



DRIVEN TO WASTE:
THE GLOBAL IMPACT OF FOOD
LOSS AND WASTE ON FARMS

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Executive summary

The project comprised four main stages:

- I. estimation of global farm stage food losses,
- II. analysis of the environmental, social and economic impacts of farm stage losses,
- III. development of case studies to sense check global farm stage food loss estimates, and
- IV. exploration of food loss drivers and mitigating actions.

The main findings were:

- Total farm stage losses were found to be more extensive than previously estimated, with significant implications for the identification of global food loss hotspots and prioritisation of mitigating actions.
- 15% of global agricultural production is lost on-farm, at harvest or immediately after harvest, however the analysis also explores the uncertainty in the application of standard food loss definitions to the farm stage.
- The concluding sections raise the issue of how appropriate these definition are as indicators of farm stage losses as a component of the United Nations Sustainable Development Goal 12.3, to halve per capita food loss and waste by 2030 .
- Total annual losses were estimated to be 1.2 billion tonnes, with an equivalent farm output value of \$370 billion per annum.
- Significant farm stage losses were apparent across a wide range of commodities and hot spots were identified in both higher- and middle-income countries and low-income countries.
- Higher- and middle-income countries, with 37% of the global population, were responsible for 58% of global harvest losses, conversely low-income countries were responsible for 54% of farm stage post-harvest losses.
- These findings challenge the long-established assumption that farm stage losses are a more significant issue within low-income countries,ⁱ and also raise concerns about the appropriateness of SDG 12.3 food waste definitions at farm stage, particularly when applied to higher- and middle-income countries.

The assessment of global environmental impacts of farm stage food losses included greenhouse gas emissions (as CO₂ eq.), eutrophication and acidification potentials, water abstraction and land use. The results confirm and exceed the scale of impacts found in other research, such as the widely quoted results from the FAO's Food Wastage Footprint report.ⁱⁱ

- The annual carbon footprint of farm stage food losses amounted to 2.2 gigatonnes CO₂ eq., approximately 16% of total global emissions from agricultural production.
- The most impactful commodity group was found to be meat and meat products (including dairy), where losses accounted for 40% of CO₂ eq. emissions associated with global farm stage food losses, yet this commodity group accounted for only 13% of food loss tonnage. In addition, this commodity group was associated with a high proportion of global food losses' acidification and eutrophication potentials.
- The land area used to produce lost food was estimated to be 4.4 million km², equivalent to a land area larger than the Indian sub-continent. Over half of this was associated with losses associated with meat and animal products (including dairy).
- Water withdrawals for agricultural production associated with global food losses were estimated to be 760 km³ of freshwater, equivalent to over 5 weeks' flow from the Amazon River into the Atlantic Ocean. Farm losses of cereals and pulses had the highest global water footprint, with hot spots associated with losses from rice production in South and Southeast Asia and wheat production in North America and Asia.

A cross-sectional sample of 10 commodity/ region case studies was conducted through stakeholder interviews and literature reviews to explore underlying issues at a greater degree of resolution. These included data quality/ uncertainty, socio-economic and environmental impacts and the specifics of key drivers and potential mitigating actions.

Apart from the lack of data points based on direct field measurements underpinning global food loss estimates, a major uncertainty identified in half of the case studies related to inconsistent food loss definitions. Formal food loss definitions developed to clarify the SDG 12.3 specify different 'destinations' of food losses to exclude from food loss definitions, such as feeding to livestock. However, few studies at the agricultural stage have been conducted with these distinctions in mind and this approach is less readily applied in the context of farms and fisheries and the working definitions of food loss and waste applied by those collecting data within the sector.

A classification of food loss drivers was built from evidence collected from the 10 global case studies. These were sub-divided into direct and indirect factors, recognising that most of the literature on farm stage losses has tended to focus only on technological drivers, such as those relating to harvesting machinery or storage systems.

Direct drivers included i) biological and environmental factors, ii) agronomy, animal husbandry and fishing practices and iii) factors linked to technology and infrastructure.

Indirect drivers included iv) market structure, governance, and investment v) human factors, including cultural practices and labour.

Limited research has been conducted on the effectiveness of different interventions to reduce losses; however, relative prioritisation of different actions was carried out using a qualitative scoring system based on evidence collated from the global case studies.

- All case studies involved actions to address biological and environmental drivers of food loss, with no distinction between case studies in high-, middle- or low-income countries.
- In less mechanised agricultural systems identified in case studies from low-income countries, there was a need to provide more holistic solutions that balance actions that address biological/ environmental drivers with initiatives covering combinations of direct and indirect actions, including access to markets and support to improve agricultural practices, with no single intervention likely to succeed unless also addressing other factors in combination.

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1 Objectives of the study

Objective 1: Collate food loss data from various regions across the globe to understand where food losses are occurring, and which commodity and country hot spots exist across both developed and developing economies. Utilise existing literature to map out these hot spots, data availability and measurement/data collection tools being used.

- Findings in Section 2: Scale of global farm stage food losses

Objective 2: Using the data gathered, analyse the environmental, social and economic impacts resulting from the losses. Where possible estimate environmental impacts e.g. GHG emissions, land use/land conversion, water use, excess agri-chemical use etc. at sub-national, national and global scales. Furthermore, seek to provide a sense of the scale of the social impacts in terms of potential lost livelihoods, economic burden and impacts on food security.

- Findings in Section 3: Environmental and socio-economic impacts

Objective 3: Conduct a series of interviews with key stakeholder groups (companies in different sectors, countries, NGOs, blocks like the EU, farmers, policy makers etc) to ascertain views on definitions of loss and waste, ground-truth some waste figures, understand the drivers for losses and identify possible solutions to minimise them.

- Findings in Section 4: Global food loss case studies

Objective 4: Summarise the key reasons for the losses occurring and propose a range of mitigation actions that can be adopted by different actors. Where possible, provide further detail on specific mitigation actions relevant to specific crop/country case studies.

