Food wastage footprint
Impacts on natural resources

Summary Report

FOOD WASTAGE FOOTPRINT

FAO FIAT PANIS

ISBN 978-92-5-107752-8

About this document

The Food Wastage Footprint model (FWF) is a project of the Natural Resources Management and Environment Department. Phase I of the project has been commissioned to BIO-Intelligence Service, France. This Summary Report presents the preliminary results of the FWF modeling, as related to the impacts of food loss and waste on climate, land, water and biodiversity. The full technical report of the FWF model is available upon request from FAO. Phase II of the FWF project is expanding the model to include modules on full-cost accounting of environmental and social externalities of food wastage, with also comparison with food wastage reduction investment costs and footprint scenarios for 2050.

Acknowledgements

Phase I of the FWF was implemented by BIO-IS staff including: Olivier Jan, Clément Tostivint, Anne Turbé, Clémentine O'Connor and Perrine Lavelle. This project 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. This FWF project is undertaken with the generous financial support of Germany.

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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 security, but also to mitigate environmental impacts and resources use from food chains. Although there is today a 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 (i.e. both food loss and food waste) along the food supply chain, focusing on impacts on climate, water, land and biodiversity. A model has been developed to answer two key questions: what is the magnitude of food wastage impacts on the environment; and 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: the world has been divided in seven regions, and a wide range of agricultural products – representing eight major food commodity groups – has been considered. Impact of food wastage has been assessed along the complete supply chain, from the field to the end-of-life of food.

The global volume of food wastage is estimated to be 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 to 3.3 Gtonnes of CO_2 equivalent: as such, food wastage ranks as the third top emitter after USA and China. Globally, the blue water footprint (i.e. the consumption of surface and groundwater resources) of food wastage 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 vainly occupies almost 1.4 billion hectares of land; this represents close to 30 percent of the world's agricultural land area. While it is difficult to estimate impacts on biodiversity at a global level, food wastage unduly compounds the negative externalities that monocropping and agriculture expansion into wild areas create on biodiversity loss, 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 food wastage of agricultural 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 seems clear that a reduction of food wastage at global, regional, and national scales would have a substantial positive effect on natural and societal resources. Food wastage reduction would not only avoid pressure on scarce natural resources but also decrease the need to raise food production by 60 percent in order to meet the 2050 population demand.

This study highlights global environmental hotspots related to food wastage at regional and sub-sectoral levels, for consideration by decision-makers wishing to engage into 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 are 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 industrialised 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, the results of this study – by regions, commodities or phases of the food supply chain – allow prioritising actions and defining opportunities for various actors' contributions to resolving this global challenge.

Introduction

This study provides a worldwide account of the environmental footprint of food wastage along the food supply chain, focusing on impacts on climate, water, land and biodiversity, as well as an economic quantification based on producer prices.

The Food Wastage Footprint (FWF) model was developed to answer two key questions: what are the impacts of food wastage on natural resources? where do these impacts come from? This required analyzing the wastage footprint by regions, commodities or phases of the food supply chain in order to identify "environmental hotspots" and thus, point towards action areas to reduce food wastage.

Context and definitions

Context

In 2011, FAO published a first report assessing global food losses and food waste (FAO 2011). This study estimated that each year, one-third of all food produced for human consumption in the world is lost or wasted. Grown but uneaten food has significant environmental and economical costs. Obviously, this food wastage represents a missed opportunity to improve global food security and to mitigate environmental impacts generated by agriculture. In addition, by 2050, food production will need to be 60 percent higher than in 2005/2007 (Alexandratos & Bruinsma 2012), if production is to meet demand of the increasing world population. Making better use of food already available with the current level of production would help meet future demand with a lower increase in agricultural production.

To date, no study has analyzed the impacts of global food wastage from an environmental perspective. It is now recognized that food production, processing, marketing, consumption and disposal have important environmental externalities because of energy and natural resources usage and associated greenhouse gas (GHG) emissions. Broadly speaking, the environmental impacts of food mostly occur during the production phase. However, beyond this general trend, large discrepancies in food consumption and waste-generation patterns exist around the world. In a context of increasing commercial flows, there are significant differences in the intensity of wastage impacts among agricultural commodities, depending on their region of origin and the environmental issue considered. Therefore, it is necessary to assess the environmental impact of this food wastage at a regional level and by commodity type in order to capture specificities and finally draw the global picture.

Definitions

Food loss refers to a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption. 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, and lack of access to markets. In addition, natural disasters play a role.
Food waste refers to food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Often this is because food has spoiled but it can be for other reasons such as oversupply due to markets, or individual consumer shopping/eating habits.
Food wastage refers to any food lost by deterioration or waste. Thus, the term "wastage" encompasses both food loss and food waste.

Scope and methodology

This study builds on previous FAO work that estimated food wastage volumes (FAO 2011)[1], and goes a step further by evaluating the impact of such losses on the environment. The scope of the study is global, including seven world regions and a wide range of agricultural products, representing eight food commodity groups. Both the regions and commodities are further divided in sub-groups, as shown in Table 1 and 2.

Table 1: World regions selected for the FWF project

Region name	Short name	Sub-region
1 – Europe	Europe	Europe
2 – North America & Oceania	NA&Oce	Australia, Canada, New Zealand, USA
3 – Industrialized Asia	Ind. Asia	China, Japan, Republic of Korea
4 – Sub-Saharan Africa	SSA	Eastern Africa, Middle Africa, Southern Africa, Western Africa
5 – North Africa, Western Asia & Central Asia	NA,WA&CA	Central Asia, Mongolia, Northern Africa, Western Asia
6 – South and Southeast Asia	S&SE Asia	Southeastern Asia, Southern Asia
7 – Latin America	LA	Caribbean, Central America, South America

Table 2: Agricultural commodity groups selected for the FWF project

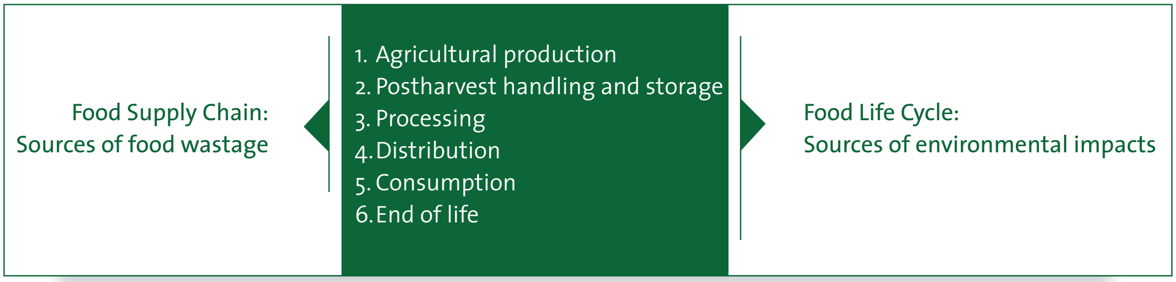
Region name	Short name	Sub-region
1 – Cereals (excluding beer)	Cereals	Wheat, Rye, Oats, Barley, Other cereals, Maize, Rice, Millet, Sorghum
2 – Starchy roots	SR	Starchy roots
3 – Oilcrops & Pulses	O&P	Oilcrops, Pulses
4 – Fruits (excluding wine)	Fruits	Apples, Bananas, Citrus, Grapes, Other fruits
5 – Meat	Meat	Bovine meat, Mutton & Goat meat, Pig meat, Poultry meat
6 – Fish & Seafood	F&S	Fish, Seafood
7 – Milk (excluding butter) & Eggs	M&E	Milk, Egg
8 – Vegetables	Veg.	Vegetables

1 Most notably, technical definitions such as grouping of the world regions and food commodity groups (slightly adjusted) are taken from the FAO (2011) study.

The environmental assessment for all commodities is based on a life cycle approach that encompasses the entire "food cycle", including agricultural production, post-harvest handling and storage, food processing, distribution, consumption and end-of-life (i.e. disposal).

Food wastage along the food supply chain (FSC) has a variety of causes, such as spillage or breakage, degradation during handling or transportation, and waste occurring during the distribution phase. The later a product is lost or wasted along the supply chain, the higher the environmental cost, as impacts arising for instance during processing, transport or cooking, will be added to the initial production impact. In this study, this mechanism is taken into account in the quantification of climate impacts.

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



The environmental footprint of food wastage is assessed through four different model components: carbon footprint; water footprint; land occupation/degradation impact; and potential biodiversity impact – complemented by an economic quantification component.

The general approach is similar for the quantification of carbon, water and land impacts, as well as for the economic component. It is based on multiplications of activity data (i.e. food wastage volumes) and specific factors (i.e. carbon, water, and land impact factor or producer prices). The biodiversity component is assessed through a combined semi-quantitative/qualitative approach, due to methodological and data difficulties.

Food wastage volumes

Method

In this study, the Food Balance Sheets (FBSs)[2] serve as the core basis to gather data on global mass flows of food for each sub-region and agricultural sub-commodity. Assembled by FAO, FBSs give the total amount of food available for human consumption in a country/region during one year. Wastage percentages[3] were applied to FBS data for 2007, in order to quantify food wastage volumes in each region, for each commodity and at each phase of the supply chain.

The study has also calculated two types of food wastage volumes: volumes for the edible and the non-edible parts of food; and food wastage for only the edible part of food. Since environmental impacts relate to the entire product and not just its edible part, most studies provide 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 and are presented in all figures (except Figure 2). This also facilitates cross-components analysis.

Results overview

The global volume of food wastage in 2007 is estimated at 1.6 Gtonnes of "primary product equivalents". The total food wastage for the edible part of food only is 1.3 Gtonnes. This amount can be weighed against the sum of the domestic agricultural production of all countries taken from FBSs, which is about 6 Gtonnes (this value includes also agricultural production for other uses than food). The amount of food wastage (edible and non-edible), the amount of food wastage for the edible part of food only, and agricultural production are presented for each commodity in Figure 2.

It must be noted that there is currently an on-going debate for defining fish wastage because, for example, what is discarded is not necessarily lost and by-catch is not accurately reported, which blurs calculations. Therefore, food wastage volumes obtained for the fish and seafood commodity group must be considered with caution.

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2 FAOSTAT, Food Balance Sheets. Available at: http://faostat.fao.org
3 Wastage percentages taken from the FAO (2011) study.

Figure 2: Total agricultural production (FBS) vs. food wastage volumes

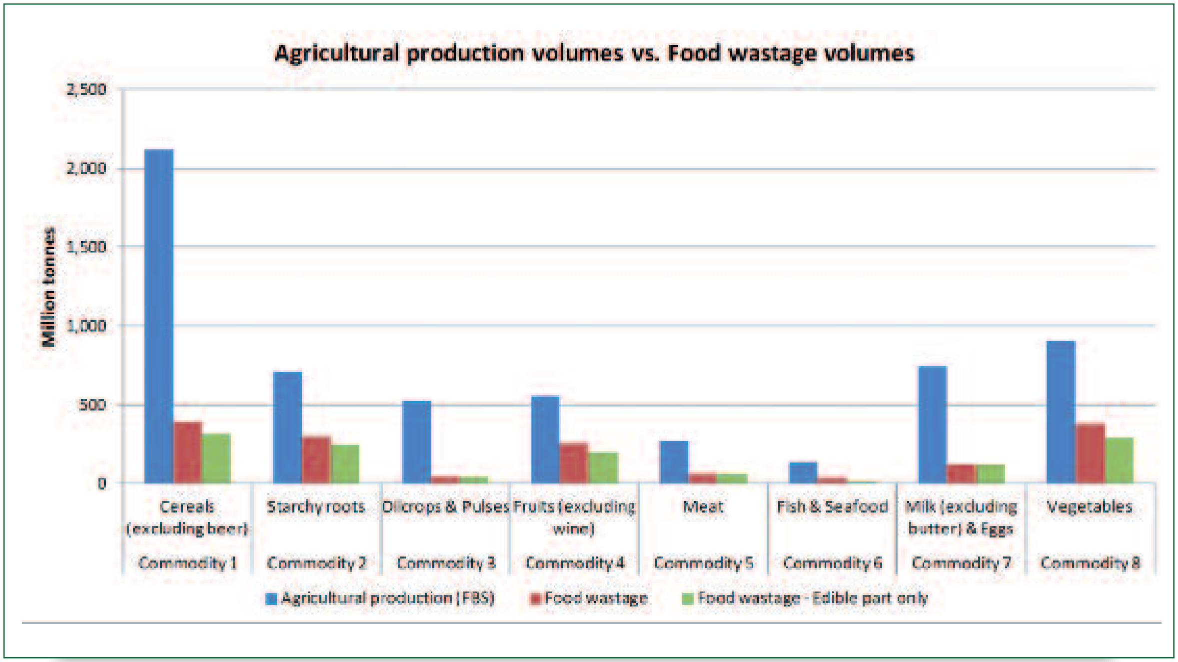


Figure 3 illustrates the amounts of food wastage along the food supply chain. Agricultural production, at 33 percent, is responsible for the greatest amount of total food wastage volumes. Upstream wastage volumes, including production, post-harvest handling and storage, represent 54 percent of total wastage, while downstream wastage volumes, including processing, distribution and consumption, is 46 percent. Thus, on average, food wastage is balanced between the upstream and downstream of the supply chain.

An analysis of the food supply chain phases by regions (Figure 4) reveals that:

- upstream, losses occurring at agricultural production phase appear homogenous across regions, representing about one-third of each region's food wastage;
- downstream, wastage occurring at consumption level is much more variable, with wastage in middle- and high-income regions at 31–39 percent, but much lower in low-income regions, at 4–16 percent.

Figure 3: Food wastage volumes, at world level by phase of the food supply chain

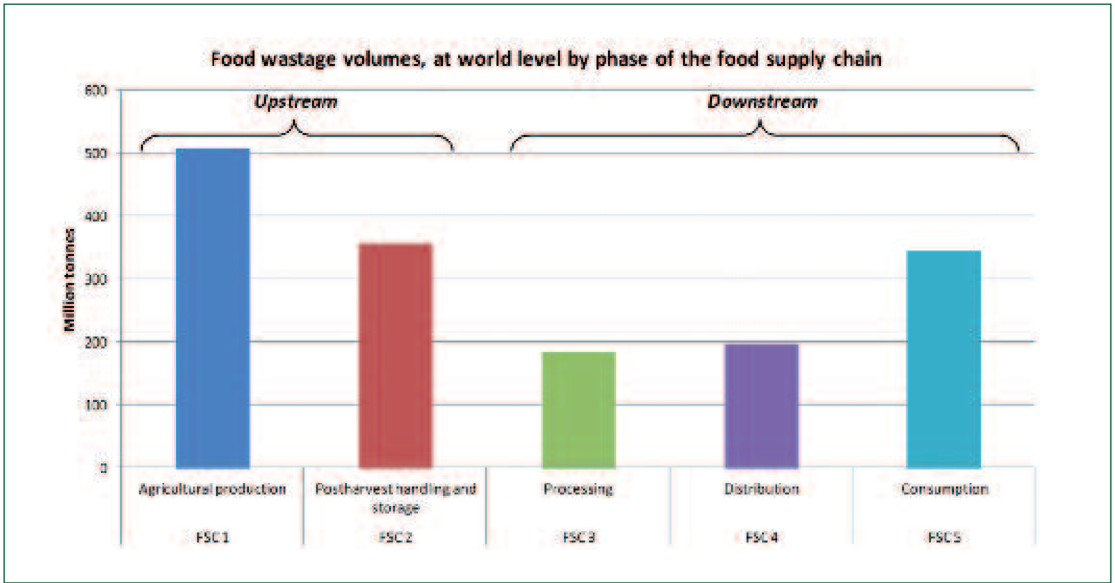
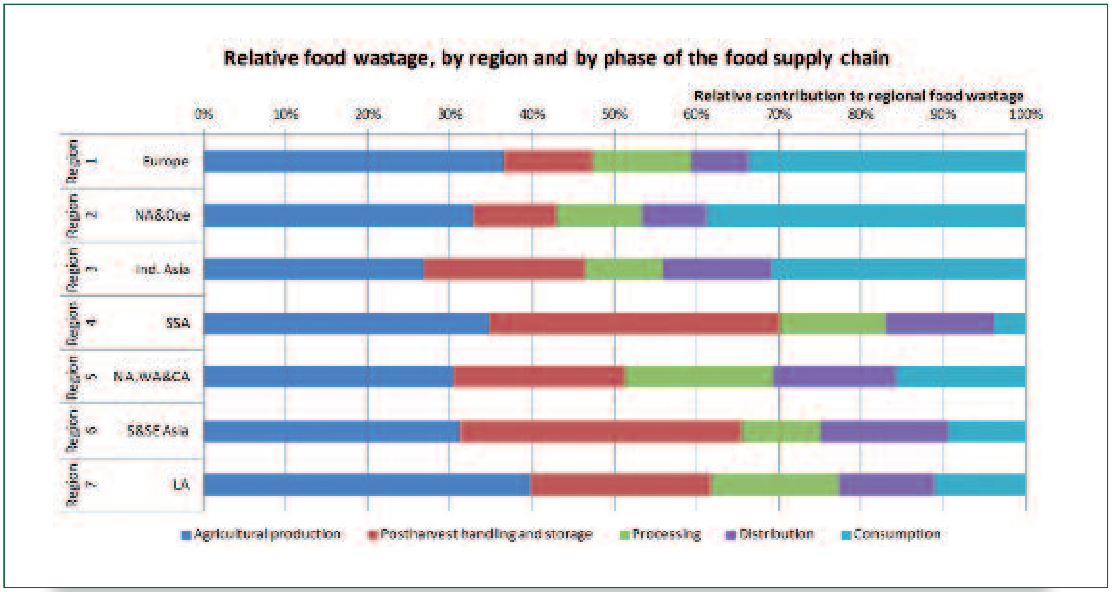


Figure 4: Relative food wastage, by region and by phase of the food supply chain



Figures 3 and 4 illustrate some fundamental characteristics of food wastage. Food wastage arises at all stages of the food supply chains for a variety of reasons that are very much dependent on the local conditions within each country.

At global level, a pattern is visible. In high-income regions, volumes of lost and wasted food are higher in downstream phases of the food chain, but just the opposite in low-income regions where more food is lost and wasted in upstream phases.

In developing countries, there are indeed significant post-harvest losses in the early stages of the supply chain, mostly because of the financial and structural limitations in harvest techniques, storage and transport infrastructures, combined with climatic conditions favourable to food spoilage.

In the most affluent societies, there is a combination of consumer behaviour and lack of communication in the supply chain. For example, with consumers there can be insufficient purchase planning or exaggerated concern over "best-before dates". As for actors in the supply chain, quality standards too restrictive, according to size or aesthetics, are responsible for a large amount of the food wasted at the end of the chain.

