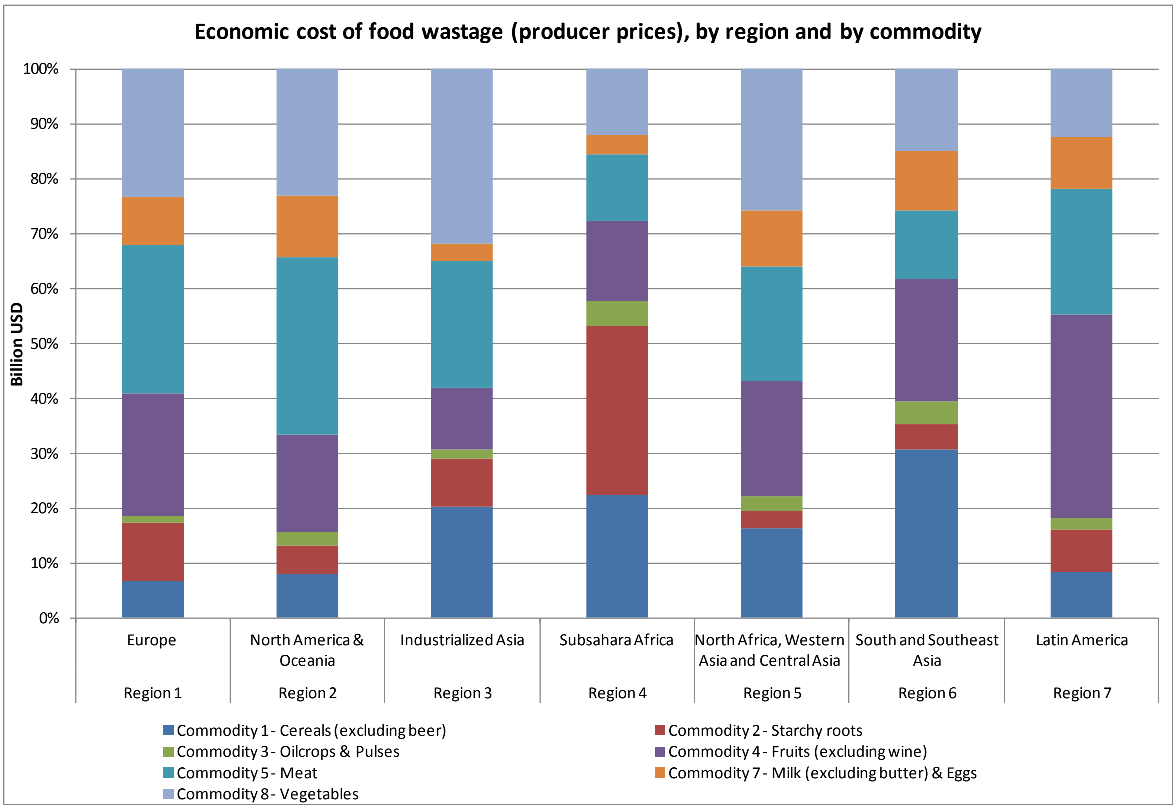

Figure 114: Relative economic cost of food wastage, by region and by commodity

4.6.4 Highlights

Box 22: Highlights for component 6 – Economic assessment results

- The global economic cost – based on the 2009 producer prices – of the total amount of food wastage in 2007 is about 750 billion USD. This amount is close to Turkey or Switzerland GDP.
- The major contributors to the economic cost of food wastage are vegetables (23% of total cost), meat (21%), fruits (19%) and cereals (18%). As regards meat, this contribution to the total cost of food wastage is clearly driven by a high producer cost per kg of meat. For cereals, the contribution to total cost is mostly driven by high food wastage volumes. For fruits and vegetables, prices and volumes have a balanced contribution.
- In terms of regional distribution, the major contributors are industrialized Asia (31% of total) and South and Southeast Asia (18%), two regions that are also the largest contributors to food wastage volumes.

4.7 Cross analysis of all environmental components

Table 10 presents a cross analysis of all quantifiable environmental components. All the region*commodity pairs that appeared in the top 10 for carbon, blue water or land occupation (arable or non-arable) are presented hereafter with their contribution to total food wastage.

Table 10: Cross analysis of all environmental components – "Region * Commodity" pairs

Region * commodity	Volume		Carbon		Blue water		Arable		Non-arable land	
Ind. Asia * Veg.	11.2%	1	10.0%	3						
Ind. Asia * Cereals	7.8%	2	14.4%	1	13.2%	2	5.4%	5		
S&SE Asia * Cereals	7.8%	3	11.1%	2	24.2%	1	9.3%	2		
SSA * SR	5.3%	4								
Ind. Asia * SR	4.5%	5								
Europe * SR	4.0%	6								
S&SE Asia * Veg.	3.9%	7	2.8%	10						
S&SE Asia * Fruits	3.6%	8			4.5%	4				
LA * Fruits	3.4%	9			3.3%	6				
Europe * Cereals	3.3%	10	3.3%	9						
Europe * Veg.	3.1%		4.2%	8						
NA,WA&CA * Veg.	2.7%				2.7%	10				
Ind. Asia * Fruits	2.7%				3.2%	7				
Europe * Fruits	2.6%				3.0%	9				
Europe * Meat & Milk	2.3%		5.2%	5			5.1%	7		
S&SE Asia * Meat & Milk	2.3%				3.4%	5	5.4%	4	16.7%	2
NA,WA&CA * Cereals	2.0%				7.8%	3	3.8%	8		
NA&Oce * Meat & Milk	2.0%		5.2%	6			3.7%	10	8.4%	5
LA * Meat & Milk	1.5%		4.9%	7			6.9%	3		
Ind. Asia * Meat & Milk	1.5%		5.3%	4			11.5%	1	11.3%	4
S&SE Asia * O&P	1.3%				3.2%	8				
SSA * Cereals	1.3%						3.7%	9		
NA,WA&CA * Meat & Milk	0.9%								33.2%	1
SSA * Meat & Milk	0.5%						5.4%	6	13.1%	3
Total top 10	**55%**		**64%**		**68%**		**60%**		**83%**	

Firstly, it can be noted that the wastage of cereals in Asia is a first level environmental hotspot because of its major impacts on carbon, blue water, and arable land. Secondly, meat & milk have noticeable impacts for land occupation (especially for non-arable land in low-income regions) and for carbon (especially in high-income regions). Thirdly, fruits and vegetables are hotspots in terms of blue water footprint; and in some regions, vegetables can contribute significantly to carbon footprint.

For further analysis, the results presented in Table 10 have been organised by commodity in Table 12 and by region in Table 11.

Table 11: Cross analysis of all environmental components – Regions

Region	Commodity	Volume		Carbon		Blue water		Arable		Non-arable	
Europe	Cereals	3.3%	10	3.3%	9						
	SR	4.0%	6								
	Fruits	2.6%				3.0%	9				
	Meat & Milk	2.3%		5.2%	5			5.1%	7		
	Veg.	3.1%		4.2%	8						
North America & Oceania	Meat & Milk	2.0%		5.2%	6			3.7%	10	8.4%	5
Industrialized Asia	Cereals	7.8%	2	14.4%	1	13.2%	2	5.4%	5		
	SR	4.5%	5								
	Fruits	2.7%				3.2%	7				
	Meat & Milk	1.5%		5.3%	4			11.5%	1	11.3%	4
	Veg.	11.2%	1	10.0%	3						
Sub-Saharan Africa	Cereals	1.3%						3.7%	9		
	SR	5.3%	4								
	Meat & Milk	0.5%						5.4%	6	13.1%	3
North Africa, Western Asia and Central Asia	Cereals	2.0%				7.8%	3	3.8%	8		
	Meat & Milk	0.9%								33.2%	1
	Veg.	2.7%				2.7%	10				
South and Southeast Asia	Cereals	7.8%	3	11.1%	2	24.2%	1	9.3%	2		
	O&P	1.3%				3.2%	8				
	Fruits	3.6%	8			4.5%	4				
	Meat & Milk	2.3%				3.4%	5	5.4%	4	16.7%	2
	Veg.	3.9%	7	2.8%	10						
Latin America	Fruits	3.4%	9			3.3%	6				
	Meat & Milk	1.5%		4.9%	7			6.9%	3		
	Total top 10	55%		64%		68%		60%		83%	

Table 12: Cross analysis of all environmental components – Commodities

Commodity	Region	Volume		Carbon		Blue water		Arable		Non-arable land	
Cereals (excluding beer)	Europe	3.3%	10	3.3%	9						
	Ind. Asia	7.8%	2	14.4%	1	13.2%	2	5.4%	5		
	SSA	1.3%						3.7%	9		
	NA,WA&CA	2.0%				7.8%	3	3.8%	8		
	S&SE Asia	7.8%	3	11.1%	2	24.2%	1	9.3%	2		
Starchy roots	Europe	4.0%	6								
	Ind. Asia	4.5%	5								
	SSA	5.3%	4								
Oilcrops & Pulses	S&SE Asia	1.3%				3.2%	8				
Fruits (excluding wine)	Europe	2.6%				3.0%	9				
	Ind. Asia	2.7%				3.2%	7				
	S&SE Asia	3.6%	8			4.5%	4				
	LA	3.4%	9			3.3%	6				
Meat & Milk	Europe	2.3%		5.2%	5			5.1%	7		
	NA&Oce	2.0%		5.2%	6			3.7%	10	8.4%	5
	Ind. Asia	1.5%		5.3%	4			11.5%	1	11.3%	4
	SSA	0.5%						5.4%	6	13.1%	3
	NA,WA&CA	0.9%								33.2%	1
	S&SE Asia	2.3%				3.4%	5	5.4%	4	16.7%	2
	LA	1.5%		4.9%	7			6.9%	3		
Vegetables	Europe	3.1%		4.2%	8						
	Ind. Asia	11.2%	1	10.0%	3						
	NA,WA&CA	2.7%				2.7%	10				
	S&SE Asia	3.9%	7	2.8%	10						
	Total top 10	55%		64%		68%		60%		83%	

Wastage of cereals in Ind. Asia and S&SE Asia is a major contributor to impacts on carbon, blue water and arable land components. The main contributing crops to such impacts are rice and wheat. Note that for the carbon footprint rice dominates. Rice is a CH_4-emitting crop because of the decomposition of organic matter in flooded paddy fields and thus has higher impact factors compared to other cereals. This mostly explains why wastage of cereals is carbon-intensive in Asia. Regarding land occupation and water footprint, the respective roles of wheat and rice are more balanced. Note that for the water footprint two sub-regions stand out: in S&SE Asia the water footprint of cereals primarily comes from the sub-region Southern Asia (because of India) and In Ind. Asia, it is because of China.

It can be seen that in terms of volume, cereals wastage is quite similar in Ind. Asia and S&SE Asia whereas some differences can be observed in the magnitude of the impacts. Indeed, the overall carbon footprint of cereals is higher in Ind. Asia. A key reason for this is that more cereals are wasted at the consumption phase than in S&SE Asia. Conversely, impacts tend to be lower for the water footprint and land occupation in Ind. Asia. In this case, it results from the fact that rice and wheat yields are higher on average in Ind. Asia, leading to less land occupied for the same production. Impacts factors for blue water are smaller in Ind. Asia (particularly in China) compared to impact factors in Southern Asia which is the sub-region responsible for most of the water impacts of the region S&SE Asia.

Even though the amounts of wasted/lost meat & milk remain relatively limited in all regions, wastage of this commodity has noticeable impacts because of its high land occupation and carbon intensity compared to crops. Meat is a carbon hotspot in high-income regions and Latin America. All these regions are in the top 10 of "region * commodity" pairs for carbon footprint because of meat. This is mostly because in absolute terms more meat is produced, consumed and wasted (in particular at consumption phase) in high-income regions and LA (80% of meat wastage for these regions) compared to other low-income regions, which do not appear in the top 10. As regards land occupation, the observed variability across regions for the contribution of arable or non-arable land is due to differences in production systems (composition of feeding rations, amount of land required to produce the constituents of the ration).

Wastage of fruits appears as a blue water footprint hotspot in Asia, LA and Europe. This seems to be more linked to food wastage volumes than to the blue water intensity of the commodity. Note that this commodity includes a wide range of products. Due to data format constraints, the "fruits, other" sub-commodity cannot be further broken down to identify key crops.

In Ind. Asia, Europe and S&SE Asia, vegetables can be considered as a second level contributor to the carbon footprint of food wastage. Note that overall the carbon footprint of this commodity is mostly driven by volumes rather than impact factors (75% of total vegetable wastage occur in these regions). Nevertheless, some differences in terms of carbon intensity can be noticed between regions. For instance, it is likely that the carbon intensity of vegetables wastage is higher in Europe due to the fact that a higher share of vegetables are grown in heated greenhouses. Note that some assumptions had to be made on these aspects and comparisons between regions should be made carefully.

Finally, it can be mentioned that starchy roots, although experiencing high volumes of wastage in SSA, Europe and Ind. Asia, is never appearing in impacts top 10. This commodity actually has low carbon, water and land intensity mostly because yields are high thus limiting the impacts per kg.

Link with biodiversity

As regards biodiversity, major impacts (current & future) are situated in the tropics. This zone of the world is a global biodiversity hotspot currently undergoing the most rapid agricultural expansion in recent years, and probably in years to come. The region*commodity pairs with greatest (current & future) impacts on biodiversity are, according to Gibbs et al. (2010):

*Central Africa * Crops (cassava, oil palm, rice, sugar cane)*

Throughout Africa, ca. 60% of new agricultural land came from intact forests, in particular in Central Africa, in the Congo basin (a biodiversity hotspot). The combined effect of increasing population densities (leading to the creation of roads and the fragmentation of habitats) and the extent of land with cultivation potential means that Congolian forests are under continued threat from deforestation (Phalan et al. 2013)

*Central & South America * Meat*

The greatest expansion of agricultural land in Latin America occurred for cattle pastures, which increased by ca. 42 million ha. Biodiversity will continue to decline in these rangeland ecosystems because of a combination of factors, including cropland expansion, habitat fragmentation and livestock grazing.

*Amazon basin * Crops*

This area is already the stage of a rapid and extensive deforestation. Given that legal protection for forests on private lands is likely to change in Brazil, further deforestation can be expected. Analyses suggest there is still land with good cultivation potential around the fringes of the Amazon Basin. Sugarcane and soybeans are responsible for the majority of changes in South America (e.g. soy is the main crop responsible for deforestation in the Mato Grosso hotspot). Cassava, rice, maize are the other important crops. Forest conversion dominated in dense humid regions but shrubland (e.g. cerrado) became increasingly important.

*Southern Asia * Crops*

Southern Asia depended mostly on disturbed forests for new land (ca 60%), whereas South East Asia relied on intact forests for nearly 60% of new agricultural land.

*Eastern Africa * Crops*

There are still small areas with high cultivation potential in the savannah woodlands of East Africa.

Chapter 5.Levers for food wastage volumes/impacts reduction

Food waste arises at all stages of the food supply chain for a variety of reasons that are very much dependent on the local conditions of each country. At global level however, a pattern is visible: in high-income regions, volumes of wasted/lost food are higher in downstream phases of the food chain, whereas in low-income regions the opposite trend is observed (see Figure 34 and Figure 35). In the developing world, there are indeed significant post-harvest losses in the early stages of the supply chain mostly because of the lack of storage and distribution infrastructures. In the most affluent societies, consumer behaviour plays a key role in the huge amount of food wasted at the end of the chain.

It should be stressed that this low-income/high-income distinction is not perfectly suited for rapidly developing countries such as BRICs and other emerging economies. In such regions, the difference lies in urban or rural settings. In fact, recent evidence suggests that consumer waste is increasing in the cities of China and Brazil, and in similar urban areas in Southeast Asia (RSIS Centre for Non-Traditional Security Studies 2013; Parfitt 2011). This trend comes along with major environmental and social implications and there is a high risk that these countries may be, in their transitional stage, even more wasteful than developed countries.

Most of the factors affecting food wastage relate to infrastructure, economic activity, level of education, rather than purely agronomic issues. In this context, it appears that identifying adequate levers for the reduction of food wastage requires a deep understanding of the linkage between pattern and scale of wastage and economic development stage. Therefore, in this chapter, causes of food wastage are presented in a first section for three broad categories of countries (adapted from IME 2013 and Parfitt 2011): developing countries, high-income countries and emerging countries. Secondly, potential levers for the reduction of food wastage volumes – and subsequently impacts – are presented and discussed in a final section.

5.1 Causes of food wastage

5.1.1 Developing countries

This group consists of developing countries that are beginning to industrialise. Such countries generally exhibit strong demographic growth and are characterised by a predominantly young age profile, such as in Africa. Major causes of food wastage in these countries are presented hereafter for each phase of the food supply chain.

Agricultural production

Food losses occurring during agricultural production are mostly related to climatic and environmental factors, the spread of disease, and the presence of parasites. The magnitude of these factors is variable depending on the products considered and agro-climatic conditions encountered in a given region (BCFN 2012).

It must be underlined that, all other things being equal, discrepancies in agronomic practices for preparing the soil, seeding, cultivation, and harvest can result in completely different yields. This is the reason for the significant gap in loss percentages that exist at this phase between developing and developed countries. More specifically, the key causes of food losses are:

Small-scale and labour-intensive agriculture often leading to inefficiencies:

- In developing countries, farmers often have limited technical, financial, and managerial resources. Therefore, most agricultural operations, including harvesting, are carried out manually. Generally, this is a slow process and frequently poor weather conditions or attacks by pests of all types reduce the quality or quantity of crop harvested, or may even destroy it entirely (IME 2013).
- Manual harvesting methods often involve the repeated handling of crops as they pass along poorly engineered transport infrastructure from field to farmyard, thus increasing the risk of damaging the product. This is typically the case of picked produce such as fruit and vegetables, which can be piled up in the field then loaded by hand into vehicles to be transported to the farmyard. Throughout the process, fruits and vegetables are often bruised or damaged. This generates loss or reduction in the shelf life of products (IME 2013).
- When it comes to animal production, a key issue in most of low-income countries is the mortality rate of animals during breeding. For instance, in rural meat production systems lack of feed or lack of pasture because of drought can lead to significant mortality. Calf mortality rates of almost 20% have been reported during the first year of age in Mali and Pakistan (Wymann et al. 2006; Z. U. Khan et al. 2007).

Premature harvests due to urgent need for food or income:

- In developing countries, poor farmers sometimes cannot wait for the crop to ripe because of a strong lack of food or revenue. This premature harvesting leads to a loss in terms of nutritional and economic value (FAO 2012c). Production may even be totally wasted if it is not suitable for consumption.

Postharvest handling and storage

A significant part of food wastage in developing countries occurs during postharvest handling and storage (FAO 2011a). Again, at this phase significant differences emerge between developed and developing countries. Many less-developed nations are located in warm and humid regions of the world; this complicates the handling of fresh food products without spoilage. Obviously, the lack of financial and technical resources also affects how products are managed at this phase. Key reasons for food losses at this phase are:

Poor storage facilities:

- Lack of proper storage facilities is a major cause of postharvest losses (FAO 2011a). In general terms, the vast majority of foodstuffs can be regarded as perishables. Ensuring adequate conditions for storing food generally requires well-controlled temperature, humidity, and oxygen level. If such conditions are not met, food is prone to deterioration by bacteria, fungi, and insects. In addition, rodents infestation can also be a critical issue (Rajendran 2002).

- Even though cereals such as wheat and maize can be stored for several years, they can deteriorate rapidly if they are not stored properly. For example, Ghana experienced in 2008 a 50% loss rate of stored maize from a total production of one million tonnes that year (WABS Consulting Ltd. 2008). In Pakistan, wheat losses amount to about 16% of production since inadequate storage infrastructure leads to widespread rodent infestation problems (IME 2013). A study conducted on maize storage in Zambia found that among surveyed farmers, almost all storage facilities were in a poor state, conducive to insect infestation and fungal contamination (Kankolongo et al. 2009).
- Root vegetables and tubers can be stored for several months under good conditions but in sub-Saharan Africa, as much as 79% of a stored tuber crop can be lost. Indeed, African farmers often have no dedicated storage facilities and instead traditionally keep potatoes on earthen floors in their mud and thatched huts. There the potatoes can be exposed to sunlight, which can lead to significant losses due to greening and sprouting, especially when doors are regularly opened and closed during the day (T. Stuart 2011).
- Soft fruit, leaf vegetables, fish, meat and dairy products are true perishables due to high nutrient and water content and can be stored only under closely controlled conditions. Fresh fish caught and sold in developing countries sometimes rot in the sun due to lack of infrastructure enabling quick transportation to markets or cooling facilities keeping newly caught fish fresh until sale (T. Stuart 2009). Regarding fruits, controlled atmosphere systems as well as temperature and humidity management are required to extend storage life (Thompson 2010). Storage facilities for fruit and vegetables indeed require engineered infrastructures of higher standard than grain crops. Developing countries, where post harvest losses of fruit and vegetables can range between 35–50% annually, lack such infrastructure (IME 2013).

Inadequate transportation systems:

- Agricultural products, especially horticultural crops are often fragile and need to be transported in an adequate way to reach markets, wholesalers, and retail stores undamaged.
- In developing countries, loss during transportation may come from the lack of proper transportation vehicles, poorly maintained roads, and absence of efficient logistical management that would allow proper conservation during transport. This often results in considerable postharvest losses of e.g. fresh fruit and vegetables due to mechanical damages during transportation (Rolle 2006).

Processing

Although processing activities may reduce food waste by extending the shelf life of food products through for example drying, fermentation and conservation, the necessary fresh food processing units are simply non-existent in many developing countries (M. M. Jowkar et al. 2005). In fact, in large parts of the developing world fresh fruit, vegetables, meat and fish are often sold at open markets through very short supply chains. Thus, primary food commodities are seldom processed or packaged (FAO 2011a).

Furthermore, when products are actually processed, the technology employed can be inadequate. Wastage derives mostly from technical malfunctions and inefficiencies in productive processes, leading to the rejection of wide batches of product. This may occurs to a greater extent in developing countries(BCFN 2012).

Distribution

In developing countries, waste can be attributed to the characteristics of the wholesale and retail markets, which are often small, overcrowded, with poor hygiene, and ineffectual refrigeration and storage equipment (Kader 2005).

An illustrative example is the main produce market of Colombo (Sri Lanka) where the Municipal Council discards some 11 tonnes of fruit and vegetables every day while thousands cannot afford to buy enough fresh food for a proper diet (Institute of Post Harvest Technology 2002).

Consumption

Compared to consumers in developed countries, consumers in developing countries waste less food (FAO 2011a). In low-income countries the share of food in the household budget is close to 50% in average (Muhammad et al. 2011). Obviously, limited income puts a lot of strain on families and individuals, making it unaffordable to waste food. Another aspect is that consumers in developing countries generally have a "buy today, eat today" food culture (Parfitt et al. 2010). They buy smaller amounts of fresh food products at the time, most likely reasons for this being limited purchasing power and no refrigeration appliances at home.

5.1.2 High-income countries

This category encompasses fully developed, mature, industrial and post-industrial societies, such as those in North America, Europe and Industrialized Asia, characterised by stable or declining populations that are increasing in age.

Agricultural production

While agricultural technologies and practices enable efficient food production in high-income countries, significant food loss and waste do however also occur early in the food supply chain for a variety of reasons.

Low market prices:

- Fluctuations in commodity prices can have a significant impact on wastage during the agricultural phase. This may indeed be considered as waste rather than loss in situations where low market prices for crops mean that the cost of harvesting them is higher than their sale value. This results in crops being left in the field. This problem worsens in years of high supply and thus low market value (Milepost 2012).
- Another factor that can make harvesting unprofitable is the cost of refrigeration and storage. Keeping products in good condition before delivery to consumer in years of low crop market value becomes less evident, also decreasing the incentive to deliver goods to redistribution channels such as foodbanks, which present their own logistical challenges (Milepost 2012).

Over-production:

- The difficulty in anticipating demand is such that it is common to grow a surplus rather than risk not being able to fulfil orders, and thus potentially lose clients (FAO 2011a). In agreements between producers and large-scale purchasers of the retail sector, penalties can be imposed for failure to deliver agreed quantities of fresh fruit and vegetables during the year (IME 2013). Planting and growing more than is expected to be sold thus provides a buffer for farmers, in which waste is expected and built into costs. This can also help mitigate weather conditions, which can strongly impact annual yields because of e.g. timing of harvest being not optimal (Smil 2004).

Postharvest handling and storage

Losses during postharvest activities are largely dependent on available technique, making them rather small in medium and high income countries (FAO 2011a).

Another issue encountered in developed countries relates to contracts with purchasers (mainly retailers) that enable orders to be cancelled without adequate warning, either based on changes in retailer stock needs or because aesthetic standards such as the colour or size are not met for fruits and vegetables for example, leading to waste of stored products.

Processing

Food waste is widely considered to be minimised in this sector, centring on technical malfunctions leading to product or packaging damage, or on by-products of products such as meat trimmings, for which no other purpose has been sought. However, less publicly available research has been conducted on this sector and thus quantities and causes are comparatively less well known. Nevertheless, problems at processing level that affect product safety can lead to whole batches of product being discarded as a security precaution, and impacts can be voluminous. The dioxin scandal in Germany in 2011 attests to the widespread food waste impact across nations when a safety alert is instigated, as does the foot-and-mouth disease crisis in the UK in 2001.

Distribution

Waste at the distribution level can be explained through the following reasons.

Stock management:

- Stock management is a key issue affecting food waste in this sector. Difficulties anticipating demand can lead to a shift of surplus stock to suppliers, or to customers through discounting. An inacceptance of empty shelves for fear that customers may patronise a competitor next time is often cited, although evidence for this fear is lacking.

Quality standards:

- Quality standards impact both how retailers manage orders with their suppliers and how they manage stock within stores, where standards of perfection and freshness may be higher than necessary.

Limited redistribution of food:

- Food waste linked to the distribution sector can be mitigated through redistribution of unsalable foodstuffs to foodbanks and other agents. While retailers communicate on this redistribution, it often represents a very small fraction of their waste and significant improvements are possible here. Retailers resistance to gleaners who collect discarded food results in the often literal locking of food in trash bins (or its voluntary destruction) where people are actively seeking to eat it.
- A significant barrier to food redistribution is the issue of the donor's liability in the event of food poisoning. In various countries, measures such as the Good Samaritan Food Donation Act in the US have been implemented to circumvent this issue.

Consumption

Causes of food waste among consumers, whether in the home or in the food service sector, are particularly diverse:

Labelling issues are frequently cited, "display until" dates used by supermarkets being a high profile source of confusion that is easily remedied. Best before dates continue to be considered interchangeably with "use by" dates by consumers, the difference of focus on quality and safety being poorly understood (BIO IS 2010; IME 2013; BCFN 2012).