- Findings in Section 5: Global food loss drivers and mitigating actions

2 Scale of global farm stage food losses

2.1 Introduction

Primary food production has been identified as a major hotspot for global food losses but has not received the same attention as food losses or waste at other points in the supply chain (WRI 2019).ⁱⁱⁱ There are many reasons for this: not least the limitations of data quality (particularly the lack of in-field measurement, discussed further in 5.1.2 and in Figure 44),^{iv} inconsistencies in data coverage and the mismatch between standard food loss definitions and differing food loss definitions applied by those conducting studies of losses at the primary production stage..

Nevertheless, it is possible to gain insights from the systematic analysis of available data (FAO 2019)^v and it is now a decade since global estimates were published that included harvest as well as post-harvest losses (FAO 2011).^{vi} The current study focuses solely on the agricultural production stage and has developed an approach designed to make the most effective use of available data, whilst also highlighting where data deficiencies limit the reliability of estimates and hotspot identification.

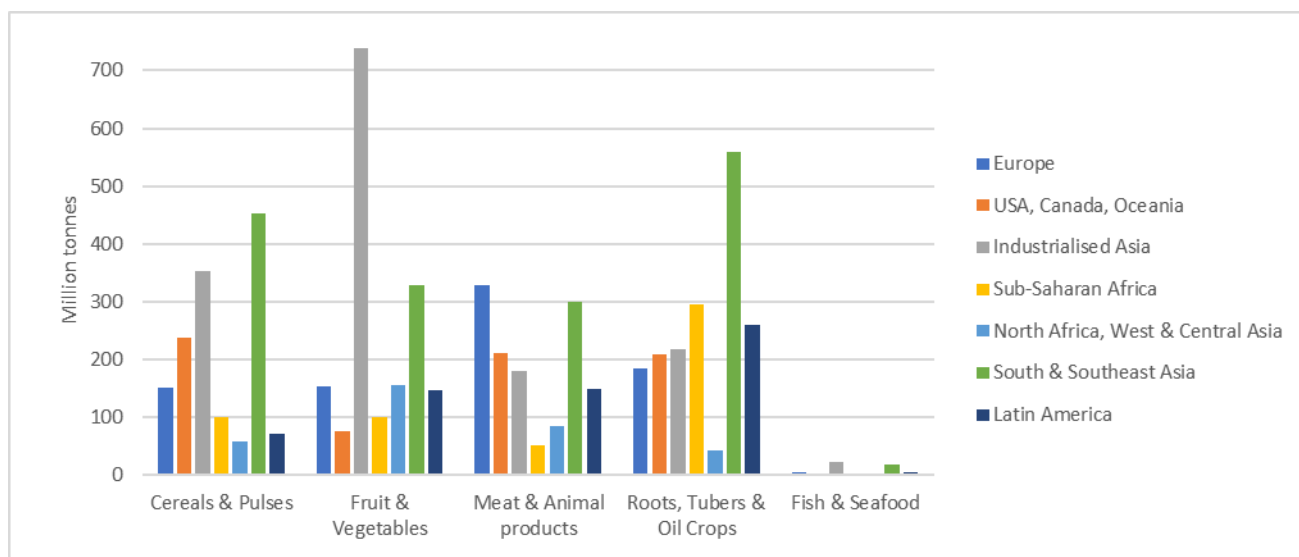
The first stage of the work identified the scale and global profile of farm stage food losses using the methodology set out in Appendix 5.1.2. The compiled loss data for harvest and post-harvest stages provided inputs into the socio-economic and environmental modelling (Sections 3 and 4) and were used to inform the selection of global case studies for further analysis (Section 4). Finally, a synthesis of key evidence relating to farm stage food loss drivers was drawn from the evidence collated in preceding stages (Section 5), linking to key mitigating actions to be considered further by the WWF/ Tesco Partnership.

2.2 Global food production

As a starting point, the analysis compiled global food production statistics from FAOSTAT data for scaling-up food loss estimates across different global regions (defined in A3) and for each commodity group (defined in A4).

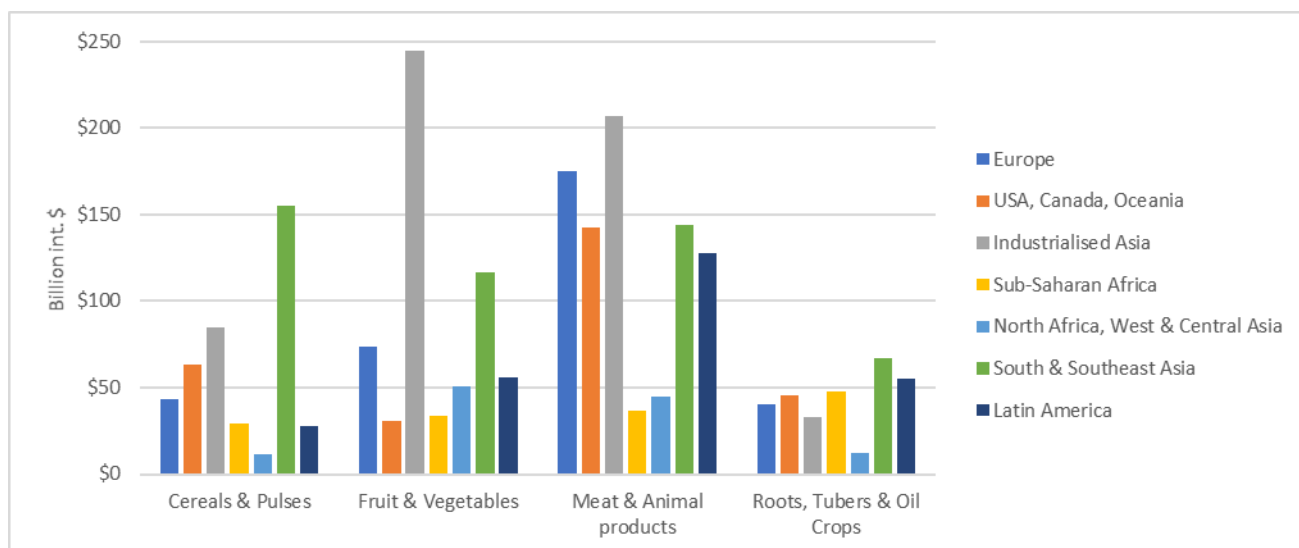
Figure 1 shows the pattern of production across the main commodity groups, excluding all elements that are not used for human food supply (such as grain fed to animals or crops processed into biofuels). A highly miscellaneous additional category of 'other' food commodities has not been shown in the charts but has been included in the analysis.