Hotspots – contribution to total food wastage

The FWF model is based on seven world regions and eight commodity groups, which multiplies out to 56 "region*commodity" pairs. The 56 pairs can be ranked according to their contributions to total food wastage volumes and used to identify hotspots, that is to say a limited number of region/commodity crossings that are major drivers of food wastage.

Figure 5 shows the ten "region*commodity" pairs (out of 56) with the highest contribution to food wastage volumes. Asia (including Ind. Asia and S&SE Asia) appears six times in the top 10 and dominates this ranking with vegetables and cereals. SSA also appears, because of its starchy root crops, as do Europe, because of starchy roots and cereals, and Latin America because of fruits. In the top 10, it seems quite natural to see, on the one hand, commodities that stood-out in the results overview per commodity and, on the other hand, regions that stood-out in the results overview per region[4].

It appears that vegetables in Ind. Asia are a key wastage hotspot. This is mostly due to wastage occurring during agricultural production, post-harvest handling and storage, and consumption phases. Although food wastage percentages at each of these phases are actually lower than in other high-income regions, the high contribution attributed to Ind. Asia is because this region dominates world vegetables production and consumption, with more than 50 percent of both.

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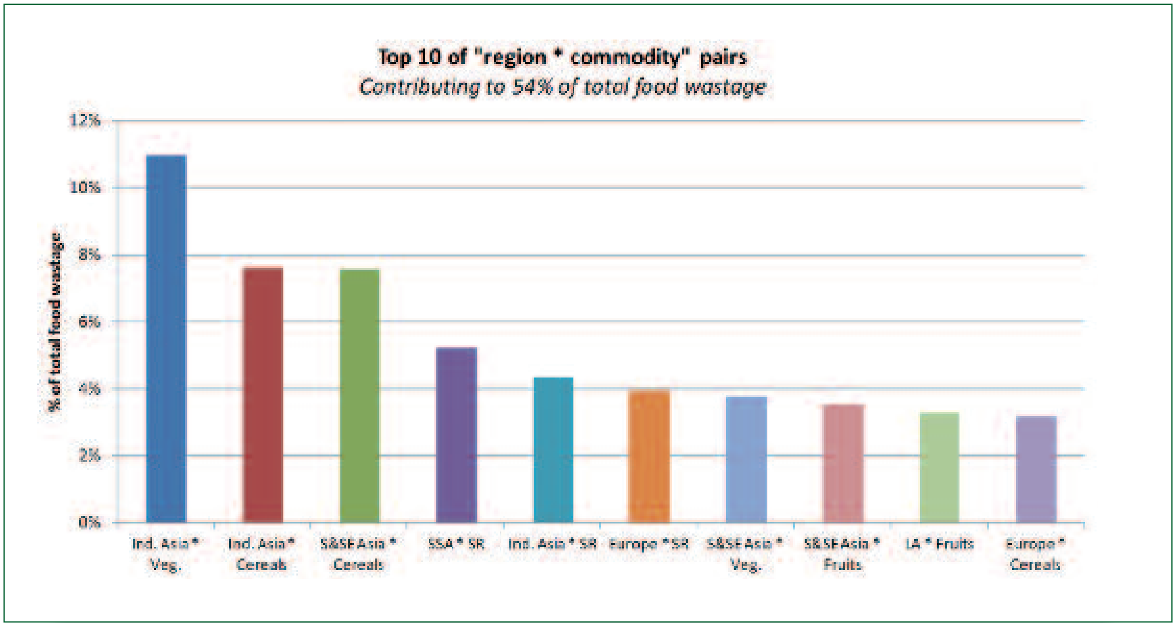
4 These results are presented in the FWF technical report.

Figure 5: Top 10 of "region*commodity" pairs for food wastage

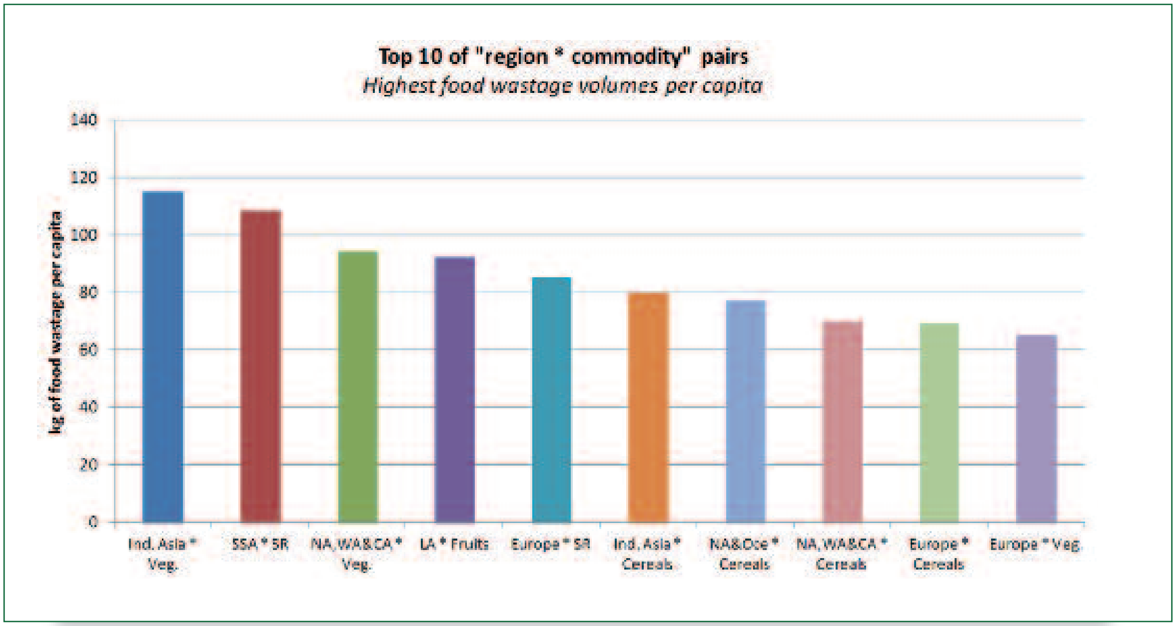


In terms of volume, cereal wastage is quite similar in Ind. Asia and S&SE Asia. However, in-depth analysis shows that more cereals are wasted at the consumption phase in Ind. Asia (similar to other middle- and high-income regions), than in S&SE Asia.

Although SSA is not a major contributor to food wastage at the global level, its wastage of starchy roots appears in the top 10 because of high wastage volumes in the agricultural and post-harvest phases. This is due to a combination of high production of starchy roots in this region (mostly cassava) and relatively high wastage percentages for these two phases, compared to other regions predominated by developing countries. Cassava is highly perishable. Deterioration of the roots starts two to three days after harvest and their consumption value decreases rapidly (Bokanga 1999).

Hotspots can also be pinpointed by calculating per capita ratios for each of the 56 "region*commodity" pairs. This calculation identifies a different top ten, as shown in Figure 6, although seven of the top ten shown in Figure 5 still appear in Figure 6. However, the S&SE Asia is no longer visible in this top 10 and, in fact, has the lowest food wastage volumes per capita. Conversely, the NA, WA&CA is prominent in this calculation, due the fact that cereals and vegetables are major contributors to food wastage in this region, which has a ratio of food wastage per capita higher than the world average.

Figure 6: Top 10 of "region*commodity" pairs for food wastage volumes per capita



Carbon footprint

Method

A product's carbon footprint is the total amount of greenhouse gases (GHGs) it emits throughout its life cycle, expressed in kilograms of CO_2 equivalents. This includes the GHG emissions during the agricultural phase, including those from on-farm energy use and non-energy-related emissions (such as CH_4 and N_2O) from soils and livestock.

Emissions due to land use change (LUC) are not accounted for in this study, but assessing and integrating them in the calculations is definitely a topic for future improvement of the present work. LUC could not be included in the FWF model, since only a fraction of Life Cycle Assessment (LCA) data sources take them into account, and such calculations are heterogeneous and continuously challenged. However, if LUC were taken into account in the FWF model, the evaluation of the global GHG emissions for food production phase would be at least 25 percent higher (Hörtenhuber et al. 2012) and potentially 40 percent higher (Tubiello et al. 2013)

Results overview

The global carbon footprint, excluding land use change, has been estimated at 3.3 Gtonnes of CO_2 equivalent in 2007. As show in Figure 7, if integrated into a country ranking of top emitters, food wastage would appear third, after USA and China, according to the latest data available (WRI 2012). This amount is more than twice the total GHG emissions of all USA road transportation in 2010 (1.5 Gtonnes of CO_2 eq.)[5].

Figure 7: Top 20 of GHG emitting countries vs. food wastage

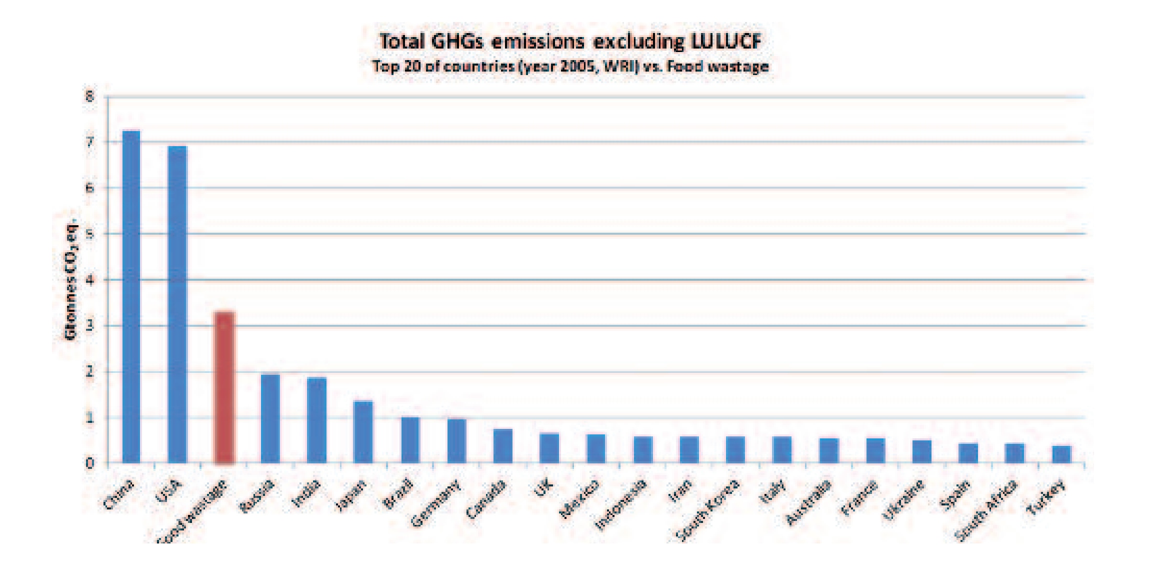
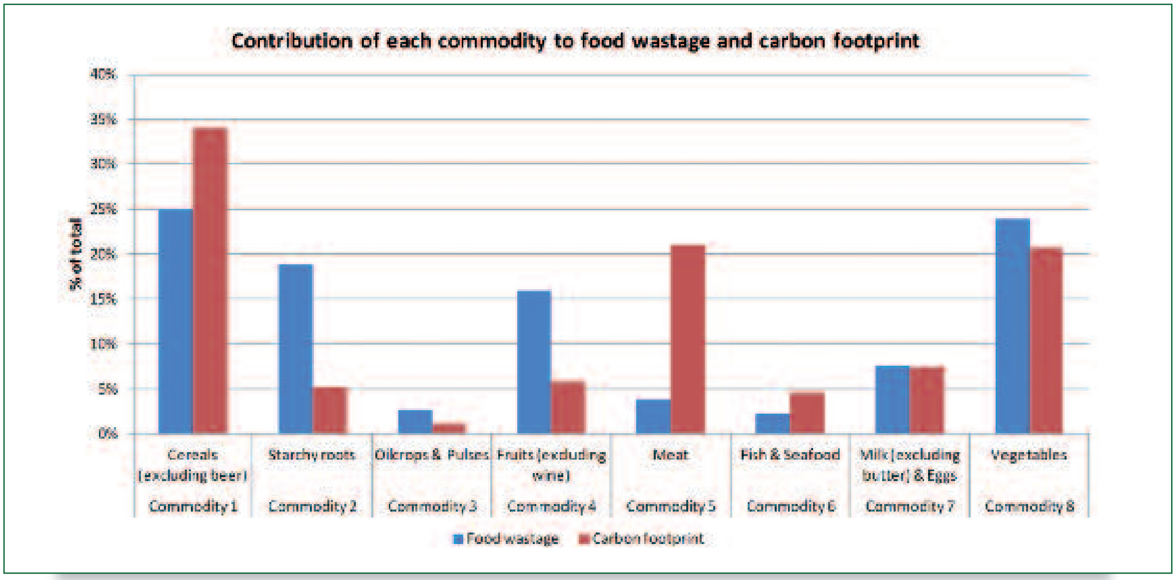


Figure 8 illustrates food wastage for each commodity, along with its carbon footprint. The major contributors to the carbon footprint of food wastage are cereals (34 percent of total), followed by meat (21 percent) and vegetables (21 percent). Products of animal origin account altogether for about 33 percent of total carbon footprint, whereas their contribution to food wastage volumes is only 15 percent. The ratio between red and blue bars of Figure 8 gives an indication of the average "carbon intensity" of each commodity group (i.e. GHG emissions per kg of product).

5 GHG data from UNFCCC, available at http://unfccc.int

Figure 8: Contribution of each commodity to food wastage and carbon footprint



All foodstuffs share a common characteristic: emissions of biogenic GHG such as methane (CH_4) and nitrous oxide (N_2O) play an important role in their carbon footprints. CH_4 and N_2O are very powerful GHGs, CH_4 having a weighting factor of 25 times CO_2 and N_2O 298 (IPCC 2007). The following discussion looks at 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 calculations.

Cereals

The production and application of nitrogen fertilizer are major contributors to the overall climate impact of cereals. In addition, the use of diesel for agricultural operations, such as ploughing, harvesting and drying the produce, results in CO_2 emissions. Differences in the emission factors for various types of cereals mostly depend on the yield level.

Pulses

Pulses, such as peas and beans, are efficient sources of protein, as compared with animal protein, because pulses need fewer inputs per kg of protein produced. In addition, the ability of grain legumes to fix nitrogen from air means that only a small amount, if any, nitrogen fertilizer 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, emissions are mainly due to the use of diesel and nitrogen fertilizers, as well as yield level. Potatoes and other roots are particularly efficient in the cultivation, because of very high yield per unit area. Thus, emissions of GHG per kg of product are low. Regarding vegetables grown in heated greenhouses, the type of heat production is the most important parameter for such products' carbon footprint.

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 (pigs and poultry), feed provision is the first contributor to emissions, followed by manure management, due to methane emissions. These emissions are dominated by N_2O from soil turnover of nitrogen and carbon emissions from production of mineral fertilizers. Energy used to maintain appropriate conditions in animal housing can be of significance for some animals, such as chickens.

CH_4 is often the major source of emissions for ruminants (cattle, sheep and goats). It mostly originates from enteric fermentation that occurs during feed digestion, although some CH_4 emissions also come from manure management. The second most important source of emissions, nitrous oxide, is related to feed provision. This includes emissions caused by production of fertilizers, soil emissions of nitrous oxide 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 on-board cooling equipment, if the refrigerants used have a high climate impact.

Aquaculture

The production of fish farm inputs (particularly feed) often dominates the climate impact of aquaculture products. It is to be noted that some fish, such as carp and tilapia, are omnivores, and can feed on crop products or residues. Other species, including popular species such as salmon, trout and cod, are predators and require some marine-based feed. In industrialized production systems, this calls for fishmeal and fish oil which increase the GHG emissions of carnivorous fish.

Figure 9: Contribution of each region to food wastage and carbon footprint

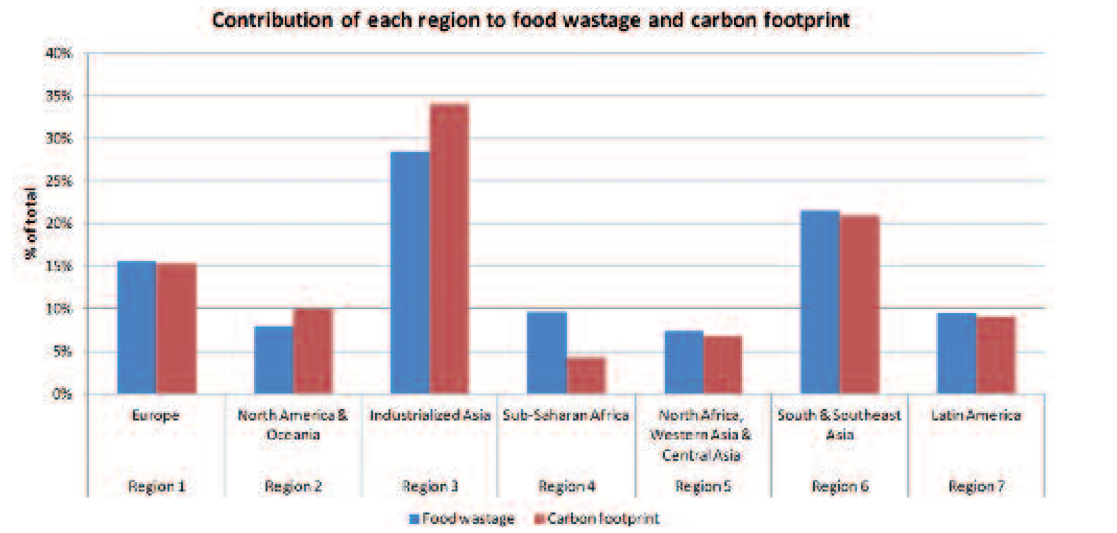


Figure 9 shows the average carbon intensity of each region. Variations are due to different mixes of commodities that are lost or wasted in each region. Regional carbon intensity is higher in North America than in Europe because the share of meat in food wastage is higher (9 percent and 5 percent of regional food wastage, respectively). Carbon intensity is very low in SSA because the share of starchy roots (a commodity with low carbon intensity) in this region is more than 50 percent. The carbon intensity in Ind. Asia is high, due to the carbon footprint of wasted cereals, most notably rice. Rice is also an important contributor to S&SE Asia's carbon intensity.

Figure 10 shows that the highest carbon footprint of wastage occurs at the consumption phase (37 percent of total), whereas consumption only accounts for 22 percent of total food wastage. This is because when food wastage occurs along the FSC, impacts of all the phases that the product has gone through (e.g. processing, transport), are added to the initial agricultural impact and the final end-of-life impact. This means, for instance, that the carbon footprint of the wastage occurring at the consumption phase comes from energy used for cooking, but it also includes the energy used when the food was grown, stored, processed and distributed, and then the end-of-life of the discarded food, such as landfill, must be factored in.