Storage can also contribute, notably as regards fresh produce that are particularly temperature sensitive (refrigerators sometimes being too cold as well as too warm for specific vegetables).

Packaging impacts the longevity of food products in the household, and inadequate or inappropriate packaging can exacerbate food waste, particularly its role in maintaining freshness. A limited range of portion sizes can also be a factor, as increasing numbers of single person households are not able to finish products in time after opening large packages.

Planning is also a factor, as modern lifestyles reduce the predictability of mealtimes, and as farmers oversupply in the field, households overbuy food for their kitchens, so that food never runs out even if they find themselves eating at home more than expected.

Along with a lack of awareness of the impacts of food waste both on the environment and on global food prices and hunger, a prevalence of the attitude that food is cheap and therefore waste unimportant contributes to the problem. The frequently cited dictum that "I don't waste food" is also an issue: consumers must be aware of the waste they generate before they are motivated to change their habits and attitudes.

In the food service sector, portion size is a leading cause of food waste. Flexible portion sizes allow customers of varying appetites to clean their plates.

5.1.3 Emerging countries

This group refers to the rapidly developing BRIC[43] countries as well as other emerging economies, located for instance in Southeast Asia (e.g. Indonesia, Philippines, Vietnam). The BRIC countries contain 40% of the world's population and have undergone rapid economic growth in recent years.

In the case of emerging countries, the usual distinction between developed countries with wastage in downstream phases of the FSC and low-income countries with wastage in upstream phases is less relevant. It overlooks worldwide trends of growing urbanisation and rising living standard that have lead to rapid transformation of FSCs with important implications on the amount of food losses and waste (T. Reardon et al. 2005).

The increasing urbanization in developing countries has resulted in the progressive lengthening of the agribusiness supply chain in order to satisfy the food requirements of the urban population. Food is transported longer distances between the place of production and that of final consumption. Agricultural production is often perishable and needs to be transported in an adequate way to reach markets, wholesalers and retail stores undamaged. The lack of proper infrastructure and transportation vehicles therefore often results in considerable postharvest losses of e.g. fresh fruit and vegetables due to mechanical damages during transportation (Rolle 2006). There is a need to improve transportation, storage, and sale infrastructure to avoid additional losses.

A second factor is the rapidly changing diets of those living in emerging countries, which is associated with an increase in available income. This phenomenon presents a particular food wastage challenge in BRICs where consumers are increasingly eating more perishable products such as meat, fish, fruits and vegetables instead of starchy diets.

As a reflection of this, supermarkets have expanded in many emerging countries to provide for these diversified diets demanded by growing urban populations. In addition, the need for higher quality products and safety standards for consumers in these markets, and the increase in the variety of food products sold, may well impact the level of waste generated.

Within this context, as the economies and food supply chains of emerging countries develop and evolve to meet the changing dietary needs of an increasingly urbanised population, there is a high risk that emerging countries will encounter the same food waste problems as currently experienced by high-income countries. It is also possible that their food supply chains will be even more wasteful during this transitional stage, due to poor infrastructure and management. Therefore, a specific challenge for emerging countries is to learn from the mistakes of the developed countries and avoid shifting from one wasteful pattern to another.

[43] Brazil, Russia, India, China

5.2 Levers for volumes/impacts reduction[44]

International organisations (FAO, UNEP)

Awareness is a key element. In addressing the agricultural phase of wastage for example, it is important to educate consumers about the impact that purchasing only perfect produce may have on the price of produce for farmers and on the wastage of produce that does not meet perceived quality standards.

Policy-makers

It has been shown that in developing countries, even relatively modest technical improvements can reduce crop losses significantly (Parfitt et al. 2010). Governments could be involved in the funding of such projects. Governments can also initiate educational activities with the help of research centres and NGOs such as for example, spreading information to farmers on efficient harvesting and crop protection techniques.

Having well-established and maintained infrastructure in the form of e.g. roads and railways is essential to prevent deterioration of fragile food products. Countrywide measures to improve the transportation infrastructure are required in many parts of developing countries, such as wider roads, upgraded surfaces and introduction of one-way traffic. Improved handling during on and off loading to reduce waiting times is also needed as well as national programs to develop cold chain systems. These measures would make transportation of fresh food products less damaging and time intensive.

In developed countries, national governments can provide incentives for redistribution to farmers, food manufacturers, retailers and the food service sector. For example, in California, a 10% tax credit for farmers on food donations is available. Reducing barriers to redistribution is also critical, for example by protecting food donors and foodbanks from civil and criminal liability for food donated in good faith. Bans or increased levies on bio-waste sent to landfill, as implemented in the Republic of Ireland, can also be an effective policy measure, by making it more expensive to businesses to send food waste to landfill and thus making more efficient management options more financially sound.

In the distribution chain, policy-makers can incentivize more reliable sales forecasting, and thus reduce the need to perennially oversupply, by providing guidance or regulation on purchasing contracts between supply chain actors. Quality standards for example, that can lead to the wastage of important tonnages of produce due to its size, shape, colour or other aesthetic attributes, may be reviewed and revised, perhaps using evidence that consumers are willing to purchase imperfect products. Clauses that give purchasers wide freedoms to refuse stock, whether based on quality standards or changes in their own needs, may need additional oversight by policymakers if significant wastage at the beginning of the supply chain in developed countries is to be addressed effectively.

Policymakers can also facilitate the transfer of otherwise wasted food to livestock feed, reducing legal barriers or providing incentives depending on the national context. Apples packed for shipping but unsold for example are much better off being fed to pigs than being sent to landfill:

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[44] For more detailed guidance, see FAO, 2013. Toolkit: Reducing the Food Wastage Footprint.

generating a combination of benefits including reduced landfill GHG emissions and increased availability of agricultural land for human crops if less is needed for animal feed.

Manufacturers and distribution

There is much room for innovation in using food that would otherwise be discarded in novel ways. An example may be a social enterprise producing apple juice from apples that would have been wasted at the major Rungis food market in Paris, but the possibilities and applications in the manufacturing, distribution and retail sector are limitless.

Packaging innovation is a promising avenue in reducing food waste. In developed countries manifold possibilities such as resealable packaging, packs easy to empty completely or a higher variety of portion sizes, could help to reduce food wastage at consumption phase. In developing countries, food is seldom packaged. More packaging during storage and transportation could reduce food waste throughout the food supply chain through better preservation of fresh food from dust and microbial contamination and thus extended shelf life.

Detailed storage instructions in order to help customers prolong the lifetime of products are also helpful, particularly for fruits and vegetables. Where these do not have packaging, in-store information can be helpful. Retailers can also contribute by removing "sell-by" dates from products, replacing these with codes that are incomprehensible to consumers. The avoidance of "buy one get one free" schemes, that can encourage customers to buy more than they need, is also helpful. Alternatives include for example Tesco's "Buy One Get One Free LATER" initiative.

Retailers also have an important potential role in customer education and awareness raising. Such actions may focus on for example how to use leftovers from given products or ingredients, or how produce, like people, are not identical and thus encouraging the acceptance of natural variation.

In the food service sector, the provision of flexible portion sizes is a major lever for waste prevention, be it by offering two serving sizes as does TGI Friday's or by providing self-service options where customers can adjust their portion to their appetite. A review of the way in which the food service sector handles portion sizes could be helpful, to consider the trade-off between smaller sizes and possible lower profits, and to suggest innovations in the delivery of flexible portions. Even mentioning the degree of one's appetite when ordering, as customers might mention allergies, could be a useful development if it were accompanied by awareness raising and social acceptance.

Chapter 6. Limitations of this study and potential improvement areas

This section provides a view on the main limitations of the study and related improvement areas.

Definition of food waste

The present study builds on the definition of food loss, food waste and food wastage from FAO's previous work (FAO 2011a; FAO 2012a). However, it must be underlined that to date, there is no single definition of "food waste" (in a broad sense), whether as an institutional definition or one in specialised scientific literature. For instance, Parfitt et al. (2010) mentions three definitions of food waste. FAO also points out contradictory approaches on what is considered waste or not (FAO 2012a), leading to data inconsistencies when comparing estimates of the proportion of food that is wasted. Aspects considered by experts and institutions when framing the concept include the stage of the food chain at which waste occurs, the part of the waste that is edible or non-edible, and whether the food was intended for humans in the first place (FAO 2011a; WRAP 2009; Parfitt et al. 2010; UNEP 2009).

There is a clear need for a harmonisation of the concept, which would enable more comparability of national data and between studies quantifying food waste estimates. Note that work is underway within the EU FUSIONS[45] project to determine a definition for food loss and waste, which will be validated with stakeholders in 2013. Consensus between the FAO, FUSIONS, the European Commission and other governments globally is important in advancing on the quantification and progressive reduction of food waste.

Linked to the issue of food waste definition is the specific case of fish discards. Discards is the proportion of fish that is returned to the sea during commercial fishing. In this perspective, there are currently some debates on how to define and quantify fish waste.

Food wastage percentages

Quantifications of food wastage volumes are made in the present study by applying waste percentages to FBS data. Wastage percentages are stemming from FAO (2011) study. These percentages of food lost and wasted have been gathered based on a thorough literature search. In addition, a number of assumptions had to be made by the authors for remaining data gaps, most notably for low-income regions.

Food wastage percentages are coming from a literature review of reports, web sites, and scientific articles since to date there is no database consolidating worldwide statistics on food loss and waste and that would provide harmonized datasets for analysis like in FAOSTAT for instance. The prerequisite for developing such a global tool is to have harmonised definitions of the major concepts linked to food waste.

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[45] www.eu-fusions.org

Commodity in the scope of the study

The study and encompass a range of products that is identical to FAO (2011). Commodity groups are built from available FBS. It must be kept in mind that beverages (e.g. beer, wine) and animal fats (e.g. butter) are not included in the scope of the study thus tending to underestimate food wastage volumes and impacts. Integrating this product could be an option for future work.

Quantifications of environmental impacts

Scope of the quantification

Due to a lack of data or other methodological constraints, some assumptions had to be made in the FWF model. In some cases, certain aspects of the environmental footprint could not be taken into account (e.g. land occupation and water footprint relating to non-agricultural phases). These limitations are discussed in dedicated boxes throughout the report and a recalled below. All these aspects offer room for improvement.

In further research, priority should be given to the integration of land use change in the carbon footprint accounting.

Land occupation

Land occupation factors used in this study were provided by the FiBL team working on the SOL-m project (FAO 2012b). SOL-m is an ongoing project and the factors provided here are preliminary figures. FiBL indicated that values should be refined during the year 2013, particularly with respect to chicken and other poultry activities. In particular, herd structure models for chickens and improved assumptions on feeding rations will be incorporated. Furthermore, an improved integration of TRADESTAT data should be made. Given the importance of animal products in the land occupation of food wastage, using these new values in future research might substantially modify the land occupations results.

Land occupation of crops wastage was calculated based on commodity yields in each region. It should be noted that the intrinsic production potential of land vary across the world with some regions having more favourable agroclimatic conditions and thus higher yields. It could be relevant in future work to integrate this land productivity dimension as an additional factor (complementary to yields and food wastage volumes) explaining the land occupation of food wastage.

Consequential analysis

It must be stressed that for all the quantifiable components assessed in this project (carbon, land, water), calculated impacts (in terms of GHG emissions, areas of land and blue water consumption) are actually the impacts attributable to a portion of global production and/or consumption equivalent to the volumes of waste and losses estimated to occur. This overview, thanks to its global scope and the variety of environment topic it addresses, gives for the first time a wide overview of the order of magnitude of the environmental footprint of food wastage. However, impacts quantified here cannot be directly seen as the impacts that would be avoided if the current global waste and losses were to be eradicated.

Indeed, the estimation of these avoided impacts would require a consequential analysis. Such approach would have to take into account the impacts of a reduction in food waste and losses on food prices and the resultant changes in the quantity and geographic location of food production and consumption, and in land management, land use and land cover.

Analysis of the variability of the results

A complementary analysis has been carried out to assess the potential range of variation of the carbon footprint of food wastage. This analysis was performed by selecting within each (sub)commodity the highest and lowest impact factor of the model. Assuming that the discrepancies between impact factors were mostly due to change in agricultural practices, this analysis gave a vision of the potential lower and upper bounds of the carbon footprint of food wastage. It was considered not relevant to make a similar analysis for water and land impact factors which are assumed to be much more related to climatic conditions of the (sub) region.

Overall, the sources of uncertainty are manifold in this study since each input of the FWF model has an attached uncertainty. Integrating an uncertainty calculation module in the model would be a valuable option to be support analyses of the outcomes of the model.

Biodiversity

The biodiversity impacts of food wastage have only been estimated semi-quantitatively, by identifying the regions where food production is likely to have the greatest impacts on biodiversity. Further research would be needed to clarify the biodiversity impacts of food throughout the supply chain, including trade issues. This could be achieved through advances towards the inclusion of biodiversity impacts in LCAs or multi-regional input-output approaches. In the short-term, a systematic assessment could be performed to identify which crops pose the greatest threats to biodiversity. This could then be used as a basis for calculating biodiversity impacts due to food production using MSA in different types of agricultural systems and world regions. The impacts estimated for marine ecosystems are preliminary, as the available global dataset used is somewhat superseded. Generally, the biodiversity module requires substantial improvements.

Economic assessment

The economic cost (based on producer prices) calculated for food wastage can be compared to the economic value of the food production obtained by crossing FBS data and PriceSTAT data. It appears that the economic cost of food wastage represent about 28% of the total economic value. However, it cannot be considered that if wastage was avoided this cost would be saved, since less food wastage would change market conditions and thus prices. Using consequential approaches (as mentioned previously) would help in that respect.

The economic component of this study is clearly a first step that would need further research to quantify the costs along the FSC. In addition, environmental cost of lost resources because of food wastage should be taken into account in future work. Food wastage generates pressure on scarce natural resources; this may lead to increasing costs of resources. For instance, the blue water being wasted in a given year might not have the same economic, social and/or environmental cost in future years.

Phase 2 of the Food Wastage Footprint project will address these gaps.

References

ADEME. 2012. Documentation Base Carbone - Section "déchets". Available at: http://www.basecarbone.fr/

Aldaya, M.M., Allan, J.A. & Hoekstra, A.Y. 2010. Strategic Importance of Green Water in International Crop Trade. *Ecological Economics*, 69(4), pp.887–894

Alexandratos, N. & Bruinsma, J. 2012. *World Agriculture Towards 2030/2050: the 2012 Revision.* ESA Working paper N°.12-03 FAO, Rome

Alkemade, R., Reid, R.S., van den Berg, M., de Leeuw, J & Jeuken, M. 2012. Assessing the Impacts of Livestock Production on Biodiversity in Rangeland Ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*

Alverson, D.L, Freeberg, M.H., Murawski, S.A. & Pope, J.G. 1994. *A Global Assessment of Fisheries By-catch and Discards*. FAO Fisheries Technical Paper No. 339, Rome, p.233

Andrade de Sá, S., Palmer, C.E. & Di Falco, S. 2012. Dynamics of Indirect Land-Use Change: Empirical Evidence from Brazil. Centre for Climate Change Economics and policy, Working Paper No. 86. Grantham Research Institute on Climate Change and the Environment, Working Paper No. 74. *CER-ETH Economics Working Paper Series*

Angelsen, A. & Kaimowitz, D. 1999. Rethinking the Causes of Deforestation: Lessons from Economic Models. *World Bank Res. Obs.* 14(1), pp.73–98

Bahor, B., Van Brunt, M., Stovall, J. & Blue, K. 2009. Integrated Waste Management as a Climate Change Stabilization Wedge. *Waste Manag. Res.*, 27(9), pp.839–49

Barilla Center for Food & Nutrition (BCFN), 2012. *Food waste: causes, impacts and proposals*, available at http://www.barillacfn.com/en/position-paper/pp-spreco-alimentare-cause/

Barreto, P., Souza Jr., C., Noguerón, R., Anderson, A. & Salomão, R. 2006. Human pressure in the Brazilian Amazon forests. *IMAZON, Global Forest Watch and World Resources Institute*

Bayramoglu, Z., Gundogmus, E. & Tatlidil, F.F. 2010. The impact of EurepGAP requirements on farm income from greenhouse tomatoes in Turkey. *Afr. J. Agric. Res*, 5(5), pp.348–355

Bertzky, M., Kapos, V. & Scharlemann, J.P.W. 2011. Indirect Land Use Change from Biofuel Production: Implications for Biodiversity, *JNCC Report* 456

Beveridge, M.C.M. & Brummett, R.E. 2012. Impacts of and on fisheries – aquaculture. In. *The Ecology of Freshwater Fisheries*. Wiley-Blackwell, Craig JF, ed (in review)

Bhagwat, S.A., Willis, K.J., Birks H.J & Whittaker, R.J. 2008. Agroforestry: a Refuge for Tropical Biodiversity? *Trends Ecol. Evol.*, 23(5), pp.261–7

BIO IS & TNO. 2011. Report for the JRC. *Analysis of the future application of product policy instruments in the EU*

BIO IS. 2009. *Projet Pilote ADEME, ANIA et FCD en vue de l'Affichage Environnemental Obligatoire en France sur les Produits de Grande Consommation* (unpublished)

BIO IS. 2010. *Preparatory Study on Food Waste Across EU 27. Technical Report - 2010 – 054*

BIO IS. 2011. *Development of an Indicator of Crop Genetic Diversity in Europe*, EEA Technical Report

BIO IS. 2012. *Assessment of Resource Efficiency in the Food Cycle. Draft final report for the European Commission* (unpublished)

BIO IS. *Impact of UK Low Carbon Technologies on Global Biodiversity* (in preparation)

Bostock, J., McAndrew, B., Richards, R., Jauncey, K., Telfer, T., Lorenzen, K., Little, D., Ross, L., Handisyde, N., Gatward, I. & Corner, R. 2010. Aquaculture: Global Status and Trends. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 365(1554), pp.2897–912

Boyd, C.E. & Clay, J.W. 1998. Shrimp Aquaculture and the Environment. *Scientific American*, 278(6), pp.59–65

British Institution Standards (BSI). 2011. *PAS 2050:2011 - Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services*. London. BSI.

Brown, A. & Matlock, M.D. 2011. *A Review of Water Scarcity Indices and Methodologies.* Sustainability Consortium - Food, Beverage & Agriculture White Paper 106

Brummett, R.E. 2006. *Role of Aquaculture in Increasing Water Productivity.* Challenge Program on Water and Food - Aquatic Ecosystems and Fisheries Review Series 4. Theme 3 of CPWF. Worldfish Center, Cairo, p.23

Brummett, R.E., Beveridge, M.C.M. & Cowx, I.G. 2012. Functional Aquatic Ecosystems, Inland Fisheries and the Millennium Development Goals. *Fish and Fisheries*

Buchanan, G.M., Donald, P.F. & Butchart, S.H.M. 2011. Identifying Priority Areas for Conservation: a Global Assessment for Forest-Dependent Birds. *PloS ONE*, 6(12), p.e29080

Busato, P., Berruto, R. & Saunders, C. 2007. Optimal Field-Bin Locations and Harvest Patterns to Improve the Combine Field Capacity: Study with a Dynamic Simulation Model. *Agricultural Engineering International*, *IX*, pp. 1-12

Butchart, Stuart H.M. *et al.* 2010. Global Biodiversity: Indicators of Recent Declines. *Science*, 328(5982), pp.1164–8

Carlsson-Kanyama, A. & Boström-Carlsson, K. 2001. *Energy Use for Cooking and Other Stages in the Life Cycle of Food: a Study of Wheat, Spaghetti, Pasta, Barley, Rice, Potatoes, Couscous and Mashed Potatoes,* FMS report 160, Forskningsgruppen för miljöstrategiska studier (FMS), Stockholm, Stockholm University

Carlsson-Kanyama, A. & Faist, M. 2000. *Energy Use in the Food Sector: a Data Survey*. Swedish Environmental Protection Agency

Chateil, C., Goldringer, I., Tarallo, L., Kerbiriou, C., Le Viol, I., Ponge, J.F., Salmon, S., Gachet, S. & Porcher, E. 2013. Crop Genetic Diversity Benefits Farmland Biodiversity in Cultivated Fields. *Agriculture, Ecosystem and Environment*, 171, pp. 25-32

Cherubini, F. & Strømman, A.H. 2011. Life cycle assessment of bioenergy systems: state of the art and future challenges. *Bioresource technology*, 102(2), pp.437–51

Coley, D., Howard, M. & Winter, M. 2009. Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. *Food Policy*, 34(2), pp.150–155

Conservation International. 2010. Responsible cultivation areas for biofuels. Sustainability in practice – Executive summary. Brazil.

Coriolis Research. 2001. *Retail supermaket globalization: who's winning?*, available at http://www.coriolisresearch.com/pdfs/coriolis_retail_supermarket_globalization.pdf

Cristea, A.D., Hummels, D., Puzzello, L. & Avetisyan, M.G. 2011. Trade and the Greenhouse Gas Emissions from International Freight Transport. *National Bureau of Economic Research Working Paper Series*, No. 17117

Cullinane, M., O'Sullivan, E., Collins, G., Collins, D.M. & More, S.J. 2012. Veterinary certificates for emergency or casualty slaughter bovine animals in the Republic of Ireland: are the welfare needs of certified animals adequately protected? *Animal Welfare*, 21(S2), p.61-67

Curran, M., de Baan, L., De Schryver, A.M., van Zelm, R., Hellweg, S., Koellner, T., Sonnemann, G. & Huijbregts, M.A.J. 2011. Toward meaningful end points of biodiversity in life cycle assessment. *Environmental science & technology*, 45(1), pp.70–9

Dalgaard, R., Schmidt, J., Halberg, N., Christensen, P., Thrane, M. & Pengue, W.A. 2007. LCA of soybean meal. *The International Journal of Life Cycle Assessment*, 13(3), pp.240–254

De Silva, S.S., Nguyen, T.T., Turchini, G.M., Amarasinghe, U.S. & Abery, N.W. 2009. Alien species in aquaculture and biodiversity: a paradox in food production. *Ambio*, 38(1), pp.24–28

DEFRA. 2006. *Environmental Impacts of Food Production and Consumption.* London, DEFRA

Donald, P.F. 2004. Biodiversity impacts of some agricultural commodity production systems. *Conservation Biology*, 18(1), pp.17–38

Dourte, D.R. & Fraisse, C.W. 2012. *What is a water footprint? An overview and applications in agriculture*. University of Florida IFAS Extension

EEA. 2010. *The European environment — State and outlook 2010 (SOER 2010).* Copenhagen, EEA

Ehrenfeld, D. 2005. The environmental limits to globalization. *Conservation Biology*, 19(2), pp.318–326

Erb, K. H, Gaube, V., Krausmann, F., Plutzar, C., Bondeau, A. & Haberl, H. 2007. A comprehensive global 5 min resolution land-use data set for the year 2000 consistent with national census data. *Journal of Land Use Science*, 2(3), pp.191–224

ESU-Services. 2012. *Life cycle inventories of electricity mixes and grid.* ESU-Services, Uster, Switzerland

European Commission. 2006. *Environmental impact of products (EIPRO): analysis of the life cycle environmental impacts related to the final consumption of the EU-25.* EU Commission, Joint Research Centre. Technical Report Series - EUR 22284. Spain

European Commission. 2010. *ILCD Handbook: general guide for life cycle assessment–Detailed guidance.* First Edit., EUR 24708 EN. Publication Office of the European Union, Luxembourg

FAO & IIASA. 2012. GAEZ v3.0 - Global Agro-ecological Zones. IIASA, Laxenburg, Austria and FAO, Rome. Available at: http://www.gaez.iiasa.ac.at/

FAO LADA. 2011. *Global Land Degradation Information System (GLADIS) version 1.0. An information database for land degradation assessment at global level.* LADA Technical Report n. 17

FAO. 2007. *The State of the world's animal genetic resources for food and agriculture.* B. Rischkowsky & Dafydd Pilling, eds., Rome

FAO. 2008. *Forests and energy - key issues*. FAO Forestry Paper No.154, Rome. Available at http://www.fao.org/docrep/010/i0139e/i0139e00.htm

FAO. 2010a. *Report of a workshop on indicators to measure trends in genetic diversity of domesticated animals, held in Rome, 9–10 February 2010* D. Pilling & B. D. Scherf, eds., Rome

FAO. 2010b. *Status and trends of animal genetic resources 2010. Intergovernmental working group on animal genetic resources for food and agriculture. Sixth session.* Commission on genetic resources for food and agriculture. Rome 24-26 November 2010

FAO. 2011a. *Global food losses and food waste - Extent, causes and prevention.* Rome. Available at http://www.fao.org/docrep/014/mb060e/mb060e00.pdf

FAO. 2011b. *The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk.* FAO & Earthscan, eds., Rome

FAO. 2012a. *Food Wastage Footprint: An environmental accounting of food loss and waste - Concept note*. Available at http://www.fao.org/nr/sustainability/food-loss-and-waste/en/

FAO. 2012b. *Sustainability and organic livestock - Model (SOL-M) - Concept note.* Available at: http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/SOL_Concept_Note.pdf

FAO. 2012c. *The role of producer organizations in reducing food loss and waste*. International year of cooperatives, Issue Brief Series, Rome. Available at http://www.fao.org/docrep/016/ap409e/ap409e.pdf

FAO. 2013. Food Wastage Footprint - Impact on Natural Resources. Summary Report. Available at http://www.fao.org/docrep/018/i3347e/i3347e.pdf

FAO. 2013b. Toolkit: Reducing Food Wastage Footprint. Available at http://www.fao.org/docrep/018/i3342e/i3342e.pdf

FAOSTAT. 2012b. FAOSTAT - Ressources. Available at: http://faostat.fao.org/

FAOSTAT. 2012c. FAOSTAT Forestry. Available at: http://faostat.fao.org/

FAOSTAT. 2012d. Food Balance Sheets. Available at: http://faostat.fao.org/

FAOSTAT. 2012e. PriceSTAT. Available at: http://faostat.fao.org

FAOSTAT. 2012f. ProdSTAT. Available at: http://faostat.fao.org/

FAOSTAT.2012a. FAO Fisheries & Aquaculture - FishStat Plus. Universal software for fishery statistical time series. Available at: http://www.fao.org/fishery/statistics/software/fishstat/en

Fearnside, P.M. 2001. Soybean cultivation as a threat to the environment in Brazil. *Environmental Conservation*, 28(01), pp.23–38

Foley, J.A. *et al.* 2005. Global consequences of land use. *Science*, 309(5734), pp.570–4

Friedlingstein, P., Houghton, R.A., Marland, G., Hackler, J., Boden, T.A., Conway, T.J., Canadell, J.G., Raupach, M.R., Clais, P. & Le Quéré, C. 2010. Update on CO_2 emissions. *Nature Geoscience*, 3(12), pp.811–812