Figure 1: Production volumes by commodity and region (million tonnes) [Source FAOSTAT]



Fruit and vegetables, and roots, tubers and oil crops are the two largest categories for global production volumes (at over 1,700 million tonnes each) but the higher prices of animal proteins means meat and animal products (\$878,000 million) replace roots, tubers and oil crops (\$301,000 million) as the top category for production values (Figure 2). The fish and seafood category was excluded from production values as it was not included within FAOSTAT production value data.

Figure 2: Production value by commodity and region (billion Int. \$) [Source: FAOSTAT]



2.3 Scale of global farm stage losses

Global farm stage losses, including harvest losses and post-harvest losses, were estimated to be 1.2 billion tonnes per year, equivalent to 15.3% of global food production (including harvest losses), split between 8.3% of production lost at or around harvest and 7.0% during farm stage post-harvest activities. These estimates were based on production volumes adjusted to include the estimated

quantities lost in the field. This component of food losses is not included in the FAOSTAT production statistics, which are based on harvest weights.

The most recently published assessment of global food losses (FAO 2019)^{vii} estimate that 14% of global food production is lost across all post-harvest stages, from farm up to but not including the retail stage. This estimate excludes harvest losses (e.g. anything left in the field) as it is based on the weight of production of the harvested crops. In addition, it is not directly comparable to our 7.0% post-harvest loss estimate, as it includes post-harvest losses beyond the farm gate. These differences are summarised in Table 1. When estimates from the current study are instead based on total harvested weight the loss rate from post-harvest activities becomes 7.6% and the equivalent of 16.6% losses at farm stage if harvest losses are also included on the same basis. Although it is not possible to combine these different estimates with the additional post-farm gate elements included within the FAO 2019 estimates, due to differences in methodology, the data suggest that between 20-25% of global production may be lost across primary production and supply chain stages, up to but not including retail. Given the prevalence of self-reporting rather than direct measurement within underlying farm stage studies (5.1.2 and in Figure 44), these loss rates are likely to be higher due to the tendency of questionnaires and indirect measurement techniques to under-estimate actual harvest and post-harvest losses.

These estimates generally support the findings of the World Resources Institute’s 2019 assessment^{viii} that identified food production and harvest as global food loss hotspots, with on-farm losses significant across a range of settings, including within the agricultural systems of higher- and middle-income countries (see country classification applied in this report, described in A3).

Table 1: Comparison of global food production % loss estimates: current study compared with FAO 2019 Food Loss Index estimates; food loss as % of agricultural production and as % total harvest weight

	Current study: Food loss as % of agricultural production Including field losses and harvested weight	Current study: Food loss as % of harvested weight	FAO 2019 Food Loss Index Farm/ fishery to retail
Harvest losses	8.3%	9.0%	Not included in FAO 2019 assessment
Post-harvest losses (PHL)	On-farm PHL only 7.0%	On-farm PHL only 7.6%	On-farm + supply chain PHL 14%
Total	15.3% [excluding supply chain PHL]	16.6% [excluding supply chain PHL]	14% [excluding farm stage harvest losses]

More detail of the scale of farm stage losses is provided in terms of total tonnes (Figure 3), as a proportion of agricultural production (Figure 4 and Figure 5) and as per capita losses (Figure 6). Figure 3 also indicates the uneven availability of food loss data points across global regions, with two regions,

Industrialised Asia and South and Southeast Asia, accounting for over 80% of usable data included in the review. Appendix 5.1.2 explains the data selection process, food waste definitions and the interpretation of available datasets. Data gaps and the difficulty of extrapolating available data to wider regions and commodities posed particular challenges to the scaling of production of estimates. All data were weighted using FAOSTAT production tonnage at the most granular level possible within commodity groups and global regions.

Higher- and middle- income countries of Europe, North America and industrialised Asia, with 37% of the global population, contribute 58% of global harvest losses (368 million tonnes). Conversely, low-income countries with 63% of the population have a 54% share of global post-harvest harvest farm stage losses (291 million tonnes). The latter mainly relate to losses arising in Sub-Saharan Africa and South and Southeast Asia. The cut-off between post-harvest operations at farm stage will differ across global regions, with more processing and sorting operations occurring at farm stage in lower-income countries, whereas a higher proportion of post-harvest losses in more affluent countries occurring in post-farm gate operations.

Figure 3: Food losses by stage and region (million tonnes) and indication of number