Figure 10: Contribution of each phase of the food supply chain to food wastage and carbon footprint

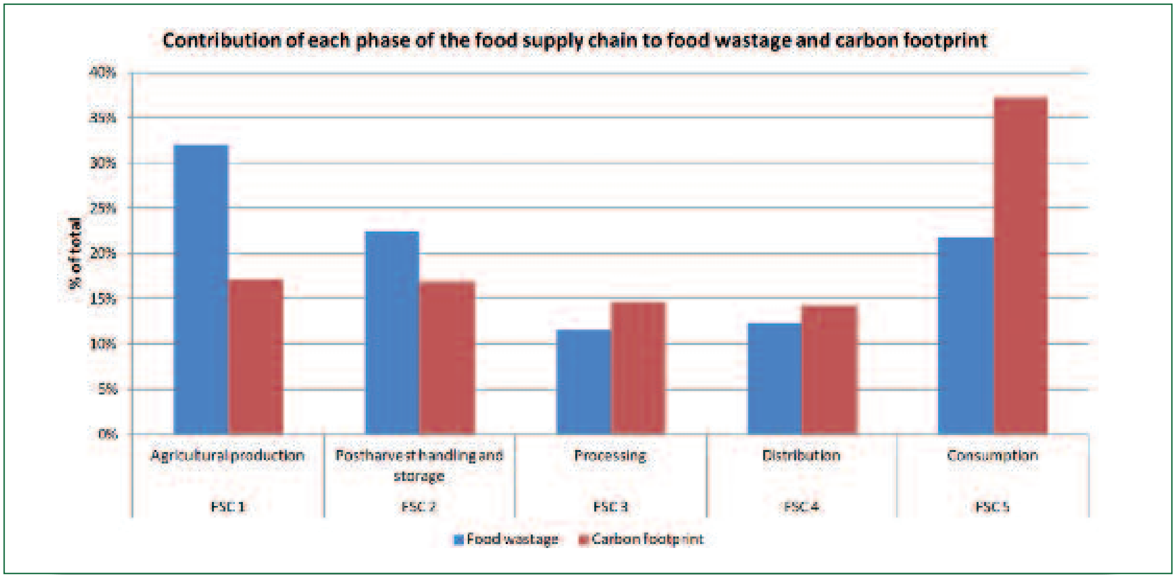


Figure 11: Carbon footprint of food wastage, by phase of the food supply chain with respective contribution of embedded life-cycle phases

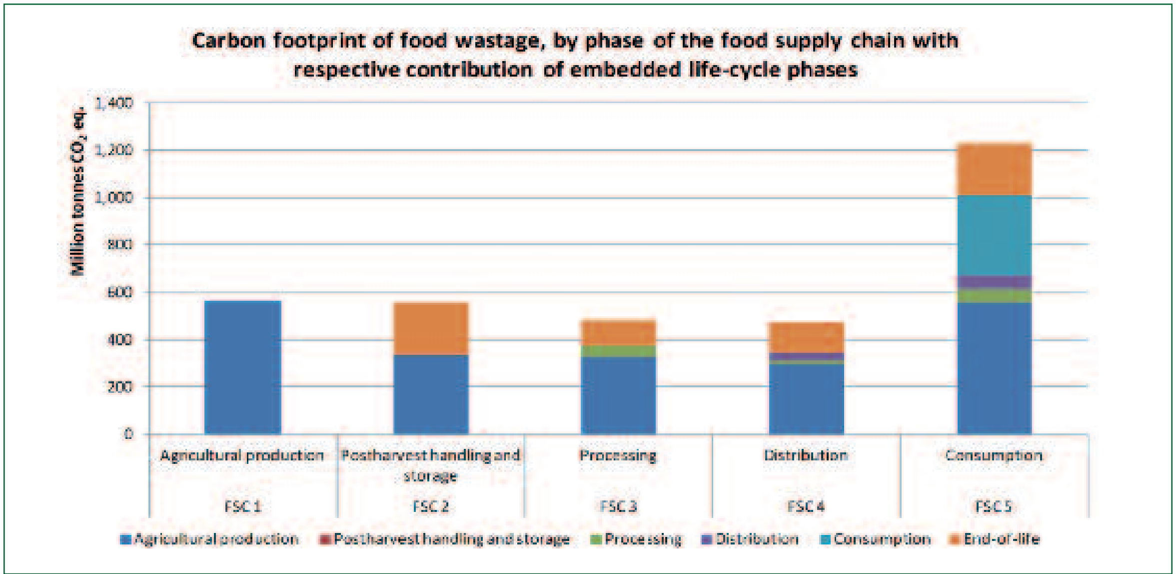


Figure 11 presents the carbon footprint of each phase of the FSC with the respective contribution of embedded life-cycle phases. As shown earlier, GHG emissions from the agricultural phase are always the major contributors to the carbon footprint of each FSC phase. At the consumption phase, the GHG emissions coming from consumption itself (i.e. energy for cooking) play a significant role. Emissions related to end-of-life are noticeable for all phases, except for the agricultural phase which has only negligible emissions[6].

The regional profiles of commodities presented in Figure 12 may vary from one region to another, but they also show some common trends:

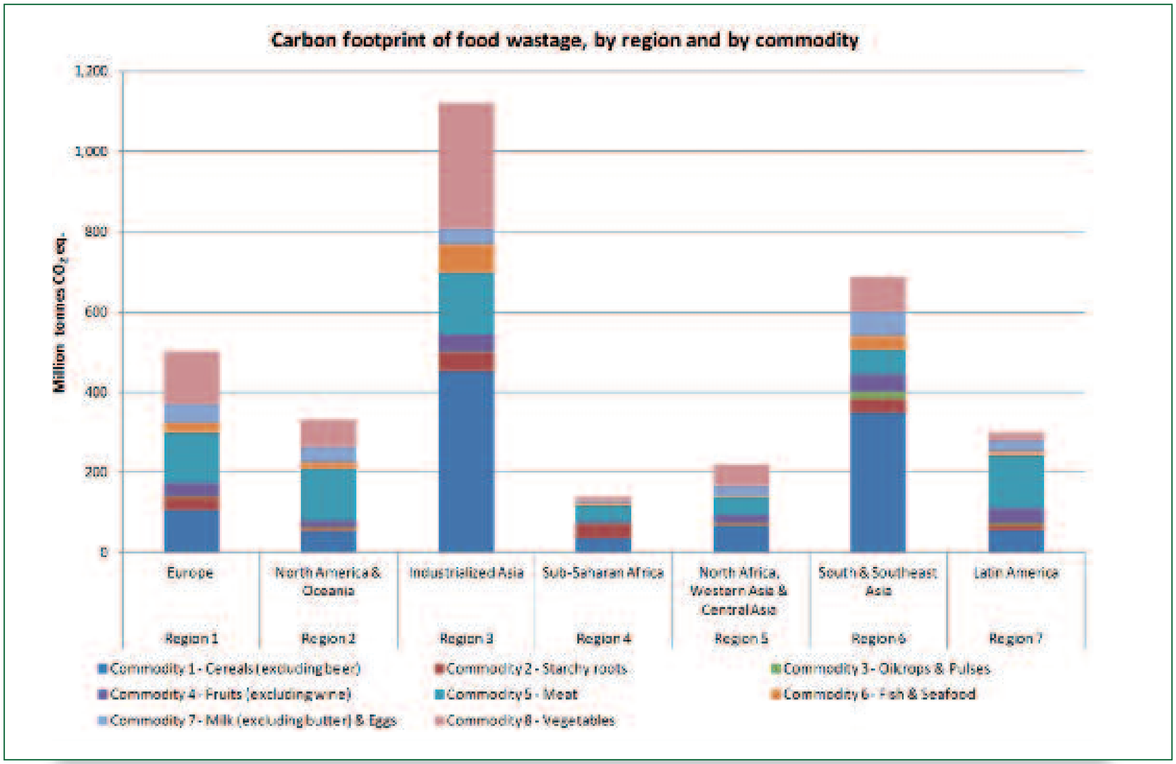
- Contribution of lost and wasted oilcrops and pulses, as well as fish and seafood, to the carbon footprint is low in all regions (1 to 6 percent of the carbon footprint of the region).
- Contribution of lost and wasted starchy root to the carbon footprint is quite low in all regions (less than 7 percent), with the notable exception of Sub-Saharan Africa (24 percent).
- Three commodities, namely cereals, meat and vegetables, contribute significantly to the carbon footprint of each region. Taken together, they account for more than 60 percent of the carbon footprint in every region. However, their respective shares are variable. For instance, the carbon footprint of cereals is as high as 51 percent and 40 percent of total in S&SE Asia and Ind. Asia, respectively. The footprint of meat is high in LA (44 percent) and NA&Oce (40 percent).

The average carbon footprint of food wastage is about 500 kg CO_2 eq. per capita and per year (Figure 13). Europe, NA&Oce and Ind. Asia have the highest per capita carbon footprint of food wastage (approximately 700 to 900 kg CO_2 eq. per capita and per year), while SSA has the smallest footprint per capita (about 180 kg CO_2 eq.). With a view to illustrate the magnitude of these results, it can be mentioned that in 2007, per capita carbon footprint (excluding land use, land use change and forestry – LULUCF) was about 23 tonnes CO_2 eq. in the USA, 10.7 in Japan and 8.4 in France[7].

6 Food wastage during the agricultural production phase is usually dealt with on-farm, through uncontrolled open burning or agriculture products simply left in the field. Climate change impacts of such practices are deemed negligible since the CO_2 emitted by the combustion of agricultural products is of biogenic origin. In addition, agricultural products left in the field are not degraded in anaerobic conditions and do not produce CH_4 as in landfills.

7 GHG data from UNFCCC, available at http://unfccc.int

Figure 12: Carbon footprint of food wastage, by region and by commodity



Hotspots – contribution of "region*commodity" pairs to total carbon footprint

As with the analysis performed for food wastage volumes, the "region*commodity" pairs can be ranked according to their contributions to total carbon footprint. Asia – Ind. Asia and S&SE Asia – appears five times in the top 10 and dominates this ranking with vegetables and cereals. Meat is present in four regions, Ind. Asia, Europe, NA&Oce and LA.

The carbon footprint is calculated as a multiplication of a food wastage amount and an impact factor. Figure 14 enables determination of which part of the multiplication is the main driver of the carbon footprint for the identified hotspots.

Figure 13: Carbon footprint of food wastage, by region – per capita results

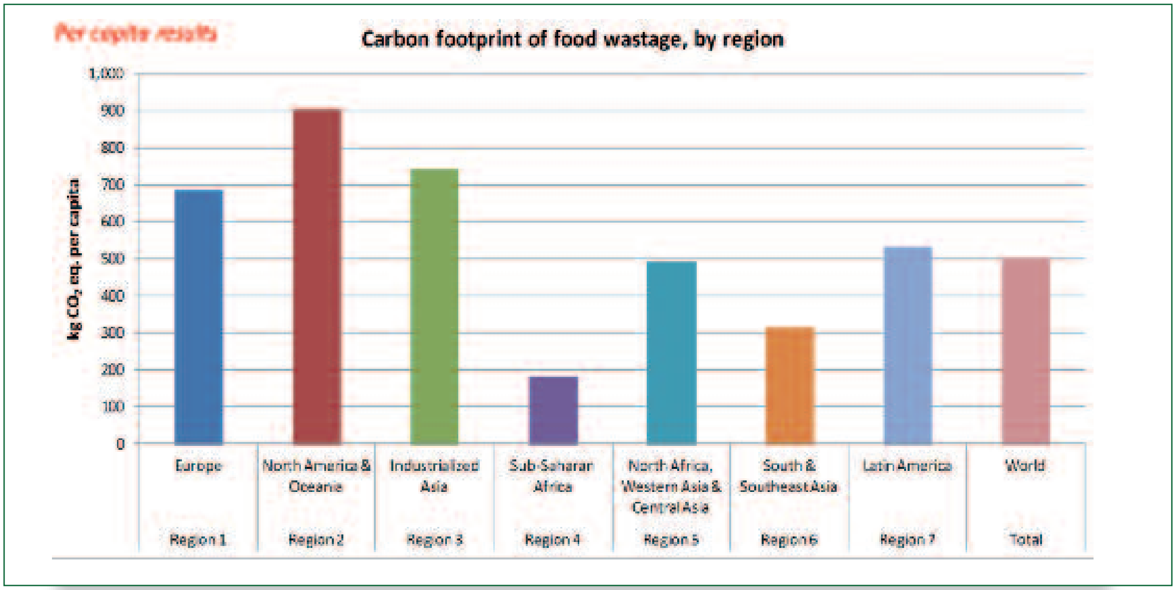
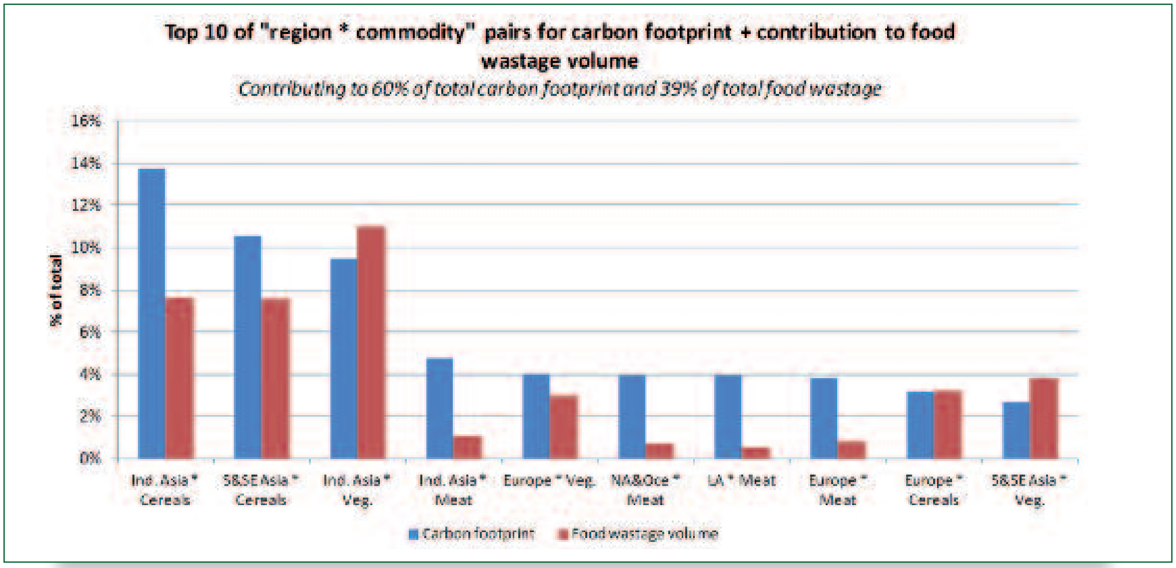


Figure 14: Top 10 of "region*commodity" pairs for carbon footprint presented along with contribution to food wastage volume



In Figure 14, the top 10 of "region*commodity" pairs for carbon footprint are presented along with their respective contribution to food wastage volume. This figure indicates whether 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). In the case of vegetables, the driver seems to be mostly the wastage 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.

Looking more precisely at each hotspot, some particular patterns can be observed. The top two hotspots are cereals in Ind. Asia and S&SE Asia. They account for 13.7 and 10.6 percent of total GHG emissions of food wastage, while their contribution to food wastage volume is 7.6 percent each. In addition, it can be observed that cereals in Europe account for 3.2 percent of the total carbon footprint and 3.2 percent of total food wastage. Thus, it appears that wastage of cereals in Europe is less carbon-intensive.

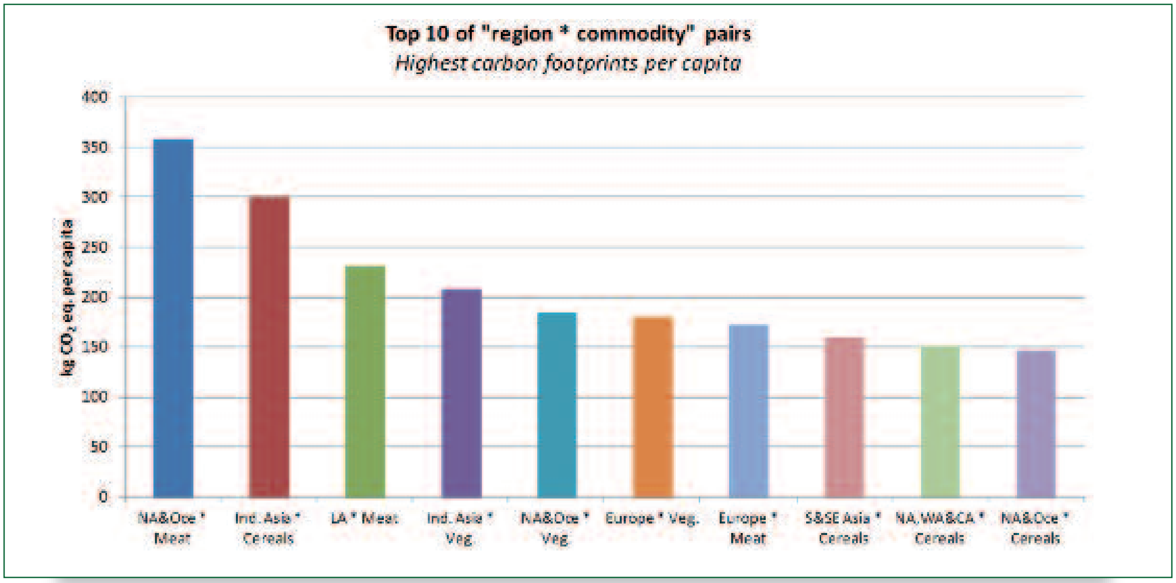
This can be explained by the fact that Asia and Europe mainly grow different cereals. In Asia, rice dominates cereals wastage with 53 percent in Ind. Asia and 72 percent in S&SE Asia, whereas in Europe, wheat dominates with 71 percent of wastage. Furthermore, average impact factors for rice in Ind. Asia and S&SE Asia are 5 and 3.4 kg CO_2 eq/kg, respectively. For wheat in Europe, the impact factor is lower, that is 2 kg CO_2 eq/kg. Note also that about 70 percent of GHG emissions of rice wastage in Ind. Asia and S&SE Asia come 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 is observed: vegetable cropping is more carbon-intensive in Europe than in Asia, which is likely due to the fact that Europe grows a higher share of its vegetables in heated greenhouses. It should be noted 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 have been made very cautiously.

Hotspots – per capita analysis

Hotspots can also be pinpointed by calculating per capita ratios for each of the 56 "region*commodity" pairs. A new top 10 based on this calculation, shown in Figure 15, is dominated by middle- and high-income regions (7 times). Cereals and vegetables are still present but meat is more visible.