GAA.2004. Global amphibian assessment. UPDATED 09/04. Conservation International, Washington

GAIN. 2003. *GAIN Report - Retail food sector - United Arab Emirates.* USDA Foreign Agricultural Service

GAIN. 2009. *GAIN Report - Retail food sector - Caribbean basin*. USDA Foreign Agricultural Service

GAIN. 2010a. *GAIN Report - Retail food sector - Ghana*. USDA Foreign Agricultural Service

GAIN. 2010b. *GAIN Report - Retail food sector - Israel*. USDA Foreign Agricultural Service

GAIN. 2010c. *GAIN Report - Retail food sector - Senegal*. USDA Foreign Agricultural Service

Gibbs, H.K., Ruesch, A.S. & Foley, J.A. 2010. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proc. Natl. Acad. Sci. USA*, 107(38), pp.16732–7

Global Footprint Network. 2009. *Ecological Footprint Standards 2009*. Oakland: Global Footprint Network. Available at www.footprintstandards.org

Green, R.E., Cornell, S.J., Scharlemann, J.P.W. & Balmford, A. 2005. Farming and the fate of wild nature. *Science*, 307(5709), pp.550–5

Groombridge, B. ed., 1992. *Global biodiversity: status of the earth's living resources.* London, Chapman & Hall

Guo, Y. 2012. *Chinese-Danish Networking Present practice, on-going research and future potential for non-chemical disease management in vegetable production in China*. Chinese-Danish Networking

Gustavsson, J., Cederberg, C. & Sonesson, U. 2011a. *Global food losses - Study 1 - Medium and high income countries.* Technical report for FAO (unpublished)

Gustavsson, J., Cederberg, C. & Sonesson, U. 2011b. *Global food losses - Study 2 - Low income countries.* Technical report for FAO (unpublished)

Hakansson, N., Flisberg, P., Algers, B., Ronnqvist, M. & Wennergren, U. 2012. A strategic analysis of slaughterhouses and animal transportation in Sweden. LiU Electronic Press

Hall, S.J., Delaporte, A., Phillips, M.J., Beveridge, M & O'Keefe, M. 2011. *Blue frontiers: managing the environmental costs of aquaculture*, Penang, Malaysia, The WorldFish Center

H**anafiah, M.M., Hendriks, A.J. & Huijbregts, M.A.J.** 2012. Comparing the ecological footprint with the biodiversity footprint of products. *Journal of Cleaner Production*, 37, pp.107–114

Hoekstra, A.Y. & Mekonnen, M.M. 2012. The water footprint of humanity. *Proc. Natl. Acad. Sci. USA*, 109(9), pp.3232–7

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. & Mekonnen, M.M. 2011. *The water footprint assessment manual: setting the global standard*. London, Earthscan

Hoornweg, D. & Bhada-Tata, P. 2012. *What a waste - A global review of solid waste management*, Urban development series. Knowledge papers no. 15. Washington, The Worldbank

Hörtenhuber, S., Theurls, M., Lindenthal, T. & Zollitsch, W. 2012. Land use change - GHG emissions from food and feedstuffs. In *8th International Conference on LCA in the Agri-Food Sector*. INNA, Rennes, France

IEA. 2011. *Energy for all - Financing access for the poor*. Paris, OECD/IEA

IME. 2013. *Global food: waste not, want not*. London. Available at http://www.imeche.org/docs/default-source/reports/Global_Food_Report.pdf?sfvrsn=0

INRA & CIRAD. 2009. *Agrimonde. Scenarios and challenges for feeding the world in 2050*. Quae

INRA. 2012. *Eau, aliments et procédés*. Rennes, France. Available at http://www.h2o.net/magazine/infrastructures-agriculture-et-environnement/eau-aliments-procedes.htm

Institute of Post Harvest Technology. 2002. *Annual Report*, Colombo, Sri Lanka

Interfel. *L'Interprofession des fruits et légumes frais.* Available at: http://www.interfel.com/

International Transport Forum. 2010. *Reducing transport greenhouse gas emissions - Trends & Data*. OECD/ITF

IPCC. 2006. *Guidelines for national greenhouse gas inventories - Volume 5 waste*. Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Japan, IGES

IPCC. 2007a. *Agriculture.* In *Climate Change 2007: Mitigation.* Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press

IPCC. 2007b. *Climate Change 2007: Impacts, adaptation and vulnerability.* Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press

ISHS. 2012. Harvesting the sun - A profile of world horticulture. *Scripta Horticulturae* No. 14, Leuven, Belgium, International Society for Horticultural Science

IUCN. 2012. The IUCN Red List of threatened species. Available at: http://www.iucnredlist.org/

Jenkins, M. 2003. Prospects for biodiversity. *Science*, 302(5648), pp.1175–7

Jetz, W., Wilcove, D.S. & Dobson, A.P. 2007. Projected impacts of climate and land-use change on the global diversity of birds. *PLoS biology*, 5(6), p.e157

Jowkar, M.M., Farshadfar, Z., Mohammadpour, H. & Jowkar, A. 2005. A look at postharvest in Iran. *Acta Hort. (ISHS)* 682, pp. 2177-2182

Kader, A.A. 2005. Increasing food availability by reducing postharvest losses of fresh produce. *Acta Hort. (ISHS)* 682, pp. 2169-2176

Kankolongo, M.A., Hell, K. & Nawa, I.N. 2009. Assessment for fungal, mycotoxin and insect spoilage in maize stored for human consumption in Zambia. *J. Sci. of Food Agric.*, 89(8), pp.1366–75

Kemp, K., Insch, A., Holdsworth, D.K. & Knight, J.G. 2010. Food miles: do UK consumers actually care?. *Food Policy*, 35(6), pp.504–513

Khan, Z.U., Khan, S., Ahmad, N. & Raziq, A. 2007. Investigation of mortality incidence and managemental practices in buffalo calves at commercial dairy farms in Peshawar City. *J. Agri. Biol. Sci.*, 2(3), pp.16–21

Kiaer, L.P., Skovgaard, I.M. & Østergård, H. 2009. Grain yield increase in cereal variety mixtures: a meta-analysis of field trials. *Field Crops Research*, 114(3), pp.361–373

Kling, M.M. & Hough, I.J. 2010. *The American carbon foodprint: understanding and reducing your food's impact on climate change*. Brighter Planet

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O. & Ward, P.J. 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment*, 438C, pp.477–489

Lapola, D.M., Schaldach, R., Alcamo, J., Condeau, A., Koch, J. Koelking, C. & Priess, J.A. 2010. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. *PNAS*, 107(8), pp.3388–93

Leaman, B.M. 1994. Bycatch mortality impacts and control for Pacific halibut. In T. Pitcher & R. Chuanpagdee, eds. *Fisheries and their impacts on the ecosystem.* Fisheries centre research reports, vol. 2(1). Vancouver, Canada, pp. p. 14–22

Leinonen, I., Williams, A. & Kyriazakis, I. 2012. Quantifying environmental impacts and their uncertainties for UK broiler and egg production systems. In *Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2012)*, 1-4 October 2012, Saint Malo, France. INRA, Rennes, France. pp. 198–203

Lemoalle, J. 2008. *Water productivity of aquatic systems.* Project CP34 - Improved fisheries productivity and management in tropical reservoirs, Penang, Malaysia. Challenge Program on Water and Food and the WorldFish Center

Loh, J., Green, R.E., Ricketts, T., Lamoreux, J., Jenkins, M., Kapos, V. & Randers., J. 2005. The Living Planet Index: using species population time series to track trends in biodiversity. *Phil. Trans. R. Soc. B*, 360(1454), pp.289–95

Lorenzen, K., Smith, L., Nguyen Koha, S., Burton, M., Garaway, C. 2007. *Guidance manual: management of impacts of irrigation development on fisheries*, Colombo, Sri Lanka. Working Papers, The WorldFish Center, 37166

Lundqvist, J., De Fraiture, C. & Molden, D. 2008. *Saving water: from field to fork. Curbing losses and wastage in the food chain.* SIWI Policy Brief. Stockholm, SIWI

Marelli, L., Ramos, F., Hiederer, R. & Koeble, R. 2011. *Estimate of GHG emissions from global land use change scenarios*. Ispra, Italy. JRC-IE

Mattila, T., Helin, T. & Antikainen, R. 2011. Land use indicators in life cycle assessment. *Int. J. Life Cycle Assess.*, 17(3), pp.277–286

MEA. 2005. *Millennium ecosystem assessment. Ecosystems and human well-being: biodiversity synthesis*. Washington DC. WRI

Mekonnen, M.M. & Hoekstra, A.Y. 2010a. The green, blue and grey water footprint of crops and derived crop products. *Hydrol. Earth Syst. Sci.*, 15, pp. 1577-1600

Mekonnen, M.M. & Hoekstra, A.Y. 2010b. *The green, blue and grey water footprint of farm animals and animal products*. Value of Water Research Report Series No. 48. Delft, The Netherlands. UNESCO-IHE

Mekonnen, M.M. & Hoekstra, A.Y. 2011. *National water footprint accounts: the green, blue and grey water footprint of production and consumption*. Volume 1: Main Report, Value of Water Research Report Series No. 50. The Netherlands, UNESCO-IHE Institute for Water Education

Meyfroidt, P., Rudel, T.K. & Lambin, E.F. 2010. Forest transitions, trade, and the global displacement of land use. *PNAS*, 107(49), pp.20917–22

Milepost. 2012. *Left-out. An investigation of the causes & quantities of crop shrink. Milepost-NRDC.* Available at http://docs.nrdc.org/health/files/hea_12121201a.pdf

Muhammad, A., Seale, J.L., Meade, Jr. B. & Regmi, A. 2011. *International evidence on food consumption patterns. An update using 2005 International Comparison Program Data.* TB-1929. USDA

Muñoz, I., Milà i Canals, L. & Fernández-Alba, A.R. 2010. Life cycle assessment of the average Spanish diet including human excretion. *Int. J. Life Cycle Assess.* 15(8), pp.794–805

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A. & Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), pp.853–8

Myers, R.A. & Worm, B. 2003. Rapid worldwide depletion of predatory fish communities. *Nature*, 423(6937), pp.280–3

Nemecek, T., Weiler, K., Plassmann, K. & Schnetzer, J. 2011. *Geographical extrapolation of environmental impact of crops by the MEXALCA method*. Unilever - ART Project No. CH-2009-0362. Final Report Phase 2

OECD. 2012. *OECD environmental outlook to 2050: the consequences of inaction.* OECD Publishing

Parfitt, J. 2011. *Foresight project on global food and farming futures. Science review : SR56 - Global food waste reduction : priorities for a world in transition*. London. The Government Office for Science

Parfitt, J., Barthel, M. & Macnaughton, S. 2010. Food waste within food supply chains : quantification and potential for change to 2050. *Phil. Trans. R. Soc. B*, 365, pp.3065–3081

Pauly, D. & Watson, R. 2005. Background and interpretation of the "Marine Trophic Index"as a measure of biodiversity. *Phil. Trans. R. Soc. B*, 360, pp.415–423

Pauly, D. 1998. Fishing down marine food webs. *Science,* 279(5352), pp.860–863

PBL. 2010. *Rethinking global biodiversity strategies: exploring structural changes in production and consumption to reduce biodiversity loss*. The Hague. Netherlands Environmental Assessment Agency

Phalan, B., Balmford, A., Green, R.E. & Scharlemann, J.P.W. 2011. Minimising the harm to biodiversity of producing more food globally. *Food Policy*, 36, pp.S62–S71

Phalan, B., Bertzky, M., Butchart, S.H.M., Donald, P.F., Scharlemann, J.P.W., Stattersfield, A.J. & Balmford, A. 2013. Crop expansion and conservation priorities in tropical countries. *PLoS ONE* 8(1): e51759

Phalan, B., Onial, M., Balmford, A. & Green, R.E. 2011. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. *Science*, 333(6047), pp.1289–91

Philpott, S.M. *et al.* 2008. Biodiversity loss in Latin American coffee landscapes: review of the evidence on ants, birds, and trees. *Conser. Biol.*, 22(5), pp.1093–1105

Poláková, J., Tucker, G., Hart, K., Dwyer, J. & Rayment, M. 2011. *Addressing biodiversity and habitat preservation through measures applied under the Common Agricultural Policy.* Report Prepared for DG Agriculture and Rural Development, Contract No. 30-CE-0388497/00-44, London

Prins, A.G., Stehfest, E., Overmars, K. & Ros, J. 2010. *Are models suitable for determining ILUC factors?*. Bilthoven, The Netherlands. Netherlands Environmental Assessment Agency

Pulkkinen, H., Krogerus, K. & Katajajuuri, J.M. 2012. Guidelines on inclusion of land use change emissions in carbon footprints of food. In *Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2012),* 1-4 October 2012, Saint Malo, France. INRA, Rennes, France. p. 732

Rahman, M.L., Tarrant, S., McCollin, D. & Ollerton, J. 2011. The conservation value of restored landfill sites in the East Midlands, UK for supporting bird communities. *Biodiversity and conservation*, 20(9), pp.1879–1893

Rajendran, S. 2002. Postharvest pest losses. In *Encyclopedia of Pest Management*. D. Pimentel, ed., pp. 654-656. New York, Marcel-Dekker

Reardon, T. 2003. *The rapid rise of supermarkets in Latin America and Asia*. Paper presented at the Global Market for High-Value Food Workshop. Washington D.C., February 14, 2003. ERS/USDA

Reardon, T., Timmer, C.P. & Berdegué, J.A. 2005. Supermarket expansion in Latin America and Asia, implications for food marketing systems. In *New directions in global food markets.* AIB-794, Economic Research Service/USDA

Reardon, T., Timmer, P. & Berdegue, J. 2004. The rapid rise of supermarkets in developing countries: induced organizational, institutional, and technological change in agrifood systems. *Electronic Journal of Agricultural and Development Economics*, 1(2), pp.168–183

Reid, R.S., Bedelian, C. & Said, M.Y. 2010. Global livestock impacts on biodiversity. In H Steinfeld et al., eds. *Livestock in a Changing Landscape. Drivers, Consequences, and Responses*. Washington D.C. Island Press, pp. 111–138

Renewable Fuels Agency. 2008. *The Gallagher Review of the indirect effects of biofuels production*. The Gallagher Review - Contents 5

Roberts, C. 2002. Deep impact: the rising toll of fishing in the deep sea. *Trends in Ecology & Evolution*, 17(5), pp.242–245

Rolle, R.S. 2006. Improving postharvest management and marketing in the Asia-Pacific region: issues and challenges. In R. S. Rolle, ed. *Postharvest management of fruit and vegetables in the*

Asia-Pacific region. Reports of the APO Seminars on reduction of postharvest losses of fruits and vegetables, India, 5-11 October, 2004, and Marketing and food safety: challenges in postharvest managem. Rome, Italy: Asian Productivity Organization (APO), pp. 23–31

RSIS Centre for Non-Traditional Security Studies. 2013. *Expert working group meeting on food wastage in Southeast Asia.* Singapore, 23–24 August 2012

Savy, M., Buba, J., Daude, C. & Auverlot, C. 2010. *Le fret mondial et le changement climatique - Perspectives et marges de progrès.* La Documentation Française, ed

SCBD. 2011. *REDD-plus and biodiversity.* CBD Technical Series No. 59. Secretariat of the Convention on Biological Diversity, ed. Montreal, Canada

Schmidt, J.H., Reinhard, J. & Weidema, B.P. 2012. A model of indirect land use change. In *Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2012),* 1-4 October 2012, Saint Malo, France. INRA, Rennes, France. pp. 245–251

Seré, C., Steinfeld, H. & Groenewold, J. 1995. *World livestock production systems: current status, issues and trends*. Rome. FAO Animal Production and Health Paper No. 127

Shiklomanov, I. 1998. Archive of world water resources and world water use. Global water data files: state Hydrological Institute. Data archive on CD-ROM from State Hydrological Institute, St. Petersburg, Russia

Smil, V. 2004. Improving efficiency and reducing waste in our food system. *Environmental Sciences*, 1(1), pp.17–26

Soil Association. 2007. *Should the Soil Association tackle the environmental impact of air freight in its organic standards?*. Bristol. Soil Association Standards Consultation - Air Freight Green Paper

Stammel, B., Kiehl, K. & Pfadenhauer, J. 2003. Alternative management on fens: response of vegetation to grazing and mowing. *Applied Vegetation Science*, 6(2), pp.245–254

Stoate, C., Baldi, A., Beja, P., Boatman, N.D., Herzon, I., van Doorn, A., de Snoo, G.R., Rakosy, L. & Ramwell, C. 2009. Ecological impacts of early 21st century agricultural change in Europe - A review. *Journal of Environmental Management*, 91(1), pp.22–46

Stuart, T. 2009. *Waste – Uncovering the global food scandal*. London, Penguin Books

Stuart, T. 2011. Post-harvest losses: a neglected field. In *2011 State of the world - Innovations that nourish the planet*. Washington D.C. The Worldwatch Institute

Thompson, A.K. 2010. *Controlled atmosphere storage of fruits and vegetables*. Secon Edition. London, CABI International

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D. & Swackhamer, D. 2001. Forecasting agriculturally driven global environmental change. *Science,* 292(5515), pp.281–4

Torrellas, M., Antón, A. & López, J.C. 2012. LCA of a tomato crop in a multi-tunnel greenhouse in Almeria. *Int. J. Life Cycle Assess.*, pp.863–875

Traill, W.B. 2006. The rapid rise of supermarkets? *Development Policy Review*, 24(2), pp.163–174

Tubiello, F.N., Salvatore, M., Rossi, S., Ferrara, A, Fitton, N. & Smith, P. 2013. The FAOSTAT Database of Greenhouse Gas Emissions from Agriculture. *Environ. Res. Lett*. 8(1)

Turbé, A., De Toni, A., Benito, P., Lavelle, Patrick, Lavelle, Perrine, Ruiz, N., van der Putten, W.H., Labouze, E. & Mudgal, S. 2010. *Soil biodiversity: functions, threats and tools for policy makers.* BIO IS, IRD, NIOO report for the European Commission (DG Env)

UNEP. 2009. *The environmental food crisis. The environment's role in averting future food crises.* UNEP, GRID-Arendal. Norway, Birkeland Trykkeri AS

UNEP. 2010a. *Assessing the environmental impacts of consumption and production: priority products and materials.* A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management

UNEP. 2010b. *Waste and climate change: global trends and strategy framework*. Osaka, International Environmental Technology Centre

UNESCO. 2012. *Managing water under uncertainty and risk.* The UN World Water Development Report 4, Volume 1.paris, United Nations Educational, Scientific and Cultural Organization

UNFCCC. *GHG total excluding LULUCF -Time series - Annex I.* Available at: http://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3814.php

UNIDO. *Pollution from food processing factories and environmental protection*. Available at http://www.unido.org/fileadmin/import/32129_25PollutionfromFoodProcessing.7.pdf

UNStats. 2012. *GDP of countries*. Available at http://unstats.un.org/unsd/snaama/Introduction.asp

Vackar, D. 2012. Ecological footprint, environmental performance and biodiversity: a cross-national comparison. *Ecological Indicators*, 16, pp.40–46

Vallan, D. 2002. Effects of anthropogenic environmental changes on amphibian diversity in the rain forests of eastern Madagascar. *Journal of Tropical Ecology*, 18(05), pp.725–742

Van de Wouw, M., Kik, C., van Hintum, T., van Treuren, R. & Visser, B. 2009. Genetic erosion in crops: concept, research results and challenges. *Plant Genetic Resources*, 8(01), pp.1–15

Van de Wouw, M., van Hintum, T., Kik, C., van Treuren, R. & Visser, B. 2010. Genetic diversity trends in twentieth century crop cultivars: a meta analysis. *TAG. Theoretical and applied genetics. Theor. Appl. Genet.*, 120(6), pp.1241–52

Venkat, K. 2011. The climate change and economic impacts of food waste in the United States. *International Journal on Food System Dynamics*, 2(4), pp.431–446

Verdegem, M.C. & Bosma, R.H. 2009. Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use. *Water Policy*, 11(S1), pp.52–68

Vickers, A. 2001. *Han*dbook of water use and conservation: homes, landscapes, businesses, industries, farms. WaterPlow Press

Watling, L. & Norse, E.A. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. *Conservation Biology*, 12(6), pp.1180–1197

Welcomme, R.L. 2006. *Role of fisheries in improving water productivity in rivers and floodplains.* Challenge Program on Water and Food, Cairo

Williams, A.G., Audsley, E. & Sandars, D.L. 2006. *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Defra project report IS0205. Bedford, Cranfield University and Defra

Willison, J.H.M. & Côté, R.P. 2009. Counting biodiversity waste in industrial eco-efficiency: fisheries case study. *Journal of Cleaner Production*, 17(3), pp.348–353

Wilson, J.D., Evans, A.D. & Grice, P.V. 2009. *Bird conservation and agriculture.* Cambridge, UK. Cambridge University Press

World Bank. 1998. Fruit and vegetable processing. In *Pollution prevention and abatement handbook 1998 - Toward cleaner production*. Washington D.C. World Bank Group

World Bank. 2011. *Missing food: the case of postharvest grain losses in Sub-Saharan Africa*. Washington D.C., World Bank

WRAP. 2009. *Household food and drink waste in the UK*. Final Report. Banbury, UK

WRAP. 2010. *Waste arisings in the supply of food and drink to households in the UK*. Final Report. Banbury, UK

WRAP. 2011. *The water and carbon footprint of household food and drink waste in the UK.* Final Report. Banbury, UK. WRAP and WWF-UK

WRI & WBCSD. 2011. *Greenhouse Gas Protocol. Product life cycle accounting and reporting standard.* USA. World Resource Institute & World business Council for Sustainable Development

WRI. 2012. Climate analysis indicators tool. Available at: http://cait.wri.org

Wright, H.L., Lake, I.R. & Dolman, P.M. 2012. Agriculture-a key element for conservation in the developing world. *Conservation Letters*, 5(1), pp.11–19

WWF. 2010. *Living planet report 2010: biodiversity, biocapacity and development*. Gland, Switzerland. WWF

Wymann, M.N., Bonfoh, B., Schelling, E., Bengaly, S., Tembely, S., Tanner, M. & Zinsstag, J. 2006. Calf mortality rate and causes of death under different herd management systems in peri-urban Bamako, Mali. *Livestock Science*, 100(2–3), pp.169–178

Yang, H., Wang, L., Abbaspour, K.C. and Zehnder, A.J.B. 2006. Virtual water highway: water use efficiency in global food trade. *Hydrol. Earth Syst. Sci. Discuss.*, 3(1)

Zbeetnoff Agro-environmental Consulting. 2006. *Update on the North American greenhouse vegetable industry*. Farm Credit Canada. Available at http://www.fcc-fac.ca/en/learningcentre/knowledge/doc/Greenhouse_study_e.pdf

Zhu, Y. *et al.*, 2000. Genetic diversity and disease control in rice. *Nature*, 406(6797), pp.718–22

Zimmer, D. & Renault, D. 2003. Virtual water in food production and global trade: review of methodological issues and preliminary results. In *Proceedings of the international expert meeting on virtual water trade*, Value of Water Research Report Series No. 12. The Netherlands, A. Hoekstra Ed.

Annex I. Screened data sources for literature review

During the first times of the project, a number of data sources were screened and the available data were studied in the perspective of the project needs.

Agrimonde "Scenarios and Challenges for Feeding the World in 2050" (INRA & CIRAD 2009) is a foresight study exploring the possible futures of farming and food systems worldwide in 2050. It provides forecasting scenarios concerning "food consumption in 2050", "land use in 2050", and the survey on "feeding the planet by preserving ecosystems".

AQUASTAT is FAO's global information system on water and agriculture. This database provides information on water resources, water uses and agricultural water management for numerous countries.

BIO IS report for the European Commission "Assessment of resource efficiency in the food cycle" (BIO IS 2012) is a deep report setting out results of an appraisal of the European food cycle with respect to resource use and emissions to the environment.

BIO IS for the European Commission "Preparatory Study on Food Waste Across EU 27" (BIO IS 2010) is a deep survey, which identifies causes of food waste, quantifies the environmental impacts of food across its lifecycle, and forecasts food waste generation.

CleanMetrics, the Climate Change Impact of US Food Waste (Venkat 2011) presents a comprehensive analysis of both the climate change and economic impacts of food waste in the United States.

CarbonScopeData™ is a life cycle inventory (LCI) database used by the society CleanMetrics. CarbonScopeData includes cradle-to-gate and unit process data for over 1100 products and processes in the food and agriculture sectors, covering a full range of crop and animal production systems, processing, packaging and waste disposal. The majority of this data is for US and Canadian production and processing, but the database also includes food production data for other parts of the world, as well as all common freight transports modes used for food products and refrigerators used for food storage.

FAO, Global Food Losses and Food Waste (FAO 2011a) is a survey conducted by SIK (Swedish Institute for Food and Biotechnology), whose aim is to quantify the losses occurring along the entire food chain, and make assessments of their magnitude. This study is used to calculate food wastage volumes (Component 1) of the Food Wastage Footprint Model.

FAOSTAT provides time-series and cross sectional data relating to food and agriculture for circa 200 countries. This database is used for building in Food Wastage Footprint Model to calculate food wastage volumes (Component 1) from Food Balance Sheets. Data from the production statistics (ProdSTAT) and price statistics (PriceSTAT) are also used in the FWF model.

GAEZ (Global Agro-Ecological Zones) is a database on soil resources, agro-climatic resources, agricultural suitability, and yields and production of crops.

GLADIS (Global Land Degradation Information System) is a database for land degradation assessment at the global level. This source gives qualitative and quantitative information on land deterioration hotspots, and explicatory data. The impact of this soil deterioration on people's economic well-being is also investigated.

LADA (Land Degradation Assessment in Drylands) project aims to establish and implement a comprehensive methodology for the assessment and mapping of land degradation, drivers and impacts within land use systems.

MEA (Millennium Ecological Assessment) assesses the consequences of ecosystems' changes on human well-being. It also provides a scientific basis for these ecosystems' conservation and sustainable use.

Water Footprint Network promotes the transition towards sustainable and efficient use of freshwater resources worldwide. This organization develops methods for water footprint accounting, and includes a database that is used for the Food Wastage Footprint Model (Component 3).

WAW (the World Agriculture Watch) is a global initiative launched by FAO, in collaboration with the research entity CIRAD (FR). Its objective is to study an inclusive policy dialogue on agricultural production systems, structural changes affecting them and their implications on sustainable development related to global economic challenges.

WRAP "The water and carbon footprint of household food and drink waste in the UK" (WRAP 2011) is a report containing quantification of the amount and types of household food and drink waste in the UK.

WRAP "Waste arisings in the supply of food and drink to households in the UK" (WRAP 2010) is a document whose aim is to develop a baseline of waste arisings within the UK food and drink supply chain, and to identify opportunities for cost savings, improved resource efficiencies and future interventions.