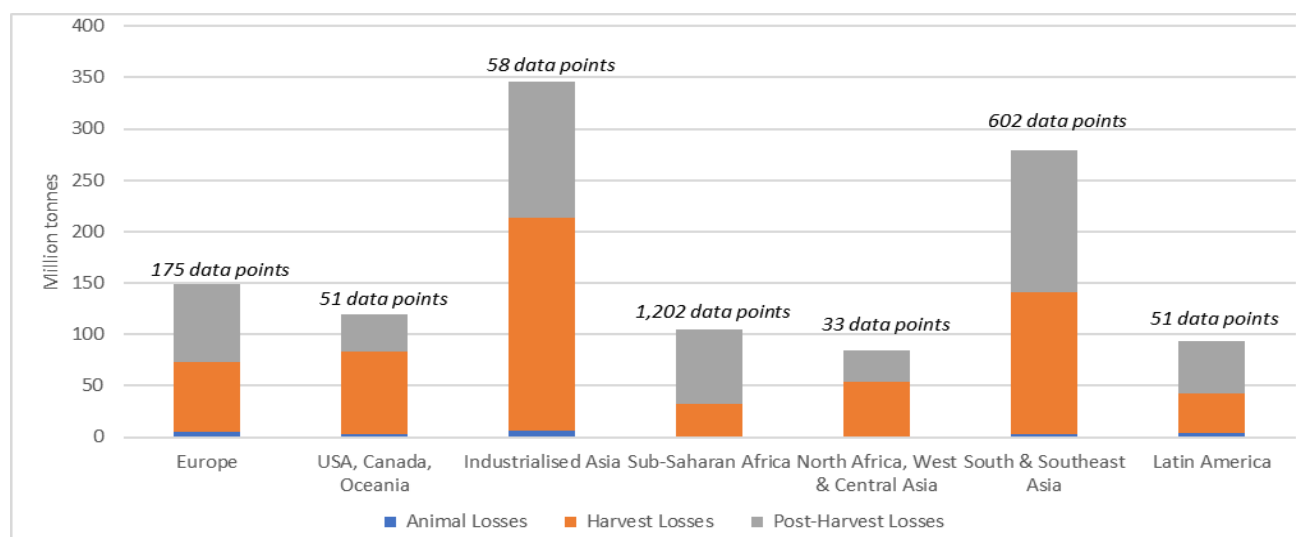


Figure 4: Farm stage food losses by region as % total food production

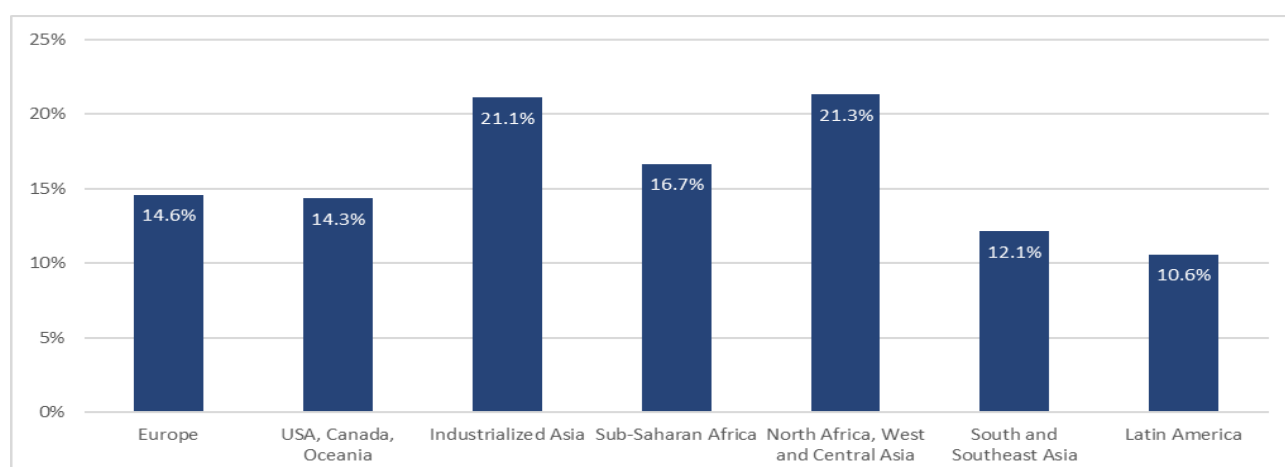
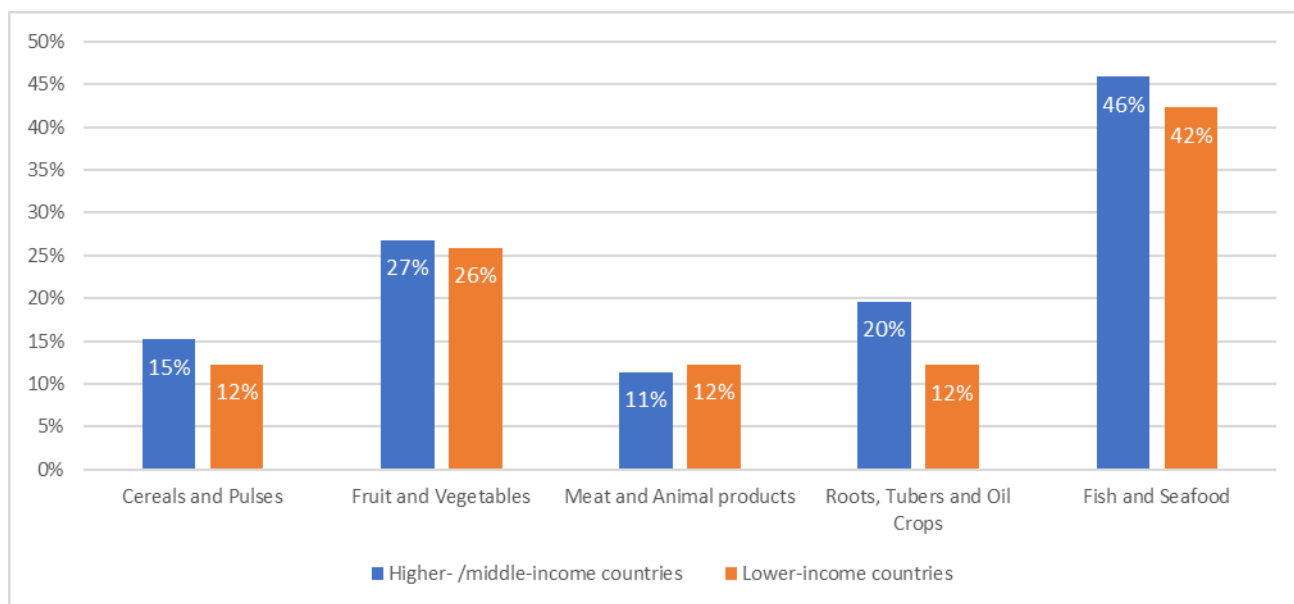


Figure 5: Farm stage food losses by commodity group as % total food production by higher- / mid- income versus lower-income countries



It is also important to note that in more industrialised countries the production of more perishable commodities per capita (fruit, vegetables, meat, dairy, fish) is approximately twice that of developing countries. This is one factor amongst many in explaining the variation in per capita farm stage losses by region (Figure 6), which are generally higher in more industrialised regions (200-300 kg/year) compared with developing countries (100-150 kg/year).