Figure 15: Top 10 of "region*commodity" pairs for carbon footprint per capita



Water footprint

Method

Accounting for water use can take two forms: withdrawal or consumption. Water withdrawal refers to water diverted or withdrawn from a surface water or groundwater source. Consumptive water use refers to water that 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. The water footprint approach addresses the issue of water consumption.

Recent work on the global water footprint of human activities or specific country studies demonstrates the major role played by agriculture. It indicates that consumption of agricultural products is responsible for 92 percent of the water footprint of humanity (Hoekstra & Mekonnen 2012). For that reason, the modelling work is focused on the agricultural production phase[8].

8 Although it can be pointed-out that water is also used for food processing (e.g. food cleaning, sanitizing, peeling, cooling), a large part of this water is released afterwards, thus limiting the water footprint of this stage.

The Global standard on water footprint assessment developed by the Water Footprint Network (WFN) has been used for water footprint assessment (Hoekstra et al. 2011). It defines the water footprint of a product as the total volume of fresh water that is used directly or indirectly to produce the product. Under the WFN definition, a water footprint consists of three sub-components that measure different sorts of water appropriation: blue water, green water and grey water.

Blue water in agriculture is the consumptive use of irrigation water taken from ground or surface water. Green water is the rainwater directly used and evaporated by non-irrigated agriculture, pastures and forests. Finally, grey water footprint does not reflect actual water consumption – it measures a theoretical volume of water that is required to dilute pollutants. This latter footprint was not calculated in the present study.

The environmental impact associated with green water use is relatively minor because it does not alter hydrological systems. However, blue water use in irrigated agriculture has the potential for causing severe environmental problems, such as water depletion, salinization, water-logging or soil degradation (Aldaya et al. 2010). This is why the present study focuses primarily on the blue water footprint.

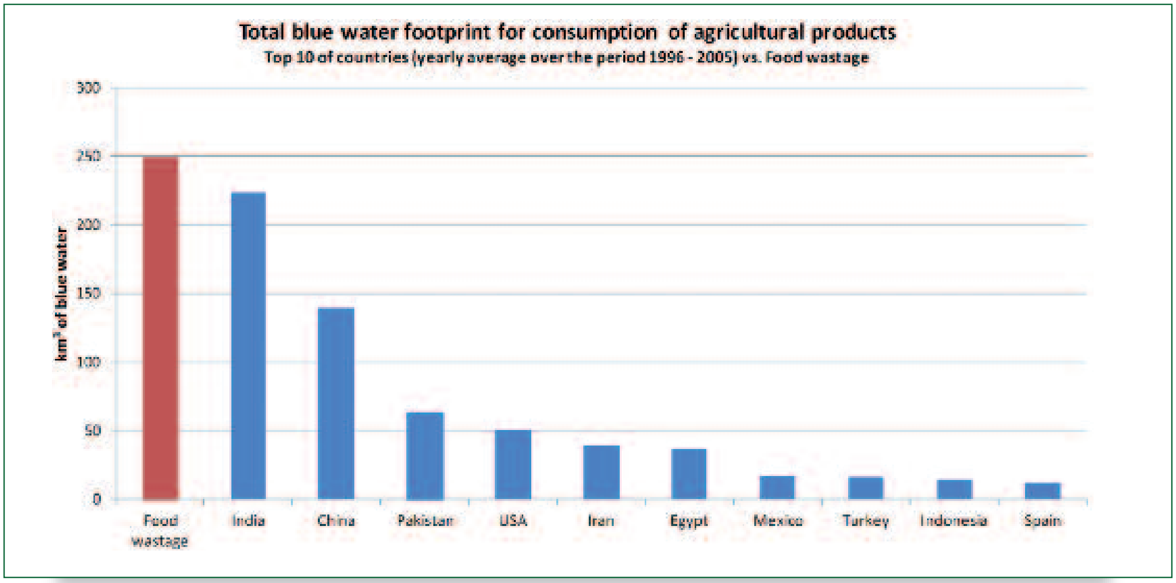
Due to lack of data, the water footprint for fish and seafood was not taken into account in this study. Several authors point-out that no water consumption can be associated with wild seafood and marine fisheries (Zimmer & Renault 2003). It can also be considered that brackish and marine aquaculture are not water-consumptive, because there is no demand or competition for marine or brackish water (Brummett 2006; Welcomme 2006). 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.

Results overview

Globally, the blue water footprint for the agricultural production of total food wastage in 2007 is about 250 km^3, which is more than 38 times the blue water footprint of USA households, or 3.6 times the blue water footprint of total USA consumption (Mekonnen & Hoekstra 2011). In terms of volume, it represents almost three times the volume of Lake Geneva, or the annual water discharge of the Volga River.

The magnitude of the blue water footprint of food wastage can also be represented by integrating it into a country ranking of largest blue water consumers. The blue water footprint of food wastage calculated in this study focuses on the footprint of agricultural production. Therefore, the national water footprint accounts (Mekonnen & Hoekstra 2011) presented in Figure 16 are for the blue water footprint of the national consumption of agricultural products.

Figure 16: Top 10 of national blue water footprint accounts for consumption of agricultural products vs. food wastage

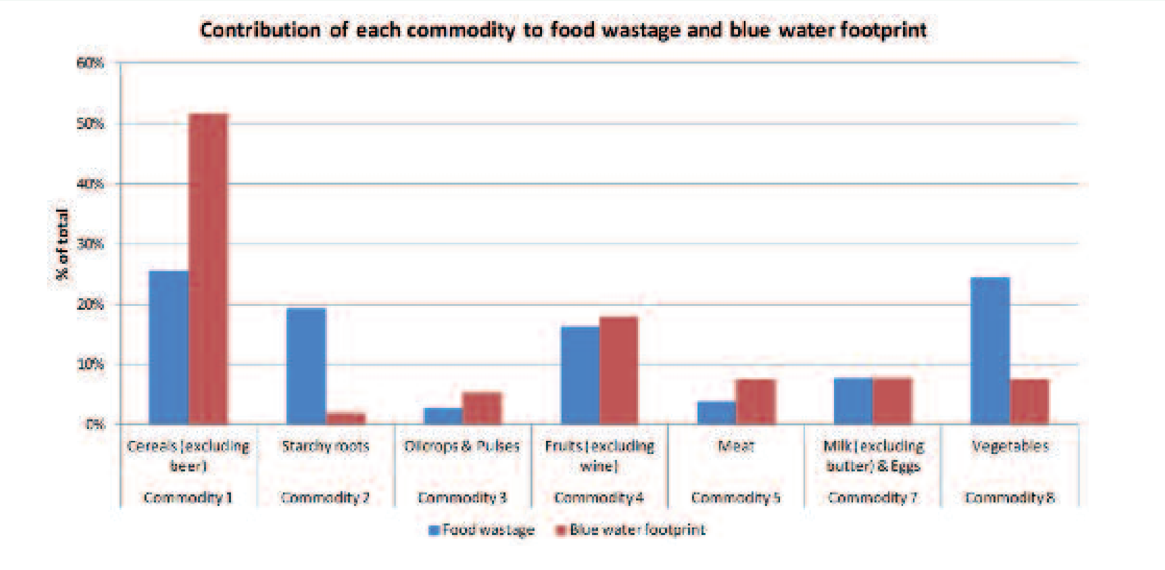


The national blue water footprint accounts for the consumption of agricultural products indicate that the global water footprint of food wastage is higher than that of any country, whether a temperate country with relatively large water use or a large country, such as India or China.

Figure 17 shows that the major contributors to the blue water footprint of food wastage are cereals (52 percent of total) and fruits (18 percent), whereas their contributions to total food wastage[9] are 26 percent and 16 percent, respectively. Conversely, starchy roots account for 2 percent of the water footprint, whereas this commodity represents 19 percent of total food wastage.

9 Excluding fish and seafood in order to allow a comparison on the same grounds.

Figure 17: Contribution of each commodity to food wastage and blue water footprint



The ratio between red and blue bars of Figure 17 indicates the average "blue water intensity" of each commodity group, expressed in m^3 of blue water per kg of product. Information on the water intensity characteristics of the individual commodities included in this study is presented below.

Crops

Comparing the water footprints of products must be done very cautiously. Global average water footprints can differ greatly from region-specific water footprints. Thus, relative performance of products may differ depending on the geographical scale.

Due mainly to the differences in crop yields, water footprints of a given crop vary across countries and regions. For instance, Europe has relatively small water footprints per tonne of cereal crops, while in most parts of Africa, the water footprints of cereal crops are quite large. 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 that have a larger fraction of their biomass 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 vary significantly across products within a commodity.

Animals

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

The feed conversion efficiency, that is the amount of feed required to produce one unit of animal product, strongly affects the water footprint. For instance, cattle's relatively low conversion efficiency leads to a 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 which the various feed components are obtained.

Figure 18: Contribution of each region to food wastage and blue water footprint

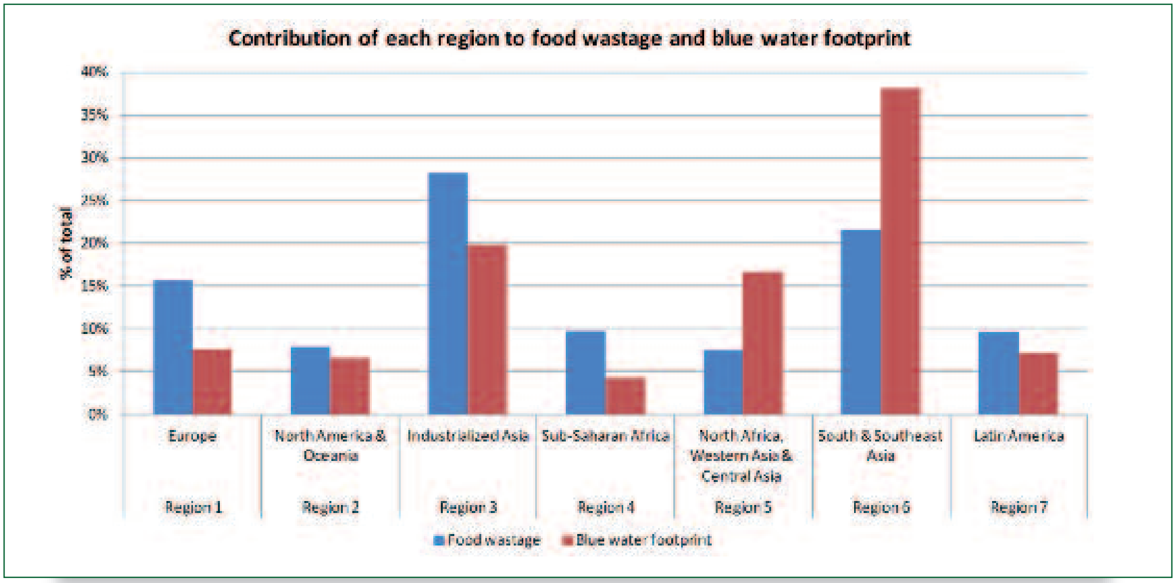
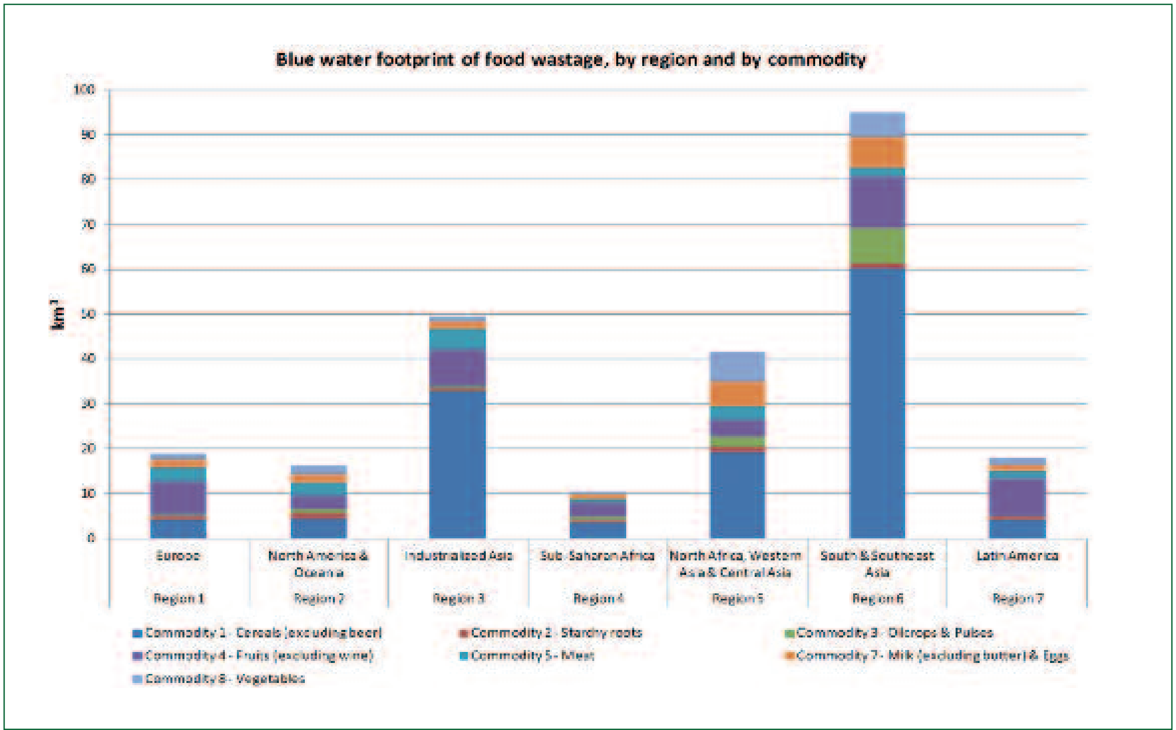


Figure 18 reflects the average blue water intensity of each region. Observed variations come from the different mixes of commodities that are lost or wasted in each region, combined with specific impact factors. Some of the interesting patterns, which are further illustrated in Figure 19, are the following:

- ✓ 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 which account for about 50 and 60 percent, respectively.
  - ✓ In NA,WA&CA, it is mostly because of wastage of: wheat and maize in the Northern Africa sub-region; and wheat and rice in the Western Asia sub-region. The impact 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 the Southeast Asia sub-region, in particular in India. The impact factor for wheat is higher than average in this sub-region.
- ✓ Regional blue water intensity is very low in SSA because the share of starchy roots (a commodity with low blue water intensity) in this region's food wastage is very high, at more than 50 percent.

Figure 19: Blue water footprint of food wastage, by region and by commodity

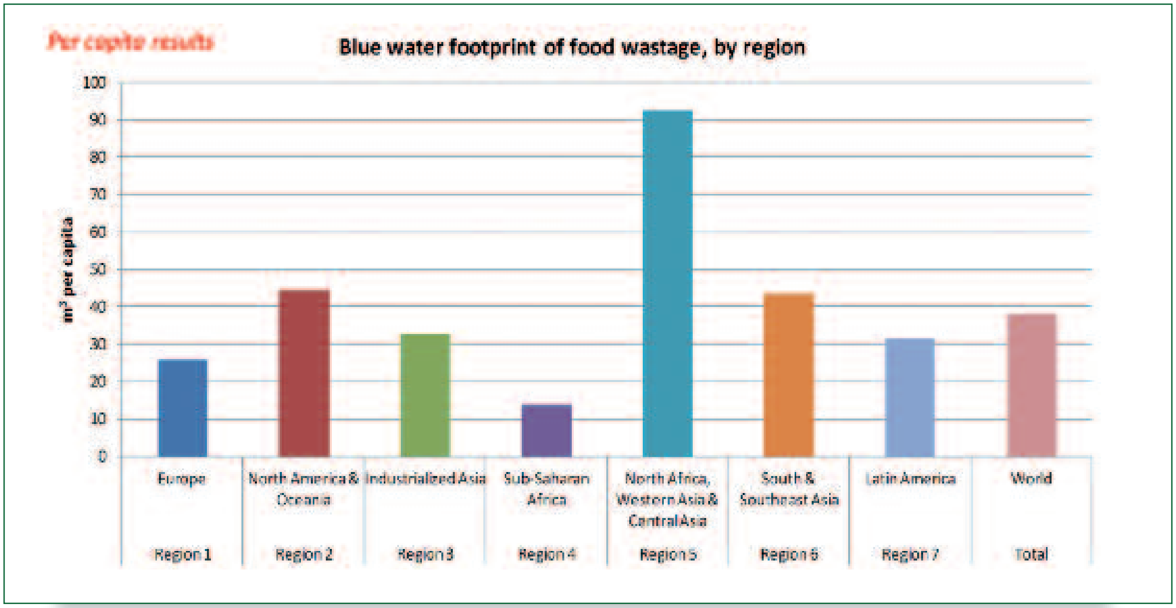


A different picture emerges from the per capita results. Most notably, S&SE Asia, the region with the highest absolute water footprint, is actually close to world average when looking at the per capita results. The average blue water footprint of food wastage is about 38 m^3 per capita and per year. NA,WA&CA stands-out as the region with the highest per capita footprint, which is more than 90 m^3 per capita and per year. Indeed, this region represents 17 percent of the total water footprint of food wastage but only 7 percent of the total population. SSA is the region with the smallest footprint per capita, at 14 m^3 per capita and per year. This region represents only 4 percent of the total water footprint of food wastage, but as much as 12 percent of the total population.

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

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

Figure 20: Blue water footprint of food wastage, by region – per capita results



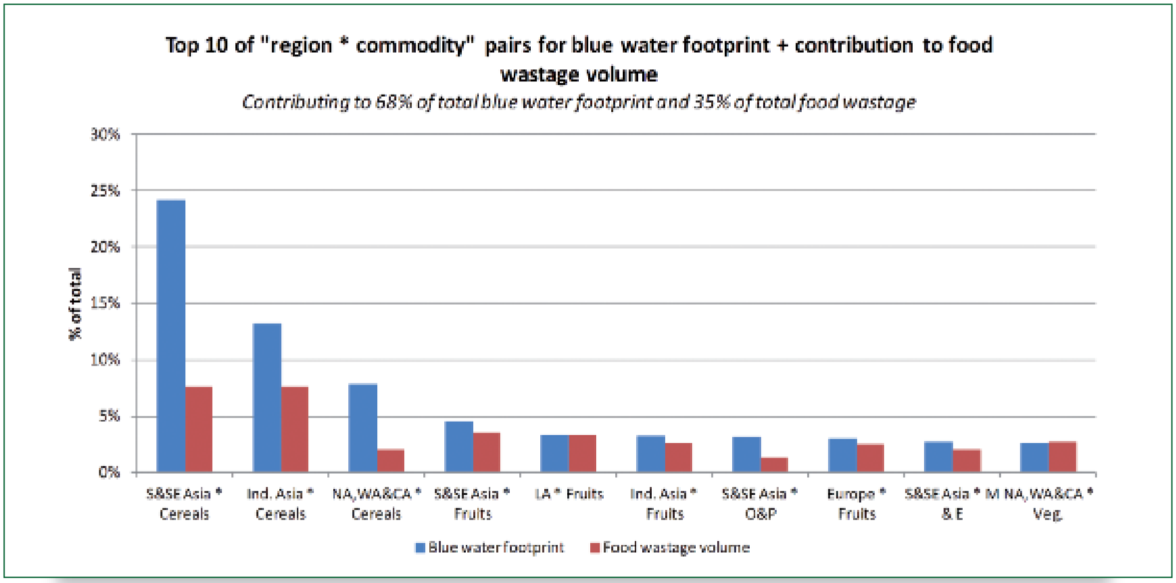
Hotspots – contribution of "region*commodity" pairs to total blue water footprint

The "region*commodity" pairs also can be ranked according to their contributions to total blue water footprint, using analysis similar to the one used for food wastage volumes.
Figure 21 shows the ten pairs with the highest contribution to blue water footprint. Cereals dominate this ranking with the three first places accounting for 45 percent of total footprint. Fruits are quite visible in the top 10, appearing four times. But the contribution of fruit (at 14 percent) remains secondary to cereals.