2006 IPCC Guidelines for National Greenhouse Gas Inventories provide internationally agreed methodologies intended for use by countries to establish the greenhouse gas inventories that are reported to the UNFCCC. The volume 5 on "Waste" (IPCC 2006) give methodological guidance for estimation of GHG emissions related to waste management.

OECD report: "Environmental outlook to 2050 : the consequence of inaction" (OECD 2012) is based on joint modelling by the OECD and the Netherlands Environmental Assessment Agency (PBL), it looks forward to the year 2050 to find out what demographic and economic trends might mean for the environment if the world does not adopt more ambitious green policies. It also looks at what policies could change that picture for the better. It focuses on 5 aspects: Socio-economic development, Climate change, Biodiversity, Water, Health and Environment

The IUCN Red list of threatened species is widely recognised as the most comprehensive, objective global approach for evaluating the conservation status of plant and animal species. Approximately 25,000 species are currently well documented, with information on ecology, population size, threats, conservation actions and utilisation. There are also about 18,000 species with distribution maps. The data cover non-threatened as well as threatened species, and certain taxonomic groups have been completely, or almost completely assessed (mammals, birds, amphibians, freshwater crabs, warm-water reef building corals, conifers and cycads).

The United Nations Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) supports national processes and promotes the involvement of all stakeholders, including Indigenous Peoples and other forest-dependent communities, in national and international REDD+ implementation. The Program also works to build international awareness and consensus about the importance of including sustainable mechanisms in a future climate change agreement.

Annex II. Mind map of food wastage

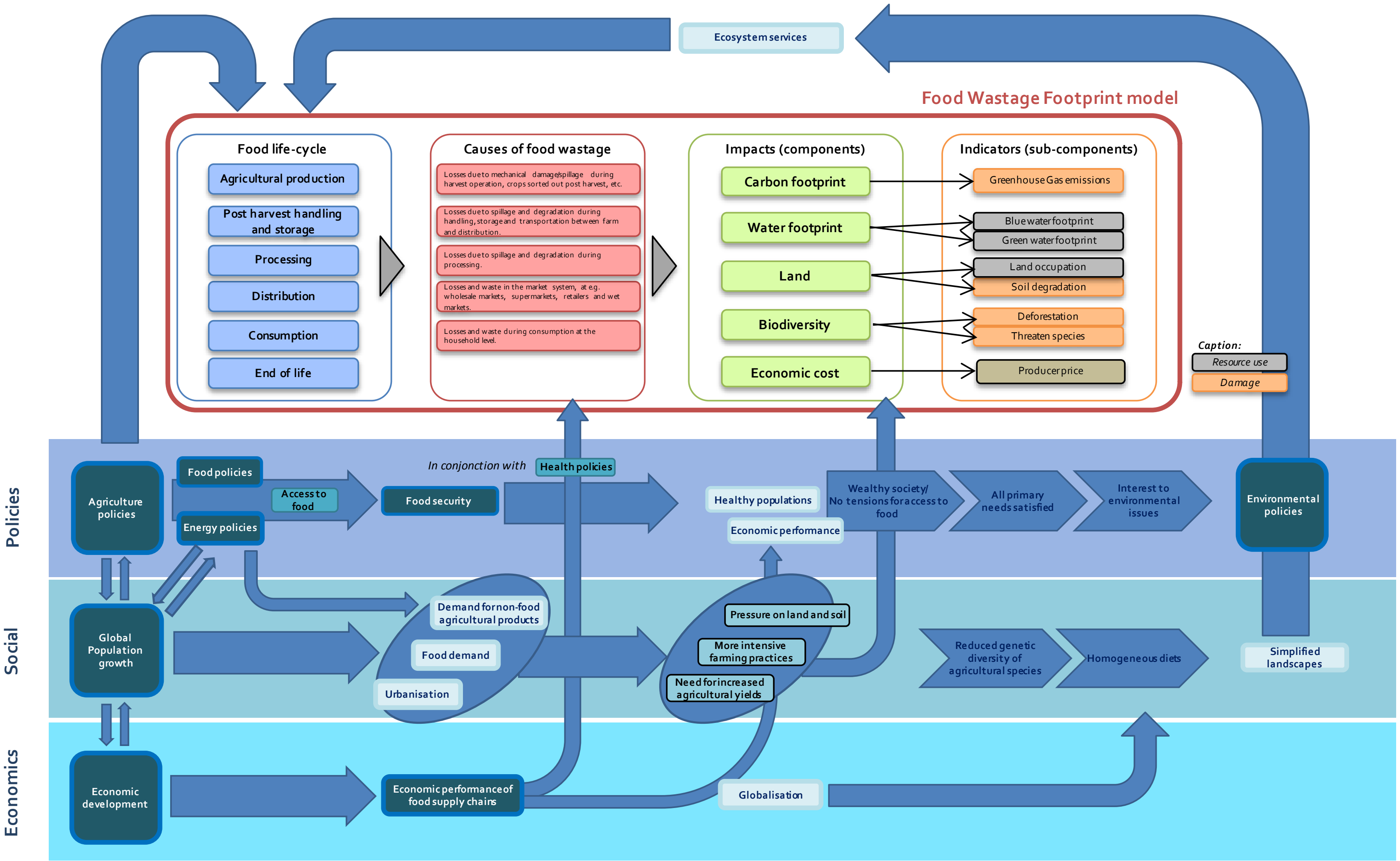


Figure 115: Mind map of food wastage

Annex III. Data used in the FWF model

Component of the model	Databases used in the FWF model	Data used in the FWF model
Component 1 – Food volumes	FAOSTAT. Food Balance Sheets for the year 2007 **>Country/region codes:** 5400, 10, 33, 156, 231, 351, 110, 117, 5101, 5102, 5104, 5105, 5301, 141, 5103, 5305, 5304, 5303, 5206, 5204, 5207 **>Commodity codes:** 2905, 2907, 2913, 2911, 2919, 2918, 2960, 2948, 2949, 2918	Production (A) Domestic supply quantity (E) Processing (H) Food (J)
Component 1 – Food wastage percentages	FAO. (2011). Global food losses and food waste - Extent causes prevention.	Food wastage percentages for each commodity, region and life cycle step
Component 2 – Production impacts	>BIO IS internal database of impact factors of food products >BIO IS report "Assessment of resource efficiency in the food cycle" (BIO IS 2012)	Impact factors for production of food products stemming from LCAs analysed and reviewed by BIO IS
Component 2 – Processing and cooking impacts	Carlsson-Kanyama, A., & Boström-Carlsson, K. (2001). Energy use for cooking and other phases in the life cycle of food.	Energy consumptions for food processing and cooking
Component 2 – End-of-life impacts	IPCC. (2006). Guidelines for National Greenhouse Gas Inventories - Volume 5 Waste.	Tier 1 approach for calculation of food waste emissions at disposal (landfill and incineration)
Component 2 – Food wastage disposal routes	Hoornweg, D., & Bhada-Tata, P. (2012). What a waste - A Global Review of Solid Waste Management.	Share of the various disposal routes (dumps, landfills, incineration, etc.) for each sub-region
Component 3 – Water footprint of crops	Mekonnen, M. M., & Hoekstra, A. Y. (2010). The green, blue and grey water footprint of crops and derived crop products. Value of Water Research Report Series, 47.	Blue, grey and green water footprints – world average for fruits Blue, grey and green water footprints – national average for other commodities
Component 3 – Water footprint of animal products	Mekonnen, M. M., & Hoekstra, A. Y. (2010). The green, blue and grey water footprint of farm animals and animal products. Value of Water Research Report Series, 48.	Blue, grey and green water footprints – national average for meat, milk and egg
Component 3 – Water scarcity	GAEZ V3.0 (FAO & IIASA 2012)	Global distribution of physical water scarcity by major river basin
Component 4 – Land occupation factor of crops	FAOSTAT. Production statistics for the year 2007.	Crop production – quantity Crop production – surface harvested
Component 4 – Land occupation factor of animal products	SOL-m data provided by FiBL	Land occupation factors for arable land and non-arable land (hectares per tonne of product)
Component 4 – Land degradation	LADA/GLADIS data (FAO LADA 2011)	Status, process, and class of land degradation for each country
Component 5 – Biodiversity	FAOSTAT Resource statistics (FAOSTAT 2012b)	Forest and agricultural surfaces
Component 5 – Biodiversity	IUCN red list	Number of threatened species (Vulnerable + Endangered + Critically Endangered) for three taxa: Mammals, Amphibians and Birds
Component 5 – Biodiversity	Trends in mean trophic levels of fisheries landings	Marine Trophic Index data extracted for each Large Marine Ecosystems (LMEs) from the Sea Around Us Project.
Component 6 – Economic assessment	FAOSTAT. Price statistics for the year 2009 (FAOSTAT 2012e)	Producer prices USD/tonne of product

Annex IV. Food products included in each commodity

Table 13: Food products included in each commodity

FWF Study		Food Balance Sheet				
Commodity #	Commodity name	Code category	Name category	Code Item	Name item	FBS definition[46]
Commodity 1	*Cereals (excluding beer)*	2905	Cereals - Excluding Beer + (Total)	2511	Wheat	15 Wheat, 16 Flour of Wheat, 18 Macaroni, 20 Bread, 21 Bulgur, 22 Pastry, 23 Starch of Wheat, 41 Breakfast Cereals, 110 Wafers; nutrient data only: 17 Bran of Wheat, 19 Germ of Wheat, 24 Gluten of Wheat, 114 Mixes and Doughs, 115 Food Prep,Flour,Malt Extract
				2515	Rye	71 Rye, 72 Flour of Rye; nutrient data only: 73 Bran of Rye
				2805	Rice (Milled Equivalent)	27 Rice, paddy, 28 Rice Husked, 29 Milled/Husked Rice, 31 Rice Milled, 32 Rice Broken, 34 Starch of Rice, 38 Rice Flour; nutrient data only: 33 Rice gluten, 35 Bran of Rice
				2514	Maize	56 Maize, 58 Flour of Maize, 64 Starch of Maize, 846 Gluten Feed and Meal; nutrient data only: 57 Germ of Maize, 59 Bran of Maize, 63 Maize gluten
				2516	Oats	75 Oats, 76 Oats Rolled; nutrient data only: 77 Bran of Oats
				2513	Barley	44 Barley, 45 Pot Barley, 46 Barley Pearled, 49 Malt, 50 Malt Extract; nutrient data only: 47 Bran of Barley, 48 Barley Flour and Grits
				2520	Cereals, other	68 Popcorn, 89 Buckwheat, 90 Flour of Buckwheat, 92 Quinoa, 94 Fonio, 95 Flour of Fonio, 97 Triticale, 98 Flour of Triticale, 101 Canary seed, 103 Mixed grain, 104 Flour of Mixed Grain, 108 Cereals, nes, 111 Flour of Cereals, 113 Cereal Preparations, Nes; nutrient data only: 91 Bran Buckwheat, 96 Bran of Fonio, 99 Bran of Triticale, 105 Bran of Mixed Grains, 112 Bran of Cereals
				2517	Millet	79 Millet, 80 Flour of Millet; nutrient data only: 81 Bran of Millet
				2518	Sorghum	83 Sorghum, 84 Flour of Sorghum; nutrient data only: 85 Bran of Sorghum
Commodity 2	*Starchy roots*	2907	Starchy Roots + (Total)	2532	Cassava	125 Cassava, 126 Flour of Cassava, 127 Tapioca of Cassava, 128 Cassava Dried, 129 Cassava Starch
				2531	Potatoes	116 Potatoes, 117 Potatoes Flour, 118 Frozen Potatoes, 119 Starch of Potatoes, 121 Tapioca of Potatoes

[46] http://faostat.fao.org/site/655/default.aspx

FWF Study		Food Balance Sheet				
Commodity #	Commodity name	Code category	Name category	Code Item	Name item	FBS definition[46]
				2533	Sweet potatoes	122 Sweet potatoes
				2535	Yams	137 Yams
				2534	Roots other	135 Yautia (cocoyam), 136 Taro (cocoyam), 149 Roots and Tubers, nes, 150 Flour of Roots and Tubers, 151 Roots and Tubers Dried
Commodity 3	*Oilcrops & Pulses*	2913	Oilcrops + (Total)	2555	Soybeans	236 Soybeans, 239 Soya Sauce, 240 Soya Paste, 241 Soya Curd
				2556	Groundnuts (Shelled Equivalent)	242 Groundnuts, with shell, 243 Groundnuts Shelled, 246 Prepared Groundnuts, 247 Peanut Butter
				2557	Sunflowerseed	267 Sunflower seed
				2558	Rape and mustardseed	No detail
				2559	Cottonseed	No detail
				2560	Coconuts (incl. copra)	249 Coconuts, 250 Coconuts Desiccated, 251 Copra
				2561	Sesame seed	289 Sesame seed
				2562	Palm kernels	
				2563	Olives	260 Olives, 262 Olives Preserved
				2570	Oilcrops, other	263 Karite Nuts (Sheanuts), 265 Castor oil seed, 275 Tung Nuts, 277 Jojoba Seeds, 280 Safflower seed, 296 Poppy seed, 299 Melonseed, 305 Tallowtree Seeds, 310 Kapok Fruit, 311 Kapokseed in Shell, 312 Kapokseed Shelled, 333 Linseed, 336 Hempseed, 339 Oilseeds, Nes, 343 Flour of Oilseeds
		2911	Pulses + (Total)	2546	Beans	176 Beans, dry
				2547	Peas	187 Peas, dry
				2549	Pulses, other	181 Broad beans, horse beans, dry, 191 Chick peas, 195 Cow peas, dry, 197 Pigeon peas, 201 Lentils, 203 Bambara beans, 205 Vetches, 210 Lupins, 211 Pulses, nes, 212 Flour of Pulses; nutrient data only: 213 Bran of Pulses
Commodity 4	*Fruits (excluding wine)*	2919	Fruits - Excluding Wine + (Total)	2611	Oranges, Mandarines	490 Oranges, 491 Orange juice, single strength, 492 Orange juice, concentrated, 495 Tangerines, mandarins, clem., 496 Tangerine Juice
				2612	Lemon, limes	497 Lemons and limes, 498 Lemon juice, single strength, 499 Lemon juice, concentrated

FWF Study		Food Balance Sheet				
Commodity #	Commodity name	Code category	Name category	Code Item	Name item	FBS definition[46]
				2613	Grapefruit	507 Grapefruit (inc. pomelos), 509 Juice of Grapefruit, 510 Grapefruit juice, concentrated
				2614	Citrus, other	512 Citrus fruit, nes, 513 Citrus juice, single strength, 514 Citrus juice, concentrated
				2620	Grapes	560 Grapes, 561 Raisins, 562 Grape Juice, 563 Must of Grapes
				2615	Bananas	486 Bananas
				2616	Plantains	489 Plantains
				2617	Apples	515 Apples, 518 Apple juice, single strength, 519 Apple juice, concentrated
				2618	Pineapples	574 Pineapples, 575 Pineapples Cand, 576 Juice of Pineapples, 580 Pineapple Juice Conc
				2619	Dates	577 Dates
				2625	Fruits, Other	521 Pears, 523 Quinces, 526 Apricots, 527 Dry Apricots, 530 Sour cherries, 531 Cherries, 534 Peaches and nectarines, 536 Plums and sloes, 537 Plums Dried (Prunes), 538 Plum juice, single strength, 539 Plum juice, concentrated, 541 Stone fruit, nes, 542 Pome fruit, nes, 544 Strawberries, 547 Raspberries, 549 Gooseberries, 550 Currants, 552 Blueberries, 554 Cranberries, 558 Berries Nes, 567 Watermelons, 568 Other melons (inc.cantaloupes), 569 Figs, 570 Figs Dried, 571 Mangoes, mangosteens, guavas, 572 Avocados, 583 Mango Juice, 587 Persimmons, 591 Cashewapple, 592 Kiwi fruit, 600 Papayas, 603 Fruit, tropical fresh nes, 604 Fruit Tropical Dried Nes, 619 Fruit Fresh Nes, 620 Fruit Dried Nes, 622 Fruit Juice Nes, 623 Fruit Prp Nes, 624 Flour of Fruits, 625 Fruit,Nut,Peel, Sugar Prs, 626 Homogen. Cooked Fruit Prp
Commodity 5	***0***	**2918**	**Meat + (Total)**	2731	Bovine meat	867 Cattle meat, 870 Meat-CattleBoneless(Beef and Veal), 872 Meat of Beef,Drd, Sltd,Smkd, 873 Meat Extracts, 874 Sausage Beef and Veal, 875 Preparations of Beef Meat, 876 Beef canned, 877 Homogen.Meat Prp., 947 Buffalo meat
				2732	Mutton & Goat Meat	977 Sheep meat, 1017 Goat meat
				2733	Pig meat	1035 Pig meat, 1038 Pork, 1039 Bacon and Ham, 1041 Sausages of Pig Meat, 1042 Prep of Pig Meat
				2734	Poultry meat	1058 Chicken meat, 1060 Fat Liver Prep (Foie Gras), 1061 Meat of Chicken Canned, 1069 Duck meat, 1073 Goose and guinea fowl meat, 1080 Turkey meat
				2735	Meat, other	1089 Bird meat, nes, 1097 Horse meat, 1108 Meat of Asses, 1111 Meat of Mules, 1127 Camel meat, 1141 Rabbit meat, 1151 Meat of Other Rod, 1158 Meat Oth Camelids, 1163 Game meat, 1164 Meat Dried Nes, 1166 Meat nes, 1172 Prepared Meat Nes, 1176 Snails, Not Sea
Commodity 6	***Fish & Seafood***	**2960**	**Fish, Seafood + (Total)**	2761	Freshwater fish	1501 Frwtr Diad F, 1502 Frwtr Fz Whl, 1503 Frwtr Fillet, 1504 Frwtr Fz Flt, 1505 Frwtr Cured, 1506 Frwtr Canned, 1507 Frwtr Pr nes, 1508 Frwtr Meals

FWF Study		Food Balance Sheet				
Commodity #	Commodity name	Code category	Name category	Code Item	Name item	FBS definition[46]
				2762	Demersal fish	1514 Dmrsl Fresh, 1515 Dmrsl Fz Whl, 1516 Dmrsl Fillet, 1517 Dmrsl Fz Flt, 1518 Dmrsl Cured, 1519 Dmrsl Canned, 1520 Dmrsl Pr nes, 1521 Dmrsl Meals
				2763	Pelagic fish	1527 Pelagic Frsh, 1528 Pelgc Fz Whl, 1529 Pelgc Fillet, 1530 Pelgc Fz Flt, 1531 Pelgc Cured, 1532 Pelgc Canned, 1533 Pelgc Pr nes, 1534 Pelgc Meals
				2764	Marine fish, other	1540 Marine nes F, 1541 Marin Fz Whl, 1542 Marin Fillet, 1543 Marin Fz Flt, 1544 Marin Cured, 1545 Marin Canned, 1546 Marin Pr nes, 1547 Marin Meals
				2766	Cephalopods	1570 Cephlp Fresh, 1571 Cphlp Frozen, 1572 Cphlp Cured, 1573 Cphlp Canned, 1574 Cphlp Pr nes, 1575 Cphlp Meals
				2765	Crustaceans	1553 Crstaceans F, 1554 Crstc Frozen, 1555 Crstc Cured, 1556 Crstc Canned, 1557 Crstc Pr nes, 1558 Crstc Meals
				2767	Molluscs, Other	1562 Mlluscs Frsh, 1563 Molsc Frozen, 1564 Molsc Cured, 1565 Molsc Canned, 1566 Molsc Meals
Commodity 7	Milk (excluding butter) & Eggs			2948	Milk - Excluding Butter + (Total)	CODE 2848 882 Cow milk, whole, fresh, 888 Milk Skm of Cows, 889 Milk Whole Cond, 890 Whey Condensed, 891 Yoghurt, 892 Yogh Conc.Or Not, 893 Butterm.,Curdl,Acid.Milk, 894 Milk Whole Evp, 895 Milk Skimmed Evp, 896 Milk Skimmed Cond, 897 Milk Whole Dried, 898 Milk Skimmed Dry, 899 Milkdry Buttrmilk, 900 Whey Dry, 901 Cheese of Whole Cow Milk, 904 Cheese of Skimmed Cow Milk, 905 Whey Cheese, 907 Processed Cheese, 908 Reconsti.Ted Milk, 917 Casein, 951 Buffalo milk, whole, fresh, 954 Milk Skim of Buf, 955 Cheese of Bufmilk, 982 Sheep milk, whole, fresh, 984 Cheese of Sheep Milk, 985 Milk Skmd Sheep, 1020 Goat milk, whole, fresh, 1021 Cheese of Goat Mlk, 1023 Milk Skimd Goats, 1130 Camel milk, whole, fresh; nutrient data only: 903 Whey Fresh, 909 Prod.of Nat.Milk Constit, 910 Ice Cream and Edible Ice
				2949	Eggs + (Total)	CODE 2744 1062 Hen eggs, in shell, 1063 Eggs Liquid, 1064 Eggs Dried, 1091 Other bird eggs,in shell; nutrient data only: 916 Egg Albumine
Commodity 8	*Vegetables*	2918	Vegetables + (Total)	2601	Tomatoes	388 Tomatoes, 389 Tomatojuice Concentrated, 390 Juice of Tomatoes, 391 Paste of Tomatoes, 392 Tomato Peeled
				2602	Onions	403 Onions, dry

FWF Study		Food Balance Sheet				
Commodity #	Commodity name	Code category	Name category	Code Item	Name item	FBS definition[46]
				2605	**Vegetables, other**	358 Cabbages and other brassicas, 366 Artichokes, 367 Asparagus, 372 Lettuce and chicory, 373 Spinach, 378 Cassava leaves, 393 Cauliflowers and broccoli, 394 Pumpkins, squash and gourds, 397 Cucumbers and gherkins, 399 Eggplants (aubergines), 401 Chillies and peppers, green, 402 Onions (inc. shallots), green, 406 Garlic, 407 Leeks, other alliaceous veg, 414 Beans, green, 417 Peas, green, 420 Leguminous vegetables, nes, 423 String beans, 426 Carrots and turnips, 430 Okra, 446 Maize, green, 447 Sweet Corn Frozen, 448 Sweet Corn Prep or Preserved, 449 Mushrooms and truffles, 450 Dried Mushrooms, 451 Canned Mushrooms, 459 Chicory roots, 461 Carobs, 463 Vegetables fresh nes, 464 Vegetables, dried nes, 465 Vegetables, canned nes, 466 Juice of Vegetables Nes, 469 Vegetables Dehydrated, 471 Vegetables in Vinegar, 472 Vegetables Preserved Nes, 473 Vegetable Frozen, 474 Veg.in Tem. Preservatives, 475 Veg.Prep. Or Pres.Frozen, 476 Homogen.Veget.Prep, 567 Watermelons, 568 Other melons (inc.cantaloupes), 658 Coffee Subst. Cont.Coffee

Annex V. Food balance sheets

A food balance sheet presents a comprehensive picture of the pattern of a country's food supply during a specified reference period. Table 14 is an illustration for cereals in France in 2007.

The food balance sheet shows for each food item i.e. each primary commodity supply elements and utilisation elements. In the present study and similarly to (FAO 2011a), each element in the Food Balance Sheet has been interpreted as follows:

A – Total domestic production: reported in primary crops for crops; carcass weight for meat; live weight equivalent for fish and total production leaving the manufacture for processed commodities.

B – Total domestic import: all movements of the commodity in question into the country/region.

C – Stock variation: changes in foremost government stocks.

D – Export quantity: all movements of the commodity in question out of the country/region.

E – Domestic supply quantity: Sum of A, B, C, and D.

F – Feed: the amounts of the commodity in question used to feed animals.

G – Seed: the amounts of the commodity in question used for reproductive purposes, e.g. seed, planting, eggs for hatching or fish for bait.

H – Processing: the amount of the commodity available for human consumption as part of processed food products, containing several commodities.

I – Other utilities/waste: the amounts of commodity lost during handling, storage and transport between production and distribution as well as amounts of the commodity used for non-food purposes, e.g. oil for oil production and wheat for bio-energy.

J – Food: all forms of the commodity available for human consumption, e.g. wheat flour, vegetable oils etc.

Table 14: Extract from FBS for France

Item	item (codes)	Supply elements					Utilisation elements				
		Production (1000 tonnes)	Import Quantity (1000 tonnes)	Stock Variation (1000 tonnes)	Export Quantity (1000 tonnes)	Domestic supply quantity (1000 tonnes)	Feed (1000 tonnes)	Seed (1000 tonnes)	Processing (1000 tonnes)	Other Util (1000 tonnes)	Food (1000 tonnes)
		A	B	C	D	E	F	G	H	I	J
Cereals - Excluding Beer + (Total)	2905	59299	3838	2209	28304	37042	21647	1176	5690	1213	7316
Wheat	2511	32764	1898	2564	17888	19338	8483	772	3292	592	6199
Rice (Milled Equivalent)	2805	58	491	-145	79	325	19	1	3	1	300
Barley	2513	9474	64	900	5102	5336	3446	235	1567	76	11
Maize	2514	14357	1080	-1110	4973	9355	7175	93	789	540	757
Rye	2515	120	22		26	116	83	3			30
Oats	2516	409	36		52	393	366	12		3	12
Millet	2517	37	4		26	14	12	2			
Sorghum	2518	288	193	0	74	408	407	1			
Cereals, Other	2520	1792	50	0	83	1759	1656	57	40		6

Annex VI. Causes and environmental impacts of food wastage

Table 15: Causes and environmental impacts of food wastage

Phase of the life cycle	Causes of food loss/waste for phase considered[47]		Environmental impacts for phase considered		Environmental impacts of food waste
	Crops	Animal products	Crops	Animal products	
1/ Agricultural production	Losses due to mechanical damage and/or spillage during harvest operation (e.g. threshing or fruit picking), crops sorted out post harvest, etc.	>For bovine, pork, and poultry meat, losses refer to animal death during breeding. >For fish, losses refer to discards during fishing. >For milk, losses refer to decreased milk production due to dairy cow sickness (mastitis).	Inputs and outputs from the sowing to the harvest. Resources consumed include e.g. seeds, fertilisers, pesticides, fuel for the mechanised work, to produce the agricultural raw material (including the by-products and residues, etc).	This phase includes all inputs and outputs occurring at farm, notably animal feeds, enteric fermentation (methane emissions), manure management.	**1/ Agricultural production** **+** **6/ End-of-life**
2/ Postharvest handling and storage	Losses due to spillage and degradation during handling, storage, and transportation between farm and distribution.	>For bovine, pork, and poultry meat, losses refer to death during transport to slaughter and condemnation at slaughterhouse. >For fish, losses refer to spillage and degradation during icing, packaging, storage, and transportation after landing. >For milk, losses refer to spillage and degradation during transportation between farm and distribution.	Inputs and outputs associated with the handling and transport from field to specific storage facilities, notably energy use for transport and frigorific storage etc.	Concerning animal products, this phase includes the inputs and outputs associated with handling and transport from farm to slaughterhouse and specific storage installations, notably energy use.	**Previous phase** **+** **2/ Postharvest handling and storage** **+** **6/ End-of-life**
3/ Processing	Losses due to spillage and degradation during industrial or domestic processing, e.g. juice production, canning and bread baking. Losses may occur when crops are	>For bovine, pork and poultry meat, losses refer to trimming spillage during slaughtering and additional industrial processing, e.g. sausage production. >For fish, losses refer to industrial	The processing and packaging phase includes inputs and outputs from food industrial processing: ingredients and by-products, e.g. for vegetables commodities juice production, canning and bread	For animal commodities canning, smoking, and sausage production for instance.	**Previous phase** **+** **3/ Processing** **+** **6/ End-of-life**

[47] Adapted from (FAO 2011a)

Phase of the life cycle	Causes of food loss/waste for phase considered[47]		Environmental impacts for phase considered		Environmental impacts of food waste
	Crops	Animal products	Crops	Animal products	
	sorted out if not suitable to process or during washing, peeling, slicing and boiling or during process interruptions and accidental spillage.	processing such as canning or smoking. >For milk, losses refer to spillage during industrial milk treatment (e.g. pasteurization) and milk processing to, e.g., cheese and yoghurt.	baking, fruits sorting before washing, peeling, slicing and boiling , or		
4/ Distribution	Losses and waste in the market system, at e.g. wholesale markets, supermarkets, retailers and wet markets.		The distribution phase includes inputs and outputs necessary for market system, e.g. wholesale, supermarkets, retailers and wet markets.		**Previous phase** **+** **4/ Distribution** **+** **6/ End-of-life**
5/ Consumption	Losses and waste during consumption at the household level.		The consumption phase includes all inputs and outputs at the household level. Moisture and fat loss are not accounted in the loss values.		**Previous phase** **+** **5/ consumption** **+** **6/ End-of-life**
6/ End-of-life	N/A	N/A	The end of life phase includes all inputs and outputs during the waste treatment and disposal.		N/A

Annex VII. Carbon footprint – LCA sources for agricultural production phase

Among the 131 studies screened, 47 were retained for use in the FWF model (based on the criteria presented in Annex VIII). These latter studies are listed in this annex, by commodity.