Figure 6: Per capita farm stage food losses by region (kg/year)

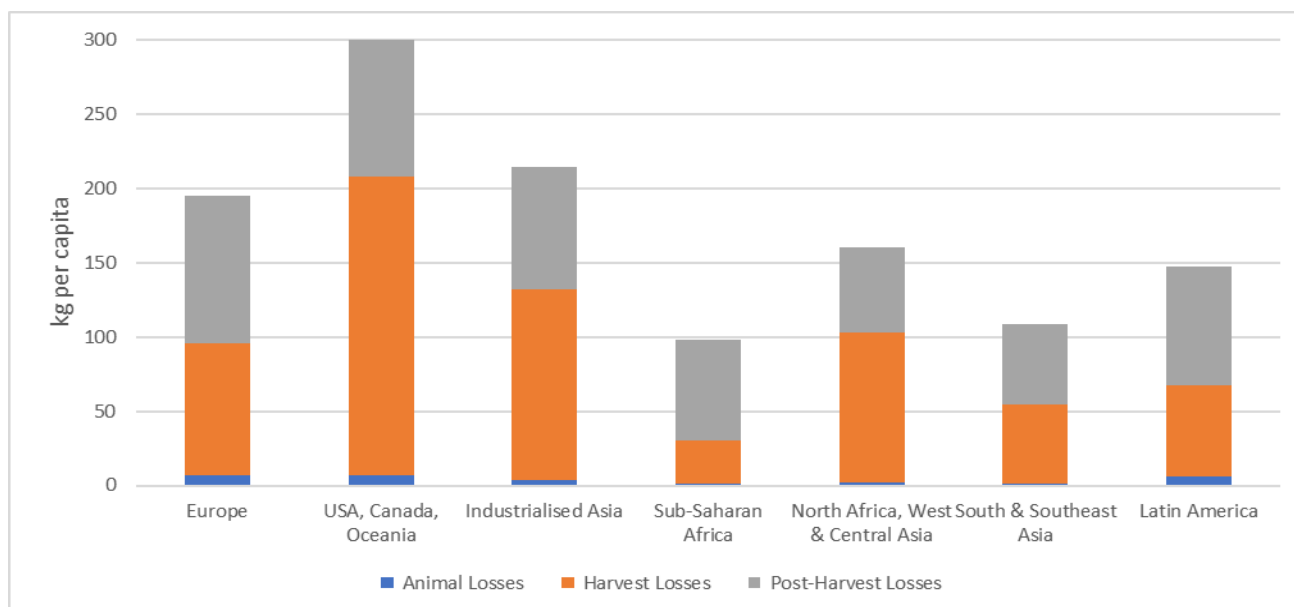


Figure 7 and Figure 8 display the same analysis split by commodity group and Figure 9 and Figure 10 focus on the lost economic value in terms of farm gate prices.

Key results are the significant scale of 'fruit and vegetable' losses in Industrialised Asia (tonnes, kg per capita and value), the high value of 'meat and meat products' losses in Europe, North America/Oceania and Latin America.

Figure 7: Food Losses by commodity & region (million tonnes)

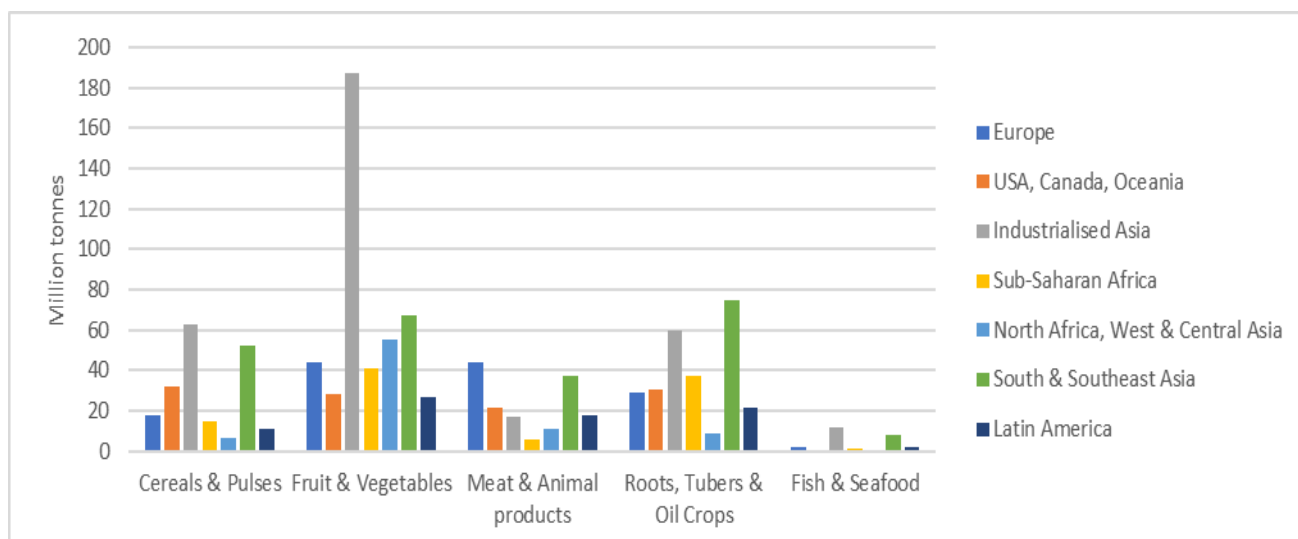
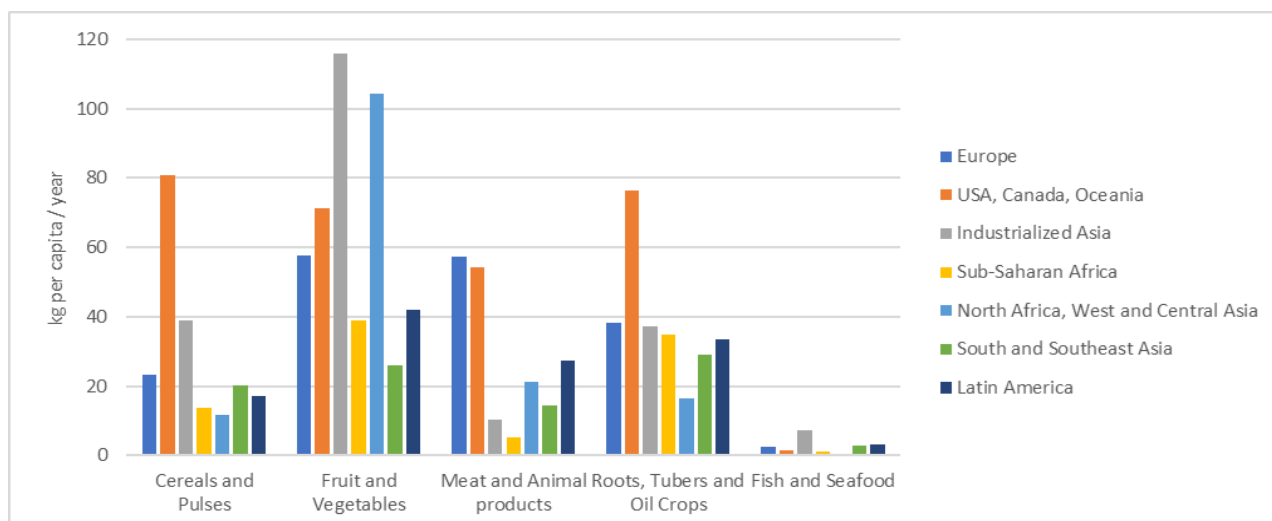