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 21 has been built for that purpose.

The Top 10 of "region*commodity" pairs for blue water footprint is presented in Figure 21, along with their respective contributions to food wastage volume. The main driver for cereals seems to be the water footprint intensity of the commodity, whereas for fruits, it seems to be more connected to the wastage volumes.

Figure 21: Top 10 of "region*commodity" pairs for blue water footprint presented along with contribution to food wastage volume



More specifically, in S&SE Asia, the water footprint of cereals primarily comes from the Southern Asia sub-region (because of India) and in Ind. Asia (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. While the estimate for fruits is fairly robust at global level, 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 sub-commodity "other fruits" which includes a wide range of product but is not further broken down in the FBS and, thus, does not allow further disagreggation in the FWF model.

Hotspots – per capita analysis

Another way to pinpoint hotspots is to calculate per capita ratios for each of the 56 "region*commodity" pairs. This identifies a new top 10, which is presented in Figure 22. The ranking is modified but six pairs of the first top 10 are still present. NA,WA&CA, which has the highest overall blue water footprint per capita, dominates this ranking. In addition, two new commodities from this region have appeared in the ranking (M&E[10] and fruits). 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 cereals and fruits (3.4 percent and 6.8 percent, respectively) but with only 5.6 percent of the total population, this makes a significant per capita ratio.

Taking water scarcity into consideration

Data available on the Global Agro-Ecological Zones (GAEZ)[11] portal of FAO and the International Institute for Applied Systems Analysis (IIASA) were adapted to the FWF model in order to complement water footprint figures with aspects of water scarcity. 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, a withdrawal rate above 20 percent of renewable water resources is considered to represent substantial pressure on water resources – and above 40 percent, is considered critical.

GAEZ identifies areas of land that have a low, moderate, high or very high water scarcity in each country of the world. The country-level areas for each level of water scarcity have been summed-up according to region, providing a view of the regions that have the largest share of land areas with high or very high water scarcity. Figure 23 places this water scarcity profile alongside food wastage in order to reveal potential linkage between the two aspects.

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10 Milk and egg

11 Over the past 30 years, IIASA and the FAO have been developing the Agro-Ecological Zones (AEZ) methodology for assessing agricultural resources and potential. The GAEZ v3.0 portal is available at http://www.gaez.iiasa.ac.at

Figure 22: Top 10 of "region*commodity" pairs for blue water footprint per capita

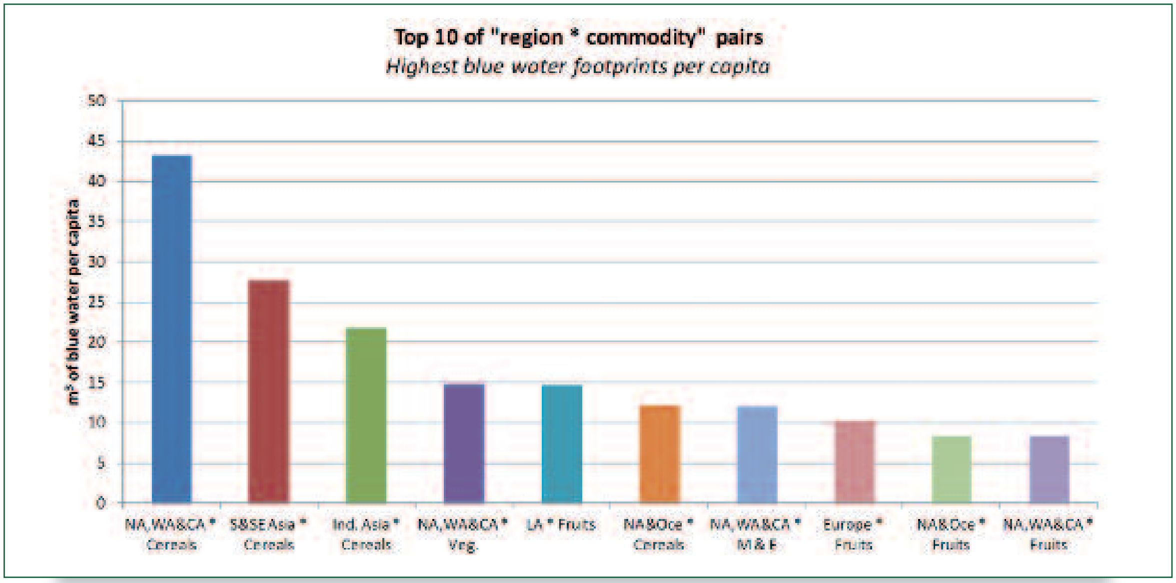
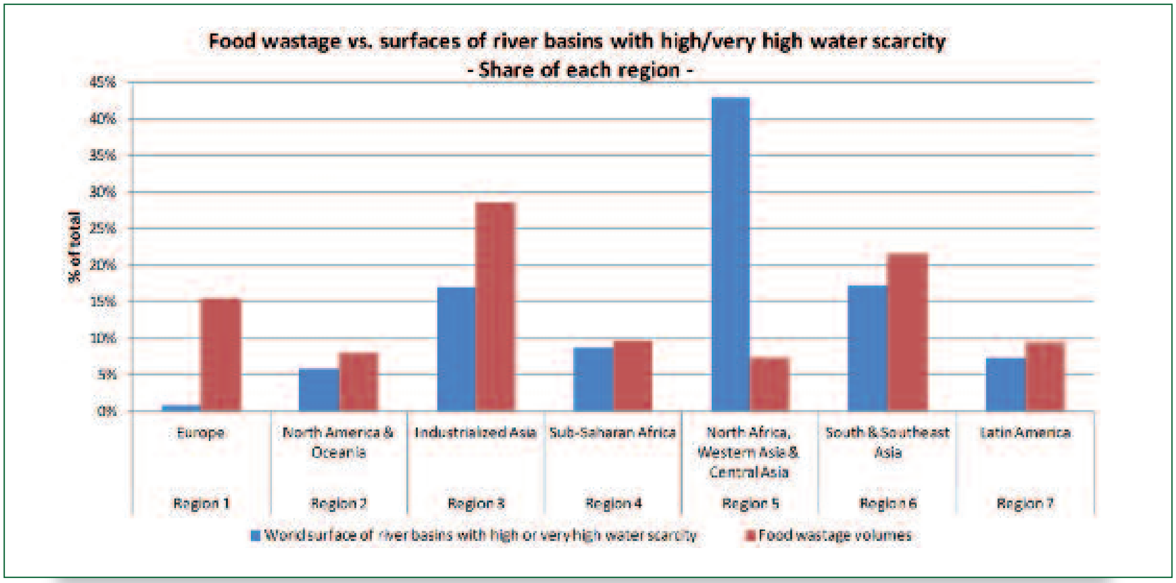


Figure 23: Food wastage vs. surfaces of river basins with high/very high water scarcity



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 food wastage puts on the water resource. In this perspective, it seems that the Ind. Asia and S&SE Asia regions raise concerns, as they significantly contribute to water scarcity through food wastage. However, making a relevant connection between water scarcity and volumes of food wastage is not so obvious. Indeed, most of NA,WA&CA has arid or semi-arid climates so, 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 in relation 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.

Land use

Method

In this study, land occupation describes the surface of land, including cropland and grassland, necessary to produce foodstuff. More specifically, it evaluates the surfaces occupied by food produced but uneaten because of wastage.

This land occupation indicator has some advantages, since it has relatively low uncertainty and is expressed in a surface area unit (e.g. ha) which is easy to understand. 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 (Mattila et al. 2011).

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 which would account for the impact of deforestation, urbanization and soil sealing. It also does not indicate if the land occupation is actually beneficial or negative for the environment, particularly regarding impacts on soil quality. Indeed, occupation of land, such as for agricultural use, can lead to a temporary or permanent lowering of the productive capacity of land. The United Nations recognizes this phenomenon, called land degradation, as a global developmental and environmental issue. In this context, the land occupation figures calculated in this study have been complemented with data from the FAO Land Degradation Assessment in Drylands (LADA) model (FAO LADA 2011) in order to give a preliminary view of the linkage between aspects of land occupation of food wastage and land degradation.

In this case, the land use factor for capture fisheries is not included, as such products obviously do not require agricultural land. Regarding aquaculture (both marine and inland), it should be noted that in some productions systems, fish can be fed with feed made from agricultural products. However, no detailed data could be found on the land occupation factor related to aquaculture.

Results overview

At world level, the total amount of food wastage in 2007 occupied almost 1.4 billion hectares, equal to about 28 percent of the world's agricultural land area. This figure can be compared to the surface of the largest countries, where land surface occupied by food produced and not consumed is second to the total land area occupied by the Russian Federation.

Figure 24: Top 20 of world's biggest countries vs. food wastage

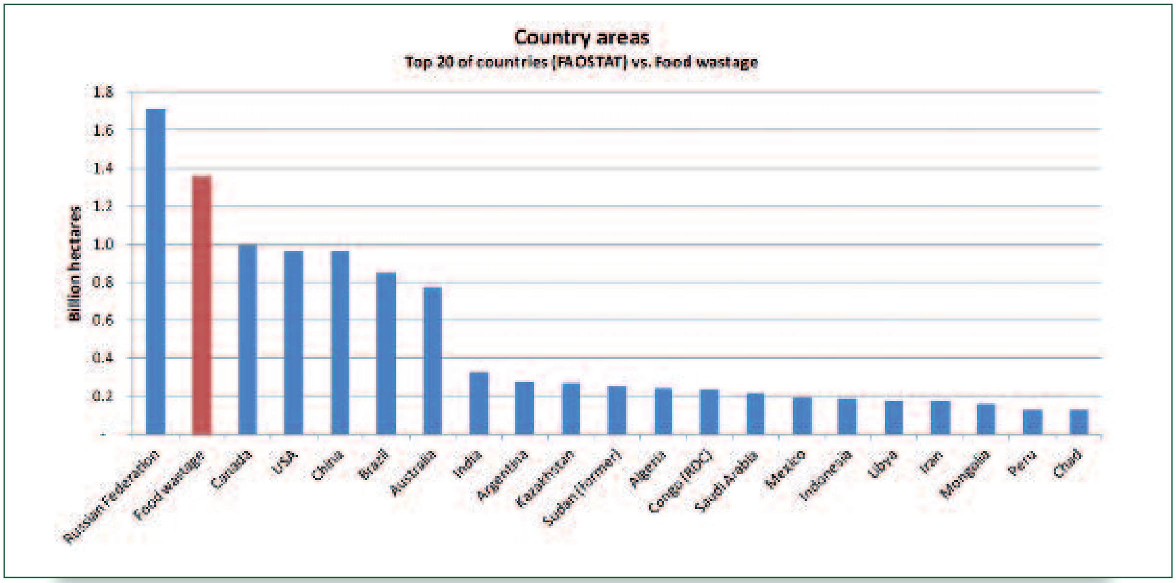
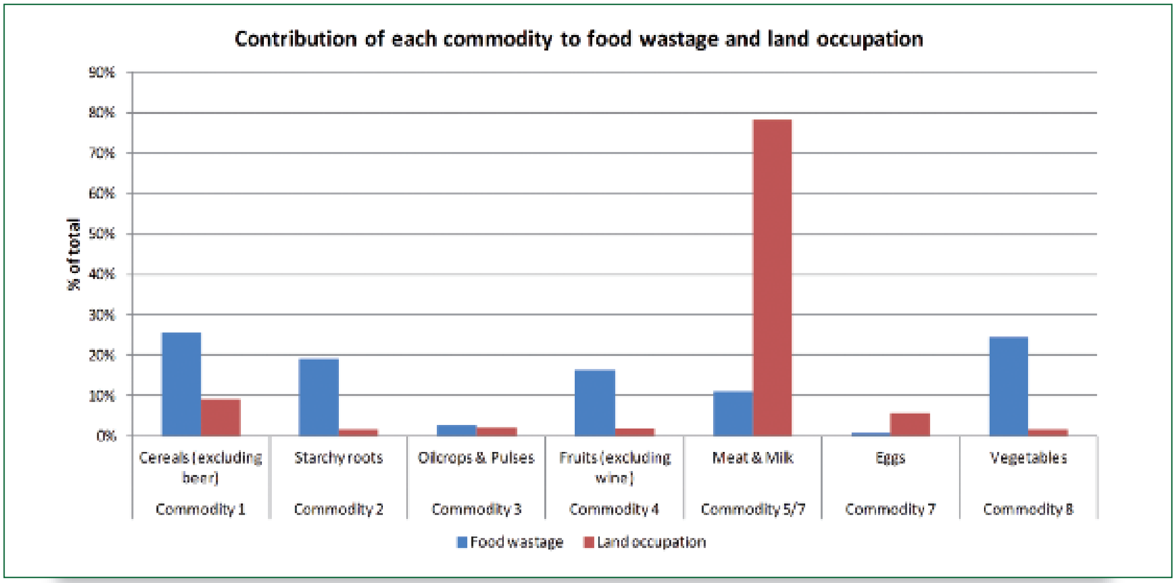


Figure 25 shows that the major contributors to land occupation of food wastage are meat and milk, with 78 percent of the total surface, whereas their contribution to total food wastage is 11 percent[12]. The ratio between red and blue bars of Figure 25 indicates the average "land intensity" of each commodity group, that is hectare of land per tonne of product. In practical terms, it illustrates that land intensity is inversely proportional to the yield.

12 Excluding fish and seafood in order to allow a comparison on the same grounds.

Figure 25: Contribution of each commodity to food wastage and land occupation



The discussion below looks at the land occupation/yield characteristics of the commodities analyzed in this study.

Crops

It should be stressed that comparing yields of crop products must be done with great caution. World average yields can vary greatly from region-specific yields. 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 (e.g. inputs intensity, water and land management) and agroclimatic conditions. For instance, Europe and USA have relatively high yields of wheat compared with 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 with crops where a small fraction of crop biomass is harvested (e.g. cereals, oilcrops).

Animals

With regards livestock production, land occupation assessment requires specific accountings of the agricultural surfaces occupied for producing 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, soymeal) and other supplements. Schematically, the share of roughages and 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 products from monogastric animals can also be divided in arable and non-arable land. Although monogastric animals do not feed on grass, they indirectly require non-arable land surfaces because milk or components of milk from ruminants (which require grassland) can be ingredients of their feeding rations.

Figure 26: Land occupation of food wastage, at world level by commodity arable land vs. non-arable land

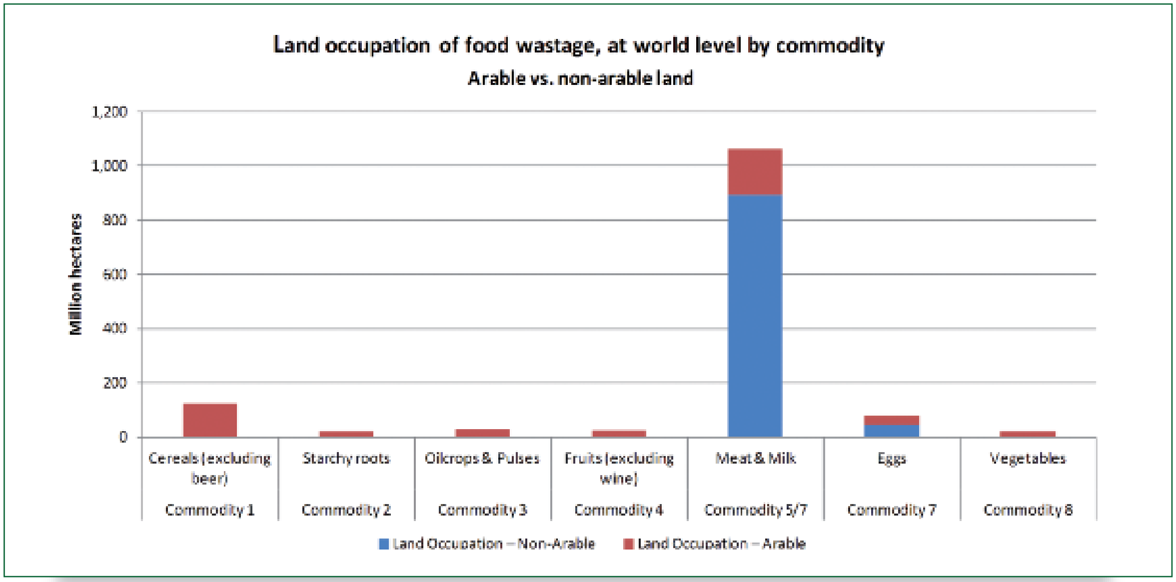


Figure 27: Contribution of each region to food wastage and land occupation

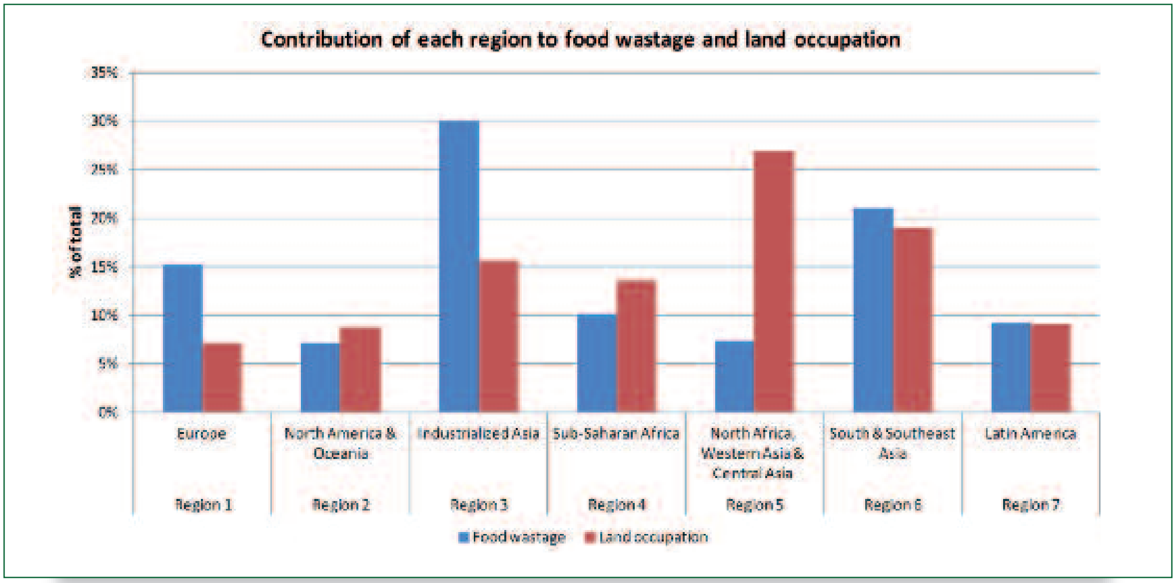


Figure 26 shows that the majority of the surfaces occupied to produce meat and milk are non-arable, meaning pastures and meadows. Meat and milk occupy 95 percent of non-arable land, the remaining 5 percent coming from eggs. Moreover, lost and wasted meat and milk occupy about 40 percent of the arable land (i.e. cropland). 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 represent about 20 percent of total land occupied by food wastage. Lost and wasted food crops only use arable land and cover 52 percent of total arable land occupied by food wastage.