Commodity 1 Cereals (excluding beer)

1. Blengini, G. A., & Busto, M. (2008). The life cycle of rice: LCA of alternative agri-food chain management systems in Vercelli (Italy). Journal of environmental management, 90(3), 1512–22.
2. Carlsson-Kanyama, A. (1998). Climate change and dietary choices – How can emissions of greenhouse gases from food consumption be reduced? Food policy, 23(3), 277–293.
3. Jones, R., Weller, R., & Bryson, R. (2006). Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.
4. Narayanaswamy, V. (2002). A Primer on Environmental Life Cycle Assessment (LCA) for Australian Grains.
5. Nemecek, T., Weiler, K., Plassmann, K., & Schnetzer, J. (2011). Geographical extrapolation of environmental impact of crops by the MEXALCA method
6. Pelletier, N., Arsenault, N., & Tyedmers, P. (2008). Scenario modeling potential eco-efficiency gains from a transition to organic agriculture: life cycle perspectives on Canadian canola, corn, soy, and wheat production. Environmental management, 42(6), 989–1001.

Commodity 2 Starchy roots

1. Jones, R., Weller, R., & Bryson, R. (2006). Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.
2. Nemecek, T., Weiler, K., Plassmann, K., & Schnetzer, J. (2011). Geographical extrapolation of environmental impact of crops by the MEXALCA method.

Commodity 3 Oilcrops & Pulses

1. Canals, L. i, Muñoz, I., & Hospido, A. (2008). Life Cycle Assessment (LCA) of Domestic vs. Imported Vegetables. Case Studies on Broccoli, Salad Crops and Green Beans.
2. Dumelin, E. E. (n.d.). Life Cycle Assessments of Vegetable Oils & Spreads.
3. Jungbluth, N., & Frischknecht, R. (2007). Life cycle assessment of imported agricultural products – impacts due to deforestation and burning of residues, 4–7.
4. Michalopoulos, G., Christodoulopoulou, L., Giakoumaki, G., Manolaraki, C., Malliaraki, S., Aggelaki, K., & Zontanou, E. (2011). Life Cycle Assessment of Extra Virgin Olive Oil produced by three groups of farmers in south Greece, 1–15.
5. Nemecek, T., Weiler, K., Plassmann, K., & Schnetzer, J. (2011). Geographical extrapolation of environmental impact of crops by the MEXALCA method.

6. Ntiamoah, A., & Afrane, G. (2008). Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach. Journal of Cleaner Production, 16(16), 1735–1740.
7. Trydeman Knudsen, M., Yu-Hui, Q., Yan, L., & Halberg, N. (2010). Environmental assessment of organic soybean (Glycine max.) imported from China to Denmark: a case study. Journal of Cleaner Production, 18(14), 1431–1439.

Commodity 4 Fruits (excluding wine)

1. Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., & Williams, A. (2010). HOW LOW CAN WE GO?
2. Gazulla Santos, C. (n.d.). ACV del vino de la Rioja.
3. Lillywhite, R., Chandler, D., Grant, W., & Lewis, K. (2007). Environmental footprint and sustainability of horticulture (including potatoes)–A comparison with other agricultural sectors. University of Warwick.
4. National Mango Board Sustainability Assessment. (2010).
5. Nemecek, T., Weiler, K., Plassmann, K., & Schnetzer, J. (2011). Geographical extrapolation of environmental impact of crops by the MEXALCA method.
6. Sanjuan, N., & Ubeda, L. (2005). LCA of integrated orange production in the Comunidad Valenciana (Spain). International Journal of Agricultural Resources, Governance and Ecology, 4(2), 163–177.
7. Venkat, K. (2012). Comparison of twelve organic and conventional farming systems : A life cycle greenhouse gas emissions perspective.
8. Yoshikawa, N., Amano, K., Shimada, K., & City, K. (n.d.). Evaluation of environmental load on fruits and vegetables consumption and its reduction potential, 1–3.

Commodity 5 Meat

1. Cederberg, C. (2009). Life cycle inventory of greenhouse gas emissions and use of land and energy in Brazilian beef production. The Swedish Institute for Food and Technology (792).
2. Dalgaard, R., & Halberg, N. (2005). Life Cycle Assessment (LCA) of Danish Pork, (3), 2–4.
3. Dollé, J., Manneville, V., Gac, A., & Charpiot, A. (2011). Emissions de gaz à effet de serre et consommations d'énergie des viandes bovines et ovines françaises : revue bibliographique et évaluations sur l'amont agricole.
4. Hakansson, S., Gavrilita, P., & Bengoa, X. (2005). Comparative Life Cycle Assessment: Pork vs. tofu.
5. Johnson, D., Phetteplace, H., Seidl, A. F., Schneider, U., & McCarl, B. . (2003). Management variations for US beef production systems: Effects on greenhouse gas emissions and profitability.
6. Jones, R., Weller, R., & Bryson, R. (2006). Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.
7. Ledgard, S. ., Lieffering, M., McDevitt, J., Boyes, M., & Kemp, R. (2010). A Greenhouse Gas Footprint Study for Exported New Zealand Lamb for Exported New Zealand Lamb.
8. Pelletier, N., Pirog, R., & Rasmussen, R. (2010). Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. Agricultural Systems, 103(6)

9. Vergé, X. P. C., Dyer, J. a., Desjardins, R. L., & Worth, D. (2009). Greenhouse gas emissions from the Canadian pork industry. Livestock Science, 121(1), 92–101.

Commodity 6 Fish & Seafood

1. Aubin, J., Mikolasek, O., Corson, M. S., Tchoumboue, J., Ombredane, D., Efole Ewoukem, T., Tomedi Eyango, M., et al. (2010). Environmental Impacts of farms integrating aquaculture and agriculture in Cameroon.
2. Ayer, N. W., & Tyedmers, P. H. (2009). Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada. Journal of Cleaner Production, 17(3), 362–373.
3. Bosma, R., Hanh, C., Potting, J., & Dung, P. (2009). Environmental impact assessment of the pangasius sector in the Mekong Delta.
4. Buchspies, B. (2011). Life Cycle Assessment of High-Sea Fish and Salmon Aquaculture. Aquaculture.
5. Cao, L., Diana, J. S., Keoleian, G. a, & Lai, Q. (2011). Life cycle assessment of Chinese shrimp farming systems targeted for export and domestic sales. Environmental science & technology, 45(15)
6. FAO. (2010). The state of World Fisheries and Aquaculture.
7. Hospido, A., & Tyedmers, P. (2005). Life cycle environmental impacts of Spanish tuna fisheries. Fisheries Research, 76(2), 174–186.
8. Papatryphon, E. lia., & Petit, J., Van der Werf, H. M. G. Kaushik, S. J. (2004). Life Cycle Assessment of trout farming in France : a farm level approach, 71–77.
9. Pelletier, N., & Tyedmers, P. (2010). Life Cycle Assessment of Frozen Tilapia Fillets From Indonesian Lake-Based and Pond-Based Intensive Aquaculture Systems. Journal of Industrial Ecology, 14(3), 467–481.
10. Pelletier, N., Tyedmers, P., Sonesson, U., Scholz, A., Ziegler, F., Flysjo, A., Kruse, S., et al. (2009). Not all salmon are created equal: life cycle assessment (LCA) of global salmon farming systems. Environmental science & technology, 43(23), 8730–6.
11. Phong, L. T., de Boer, I. J. M., & Udo, H. M. J. (2011). Life cycle assessment of food production in integrated agriculture–aquaculture systems of the Mekong Delta. Livestock Science, 139(1-2), 80–90.
12. Schmidt, J., & Thrane, M. (2006). LCA case study of pickled herring.
13. Vázquez-Rowe, I., Moreira, M. T., & Feijoo, G. (2011). Life Cycle Assessment of fresh hake fillets captured by the Galician fleet in the Northern Stock. Fisheries Research, 110(1), 128–135.
14. Vázquez-Rowe, I., Moreira, M. T., & Feijoo, G. (2012). Corrigendum to: "Life Cycle Assessment of fresh Hake fillets captured by the Galician fleet in the Northern Stock." Fisheries Research, (2010), 1–2.
15. d' Orbcastel, E. R., Blancheton, J.-P., & Aubin, J. (2009). Towards environmentally sustainable aquaculture: Comparison between two trout farming systems using Life Cycle Assessment. Aquacultural Engineering, 40(3), 113–119.

Commodity 7 Milk (excluding butter) & Eggs

1. Basset-mens, C., Ledgard, S., & Carran, A. (2005). First life cycle assessment of milk production from New Zealand dairy farm systems, 2003, 258–265.
2. Jones, R., Weller, R., & Bryson, R. (2006). Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.

Commodity 8 Vegetables

1. Canals, L. i, Muñoz, I., & Hospido, A. (2008). Life Cycle Assessment (LCA) of Domestic vs. Imported Vegetables. Case Studies on Broccoli, Salad Crops and Green Beans.
2. Carlsson-Kanyama, A., & Fuentes, C. (2006). Environmental information in the food supply system.
3. Lillywhite, R., Chandler, D., Grant, W., & Lewis, K. (2007). Environmental footprint and sustainability of horticulture (including potatoes)–A comparison with other agricultural sectors. University of Warwick
4. Nemecek, T., Weiler, K., Plassmann, K., & Schnetzer, J. (2011). Geographical extrapolation of environmental impact of crops by the MEXALCA method.
5. Saunders, C., Barber, A., & Taylor, G. (2006). Food Miles – Comparative Energy/Emissions Performance of New Zealand's Agriculture Industry.
6. The Swedish Institute for Food and Biotechnology. (2007). LCA in Foods, (April).
7. Torrellas, M., Antón, A., López, J. C., Baeza, E. J., Parra, J. P., Muñoz, P., & Montero, J. I. (2012). LCA of a tomato crop in a multi-tunnel greenhouse in Almeria. The International Journal of Life Cycle Assessment, 863–875.
8. Yoshikawa, N., Amano, K., Shimada, K., & City, K. (n.d.). Evaluation of environmental load on fruits and vegetables consumption and its reduction potential, 1–3.

Annex VIII. Quality criteria used to select LCA studies

A simplified list of quality criteria was used to screen the hundred over publications that were indentified for food production phase. The criteria were selected based on what minimum information was available in the publications that could serve as an indication of the quality of the study (see Table 16). This initial screening brought the number of relevant publications to be used around 40.

Table 16: Simplified criteria for identifying the most reliable LCA studies

Criteria for selecting LCA studies for further investigation	Description
Date of data	Data that was more than 10 years old was considered outdated
Peer reviewed	A critical review by another LCA practitioner is the best indication of quality. If the reviewer and reviewing process was not mentioned or performed, the acceptance of the study in a peer-reviewed journal was used as an indication of the scientific quality
Performed for	LCAs are sometimes commissioned by different stakeholders, which may influence the LCA practitioner to only present results that supports the stakeholder's point of view
Performed by	LCAs are performed by researchers and practitioners in universities, research institutions, and private organizations. Although not always the case, independent researchers tend to be more trustworthy than consultants paid by private companies.
Methodology of inventory	The scope and inventory of flows, processes and emissions must be extensive in order to provide a full picture of the environmental impacts
Methodology of impact assessment	A recognised and established impact assessment methodology can give an indication of whether the LCA was performed professionally
Tool	Although the tool in itself does not guarantee the quality of the results, if the LCA practitioner uses his own tools, it can be difficult to check whether the output data is correct
Data quality	Likewise, if the LCA practitioner (or his/her client) uses data they have generated themselves and not validated by others, it can be difficult to know whether the data is truly representative. When possible, the six different dimensions of data quality were used: • Completeness • Technological representativeness • Geographical representativeness • Time-related representativeness • Precision uncertainty • Methodological appropriateness and consistency

Annex IX. Complementary information on processing modelling used in carbon footprint

Table 17: Shares for processed and unprocessed food, by commodity

<table>
<tr><th>Region #</th><th>Region name</th><th>Commodity 1
Cereals</th><th>Commodity 2
Starchy roots</th><th>Commodity 3
Oilcrops & Pulses</th><th>Commodity 4
Fruits (excluding wine)</th><th>Commodity 5
Meat</th><th>Commodity 6
Fish & Seafood</th><th>Commodity 7
Milk (excluding butter) & Eggs</th><th>Commodity 8
Vegetables</th></tr>
<tr><td>Region 1</td><td>Europe</td><td rowspan="7">Wheat + Rye: 100% processed

Oats + Barley + Cereals, other: 100% processed

Maize: 100% processed

Rice: 100% polished[a]

Millet + Sorghum: 100% processed</td><td rowspan="2">Potatoes:
73% processed
27% unprocessed</td><td rowspan="7">Oilcrops: 100% processed[a]

Pulses: 0%[a]</td><td rowspan="2">60% processed
40% unprocessed</td><td rowspan="7">Meat slaughtered and chilled: 33%[b]

Meat frozen: 67%[b]</td><td rowspan="2">96% processed
4% unprocessed</td><td rowspan="7">Milk (excluding butter):
70% unprocessed[c]
30% processed[c]

Eggs: 100%[a] unprocessed</td><td rowspan="2">60% processed
40% unprocessed</td></tr>
<tr><td>Region 2</td><td>North America & Oceania</td></tr>
<tr><td>Region 3</td><td>Industrialized Asia</td><td>Potatoes:
15% processed
85% unprocessed</td><td>4% processed
96% unprocessed</td><td rowspan="5">40% processed
60% unprocessed</td><td>4% processed
96% unprocessed</td></tr>
<tr><td>Region 4</td><td>Sub-Saharan Africa</td><td>Cassava:
50% processed
50% unprocessed</td><td>1% processed
99% unprocessed</td><td>1% processed
99% unprocessed</td></tr>
<tr><td>Region 5</td><td>North Africa, Western Asia and Central Asia</td><td>Potatoes:
19% processed
81% unprocessed</td><td>50% processed
50% unprocessed</td><td>50% processed
50% unprocessed</td></tr>
<tr><td>Region 6</td><td>South and Southeast Asia</td><td>Potatoes:
10% processed
90% unprocessed</td><td>5% processed
95% unprocessed</td><td>5% processed
95% unprocessed</td></tr>
<tr><td>Region 7</td><td>Latin America</td><td>Potatoes:
10% processed
90% unprocessed</td><td>50% processed
50% unprocessed</td><td>10% processed
90% unprocessed</td></tr>
<tr><td colspan="10">All figures coming from the study FAO (2011), unless specified.
[a] BIO IS assumption.
[b] (Venkat 2011)
[c] based on data for Europe and the USA. IDF, 2010, The World dairy situation.</td></tr>
</table>

Annex X. Complementary information on distribution modelling used in carbon footprint

Table 18: Supermarket share in food retail

Region #	Region name	Sub-region #	Sub-region name	Supermarket share (%)	Source
Region 1	Europe	R1-1	Europe	80	(Thomas Reardon et al. 2004) for Western Europe, extrapolated to whole Europe
Region 2	North America & Oceania	R2-1	Australia	80	BIO IS assumption (assumed similar to Europe)
		R2-2	Canada	80	BIO IS assumption (assumed similar to Europe)
		R2-3	New Zealand	80	BIO IS assumption (assumed similar to Europe)
		R2-4	USA	90	(Traill 2006)
Region 3	Industrialized Asia	R3-1	China	48	(Thomas Reardon 2003)
		R3-2	Japan	65	(Thomas Reardon 2003)
		R3-3	Republic of Korea	80	BIO IS assumption (assumed similar to Europe)
Region 4	Sub-Saharan Africa	R4-1	Eastern Africa	30	BIO IS assumption based on (Traill 2006)
		R4-2	Middle Africa	3	BIO IS assumption based on (Traill 2006)
		R4-3	Southern Africa	27	BIO IS assumption based on (Thomas Reardon 2003) and (Coriolis Research 2001)
		R4-4	Western Africa	3	BIO IS assumption based on (GAIN 2010a; GAIN 2010c)
Region 5	North Africa, Western Asia and Central Asia	R5-1	Central Asia	39	BIO IS assumption (assumed similar to South-Eastern Asia)
		R5-2	Mongolia	39	BIO IS assumption (assumed similar to South-Eastern Asia)
		R5-3	Northern Africa	7	BIO IS assumption based on (Traill 2006)
		R5-4	Western Asia	50	BIO IS assumption based on (Traill 2006) and (GAIN 2010b; GAIN 2003)
Region 6	South and Southeast Asia	R6-1	South-Eastern Asia	39	BIO IS assumption based on (Thomas Reardon 2003)
		R6-2	Southern Asia	1	BIO IS assumption based on (Traill 2006)
Region 7	Latin America	R7-1	Caribbean	50	(GAIN 2009)
		R7-2	Central America	44	BIO IS assumption based on (Thomas Reardon 2003)
		R7-3	South America	55	BIO IS assumption based on (Thomas Reardon 2003)

Table 19: Share of commodities distributed to supermarkets at room temperature, refrigerated or frozen

Commodity #	Commodity name	Ambient Temperature (%)	Refrigerated (%)	Frozen (%)	Source
Commodity 1	Cereals (excluding beer)	100	0	0	BIO IS assumption
Commodity 2	Starchy roots	100	0	0	BIO IS assumption
Commodity 3	Oilcrops & Pulses	100	0	0	BIO IS assumption
Commodity 4	Fruits (excluding wine)	0	100	0	BIO IS assumption
Commodity 5	Meat	0	33	67	(Venkat 2011)
Commodity 6	Fish & Seafood	0	33	67	(Venkat 2011)
Commodity 7	Milk (excluding butter) & Eggs	0	100	0	BIO IS assumption
Commodity 8	Vegetables	0	100	0	BIO IS assumption

Annex XI. Complementary information on end-of-life modelling used in carbon footprint

Table 20: Adaptation of data from literature source

Income level (Hoornweg & Bhada-Tata 2012)	Corresponding sub-regions (this study)
High Income	Europe; Australia; Canada; New Zealand; USA; Japan Republic of Korea
Upper Middle Income	Southern Africa; Northern Africa; Western Asia
Lower Middle Income	China; Central Asia; Mongolia; South-Eastern Asia; Southern Asia
Low Income	Eastern Africa; Middle Africa; Western Africa

Table 21: Municipal solid waste composition by income Level

	Organic* %	Paper %	Plastic %	Glass %	Metal %	Other %
High Income	28	31	11	7	6	17
Upper Middle Income	54	14	11	5	3	13
Lower Middle Income	59	9	12	3	2	15
Low Income	64	5	8	3	3	17

From (Hoornweg & Bhada-Tata 2012)
*Organic: Food scraps, yard (leaves, grass, brush) waste, wood, process residues

Table 22: Municipal solid waste disposal by income level

	Dumps %	Landfills %	Compost %	Recycled* %	Incinerated %	Other* %
High Income	0	43	11	22	21	4
Upper Middle Income	32	59	1	1	0	6
Lower Middle Income	49	11	2	5	0	33
Low Income	13	59	1	1	1	26

Adapted from (Hoornweg & Bhada-Tata 2012)
(*) not taken into account in calculations, other values brought back to 100%

Table 23: Collection rates of municipal solid waste by income level

	Collection rate %
High Income	98
Upper Middle Income	85
Lower Middle Income	68
Lower Income	41

From (Hoornweg & Bhada-Tata 2012)

Table 24: Emission factors for food wastage treatments

	Emission factor kg eq. CO_2 / kg of food waste
Dumps	0.75
Landfills	1.25
Compost	0.19
Incineration	0.02
From calculations based on (IPCC 2006)	

Annex XII. Extracts of WFN database

For illustrative purpose, here are two extracts of the crops and livestock waterfootprint impact factors dabases.

Table 25: Extract of crops water footprint database (Mekonnen & Hoekstra 2010a)

Appendix II. Water footprint per ton of crop or derived crop product at national and sub-national level (m^3/ton) (1996-2005)

								Country >>>	Global average	Turkey	Turkey	Turkey	Turkmenistan	Turkmenistan	Turkmenistan	Turkmenistan	Turkmenistan	Turkmenistan	Tuvalu	Uganda	Uganda	Uganda
Product code (FAOSTAT)	Product code (HS)	Product code (SITC)	Product description (HS)	Product description (FAOSTAT)	Root product (HS)	Product fraction (pf)	Value fraction (vf)	Province/ state >>>	Global average	Bartin li	Igdir	CNTRY-average	Ahal	Balkan	Dashhowuz	Lebap	Mary	CNTRY-average	CNTRY-average	Apac	Arua	Bundibugyo
								WF type														
15	100110 / 100	0411	Wheat (Durum wheat, Wheat nes and meslin)	Wheat	100110 / 100	1,00	1,00	Green	1277	1853	1506	2074	988	1079	603	1093	1179	1046		1567	1869	1161
								Blue	342	73	320	130	274	224	436	305	185	223				
								Grey	207	166	171	196								541	699	250
	110100	0461	Wheat or meslin flour		100190	0,79	0,80	Green	1292	1875	1524	2096	1000	1092	611	1106	1193	1058		1586	1891	1175
								Blue	347	74	324	132	278	227	441	308	187	226				
								Grey	210	182	173	198								547	707	253
	110100a		Wheat bread		110100	1,15	1,00	Green	1124	1631	1325	1825	869	950	531	961	1037	920		1379	1644	1022
								Blue	301	64	282	115	241	187	383	268	93	196				
								Grey	183	158	150	172								476	615	220
	110100b		Dry pasta		110100	1,00	1,00	Green	1292	1875	1524	2096	1000	1092	611	1106	1193	1058		1586	1891	1175
								Blue	347	74	324	132	278	227	441	308	187	226				
								Grey	210	182	173	198								547	707	253
	110311	0462	Wheat groats and meal		110321	1,00	1,00	Green	1423	2065	1678	2311	1101	1203	673	1218	1314	1165		1747	2083	1294
								Blue	362	82	357	145	306	250	485	339	118	249				
								Grey	231	200	191	218								603	779	279
	110321	0462	Wheat pellets		100110	0,18	0,20	Green	1423	2065	1678	2311	1101	1203	673	1218	1314	1165		1747	2083	1294
								Blue	362	82	357	145	306	250	485	339	118	249				
								Grey	231	200	191	218								603	779	279
	110811	59211	Wheat, starch		110100	0,85	0,86	Green	1104	1468	1163	1630	777	848	474	859	926	822		1232	1469	912
								Blue	269	58	252	182	216	176	342	238	83	175				
								Grey	167	141	134	154								425	549	197
	110900	59217	Wheat gluten, whether or not dried		110100	0,15	0,34	Green	2828	4248	3452	4754	2265	2475	1383	2505	2782	2397		3593	4284	2661
								Blue	785	168	734	299	629	514	998	898	242	512				
								Grey	476	412	392	448								1240	1602	574
27	100610	0421	Rice in the husk (paddy or rough)	Rice, paddy	100610	1,00	1,00	Green	1146			382	626	897	338	1764	2134	1148		2099	2124	2055
								Blue	341			888	4024	4321	3748	3000	2467	3414				
								Grey	187			219					1	1		44	44	47
	100620	0422	Rice, husked (brown)		100610	0,77	1,00	Green	1488			392	613	808	428	2291	2771	1491		2728	2758	2069
								Blue	443			1150	5228	5612	4885	3895	3284	4434				

Table 26: Extract of livestock water footprint database (Mekonnen & Hoekstra 2010a)