Figure 8: Per capita farm stage food losses by commodity & region



2.4 Lost value of food from global farm stage food losses

The total value of global food losses, based on output prices at farm gate (FAOSTAT Value of Agricultural Production)^x, is estimated to be \$370 billion. This is within the same ballpark as the \$930 billion reported for whole supply chain food losses by the FAO in 2014 ^x, considering that the latter included the higher added value of losses in the supply chain beyond the farm gate (e.g. retail and consumer stages). Both sets of estimates exclude those from fisheries, as these are not covered by FAOSTAT data.

More detailed analysis of food loss data is presented in Section 4 -Global food loss case studies for each of the five main food commodity groups to which the case studies relate.

Figure 9: Food Losses - value by commodity & region (billion Int. \$), excluding fisheries

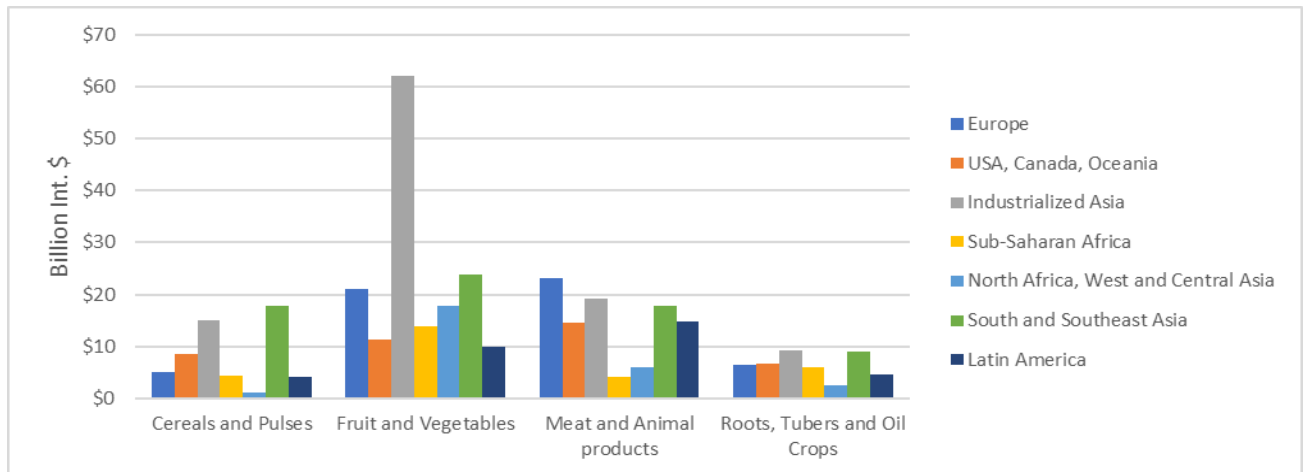
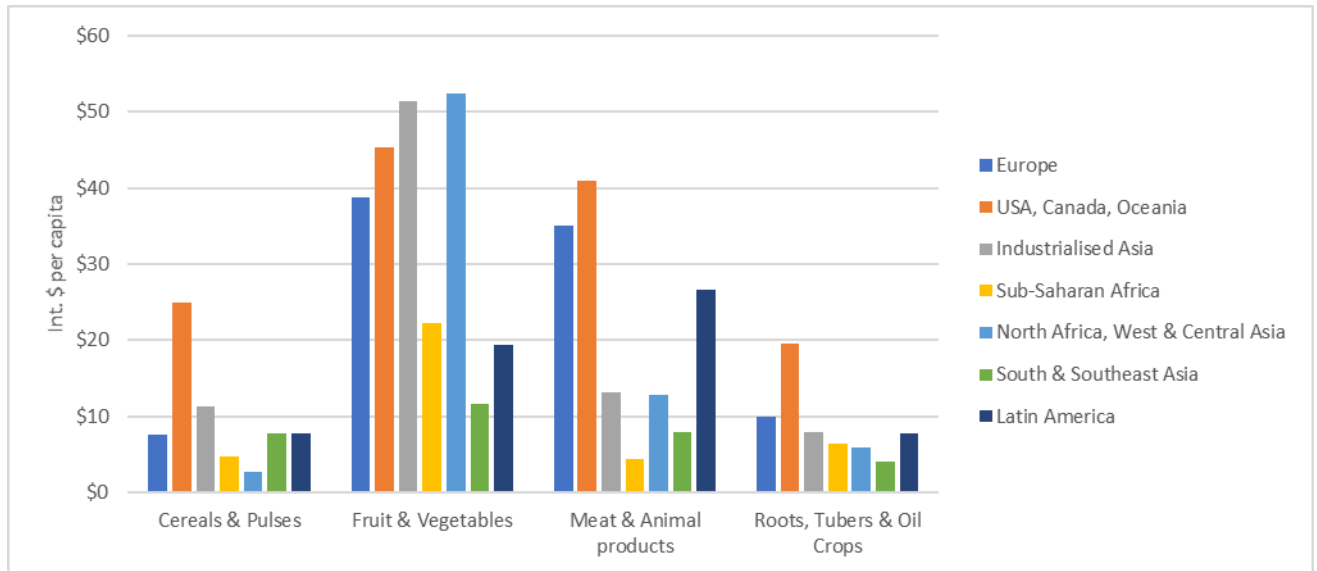