Regarding the role of each region in the surfaces occupied by food wastage, Figure 27 shows that the major contributor is NA,WA&CA, which accounts for 27 percent of the area occupied by food wastage globally. Low-income regions account for about two-thirds of total land occupation, while their contribution to total food wastage is about 50 percent.

Figure 27 reflects the average "land occupation intensity" of each region. Observed variations come from the different mixes of commodities that are lost or wasted in each region, combined with specific shares of arable and non-arable land. Patterns worth noting include the following (see also Figure 29).

- Land occupation intensity is much higher in NA,WA&CA than in other regions. In this region, 85 percent of the land occupation of food wastage is non-arable land for meat and milk, in particular for bovine, ovine and caprine animals. In this region, the non-arable land impact factor is very high, because the production 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. The share of non-arable land for meat and milk is still the largest contributor to land occupation but, in parallel, the share of arable land for meat and milk is higher than in other regions. In these regions, the non-arable land impact factors are lower because production systems generally rely less on grassland and because grasslands are more productive. Feeding rations include higher shares of concentrates, resulting in more arable-land occupation but less non-arable land occupation. This results in lower total land occupation intensity.
- The difference between Ind. Asia and S&SE Asia is mostly due to differences in cattle production systems. The higher grassland productivity and higher share of concentrates in feeding rations in Ind. Asia result in higher productivity.

Figure 28: Land occupation of food wastage, at world level by region – Arable land vs. non-arable land

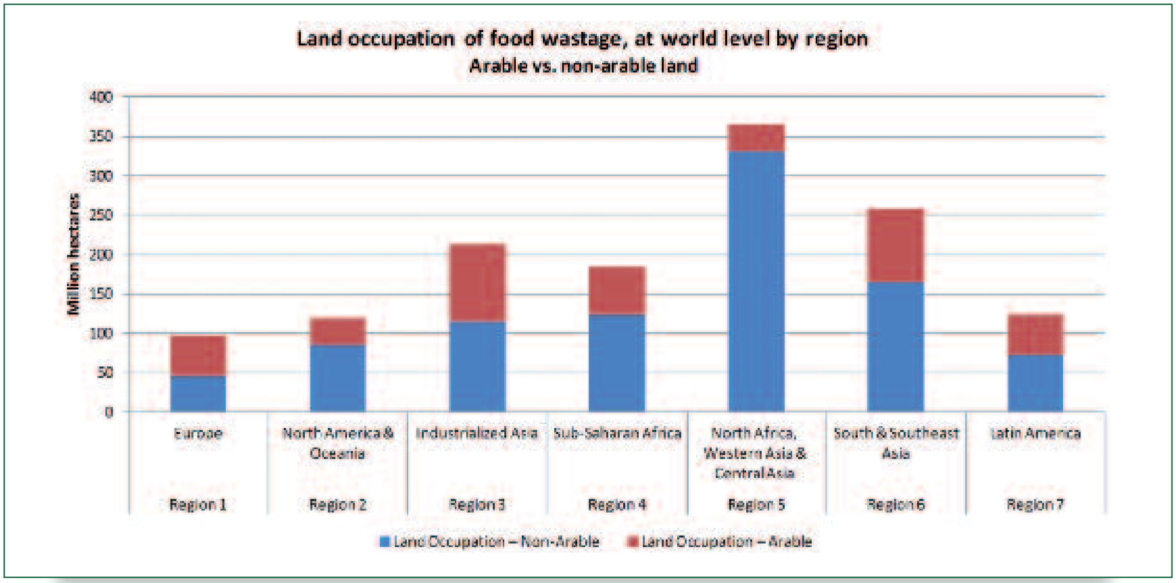


Figure 28 shows that in NA,WA&CA, more than 90 percent of the land occupation happens on non-arable land. In other regions, the share of non-arable land fluctuates between 47 percent for Europe and 71 percent for NA&Oce. In all regions, meat and milk are the largest contributors to non-arable land occupation. These commodities are also key drivers of arable land occupation. Consequently, the share of 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.

The major features of the regional profiles of commodities presented in Figure 29 are as follows:

- ✓ Surfaces of non-arable land occupied to produce lost/wasted milk and meat contribute as much as 46–85 percent of the total land occupation of food wastage in each region.
- ✓ Lost/wasted milk and meat account for large surfaces of arable land. Arable land used by these commodities contributes to more than 10 percent of total land occupation of food wastage in all regions except NA,WA&CA and S&SE Asia, where production systems rely more on grasslands, which are low productive.
- ✓ 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 percent of total land occupation of food wastage in each region.
- ✓ In spite of significant food wastage volumes, starchy roots, vegetables and legumes are not very visible in the profiles because of their generally high yields.

Hotspots – contribution of "region*commodity" pairs to total land occupation

For this component, a distinction is made between hotspots related to arable land occupation and hotspots related to non-arable land occupation. In Figure 30 and 31, top "region*commodity" pairs are presented along with their respective contribution to food wastage volume[13].

It can be noted that for meat and milk, the driver seems to be mostly the land occupation intensity of the commodity, for both arable and non-arable land. The observed variability in the impact factors of meat and milk across regions is due to differences in production systems, mainly factors such as the composition of the feeding ration and the amount of land required to produce the constituents of the ration.

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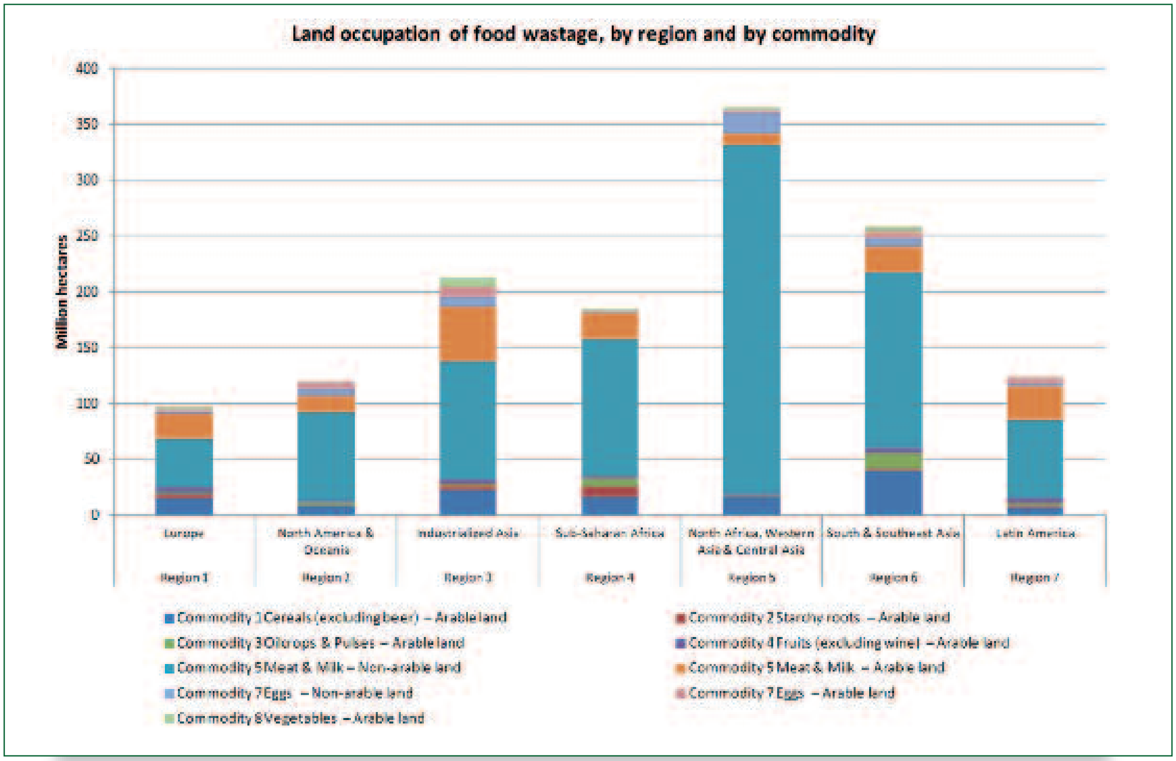
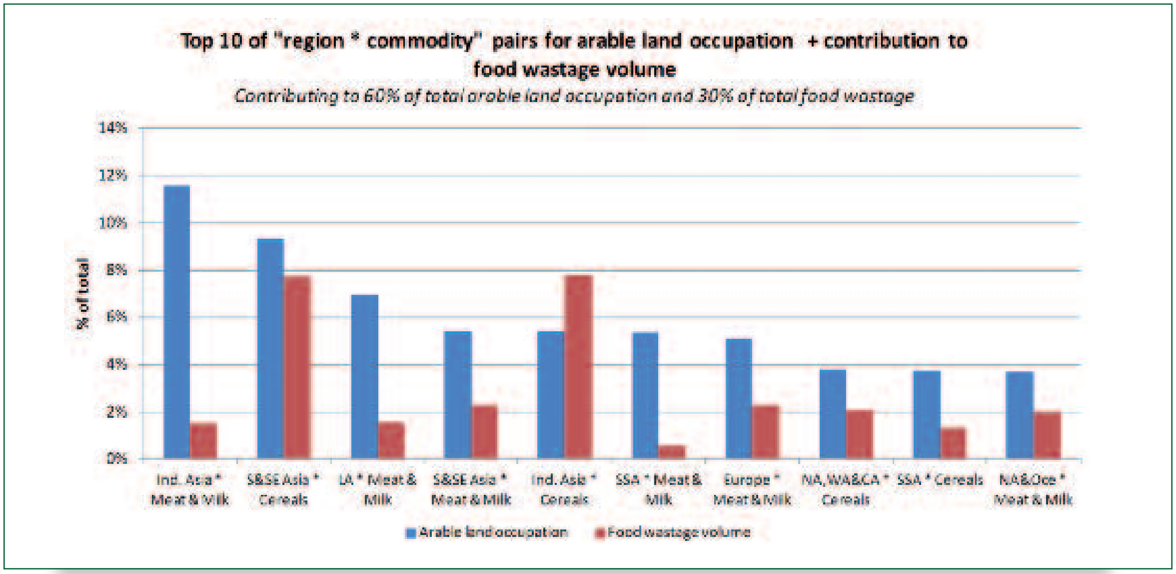
13 Figure 31 is only a top 5, because the number of potential "hotspot" pairs is reduced (only meat, milk and eggs have an arable-land occupation). This top 5 contributes to 83 percent of total non-arable land occupation.

Figure 29: Land occupation of food wastage, by region and by commodity



With cereals, wastage volumes play a role in arable land occupation but impact factors can accentuate or limit the effect of volume. For instance, cereals in S&SE Asia and Ind. Asia make the same contribution to total food wastage volumes but make different contributions to arable land occupation. The average land occupation factors for cereals in these two regions are different mainly because rice, relative to other cereals, has higher wastage in S&SE Asia, where rice yields are lower than in Ind. Asia. This results in a higher average impact factor for cereals in S&SE Asia.

Figure 30: Top 10 of “region*commodity” pairs for arable land occupation presented along with contribution to food wastage volume



Hotspots – per capita analysis

Another way to pinpoint hotspots is to calculate per capita ratios for each of the “region*commodity” pairs. Figure 32 presents the top 10 for total land occupation, with animal products clearly dominating the ranking. The major per capita hotspots are in NA,WA&CA, which has the highest total land occupation per capita.

Linkage with land degradation

Land degradation is defined by the FAO/LADA project as the reduction of land capacity to provide ecosystem goods (e.g. food, water, construction material) and services (e.g. maintaining hydrological cycles, regulating climate, cleaning water and air), over a period of time for its beneficiaries.

Figure 31: Top 5 of "region*commodity" pairs for non-arable land occupation presented along with contribution to food wastage volume

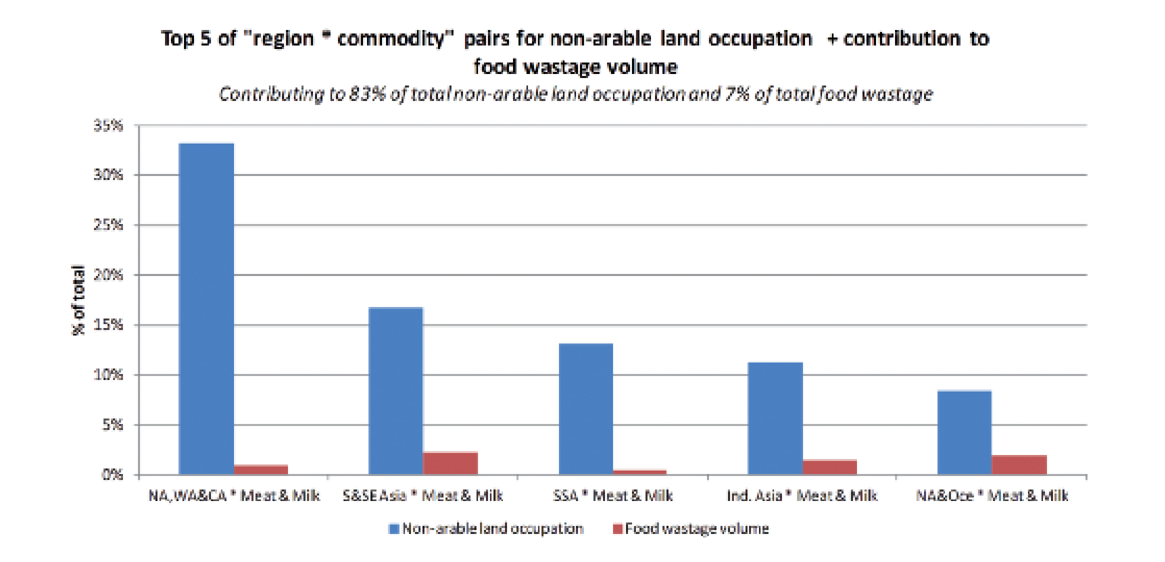
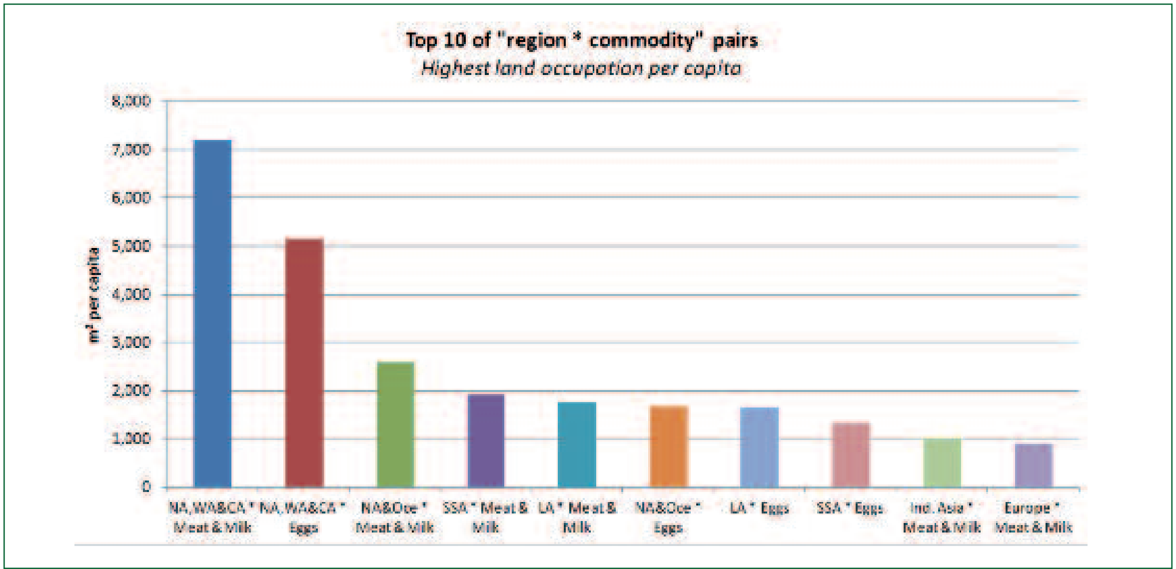


Figure 32: Top 10 of "region*commodity" pairs for land occupation per capita



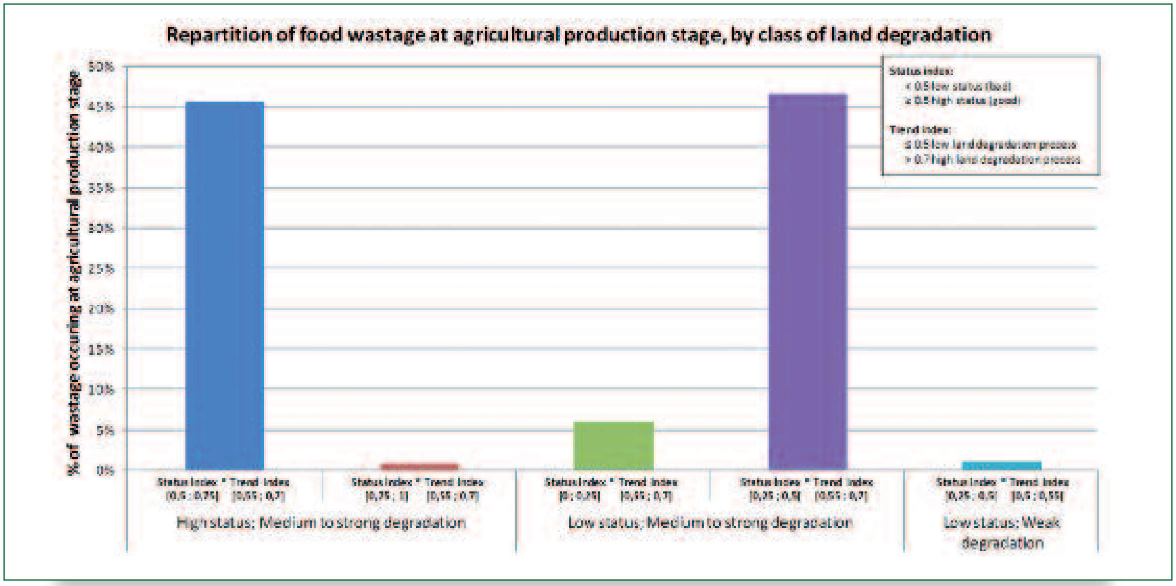
Degradation or decline in ecosystem services corresponds with a change in state of these services due to pressures and resulting in various degradation processes, that is, the land degradation trend. However, before quantifying these changes, the baseline of the actual status of each ecosystem needs to be determined, that is, the land degradation status. Trend and status can be further combined in classes of land degradation, that is to say particular "trend*status" pairs.