Appendix V. Water footprint of animal products (m^3/ton). Period 1996-2005

HS (PC-TAS) code	SITC Rev 3 (SITA) code	Product dacription (HS)	Product description (SITC)	Rootproduct (HS)	Rootproduct (SITC)	Product fraction	Value fraction	Country	World Average				Afghanistan				Albania			
								Production system >>	Grazing	Mixed	Industrial	Weighted average	Grazing	Mixed	Industrial	Weighted average	Grazing	Mixed	Industrial	Weighte average
010111	00151	Horses, live pure-bred breeding	Horses	010111	00151	1,00	1,00	Green	40317	34717	33337	37179	44732	0	0	44732	0	43020	0	4382
								Blue	1470	3534	2183	2462	15447	0	0	15447	0	2001	0	200
								Grey	675	1179	1469	971	123	0	0	123	0	757	0	75
010119	00151a	Horses, live except pure-bred breeding		010111		1,00	1,00	Green	40317	34717	33337	37179	44732	0	0	44732	0	43020	0	4382
								Blue	1470	3534	2183	2462	15447	0	0	15447	0	2001	0	200
								Grey	675	1179	1469	971	123	0	0	123	0	757	0	75
010120	00152	Asses, mules and hinnies, live	Asses, mules, hinnies	010111	00151	1,00	1,00	Green	40317	34717	33337	37179	44732	0	0	44732	0	43020	0	4382
								Blue	1470	3534	2183	2462	15447	0	0	15447	0	2001	0	200
								Grey	675	1179	1469	971	123	0	0	123	0	757	0	75
010210	00111	Bovine, live pure-bred breeding	Bov.animals,pure,breedng.	010210	00111	1,00	1,00	Green	9197	7348	4174	7002	3608	8814	4073	5797	8901	5717	1955	617
								Blue	192	241	311	256	879	4308	5523	3454	177	213	409	25
								Grey	108	199	336	219	27	143	185	114	86	59	55	7
010290	00119	Bovine, live except pure-bred breeding	Other bovine animals	010210	00111	1,00	1,00	Green	9197	7348	4174	7002	3608	8814	4073	5797	8901	5717	1955	617
								Blue	192	241	311	256	879	4308	5523	3454	177	213	409	25
								Grey	108	199	336	219	27	143	185	114	86	59	55	7
010310	00131	Swine, live pure-bred breeding	Swine,pure,for breeding	010310	00131	1,00	1,00	Green	5037	3353	2589	3155	0	0	0	0	4120	3011	2159	321
								Blue	264	261	293	276	0	0	0	0	947	1190	971	108
								Grey	416	374	439	400	0	0	0	0	256	186	133	15
010391	00139	Swine, live except pure-bred breeding weighing less than 50 kg	Other swine, live	010310	00131	1,00	1,00	Green	5037	3353	2589	3155	0	0	0	0	4120	3011	2159	321
								Blue	264	261	293	276	0	0	0	0	947	1190	971	108
								Grey	416	374	439	400	0	0	0	0	256	186	133	15
010392	00139a	Swine, live except pure-bred breeding weighing 50 kg or more		010310		1,00	1,00	Green	5037	3353	2589	3155	0	0	0	0	4120	3011	2159	321
								Blue	264	261	293	276	0	0	0	0	947	1190	971	108
								Grey	416	374	439	400	0	0	0	0	256	186	133	15
010410	00121	Sheep, live	Sheep, live	010410	00121	1,00	1,00	Green	7126	3490	2026	4278	6737	6361	1651	5331	5160	2666	1158	338
								Blue	168	196	321	207	240	461	707	434	284	321	410	33
								Grey	8	30	95	33	5	16	38	15	4	10	13	
010420	00122	Goats, live	Goats, live	010420	00122	1,00	1,00	Green	5260	2685	1348	2900	3647	5899	864	3345	4054	2126	912	256
								Blue	152	169	219	175	159	183	221	191	207	238	313	25
								Grey	0	2	10	3	0	1	2	1	0	0	0	
010511	00141	Fowls, live domestic weighing not more than 185 g	Poultry, live, to 185g	010599	00149	10,00	1,00	Green	818	317	182	277	147	302	362	273	581	345	173	36
								Blue	56	28	15	23	327	868	777	604	290	173	87	19
								Grey	56	45	25	38	10	21	24	19	41	25	12	2
010519	00141a	Poultry, live except domestic fowls, weighing not more than 185 g		010599		1,00	1,00	Green	8177	3171	1823	2765	1470	3020	3521	2731	5888	3450	1730	390
								Blue	563	281	154	234	3266	6602	7774	6042	2985	1733	871	195
								Grey	560	448	254	384	100	208	245	188	414	248	123	27
010599	00149	Poultry, live except domestic fowls, weighing	Poultry, live over 185g	010599	00149	1,00	1,00	Green	8177	3171	1823	2765	1470	3020	3521	2731	5888	3450	1730	390

Annex XIII. Impact factors for carbon footprint

Table 27: Impact factors for carbon footprint of agricultural production

Region # / Region name / Sub-region name	Commodity 1 Cereals (excluding beer)					Commodity 2 Starchy roots	Commodity 3 Oilcrops & Pulses		Commodity 4 Fruits (excluding wine)					Commodity 5 Meat				Commodity 6 Fish & Seafood	Commodity 7 Milk (excluding butter) & Eggs		Commodity 8 Vegetables
kg CO_2 eq. / kg food	Wheat + Rye	Oats + Barley + Cereals, other	Maize	Rice	Millet + Sorghum	Starchy roots	Oilcrops	Pulses	Apples	Bananas	Citrus	Grapes	Fruits, other	Bovine Meat	Mutton & Goat Meat	Pigmeat	Poultry Meat	Fish & Seafood	Milk	Egg	Vegetables
Region 1 - Europe																					
Europe	0.80	0.93	0.65	2.60	0.93	0.24	0.75	0.37	0.18	0.35	0.29	0.40	0.42	20.20	15.92	4.88	4.48	4.46	1.03	5.54	2.34
Region 2 - North America & Oceania																					
Australia	0.42	0.93	0.43	1.77	0.93	0.16	0.47	0.37	0.18	0.34	0.11	0.67	0.29	23.11	15.92	4.88	4.48	4.18	0.72	5.20	2.18
Canada	0.38	0.93	0.33	1.77	0.93	0.16	0.26	0.37	0.18	0.34	0.11	0.67	0.29	23.11	15.92	4.88	4.48	4.48	0.72	5.20	2.40
New Zealand	0.65	0.93	0.43	1.77	0.93	0.16	0.47	0.37	0.18	0.34	0.11	0.67	0.29	23.11	15.92	4.88	4.48	4.36	0.72	5.20	2.47
USA	0.65	0.93	0.43	1.77	0.93	0.16	0.47	0.37	0.18	0.34	0.11	0.67	0.29	23.11	15.92	4.88	4.48	4.57	0.72	5.20	2.41
Region 3 - Industrialized Asia																					
China	0.59	0.93	0.57	2.88	0.93	0.18	0.51	0.37	0.22	0.56	0.17	0.62	0.25	22.54	12.61	5.57	4.48	4.04	1.03	5.20	0.96
Japan	0.59	0.93	0.57	2.88	0.93	0.18	0.51	0.37	0.22	0.56	0.17	0.62	0.25	23.11	6.63	4.88	4.48	2.69	1.03	5.20	0.91
Republic of Korea	0.59	0.93	0.57	2.88	0.93	0.18	0.51	0.37	0.22	0.56	0.17	0.62	0.25	22.54	12.61	5.57	4.48	2.85	1.03	5.20	0.06
Region 4 - Subsahara Africa																					
Eastern Africa	0.38	0.93	0.66	3.83	0.93	0.18	0.33	0.15	0.15	0.19	0.19	0.40	0.23	26.11	5.77	5.94	4.89	1.79	1.03	6.18	0.57
Middle Africa	0.38	0.93	0.76	5.19	0.93	0.41	0.32	0.05	0.15	0.09	0.09	0.40	0.23	26.11	5.77	5.94	4.89	1.64	1.03	6.18	0.56
Southern Africa	0.38	0.93	0.45	5.19	0.93	0.08	0.33	0.15	0.15	0.23	0.07	0.40	0.23	26.11	5.77	5.94	4.89	1.64	1.03	6.18	0.48
Western Africa	0.38	0.93	0.50	5.19	0.93	0.41	0.33	0.15	0.15	0.10	0.19	0.40	0.23	26.11	5.77	5.94	4.89	1.80	1.03	6.18	0.57
Region 5 - North Africa, Western Asia and Central Asia																					
Central Asia	0.47	0.93	0.57	2.88	0.93	0.12	0.80	0.37	0.22	0.35	0.17	0.62	0.46	22.63	14.62	5.67	4.55	2.48	1.03	5.54	0.70
Mongolia	0.47	0.93	0.57	2.88	0.93	0.12	0.81	0.37	0.22	0.35	0.17	0.62	0.46	22.63	14.62	5.67	4.55	2.32	1.03	5.54	0.81
Northern Africa	0.78	0.93	0.66	1.83	0.93	0.13	0.87	0.37	0.15	0.66	0.19	0.40	0.47	22.63	14.62	5.67	4.55	2.81	1.03	5.54	0.70
Western Asia	0.47	0.93	0.43	1.83	0.93	0.12	0.81	0.37	0.13	0.35	0.11	0.62	0.39	22.63	14.62	5.67	4.55	2.60	1.03	5.54	0.73
Region 6 - South and Southeast Asia																					
South-Eastern Asia	0.77	0.93	0.57	2.88	0.93	0.18	0.36	0.37	0.17	0.56	0.17	0.62	0.23	22.54	12.61	5.57	4.48	3.12	1.03	5.54	0.94
Southern Asia	0.62	0.93	0.55	2.46	0.93	0.16	0.38	0.37	0.15	0.45	0.13	0.62	0.23	22.54	12.61	5.57	4.48	3.41	1.03	5.54	0.88
Region 7 - Latin America																					
Caribbean	0.44	0.93	0.49	2.46	0.93	0.14	1.57	0.15	0.18	0.25	0.08	0.67	0.33	29.53	15.93	4.65	4.56	1.92	0.72	5.20	0.52
Central America	0.44	0.93	0.49	2.46	0.93	0.11	1.57	0.15	0.18	0.34	0.11	0.67	0.33	29.53	15.93	4.65	4.56	1.85	0.72	5.20	0.48
South America	0.45	0.93	0.42	2.17	0.93	0.14	1.57	0.15	0.18	0.33	0.08	0.67	0.32	29.53	15.93	4.65	4.56	1.93	0.72	5.20	0.42

Annex XIV. Impact factors for blue water footprint

Table 28: Impact factors for blue water footprint

Region # Region name Sub-region name	Commodity 1 Cereals (excluding beer)					Commodity 2 Starchy roots	Commodity 3 Oilcrops & Pulses		Commodity 4 Fruits (excluding wine)					Commodity 5 Meat				Commodity 6 Fish & Seafood	Commodity 7 Milk (excluding butter) & Eggs		Commodity 8 Vegetables
All figures in m³ / tonne	Wheat + Rye	Oats + Barley + Cereals, other	Maize	Rice	Millet + Sorghum	Starchy roots	Oilcrops	Pulses	Apples	Bananas	Citrus	Grapes	Fruits, other	Bovine Meat	Mutton & Goat Meat	Pigmeat	Poultry Meat	Fish & Seafood	Milk	Egg	Vegetables
Region 1 - Europe																					
Europe	39	59	124	906	87	9	190	90	142	98	116	114	302	302	428	283	117	0	61	128	33
Region 2 - North America & Oceania																					
Australia	16	98	676	1 150	66	97	598	122	142	98	116	114	302	433	325	885	127	0	82	106	124
Canada	5	9	6	852	69	33	196	130	142	98	116	114	302	192	317	210	31	0	33	33	52
New Zealand	342	78	264	852	69	33	219	98	142	98	116	114	302	267	366	341	28	0	62	71	51
USA	92	310	63	847	69	88	159	294	142	98	116	114	302	371	232	461	136	0	77	130	94
Region 3 - Industrialized Asia																					
China	463	25	74	246	41	5	202	146	142	98	116	114	302	350	328	286	209	0	188	217	5
Japan	5	1	37	171	57	2	77	29	142	98	116	114	302	283	279	382	114	0	59	109	32
Republic of Korea	342	75	81	116	88	9	34	182	142	98	116	114	302	211	389	411	206	0	87	206	6
Region 4 - Subsahara Africa																					
Eastern Africa	144	16	26	631	56	7	194	88	142	98	116	114	302	241	341	278	287	0	219	203	95
Middle Africa	1 344	11	21	224	76	3	167	110	142	98	116	114	302	171	353	265	67	0	103	104	45
Southern Africa	231	623	35	3 360	77	67	340	549	142	98	116	114	302	162	301	482	135	0	59	138	160
Western Africa	555	7	68	373	74	1	256	34	142	98	116	114	302	213	300	307	144	0	164	196	52
Region 5 - North Africa, Western Asia and Central Asia																					
Central Asia	77	683	1 030	3 009	2 564	110	3 100	866	142	98	116	114	302	1 380	452	2 025	2 300	0	716	2 253	235
Mongolia	342	81	873	1 408	477	289	1 922	250	142	98	116	114	302	198	354	484	873	0	116	847	232
Northern Africa	614	322	1 148	1 008	335	185	1 501	951	142	98	116	114	302	1 726	579	2 567	1 217	0	498	974	158
Western Asia	485	387	475	3 027	1 330	158	1 355	324	142	98	116	114	302	1 096	422	793	734	0	263	635	131
Region 6 - South and Southeast Asia																					
South-Eastern Asia	707	41	58	202	68	2	18	28	142	98	116	114	302	283	390	290	180	0	115	188	62
Southern Asia	1 178	473	263	520	119	51	743	316	142	98	116	114	302	598	409	840	1 019	0	212	811	96
Region 7 - Latin America																					
Caribbean	101	327	21	687	103	9	14	86	142	98	116	114	302	266	349	369	257	0	93	210	38
Central America	558	959	55	173	173	74	305	150	142	98	116	114	302	493	338	573	269	0	147	273	72
South America	33	199	22	383	21	25	12	106	142	98	116	114	302	131	408	502	89	0	46	102	70

Table 29: Impact factors for green water footprint

Region # Region name Sub-region name *All figures in m^3 / tonne*	Commodity 1 Cereals (excluding beer)					Commodity 2 Starchy roots	Commodity 3 Oilcrops & Pulses	
	Wheat + Rye	Oats + Barley + Cereals, other	Maize	Rice	Millet + Sorghum	Starchy roots	Oilcrops	Pulses
Region 1 - Europe								
Europe	1 265	1 144	630	550	1 893	213	2 119	1 212
Region 2 - North America & Oceania								
Australia	2 002	1 654	751	253	1 586	58	1 823	1 471
Canada	1 343	985	492	419	1 160	137	2 447	1 436
New Zealand	719	654	352	419	1 160	86	2 129	606
USA	1 873	1 032	522	422	1 116	56	1 630	1 227
Region 3 - Industrialized Asia								
China	827	845	791	549	1 236	233	1 784	1 723
Japan	1 078	916	1 506	576	2 380	129	2 919	1 464
Republic of Korea	1 392	658	1 294	712	3 267	164	4 521	2 983
Region 4 - Subsahara Africa								
Eastern Africa	3 518	4 057	3 377	2 589	4 583	639	5 870	3 612
Middle Africa	1 899	3 389	4 083	4 258	5 158	691	5 350	2 959
Southern Africa	1 094	1 275	1 723	851	5 012	165	2 875	1 639
Western Africa	1 339	4 386	1 946	2 501	4 751	494	3 496	9 446
Region 5 - North Africa, Western Asia and Central Asia								
Central Asia	2 468	2 574	481	523	2 742	100	982	1 477
Mongolia	1 304	1 370	428	127	5 791	367	2 188	2 819
Northern Africa	1 317	3 193	228	65	6 304	76	4 155	1 450
Western Asia	1 828	1 872	677	285	2 484	72	1 419	1 743
Region 6 - South and Southeast Asia								
South-Eastern Asia	1 973	4 318	1 436	1 630	5 322	484	3 150	3 530
Southern Asia	935	1 339	2 002	1 300	4 438	223	3 747	4 985
Region 7 - Latin America								
Caribbean	1 643	1 755	3 114	1 211	5 334	1 040	3 311	3 888
Central America	340	1 070	1 948	1 432	1 141	234	1 911	4 096
South America	1 837	1 894	1 500	1 466	1 417	401	2 214	2 493

Region # Region name Sub-region name *All figures in m^3 / tonne*	Commodity 4 Fruits (excluding wine)					Commodity 5 Meat				Commodity 6 Fish & Seafood	Commodity 7 Milk (excluding butter) & Eggs		Commodity 8 Vegetables
	Apples	Bananas	Citrus	Grapes	Fruits, other	Bovine Meat	Mutton & Goat Meat	Pigmeat	Poultry Meat	Fish & Seafood	Milk	Egg	Vegetables
Region 1 - Europe													
Europe	612	903	491	409	960	6 983	6 304	3 311	2 501	0	990	2 702	162
Region 2 - North America & Oceania													
Australia	612	903	491	409	960	10 300	8 019	3 858	2 311	0	913	1 555	112
Canada	612	903	491	409	960	8 817	8 195	3 562	1 513	0	900	1 304	156
New Zealand	612	903	491	409	960	6 230	4 423	1 062	1 006	0	674	1 008	153
USA	612	903	491	409	960	9 182	8 758	2 994	1 348	0	839	1 206	86
Region 3 - Industrialized Asia													
China	612	903	491	409	960	9 085	3 671	3 686	2 212	0	1 203	2 211	232
Japan	612	903	491	409	960	6 980	3 191	3 352	1 660	0	1 054	1 536	139
Republic of Korea	612	903	491	409	960	11 627	2 856	3 603	2 834	0	1 230	2 726	168
Region 4 - Subsahara Africa													
Eastern Africa	612	903	491	409	960	18 323	7 912	4 365	5 078	0	1 858	4 373	450
Middle Africa	612	903	491	409	960	9 372	7 415	5 372	6 387	0	2 297	6 165	624
Southern Africa	612	903	491	409	960	12 687	8 772	5 620	3 839	0	1 388	3 561	211
Western Africa	612	903	491	409	960	15 763	7 194	5 922	7 627	0	3 758	7 776	283
Region 5 - North Africa, Western Asia and Central Asia													
Central Asia	612	903	491	409	960	9 493	20 850	5 705	5 441	0	1 617	4 316	127
Mongolia	612	903	491	409	960	24 640	23 774	3 738	8 342	0	1 184	8 280	247
Northern Africa	612	903	491	409	960	8 675	8 029	5 785	4 362	0	1 584	4 478	80
Western Asia	612	903	491	409	960	17 825	8 898	5 810	4 382	0	1 697	4 097	110
Region 6 - South and Southeast Asia													
South-Eastern Asia	612	903	491	409	960	13 734	6 057	3 781	4 228	0	1 953	3 639	401
Southern Asia	612	903	491	409	960	13 700	6 395	3 999	4 514	0	1 191	4 348	172
Region 7 - Latin America													
Caribbean	612	903	491	409	960	12 889	8 976	3 990	3 787	0	2 002	3 743	310
Central America	612	903	491	409	960	10 117	13 752	5 100	3 701	0	1 892	3 271	157
South America	612	903	491	409	960	12 023	12 280	4 424	3 168	0	1 523	2 668	254

Annex XV. Impact factors for land occupation

Table 30: Impact factors for arable land occupation

Region # Region name Sub-region name *All figures in Ha / tonne*	Commodity 1 Cereals (excluding beer)					Commodity 2 Starchy roots	Commodity 3 Oilcrops & Pulses		Commodity 4 Fruits (excluding wine)					Commodity 5 Meat				Commodity 7 Milk (excluding butter) & Eggs		Commodity 8 Vegetables
	Wheat + Rye	Oats + Barley + Cereals, other	Maize	Rice	Millet + Sorghum	Starchy roots	Oilcrops	Pulses	Apples	Bananas	Citrus	Grapes	Fruits, other	Bovine Meat	Mutton & Goat Meat	Pigmeat	Poultry Meat	Milk	Egg	Vegetables
Region 1 - Europe																				
Europe	0.30	0.35	0.20	0.17	0.56	0.05	0.54	0.55	0.07	0.08	0.07	0.12	0.11	1.29	0.77	1.53	2.30	0.07	2.21	0.05
Region 2 - North America & Oceania																				
Australia	0.93	0.71	0.20	0.12	0.49	0.03	0.80	1.09	0.07	0.08	0.07	0.12	0.11	0.95	0.73	1.47	1.78	0.12	5.40	0.04
Canada	0.43	0.38	0.12	0.00	0.00	0.03	0.63	0.56	0.07	0.08	0.07	0.12	0.11	0.95	0.73	1.47	1.78	0.12	5.40	0.04
New Zealand	0.12	0.15	0.09	0.00	0.00	0.03	0.78	0.32	0.07	0.08	0.07	0.12	0.11	0.95	0.73	1.47	1.78	0.12	5.40	0.04
USA	0.37	0.35	0.11	0.12	0.23	0.02	0.34	0.51	0.07	0.08	0.07	0.12	0.11	0.95	0.73	1.47	1.78	0.12	5.40	0.03
Region 3 - Industrialized Asia																				
China	0.22	0.45	0.19	0.16	0.39	0.06	0.37	0.68	0.07	0.08	0.07	0.12	0.11	2.91	0.73	1.94	5.54	0.46	2.02	0.05
Japan	0.23	0.45	0.38	0.15	0.99	0.04	0.60	0.49	0.07	0.08	0.07	0.12	0.11	2.91	0.73	1.94	5.54	0.46	2.02	0.03
Republic of Korea	0.26	0.34	0.20	0.16	0.66	0.04	0.83	0.84	0.07	0.08	0.07	0.12	0.11	2.91	0.73	1.94	5.54	0.46	2.02	0.03
Region 4 - Subsahara Africa																				
Eastern Africa	0.61	0.93	0.66	0.39	0.91	0.13	1.12	1.33	0.07	0.08	0.07	0.12	0.11	11.66	2.55	6.52	5.49	2.60	7.32	0.16
Middle Africa	0.61	0.69	1.08	1.13	1.29	0.12	1.06	1.63	0.07	0.08	0.07	0.12	0.11	11.66	2.55	6.52	5.49	2.60	7.32	0.17
Southern Africa	0.34	0.48	0.38	0.33	1.33	0.06	0.92	1.58	0.07	0.08	0.07	0.12	0.11	11.66	2.55	6.52	5.49	2.60	7.32	0.06
Western Africa	0.57	1.15	0.66	0.63	1.10	0.11	0.73	2.39	0.07	0.08	0.07	0.12	0.11	11.66	2.55	6.52	5.49	2.60	7.32	0.17
Region 5 - North Africa, Western Asia and Central Asia																				
Central Asia	0.58	0.75	0.20	0.32	0.82	0.06	0.20	0.62	0.07	0.08	0.07	0.12	0.11	4.88	1.60	1.51	3.86	0.47	5.64	0.05
Mongolia	1.06	0.98	0.00	0.00	0.00	0.10	1.15	1.04	0.07	0.08	0.07	0.12	0.11	4.88	1.60	1.51	3.86	0.47	5.64	0.09
Northern Africa	0.49	1.33	0.16	0.10	1.35	0.05	0.47	0.96	0.07	0.08	0.07	0.12	0.11	4.88	1.60	1.51	3.86	0.47	5.64	0.05
Western Asia	0.45	0.64	0.20	0.21	0.91	0.04	0.00	0.85	0.07	0.08	0.07	0.12	0.11	4.88	1.60	1.51	3.86	0.47	5.64	0.05
Region 6 - South and Southeast Asia																				
South-Eastern Asia	0.63	1.39	0.30	0.25	0.95	0.06	0.23	0.93	0.07	0.08	0.07	0.12	0.11	6.96	1.50	2.54	5.36	0.32	5.58	0.10
Southern Asia	0.39	0.54	0.38	0.29	1.03	0.06	0.54	1.60	0.07	0.08	0.07	0.12	0.11	6.96	1.50	2.54	5.36	0.32	5.58	0.07
Region 7 - Latin America																				
Caribbean	0.00	0.00	0.76	0.27	1.14	0.18	0.32	1.17	0.07	0.08	0.07	0.12	0.11	5.37	2.62	2.94	2.06	1.22	5.22	0.09
Central America	0.20	0.46	0.33	0.28	0.30	0.05	0.25	1.24	0.07	0.08	0.07	0.12	0.11	5.37	2.62	2.94	2.06	1.22	5.22	0.05
South America	0.38	0.44	0.24	0.22	0.31	0.07	0.35	1.11	0.07	0.08	0.07	0.12	0.11	5.37	2.62	2.94	2.06	1.22	5.22	0.06

Table 31: Impact factors for non-arable land occupation

Region # Region name Sub-region name *All figures in Ha / tonne*	Commodity 5 Meat				Commodity 7 Milk (excluding butter) & Eggs	
	Bovine Meat	Mutton & Goat Meat	Pigmeat	Poultry Meat	Milk	Egg
Region 1 - Europe						
Europe	9.80	19.27	0.75	1.25	0.63	1.27
Region 2 - North America & Oceania						
Australia	18.22	27.12	1.35	1.70	2.39	5.17
Canada	18.22	27.12	1.35	1.70	2.39	5.17
New Zealand	18.22	27.12	1.35	1.70	2.39	5.17
USA	18.22	27.12	1.35	1.70	2.39	5.17
Region 3 - Industrialized Asia						
China	23.10	17.42	2.13	6.03	4.49	2.15
Japan	23.10	17.42	2.13	6.03	4.49	2.15
Republic of Korea	23.10	17.42	2.13	6.03	4.49	2.15
Region 4 - Subsahara Africa						
Eastern Africa	57.22	56.70	3.55	3.79	17.16	5.16
Middle Africa	57.22	56.70	3.55	3.79	17.16	5.16
Southern Africa	57.22	56.70	3.55	3.79	17.16	5.16
Western Africa	57.22	56.70	3.55	3.79	17.16	5.16
Region 5 - North Africa, Western Asia and Central Asia						
Central Asia	123.14	178.30	3.84	30.40	18.42	41.55
Mongolia	123.14	178.30	3.84	30.40	18.42	41.55
Northern Africa	123.14	178.30	3.84	30.40	18.42	41.55
Western Asia	123.14	178.30	3.84	30.40	18.42	41.55
Region 6 - South and Southeast Asia						
South-Eastern Asia	65.99	72.83	1.24	6.28	4.29	7.00
Southern Asia	65.99	72.83	1.24	6.28	4.29	7.00
Region 7 - Latin America						
Caribbean	17.76	45.72	1.96	1.39	4.27	3.28
Central America	17.76	45.72	1.96	1.39	4.27	3.28
South America	17.76	45.72	1.96	1.39	4.27	3.28