Figure 10: Food Losses- value per capita by commodity & region (Int. \$ per capita / year), excluding fisheries



3 Environmental and socio-economic impacts

Food production and associated losses is associated with a wide range of environmental impacts; our assessment covers greenhouse gas emissions, land-use, eutrophication potential, acidification potential and freshwater use. For each food commodity, the lifecycle impacts up to the farm gate (including production of capital goods and seed) have been included, based on the complete set of life cycle analyses taken from a meta-analysis study (J. Poore and T. Nemecek (2018)).^{xi} In the case of wild-caught fish, only the greenhouse gas emissions from fishing vessels have been included, through the lack of suitable LCA data covering other impacts.

Within this section of the report, each environmental impact is measured per kg of food production. This factor is multiplied by estimated farm level food losses to obtain overall food loss impacts for each food commodity and region. This is, broadly speaking, the additional impacts of food loss, or put another way – food going into the supply chain could increase by the level of the tonnages lost without creating additional environmental impacts at the farm level.

Further impacts are explored within Section 4, which focuses on 10 case study commodities /regions identified from the profiling of global food loss data. Here impacts are put in the context of related environmental indices from the Yale Environmental Performance Index and World Resources Institute Water Stress Index.

The social impacts of food production are wide-ranging and vary significantly within countries by crop type and between countries for the same crop types. The approach is therefore to look at the narrow social context in terms of poverty and malnutrition for key countries within the case study regions. Sustainable Development Goals SDG 1 (zero poverty) and SDG 2 (zero hunger) have been used for this and the outputs are described in Section 4. Details of the methodology used to model impacts can be found in A2.

Table 2 below shows a summary of the global environmental impacts of farm stage food waste explored in more detail in Sections 3.1 to 3.3.

Table 2: Summary of main global environmental impacts of farm stage food losses

Impact category		Units	Section
GHG emissions	2.2	Gt CO ₂ eq.	3.1.1
Acidification potential	12.0	Gt SO ₂ eq.,	3.1.2
Eutrophication potential	10.1	Gt of PO ₄ ³⁻ eq.	
Water use	760	km ³	3.2
Land use	442	Million ha	3.3

3.1 Environmental emissions associated with food losses

3.1.1 GHG emissions

The carbon footprint includes GHG emissions resulting from farm stage activities, including those associated with harvest, on-farm handling, processing, and storage, but before transportation off farm for any further processing, storage and distribution.

The calculated carbon footprint includes greenhouse gas emissions to air from CO₂, CH₄ and N₂O, expressed as CO₂ equivalent (CO₂ eq.).

The following emission sources were included:

Harvest emissions

- emissions associated with fertilizer and other inputs to production, feed, cultivation methods, crop residues left in the field and manure management, if applicable
- emissions generated through land use change from agricultural activities
- releases from carbon stock changes, taking account of different climatic areas and soil types

Post-harvest emissions

- emissions generated through drying, grading and storing.

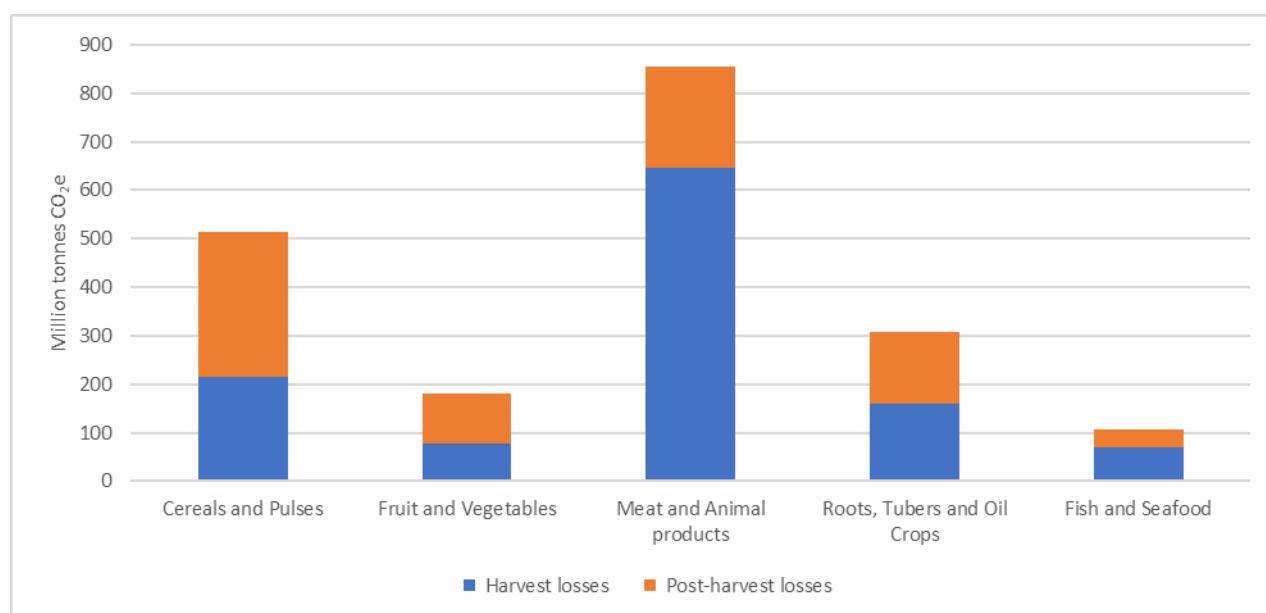
GHG emissions use the IPCC 100-year factors for climate-carbon feedbacks where possible.