Land on which the agricultural production of food eventually lost/wasted occurred falls into three classes of land degradation (as defined in FAO LADA, 2011):

- ✓ Class 1: high (good) land status + medium to strong land degradation
- ✓ Class 2: low (bad) land status + medium to strong land degradation
- ✓ Class 3: low (bad) land status + weak land degradation

Figure 33 offers a view of the land degradation class/status/trend of the surfaces occupied to grow food lost at the agricultural production phase.

Figure 33: Repartition of food wastage at agricultural production stage, by class of land degradation



Almost 99 percent of food wastage at agricultural production stage appears to be produced in regions whose soils are experiencing, on average, medium to strong land degradation, thus adding pressure unduly. In addition, more than 50 percent of food wastage at the agricultural production stage appears to be produced in regions whose soils are, on average, currently at a low status in terms of soil degradation.

Biodiversity

Method

Biodiversity comprises the diversity of life on Earth, across genes, species and ecosystems. In this study, the impact of food wastage on biodiversity is focused on the agricultural production phase. Clearly, damages caused to natural habitats during the production phase are considerably greater than biodiversity impacts due to the disposal of unused parts of food. Biodiversity impacts are discussed where production occurs. Therefore, food wastage responsibility related to international trade is deliberately excluded from the assessment, as this important aspect requires detailed global supply chain models not contemplated in this study.

Biodiversity impacts related to agricultural production are assessed both at ecosystem level, through the extent of deforestation due to agriculture, and at species level, through the extent of Red Listed species of mammals, birds and amphibians threatened by agriculture. The biodiversity impacts related to fisheries are assessed at community level, by considering trends in mean trophic levels of species in a Large Marine Ecosystem (LME) since 1950. The Marine Trophic Index (MTI) measures the decline in abundance and diversity of fish high in the food chain, thus reflecting the complex interaction between fisheries and marine ecosystems (Pauly & Watson 2005). These three biodiversity indicators were chosen as they were the most meaningful and available ones to assess the impacts of food production at global level. Other indicators, such as trends in genetic diversity or trends in invasive species, are not fully developed or could not easily be linked to food production.

The quantitative assessment that follows is focused on terrestrial and marine biodiversity at regional or sub-regional level, but not at commodity level. This means that food wastage volumes could not be directly related to impacts on biodiversity, as for the other categories of environmental impacts. However, this study offers a qualitative review of evidence about the impacts of the different food commodities on biodiversity. This evidence base is then used to help interpret the relation between the quantitative biodiversity indicators and the regional information on food wastage per commodity. It should also be noted that in the quantitative assessment, the importance of the production system type (e.g. intensity level, traditional vs. industrial) could not be accounted directly, due to data availability issues. Moreover, the estimates of extent of deforestation from agriculture are maximum values, assuming all land deforested between 1990 and 2010 was due to conversion to agriculture. In reality, the extent of deforestation due to food production is probably smaller, as some of this agricultural land may not go to food production (e.g. biofuels) and as not all new agricultural land actually comes from forest areas. In addition these estimates do not consider a number of other factors that can affect the magnitude of biodiversity impacts, such as the initial state of the forest (i.e. whether it was already degraded or not), or whether several conversions occurred in the 20-year period taken into consideration.

The review of evidence highlights that the greatest threats posed by crop expansion are likely to occur in the tropics, which support the highest species richness and endemism, while providing the greatest scope for increasing global agricultural production. In the developed world, there is generally poor conservation of biodiversity because industrial agriculture and urban expansion have led to declines in farmland diversity, ecosystems' pollution and habitat loss. Current trends towards agricultural land abandonment may lead to further biodiversity declines through reductions in habitat heterogeneity.

Animal husbandry has widespread impacts on biodiversity, mostly due to the conversion of natural areas to pastures and the production of forage, but also due to grazing and loss of livestock genetic diversity. Livestock production is concentrated in areas of cheap food supply, while becoming more industrialised. Generally, biodiversity decreases along a gradient of grazing intensities, where low-input rangelands have the highest biodiversity value, while rangelands with high stocking rates have the lowest biodiversity value. In the developing world, livestock production can play an important role in deforestation. In the developed world, livestock farming with low grazing intensity is often essential in maintaining semi-natural habitats of high ecological value, which are gradually being lost to high-input and more productive pastures.

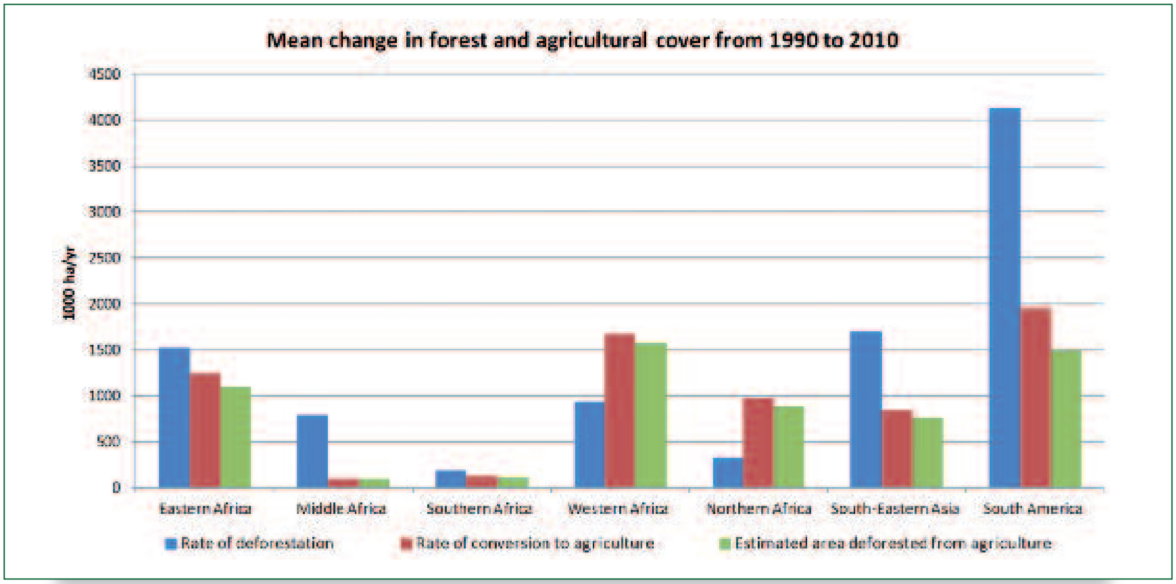
Fish and seafood production are also a considerable source of biodiversity decline. Marine fisheries have severely depleted and damaged fishery resources and fundamentally altered marine ecosystems. In fact, the number of overexploited, depleted or recovering marine fish stocks increased in 2008 to 32 percent, the highest in history. In addition, about half of the marine fish stocks are estimated as fully exploited, and for the ten species that have the highest share in catches, most of the stocks are overexploited (FAO 2010). This is largely due to modern industrial fishing, which causes significant collateral damage by destroying sea floor habitats and by-catch of unwanted species that is discarded as waste at sea. Aquaculture may also pose significant threats to biodiversity, but at the same time, it can have some locally positive impacts. For example, effluents in oligotrophic marine waters increase local biodiversity. The main causes of biodiversity decline due to aquaculture involve the escape of alien species, increasing use of hormones and antibiotics and discharge of other pollutants in the aquaculture process, genetic alterations of wild fish stocks and transmission of diseases.

Results overview

Farming, including conversion of wild lands and intensification, is a major threat for biodiversity worldwide. However, most of the impacts of food production on biodiversity occur in low-income regions, such as Sub-Saharan Africa and Latin America. Deforestation due to agricultural expansion seems to occur today mainly in tropical and sub-tropical areas of the African continent, Western and Southeastern Asia and Southern America (Figure 34). This is in line with existing findings showing that, between 1980 and

2000 across the tropics, more than 55 percent of new agricultural land came at the expense of intact forests and another 28 percent came from disturbed forests (Gibbs et al. 2010). While bioenergy crops have witnessed a rapid expansion over the past 10 years, especially in the tropics, deforestation remains largely due to the production of food commodities (Phalan et al. 2013). Maize, sorghum and cassava show somewhat lower rates of expansion than bioenergy crops but concern larger extents of land (Phalan et al. 2013), and thus are significant cause of land conversion.

Figure 34: Maximum area of forest converted to agriculture from 1990 to 2010, in regions where deforestation occurred



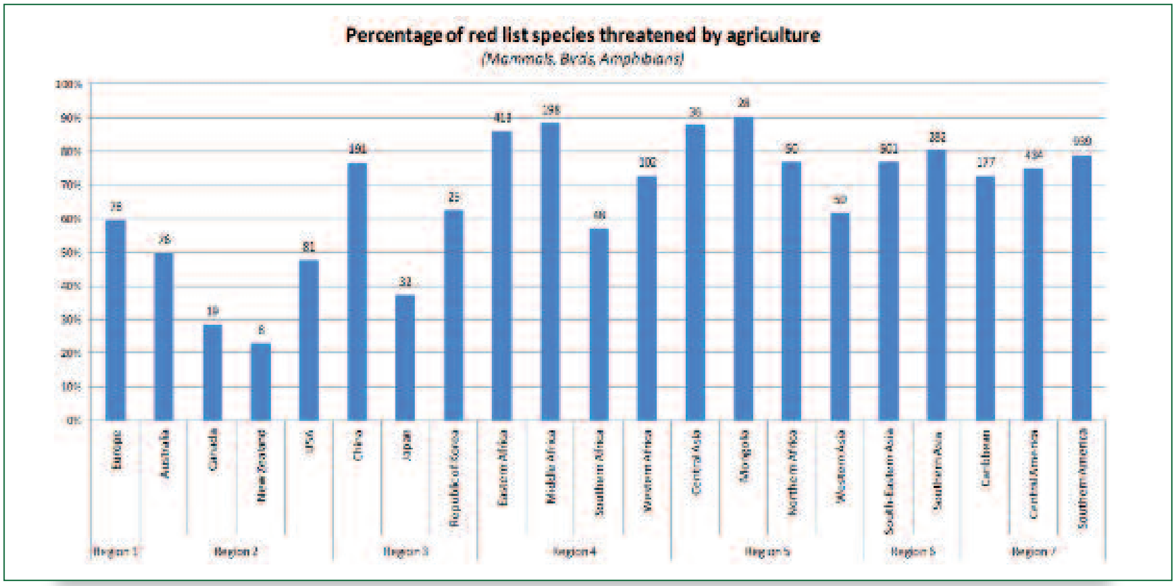
Threats to biodiversity are considerably higher in developing countries than in developed countries: on average, crops are responsible for 44 percent of species threats in developed countries, compared with 72 percent in developing countries. The threat is lower for livestock production, with developed countries responsible, on average, for 21 percent of the threats, compared with 34 percent for developing countries. The main biodiversity impacts are also located in tropical and sub-tropical regions, including Central and Southern Asia, Central and South America, and Africa.

Overall, this study shows that agriculture is responsible for 66 percent of threats to species (Figure 35), but there is considerable regional variability, since agriculture causes only 23 percent of threats to species in New Zealand, but up to 90 percent of threats in Mongolia. The production of food crops has approximately twice as much impact on mammals, birds and amphibian biodiversity than livestock production:

70 percent vs. 33 percent of threats to species, respectively (Figure 36). This difference is striking and partly reflects the fact that rangelands, especially low-input and low density ones, promote habitat diversity, making them relatively biodiversity-friendly.

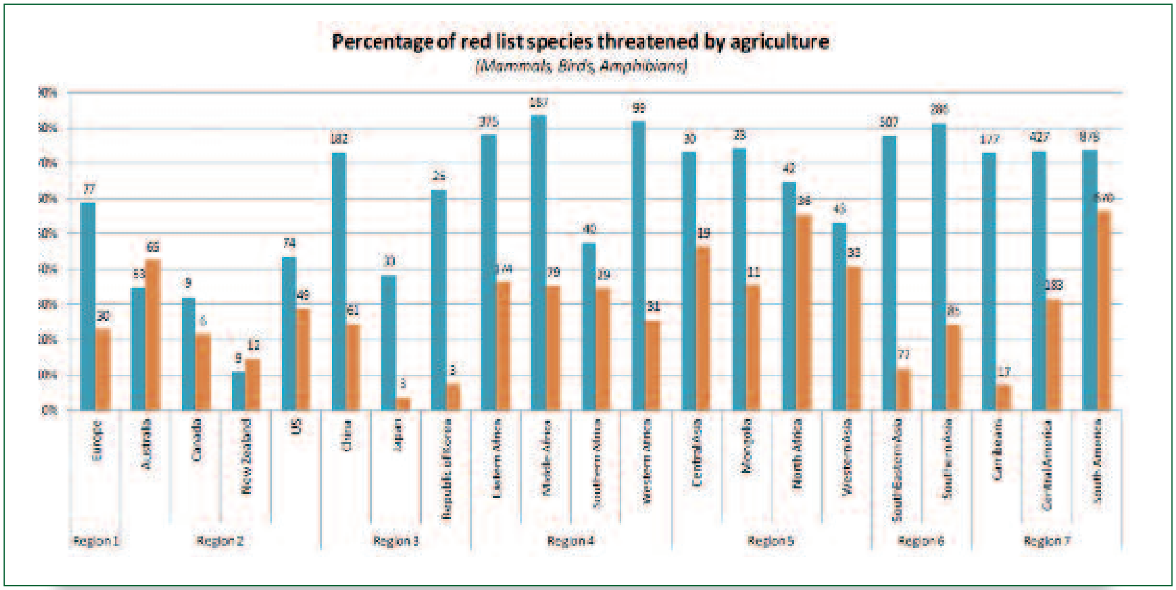
Overall, mammals, birds and amphibians show similar responses to food production activities. However, bird species appear especially vulnerable to food production activities in tropical and sub-tropical regions, probably because of the relatively high number of forest-dependent species in this group. Mammals tend to be less vulnerable than the other two taxonomic groups.

Figure 35: Percentage of Red List species of Birds, Mammals and Amphibians that are threatened by agriculture (both crops and livestock). The number of threatened species is indicated above the bars



The Marine Tropic Index measures the degree to which countries are "fishing down the food chain," with fish catches increasingly consisting of smaller fish that are lower in the food chain. The average mean trophic level has been declining in most LMEs since 1950 (Figures 37 and 38), but this decline occurs at very different rates in different seas and regions. Middle- and high-income regions which have a diversity of seas (i.e. Europe, NA&Oce, Ind. Asia) have approximately two thirds of their seas showing declining trends in MTI since 1950. This is likely due to the importance of commercial fishing and its impacts on the food webs. For example, in the Humboldt current (i.e. NA&Oce), MTI plummeted as soon as fisheries of anchoveta, a low trophic level species, took-off in 1955. In contrast, developing regions with few seas (i.e. SSA, NA,WA&CA, S&SE Asia) show relatively stable or positive trends in MTI since 1950.

Figure 36: Percentage of Red List species of Birds, Mammals and Amphibians that are threatened by crop production (blue bars) and livestock farming (orange bars). The number of threatened species is indicated above the bars



This probably reflects the fact that fishing mostly occurs at artisanal or subsistence levels in these areas. Developed regions (i.e. Europe, NA&Oce, LA) also show a number of stable or increasing trends in MTI values, that may in some cases reflect the uptake of more sustainable fishing practices, but also mask some biodiversity declines. For instance, in the Agulhas current (LA), the sharp increase in mean trophic level since the 1970s reflects the collapse of the fisheries for pilchard and anchovies, which are two low trophic level species[14].

These biodiversity impacts can then be linked to food wastage through the production phase for each commodity and region to detect hotspots of biodiversity impacts. In some cases, the greatest biodiversity impacts are for those commodities and regions which also have the greatest amounts of food wasted and/or largest environmental impacts. For example, cereal production is a main cause of food wastage in most regions, probably constituting the main threat to biodiversity, both in terms of deforestation and species' threats. This is due to the large extents of land that need to be converted for their production, usually leading to simplification and degradation of habitats. The hostpots of biodiversity impacts linked to crop production are located around the tropics, which is both a global biodiversity hotspot that, in re-

14 http://www.lme.noaa.gov

cent years, has also experienced the most rapid agricultural expansion. Wastage of cereals in S&SE Asia is thus expected to be an important threat to biodiversity (as for other environmental components), due to related deforestation (Figure 34). More generally, important food crops in LA and SSA, such as cassava, rice, maize are continuing causes of deforestation (Figure 34).

More locally, starchy roots can represent important volumes of wastage, but they do not translate into large environmental impacts. However, they may sometimes lead to significant biodiversity impacts. For example, cassava in Thailand and Brazil is increasingly grown in large scale monocultures and it is a cause of deforestation in central Africa (Phalan et al. 2013).

In contrast, while vegetable and fruit production is a considerable source of food wastage, especially in the tropics, with large water footprint, it is likely to have relatively less important impacts on biodiversity than cereal production. Fruits and vegetables are usually grown on smaller scales and involve a diversity of crop types, which may contribute to maintaining a certain habitat diversity.

There may also be some trade-offs between the quantities of food wasted and their impact on biodiversity. Meat, fish and seafood, and oilcrops and pulses represent small volumes of food wastage in all regions. However, they represent important production volumes and intensities and thus, have considerable impacts on biodiversity. Fisheries have been declining or collapsing in most regions, largely as a result of the over-exploitation of fish stocks by large commercial fisheries (Figures 37 and 38). Likewise, while oilcrops and pulses are not important in terms of food wastage, when grown in large scales plantations, their impacts on biodiversity are similar to those of cereals.