Annex XVI. Complementary results – Component 1

Focus on some commodities

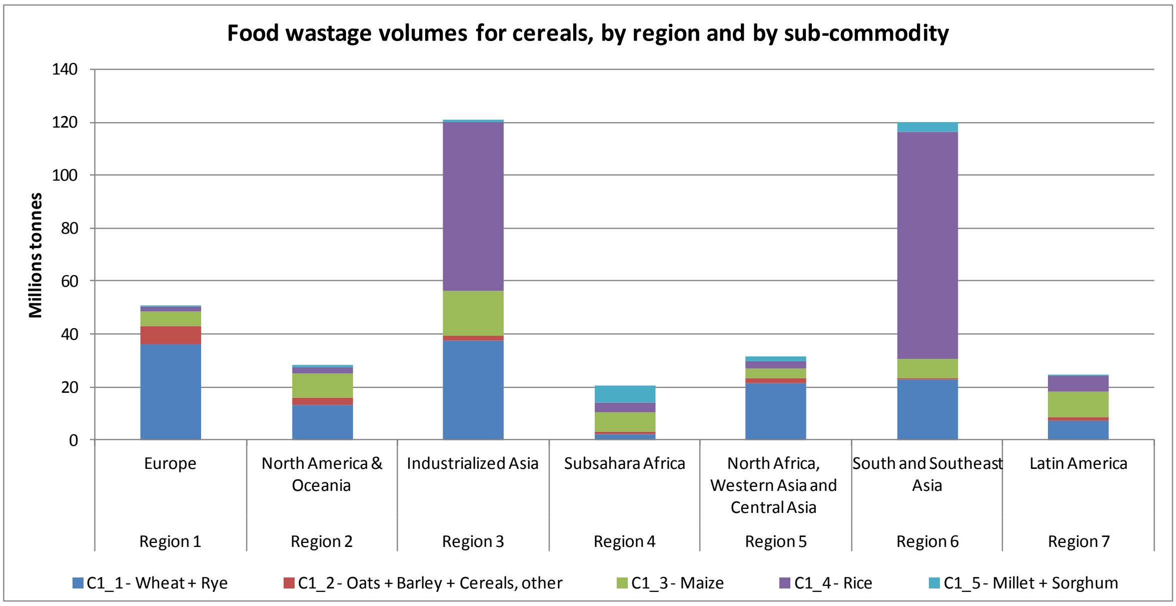


Figure 116: Food wastage volumes for cereals, by region and by sub-commodity

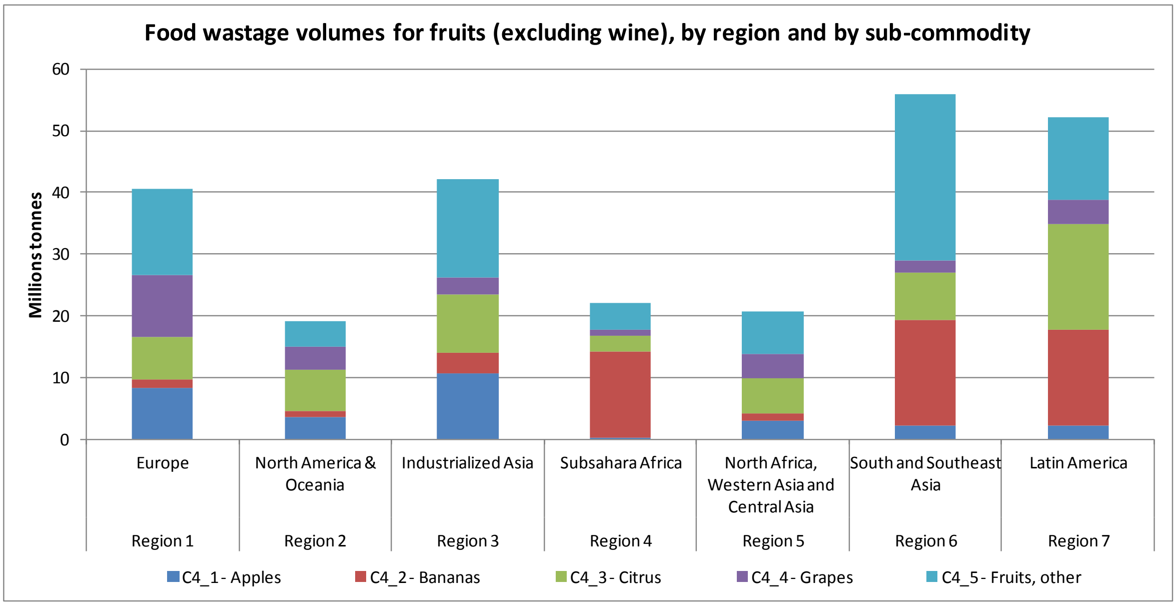


Figure 117: Food wastage volumes for fruits (excluding wine), by region and by sub-commodity

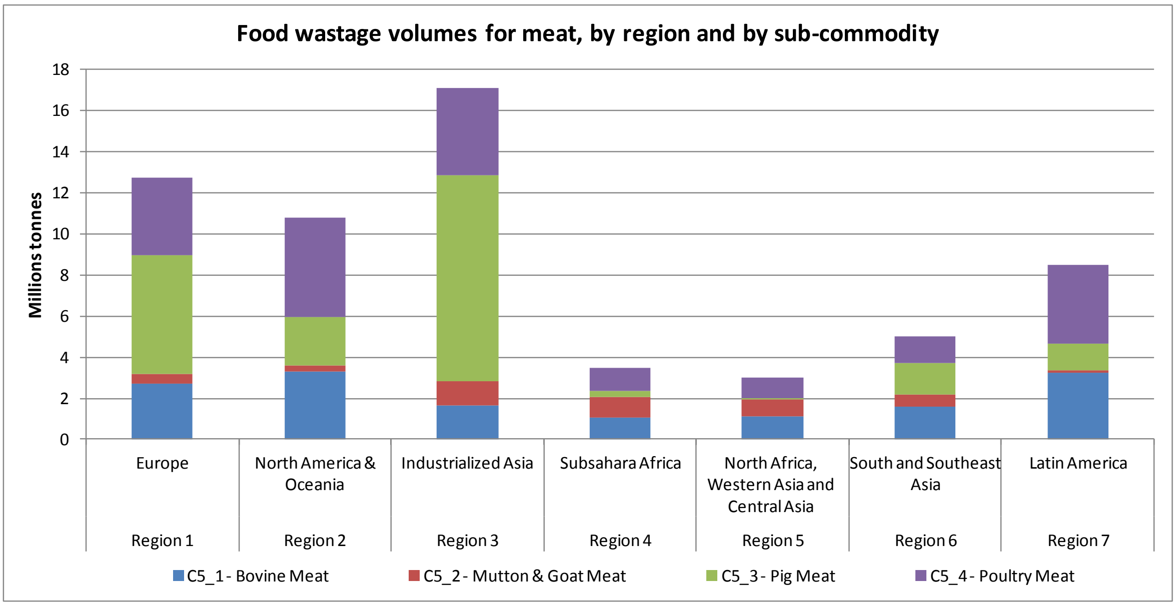


Figure 118: Food wastage volumes for meat, by region and by sub-commodity

Annex XVII. Complementary results – Component 2

Focus on some commodities for carbon footprint

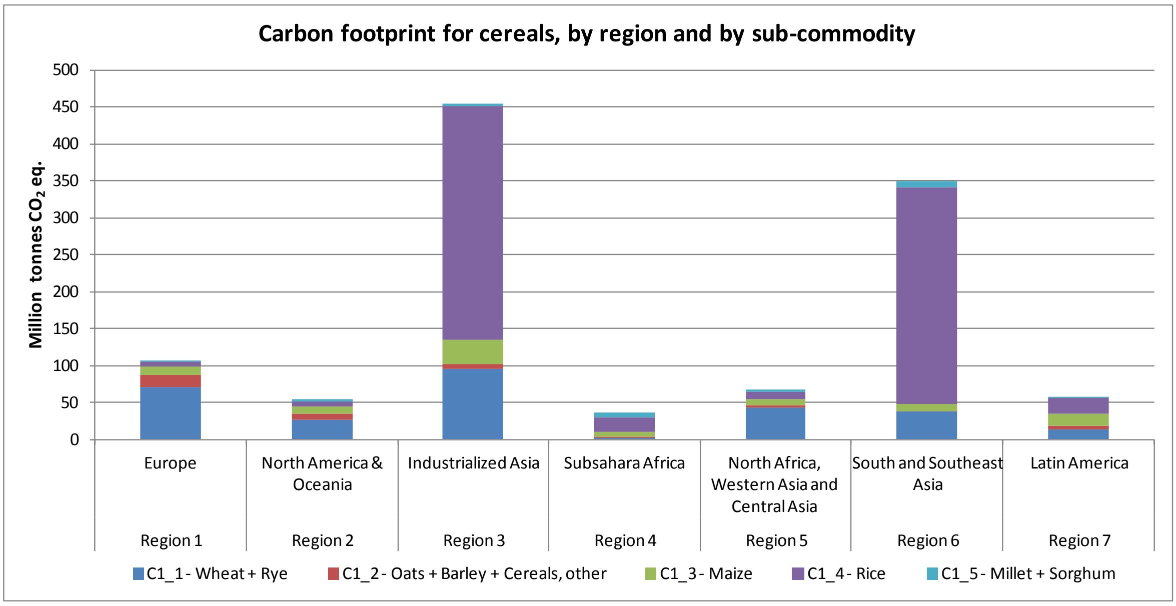


Figure 119: Carbon footprint for cereals, by region and by sub-commodity

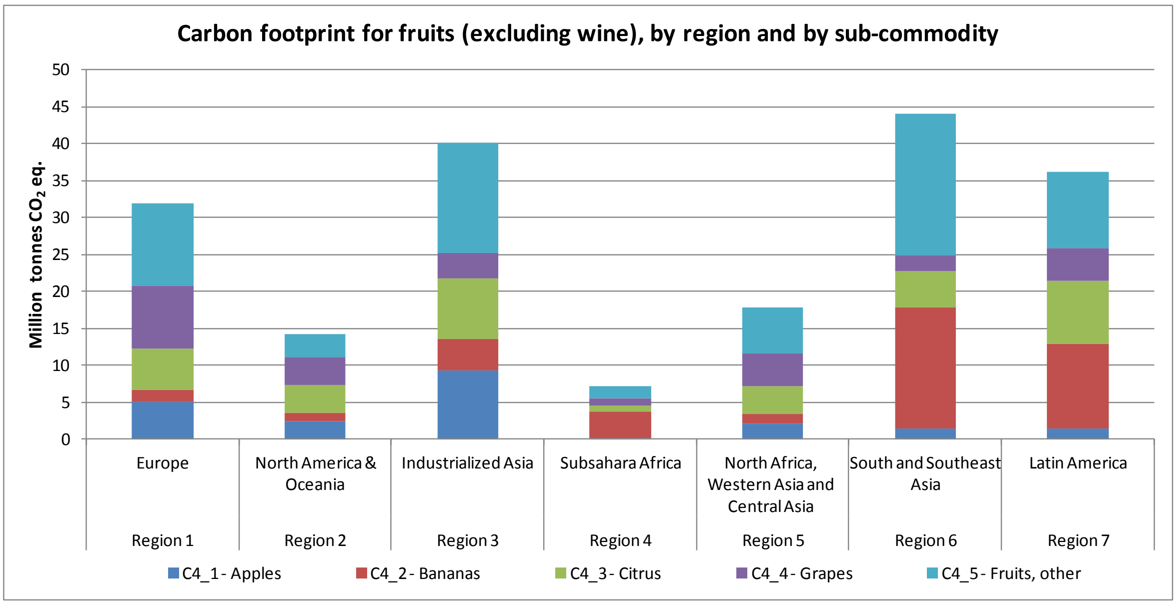


Figure 120: Carbon footprint for fruits (excluding wine), by region and by sub-commodity

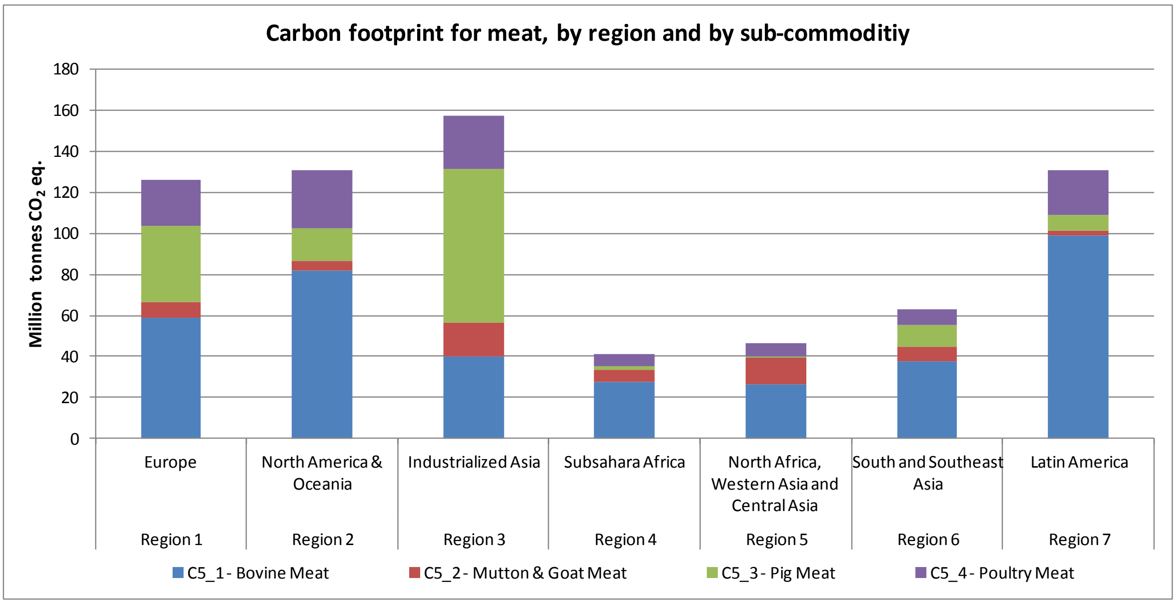


Figure 121: Carbon footprint for meat, by region and by sub-commodity

Focus on carbon intensity

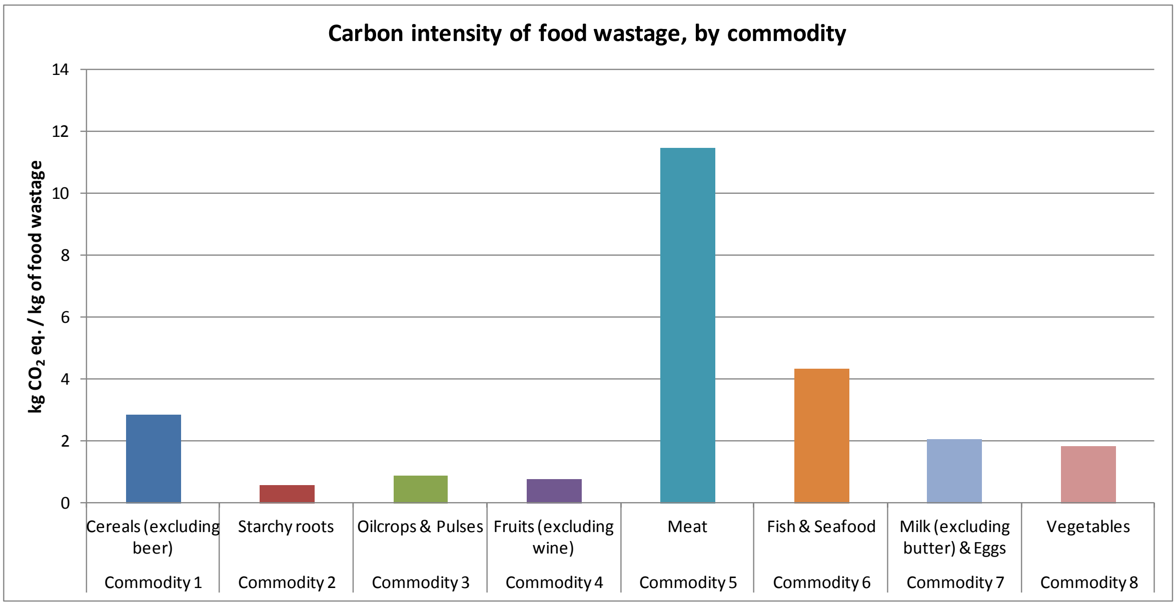


Figure 122: Carbon intensity of food wastage, by commodity

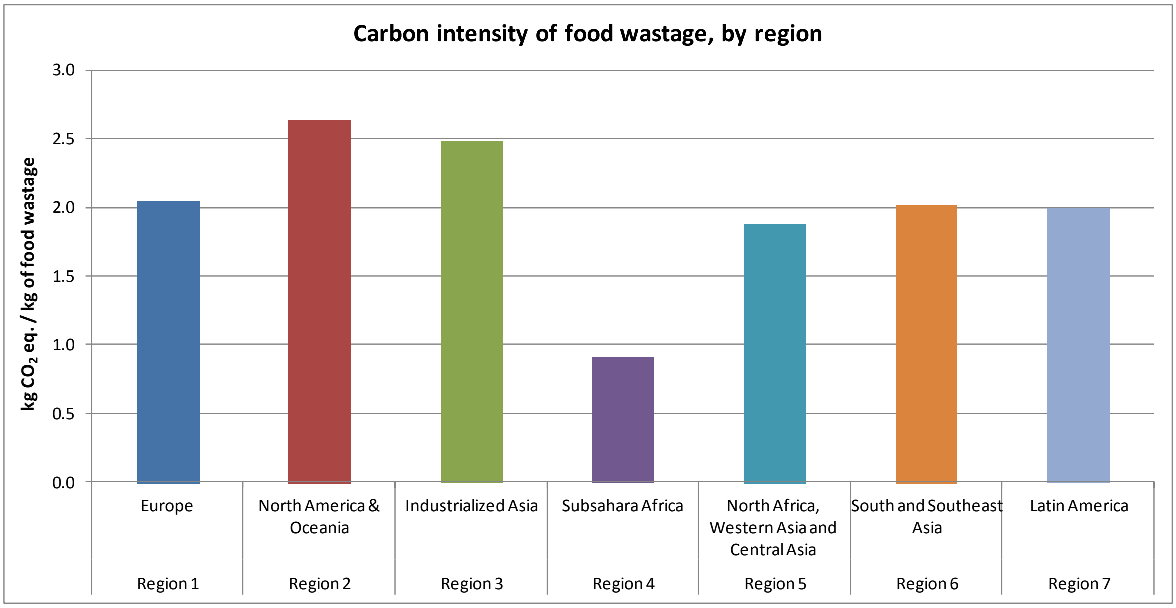
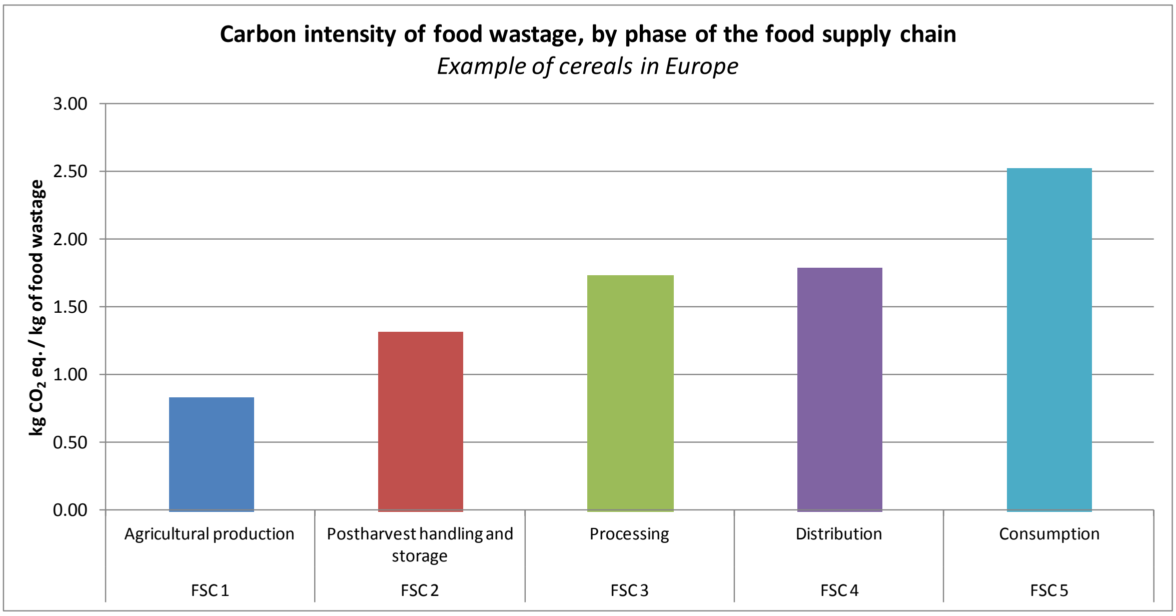


Figure 123: Carbon intensity of food wastage, by region



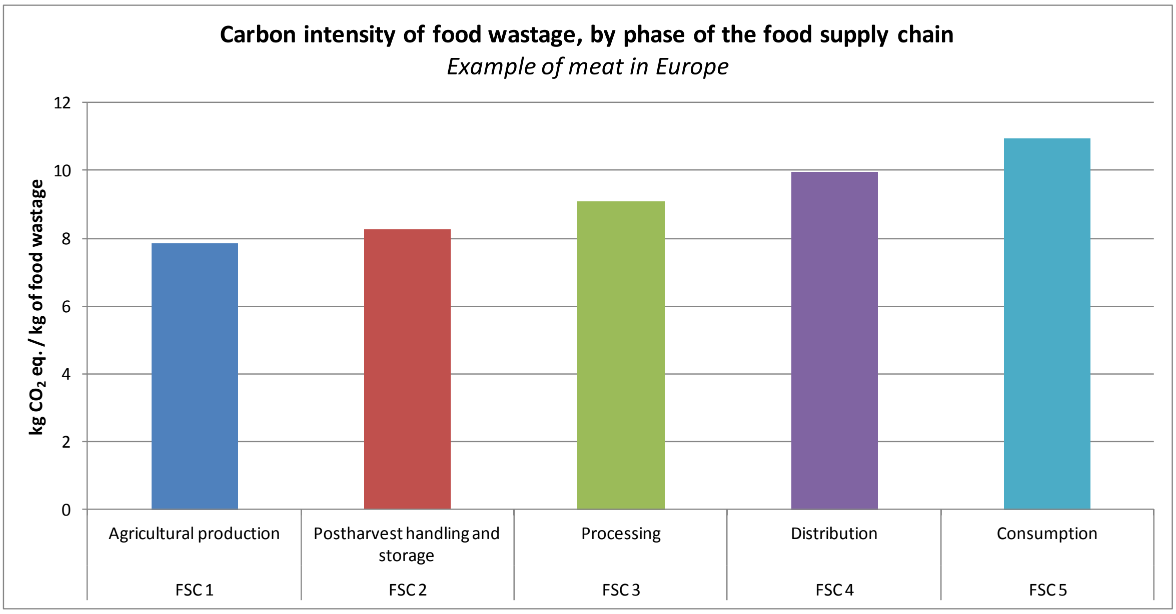


Figure 124: Examples of carbon intensity by phase of the food supply chain

Annex XVIII. Complementary results – Component 3

Focus on some commodities for blue water

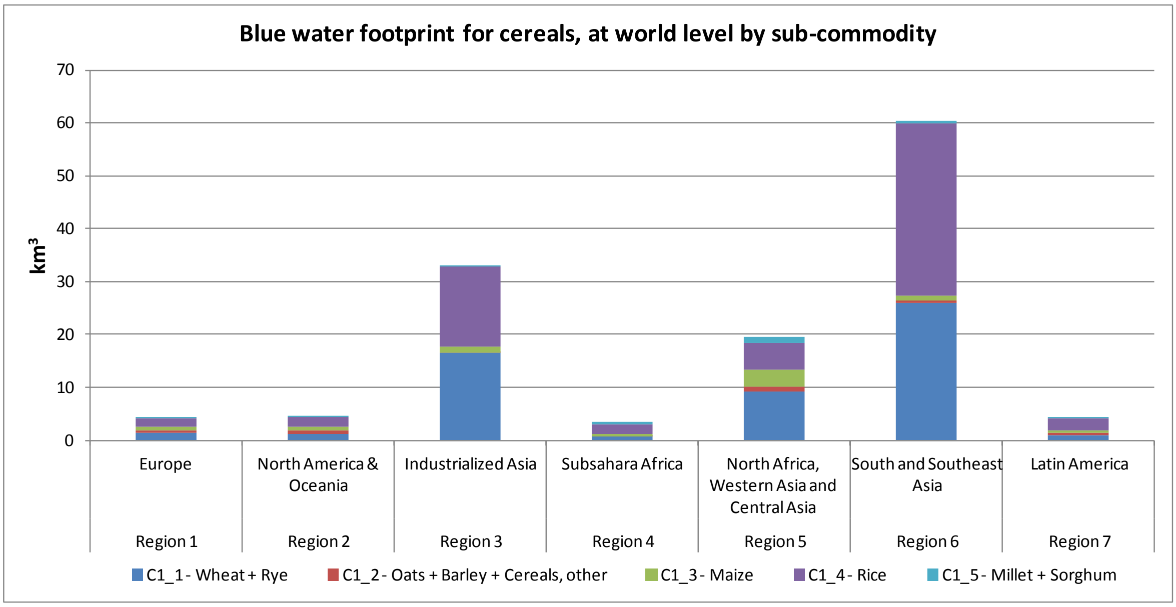


Figure 125: Blue water footprint for cereals, by region and by sub-commodity

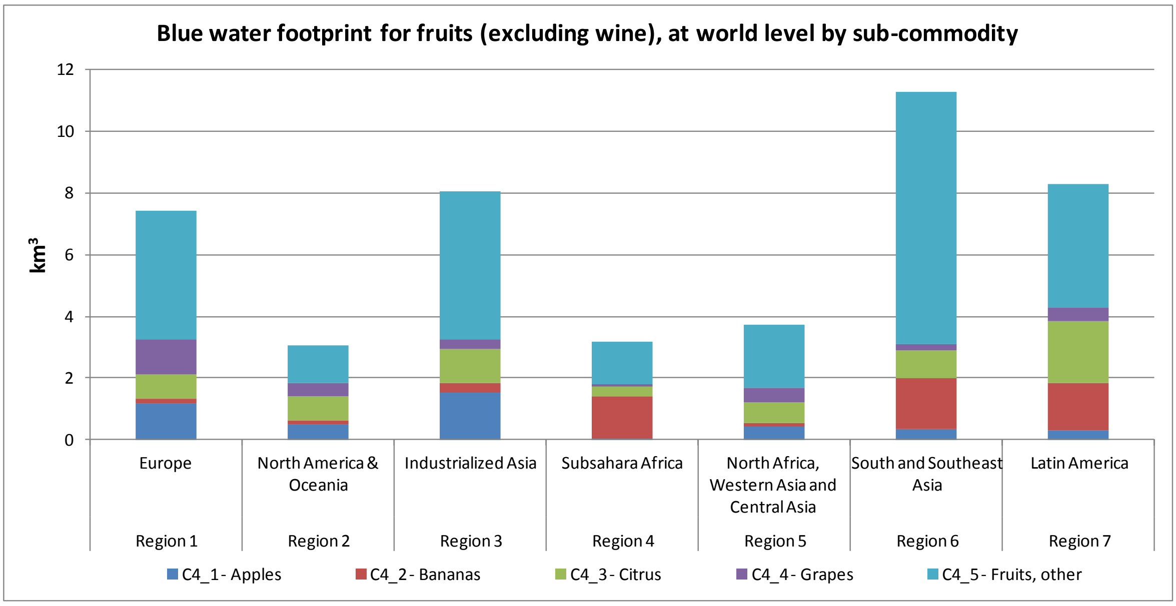


Figure 126: Blue water footprint for fruits (excluding wine), by region and by sub-commodity

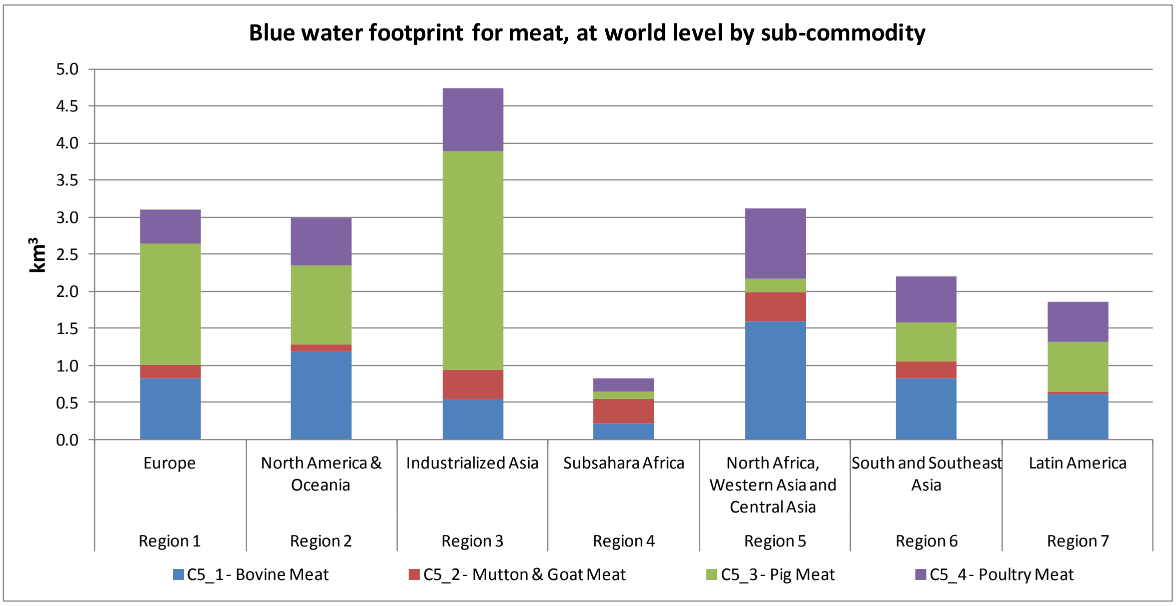


Figure 127: Blue water footprint for meat, by region and by sub-commodity

Focus on blue water intensity

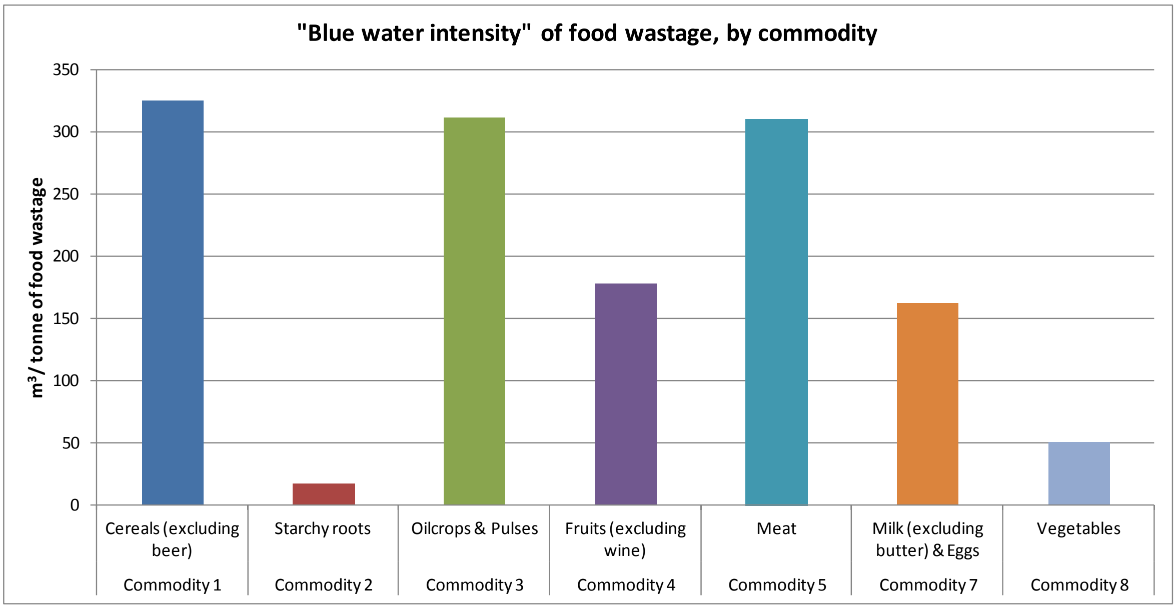


Figure 128: Blue water intensity of food wastage, by commodity

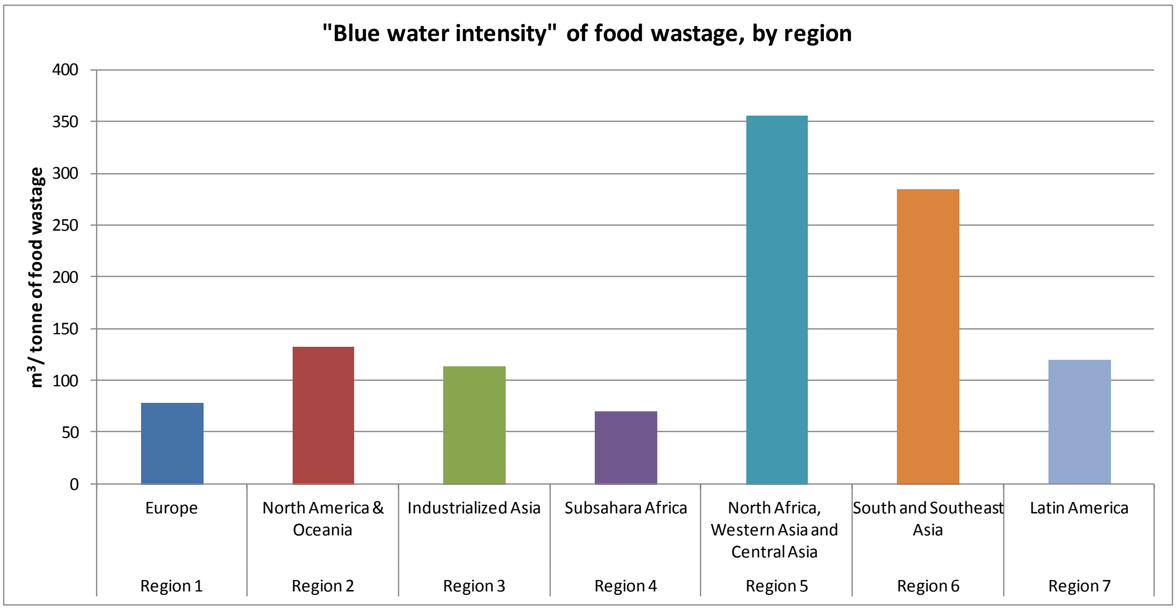


Figure 129: Blue water intensity of food wastage, by region

Results for green water footprint

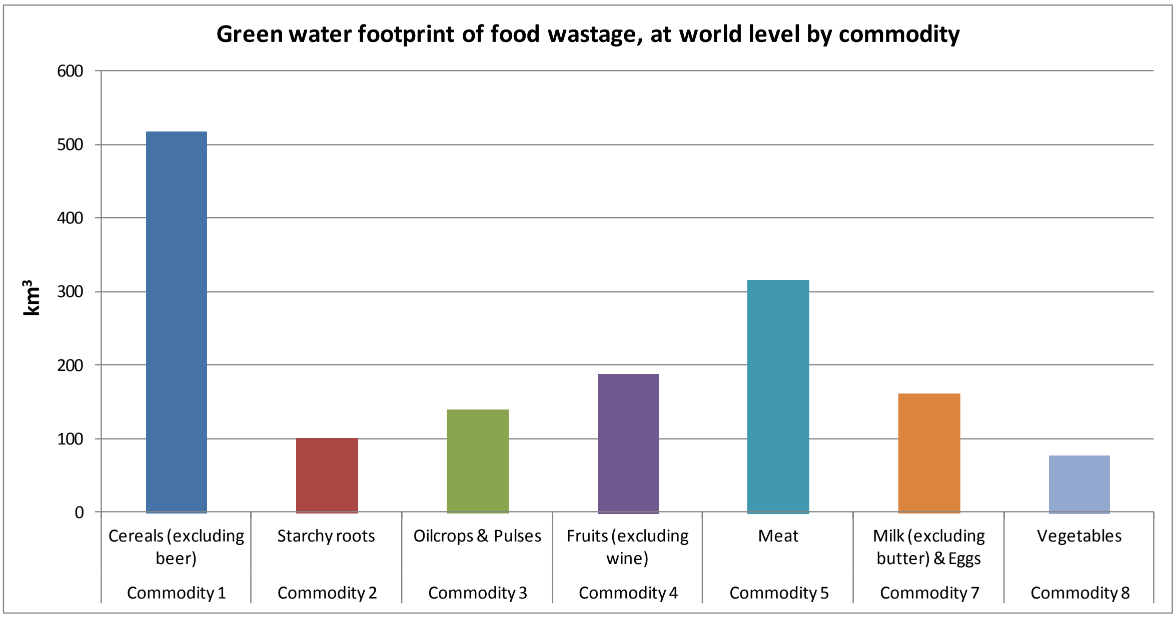


Figure 130: Green water footprint of food wastage, at world level by commodity

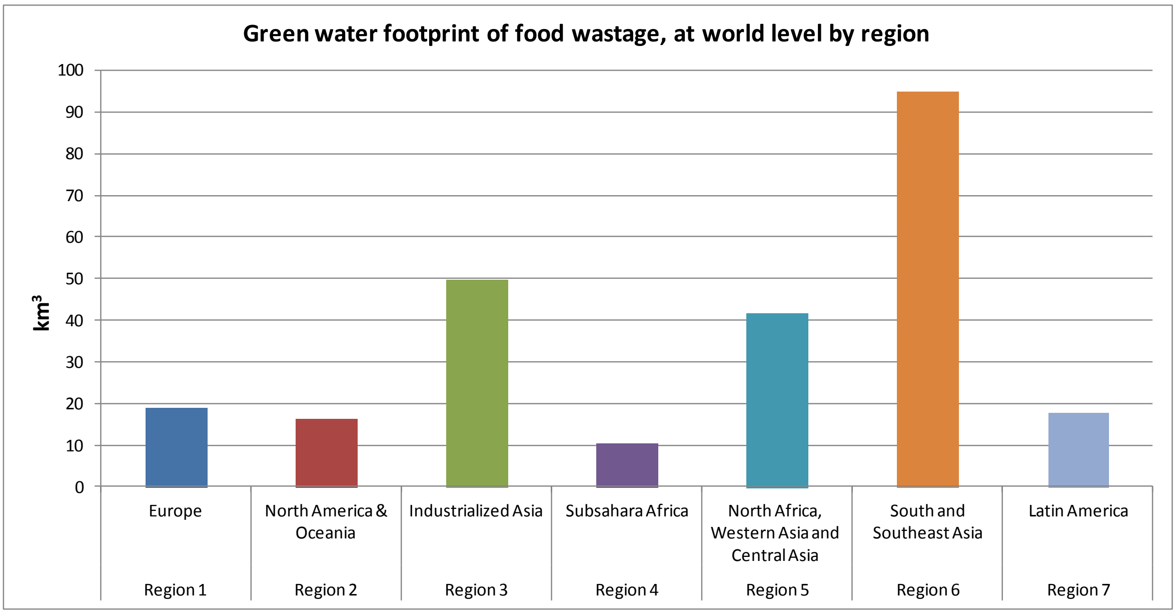


Figure 131: Green water footprint of food wastage, at world level by region

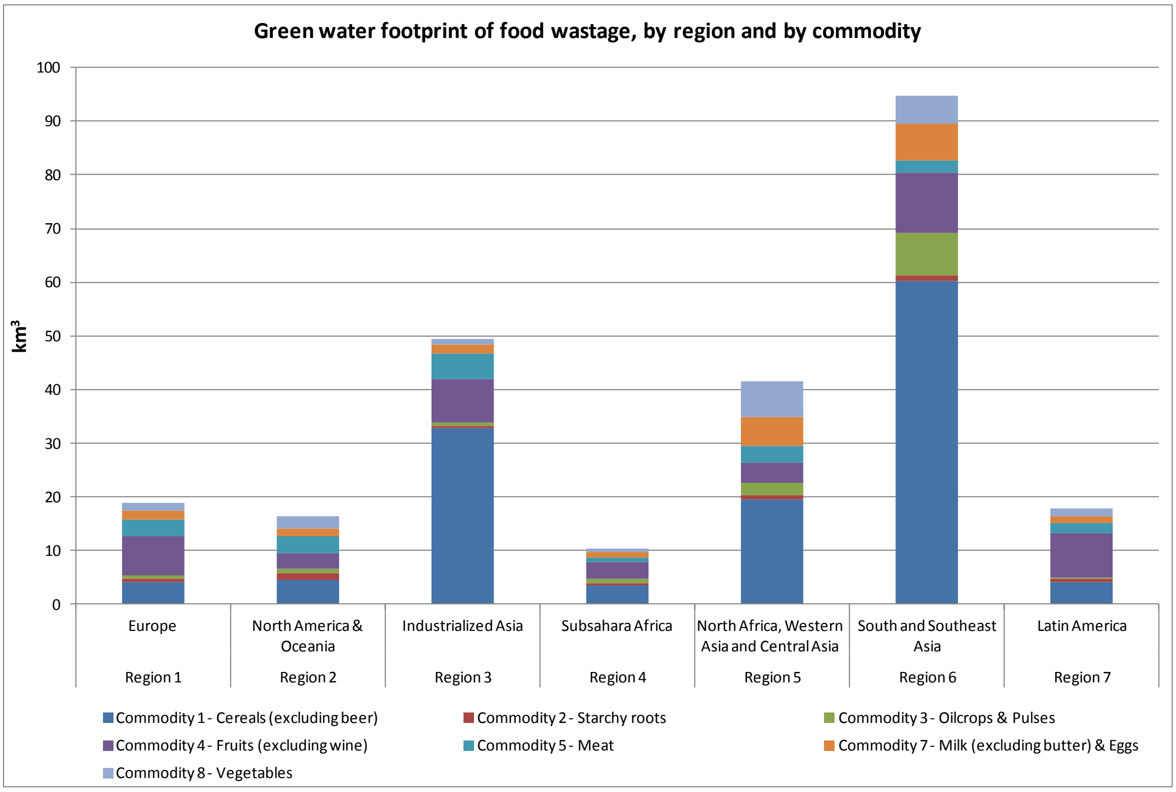


Figure 132: Green water footprint of food wastage, by region and by commodity

Annex XIX. Complementary results – Component 4

Focus on some commodities

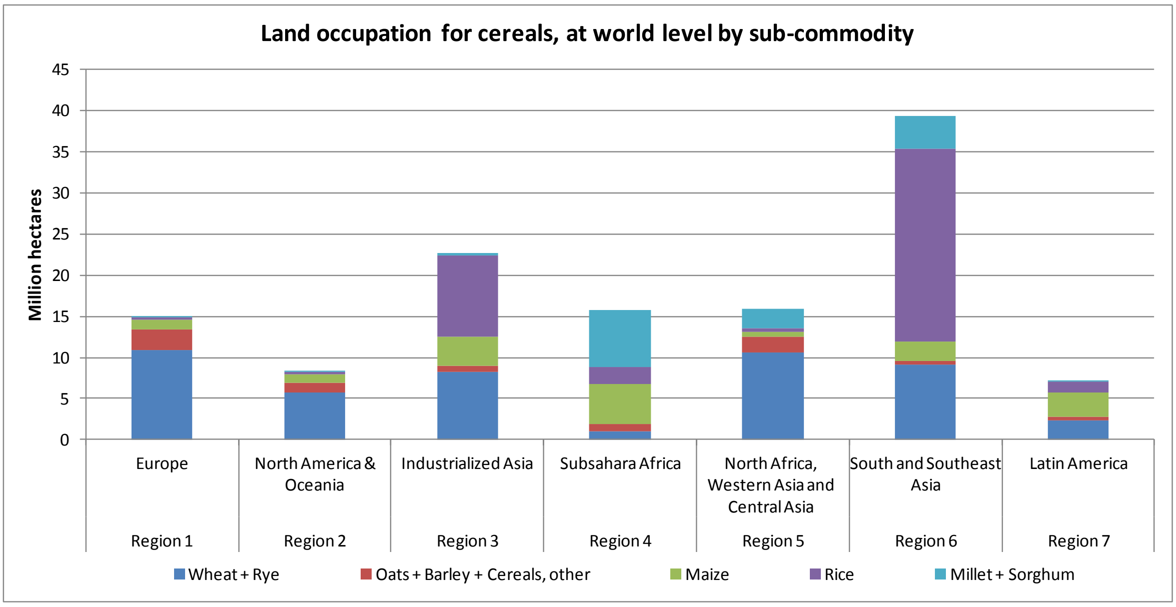


Figure 133: Land occupation for cereals, by region and by sub-commodity

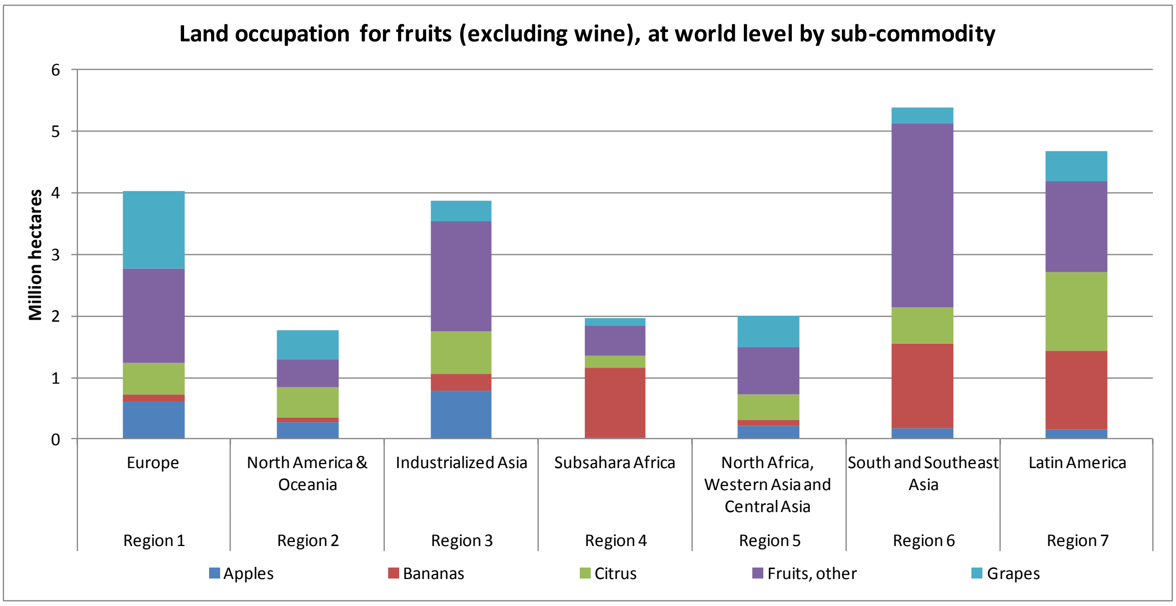


Figure 134: Land occupation for fruits (excluding wine), by region and by sub-commodity

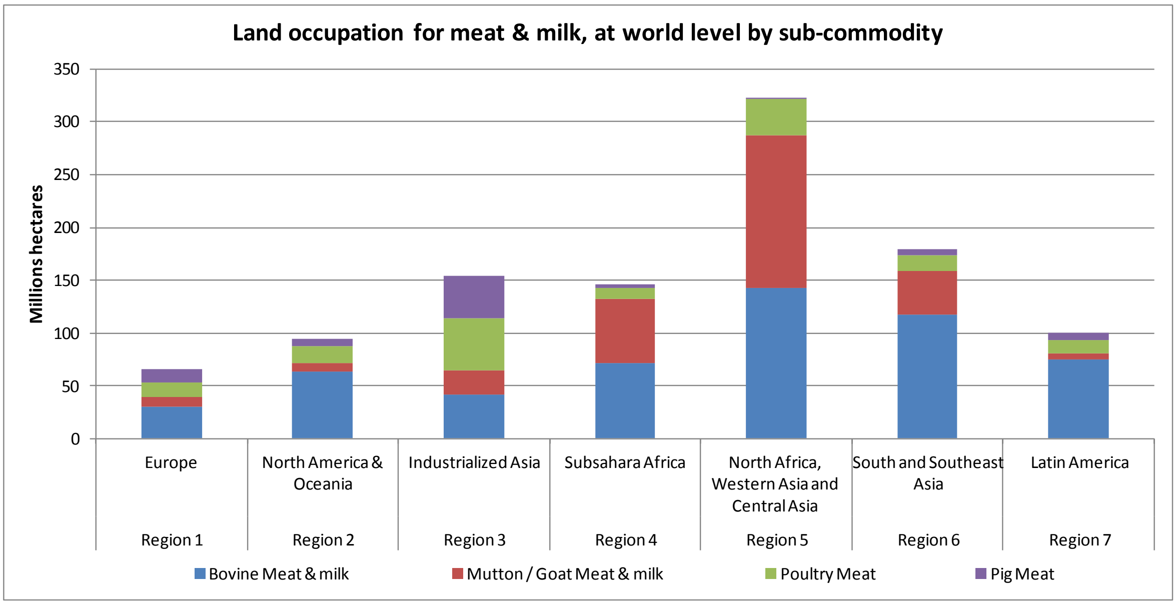


Figure 135: Land occupation for meat & milk, by region and by sub-commodity

Focus on land occupation intensity

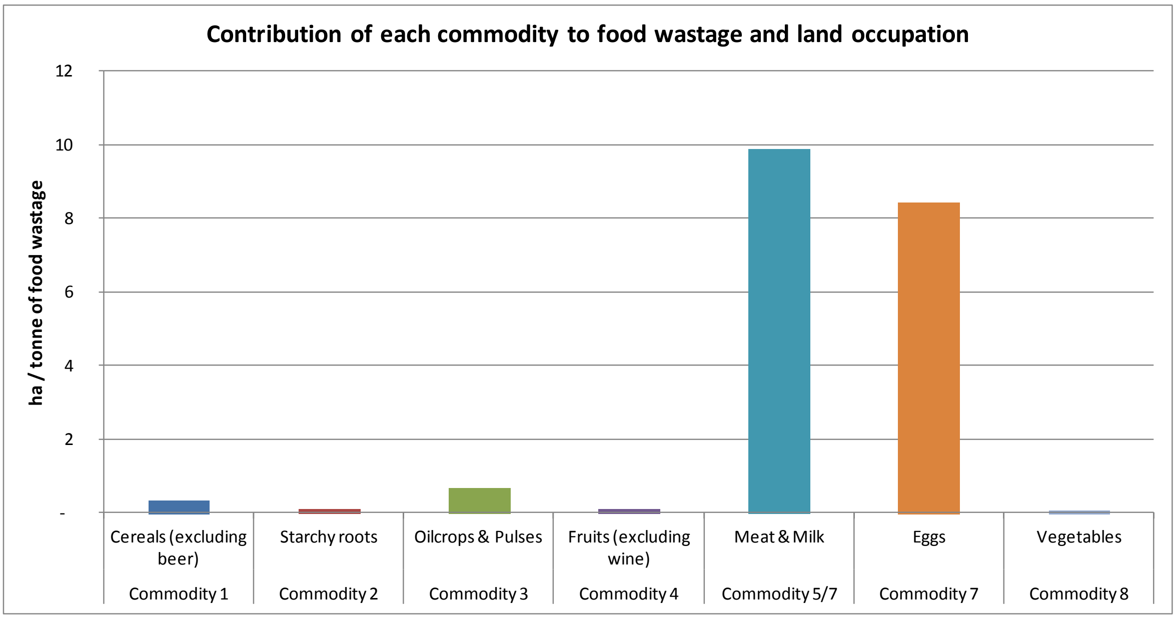


Figure 136: Land occupation intensity of food wastage, by commodity

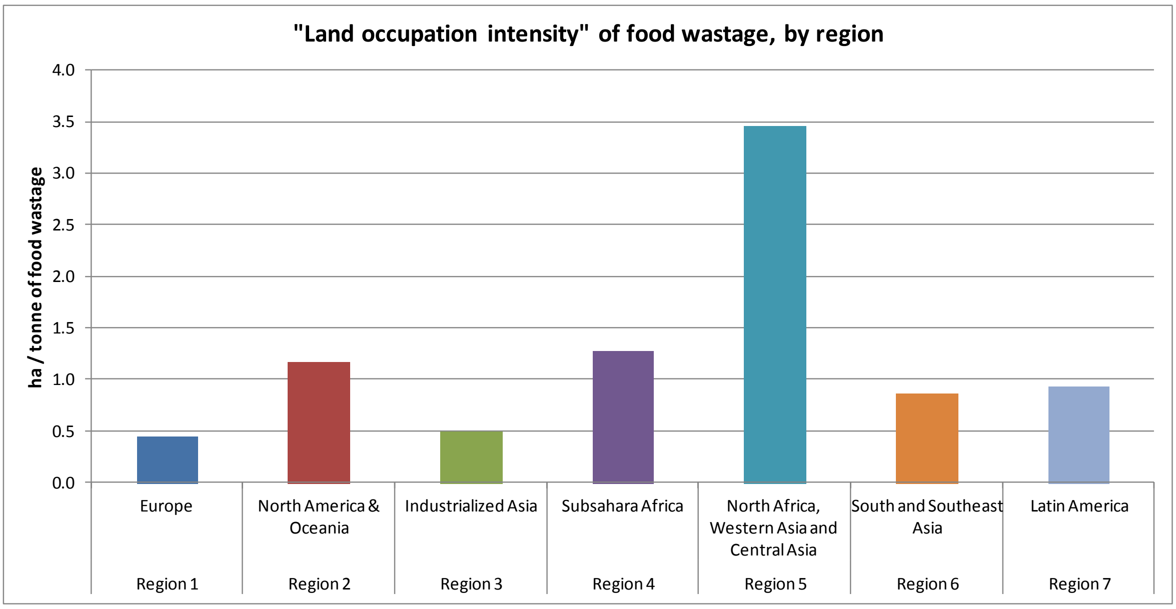


Figure 137: Land occupation intensity of food wastage, by region

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