Meat wastage actually has overall high environmental impacts because of its land take, and the main producing regions (i.e. Europe, NA&Oce and LA) are expected to also experience high biodiversity impacts. While species threats due to livestock production represent only a third of those induced by agricultural crops (Figure 36), they remain significant. There are higher in developing regions, and LA is a likely biodiversity hotspot of meat wastage. Indeed, in LA, most new agricultural land is cleared for cattle pastures, leading to increasing habitat fragmentation and degradation, resulting in biodiversity declines.

Figure 37: Average change in mean trophic level since 1950 in selected Large Marine Ecosystems (LMEs) of Europe, NA&Oce and Ind. Asia. The percent change is indicated above the bars, blue bars represent significant changes, while red bars represent non-significant changes

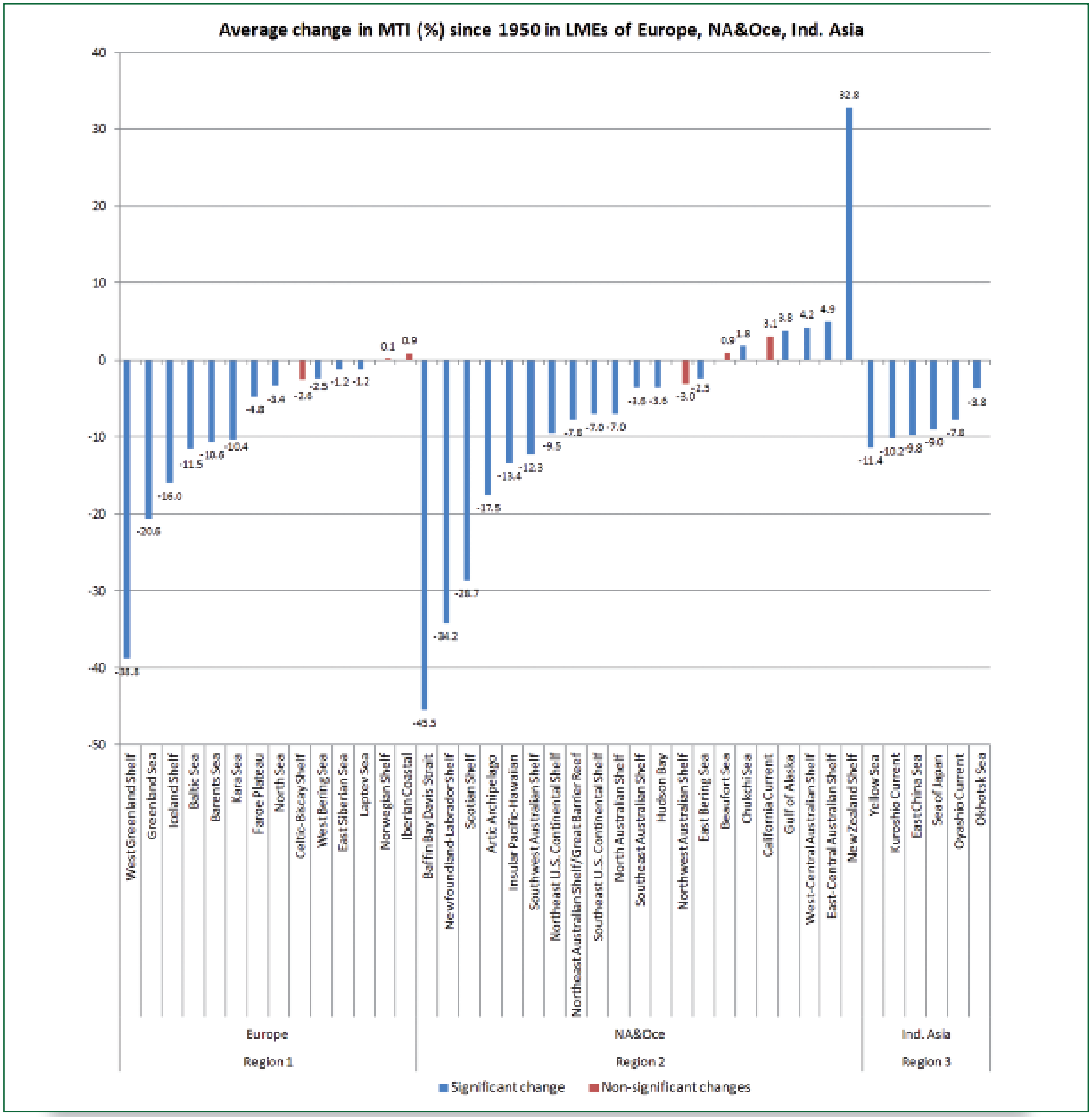
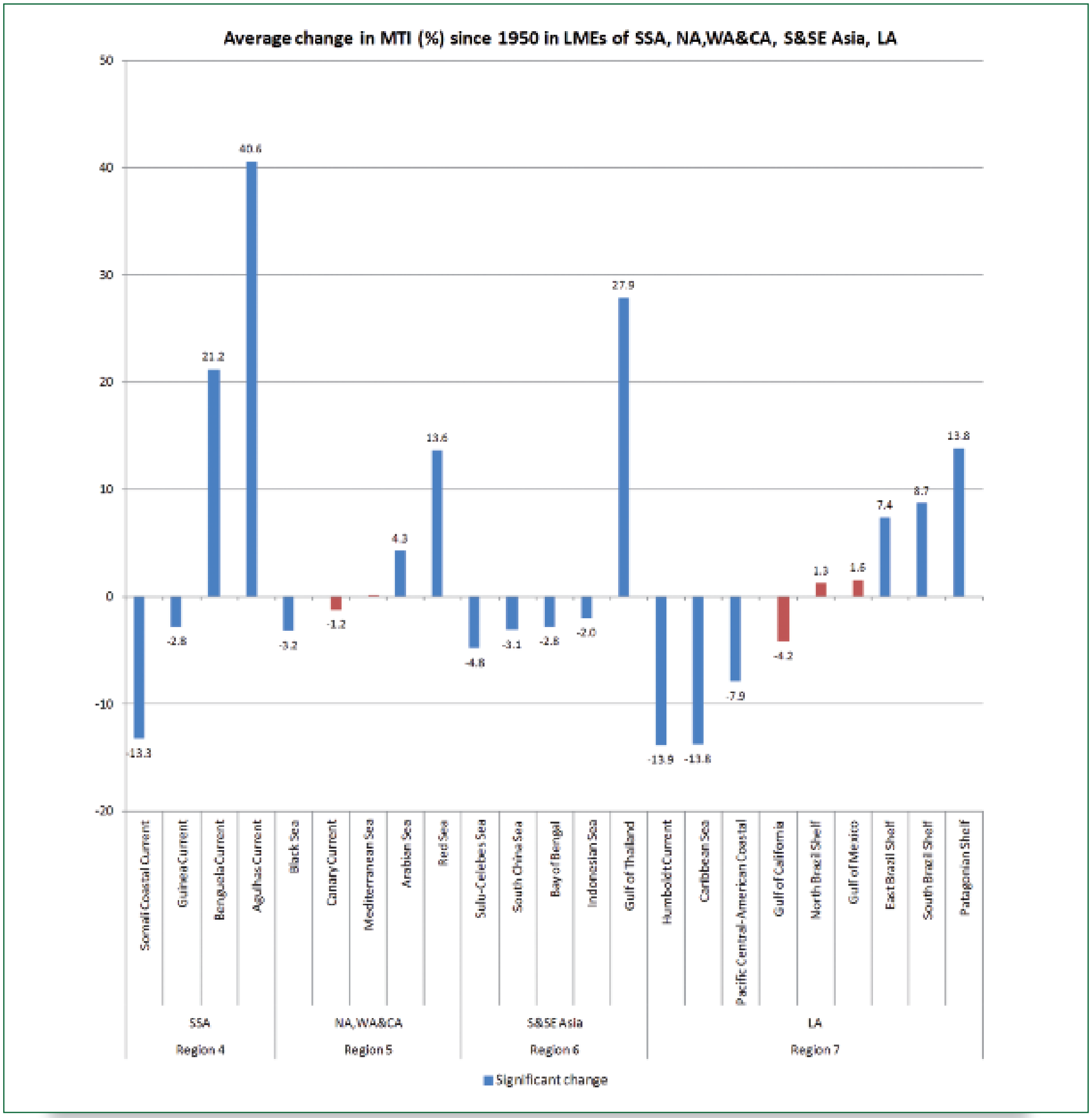


Figure 38: Average change in mean trophic level since 1950 in selected Large Marine Ecosystems (LMEs) of SSA, NA, WA&CA, S&SE Asia, and LA. The percent change is indicated above the bars, blue bars represent significant changes, while red bars represent non-significant changes



Economic assessment

Method

The economic cost of food wastage is based on 2009 producer prices, taken from FAO's PriceSTAT database 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. This dataset provides a large vision of producer prices distribution at the world level. The data available are the prices at the agricultural phase (farmgate, expressed in USD/tonne). Due to the lack of data on prices, economic costs for fish and seafood were not accounted for.

Results overview

Besides its environmental cost, food wastage also represents a loss of economic value. On a global scale, the economic cost, based on 2009 producer prices, of the overall amount of food wastage in year 2007 totalled about USD 750 billion. This is approximately the GDP of Turkey or Switzerland in 2011[15].

Figure 39 shows vegetables as the major contributors to the economic cost of food lost and wasted (23 percent of total cost), followed by meat (21 percent), fruits (19 percent) and cereals (18 percent). Meat's contribution to the total cost of food wastage is clearly driven by its high producer cost per kilogram. Indeed, meat accounts for about 4 percent[16] of total food wastage, but for about 20 percent of the total economic costs of this wastage. On the other hand, cereals 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 40 illustrates that food wastage volumes and economic cost have relatively comparable regional distribution. The major contributors are Ind. Asia (31 percent of total) and S&SE Asia (18 percent), the two regions that are also the largest contributors to food wastage volumes. However, these values are very low estimates, especially in high-income countries, as they only integrate producer prices.

15 UNStats, GDP of countries. Available at: http://unstats.un.org/unsd/snaama/Introduction.asp
16 Excluding fish and seafood in order to allow a comparison on the same grounds.

Figure 39: Contribution of each commodity to food wastage and economic cost

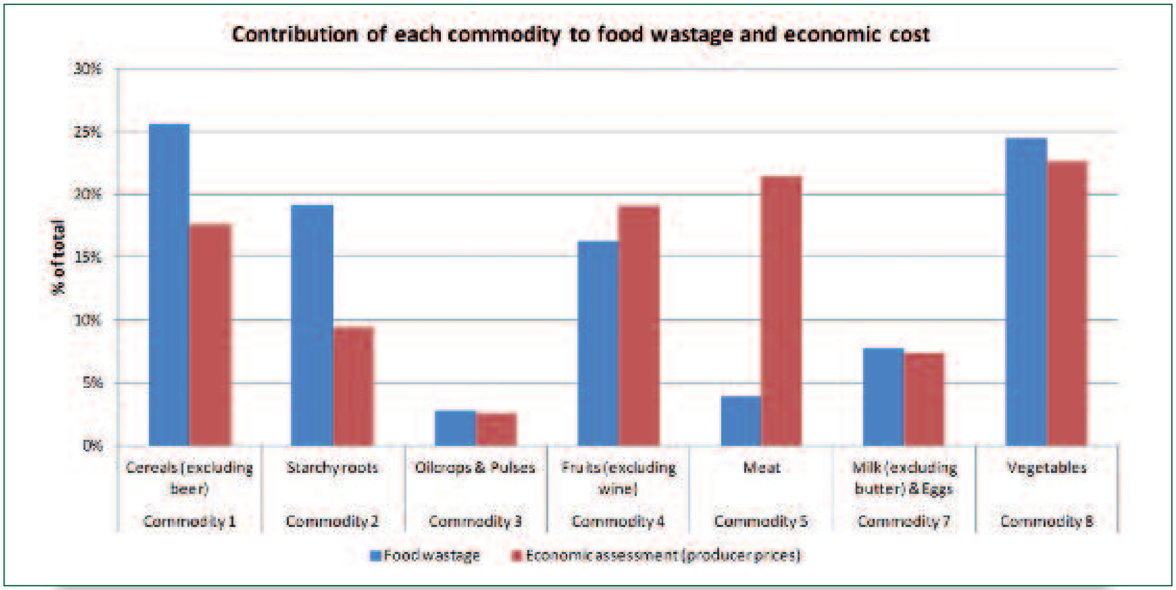
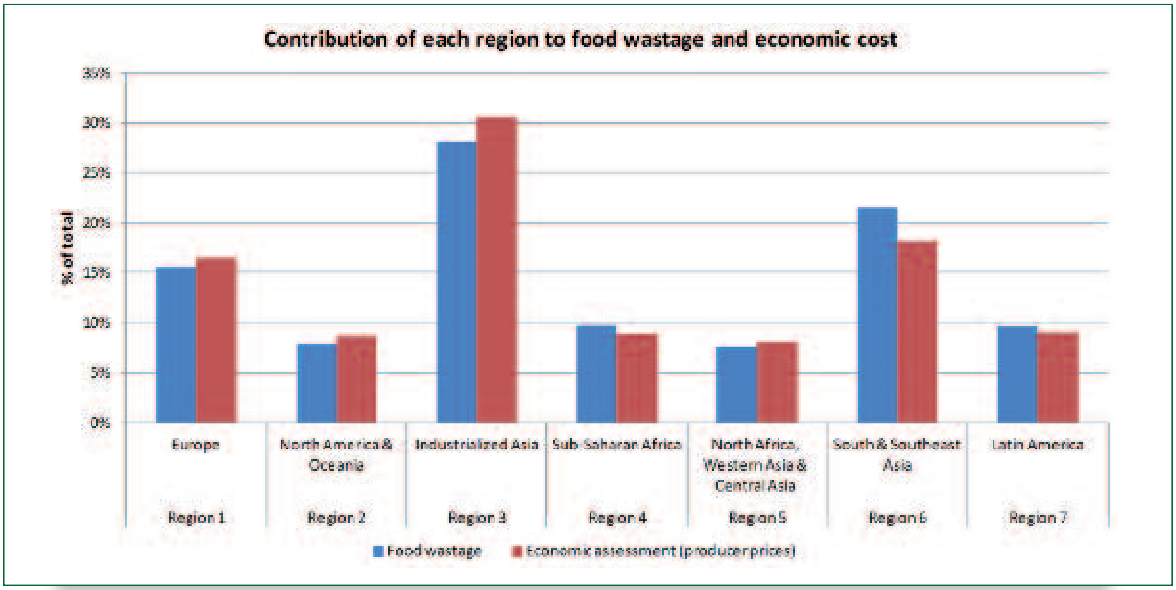


Figure 40: Contribution of each region to food wastage and economic cost



Cross-analysis and key findings

Table 3 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 here with their contribution to total food wastage[17].

Table 3: Cross-analysis of all environmental components, by "Region*Commodity" pairs.
In each column: contribution to total in percent and ranking from 1 to 10 (or 5) in bold

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%**	

17 Excluding fish and seafood, in order to allow a comparison on the same grounds. This is why percentages presented here for food wastage volumes and carbon are not exactly similar to those presented in Figure 14.

While from an environmental assessment perspective, combining environmental impacts to define a ranking of hotspots is precarious, it is nevertheless possible to distinguish a number of key findings, as follows:

- Cereal wastage in Asia emerges as a significant environmental hotspot, with major impacts on carbon, blue water and arable land. The relative importance of rice is underlined, given its high carbon intensity, combined with high levels of wastage. While cereal wastage is similar in Ind. Asia and S&SE Asia, the overall carbon footprint is higher in the former, as more cereals are wasted at the consumption phase. However, higher yields for rice and wheat result in a lower water footprint and lower land occupation in Ind. Asia: less land is being used for the same level of production. This echoes a broadly recognizable global pattern: high efficiency and high consumer level waste in middle- and high-income regions versus lower production efficiency and lower consumer level waste in low-income regions. The main contributing crops in this hotspot identification are rice and wheat. Rice emerges as an important element, with high carbon intensity and high levels of wastage. Rice crops emit CH_4 because of the decomposition of organic matter in flooded paddy fields and thus, has higher impact factors compared to other cereals. In terms of land occupation and water footprints, the impacts of rice and wheat are more similar. It can be noted that India and China are the major contributors of the water footprint of cereals in their respective regions.
- Meat has high impacts in terms of land occupation and carbon footprint, making it a major environmental hotspot, although wastage volumes in all regions are comparatively low. Meat is a carbon hotspot in high-income regions and Latin America. In absolute terms, more meat is produced, consumed and wasted in high-income regions (in particular at consumption phase) and Latin America compared with low-income regions. High-income regions and Latin America account for 80 percent of meat wastage. Regarding land occupation, the observed variability across regions for the contribution of arable or non-arable land is due to differences in production systems. This can include composition of feeding rations and amount of land required to produce the constituents of the ration.
- Fruit wastage emerges as a blue water hotspot in Asia, Latin America and Europe, but it is linked more to food wastage volumes than to the blue water intensity of the commodity. Due to data limitations, FAOSTAT identifies a particularly voluminous category in its Food Balance Sheets as "other fruits", which prevents detailing this hotspot by key crop.
- The carbon footprint of vegetables singles them out as a hotspot in Ind. Asia, Europe, and S&SE Asia, mainly due to large food wastage volumes. Nevertheless, some differences in terms of carbon intensity can be seen 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 is grown in heated greenhouses. It can be noted that some assumptions had to be made on these aspects.
- Starchy roots, although experiencing high volumes of wastage in SSA, Europe and Ind. Asia, never appear 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.

Potential improvement areas

Food wastage percentage

This study quantifies food wastage volumes by applying waste percentages to Food Balance Sheets data. These percentages of food lost and wasted have been gathered based on a thorough literature search, carried-out for the FAO (2011) study. The authors also had to make a number of assumptions for remaining data gaps, most notably for low-income regions. To date, no database consolidates worldwide statistics on food wastage which would provide harmonized datasets for analysis. The prerequisite for developing such a global tool is to have harmonized definitions of the major concepts linked to food loss and waste.

Quantifications of environmental impacts

Due to a lack of data or other methodological constraints, a number of assumptions had to be made to quantify environmental impacts. In some cases, certain aspects of the environmental footprint could not be taken into account, such as land occupation and water footprint relating to non-agricultural phases. All these aspects offer room for improvement. In particular, priority should be given in further research to the integration of land use change in carbon footprint accounting. Moreover, 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 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 life-cycle analysis tools, or multiregional input-output approaches.

Economic assessment

The economic component of this study is a first step that calls for further research to quantify the costs along the food supply chain. In addition, the environmental cost of lost natural resources due to food wastage could be taken into account in future work. For instance, the blue water wasted in a given year might not have the same economic, social and/or environmental cost in future years.

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ISBN 978-92-5-107752-8

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I3347E/1/06.13