For wild-caught fish the greenhouse gas impact comes from fuel used by fishing vessels as the LCA model did not include any wild fishing.

Results overview

The overall carbon footprint of farm stage food losses amounts to 2.2 gigatonnes CO₂ eq., which is illustrated in Figure 11. Of these, 55% came from harvest sources and 45% from post-harvest sources. For reference, the total GHG emissions from global agriculture inclusive of food loss and waste are estimated to be 13.7 gigatonnes/ year (based on Poore, J. and Nemecek, T. 2018).^{xii}

Figure 11: Estimated GHG emissions from food losses, million tonnes CO₂ eq. / year



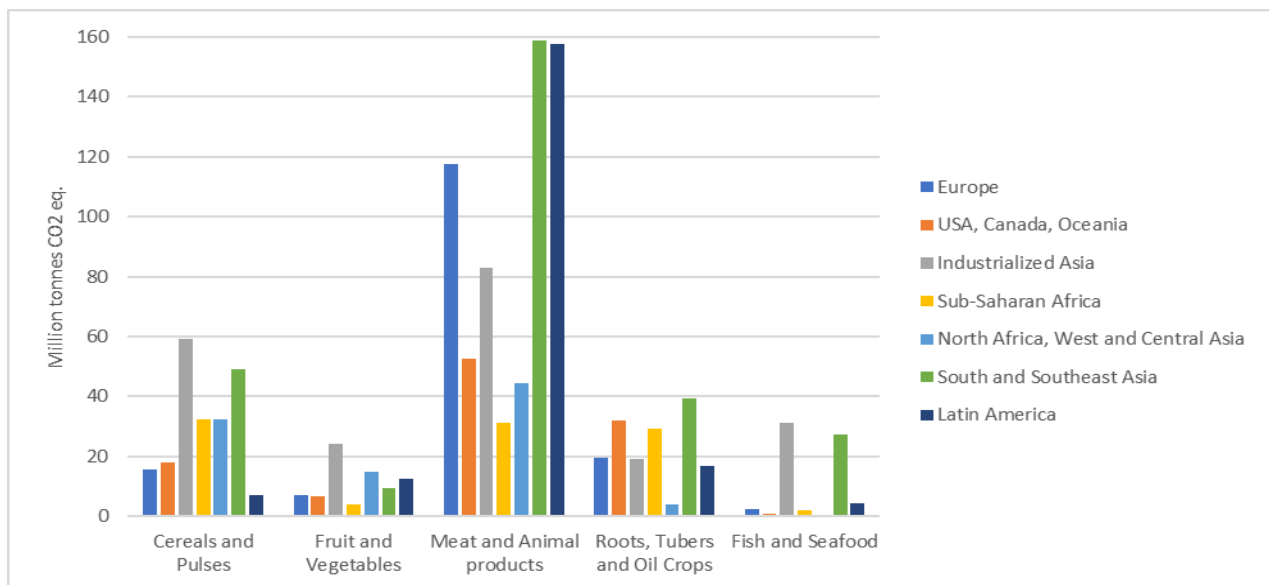
FAO’s Food wastage footprint report^{xiii} estimated a higher impact associated with whole supply chain food loss and waste at 4.4 gigatonnes. This estimate was based on the FAO 2011 assessment of food waste quantities^{xiv} which included all supply chain losses from harvest through to consumer food waste, including field losses..

One notable difference with the FAO report is that our modelling results in significantly lower greenhouse gas emissions from fruit and vegetables. This difference is explained by the underlying LCA model which indicates that fruit and vegetable production is generally much less carbon-intensive than other crops such as cereals. The LCA studies for fruit and vegetables do not always split emissions between stages but the main sources at the farm stage, where identifiable, are fuel use and embodied emissions in machinery with important but lesser contributions from nitrous oxide from fertiliser and crop residues. This contrasts with cereals, where the largest impacts come from nitrous oxide and, in the case of rice, methane emissions from rice paddies.

Meat and animal products form the largest share (856Mt, 40%) of CO₂ eq. emissions associated with food losses followed by cereals and pulses (515Mt, 24%) and roots, tubers and oil crops (307Mt, 14%), fruit and vegetables (182Mt, 8%) and ‘fish and seafood’ (107Mt, 5%). All charts exclude crops categorised as “other” – a miscellaneous group of commodities (including tea, coffee, sugars, tree nuts) that contribute a further 187Mt (9%) to total emissions, mostly from post-harvest activities (e.g. drying).

Figure 12 provides a breakdown of the carbon footprint of animal and harvest losses by region and commodity type. Meat and animal products from Europe, Asia and Latin America dominate followed by cereals and pulses in Asia.

Figure 12: GHG Emissions by commodity group & region – animal and harvest losses, million tonnes CO₂ eq. / year



The pattern of CO₂ eq. emissions from farm stage post-harvest losses (Figure 13) is very different to that from harvest and animal losses. Emissions associated with losses from cereals and pulses now dominate, with South/Southeast Asia (115Mt) and Sub-Saharan Africa (75Mt) contributing the most. Meat and animal products in South/Southeast Asia and Latin America and roots, tubers and oil crops tie for the next largest sources. The region contributing least overall to the post-harvest carbon footprint was the USA, Canada and Oceania, followed by Europe, which only shows high emissions for meat and animal products.

Figure 13: GHG Emissions by commodity group & region - post-harvest losses, million tonnes CO₂ eq. / year

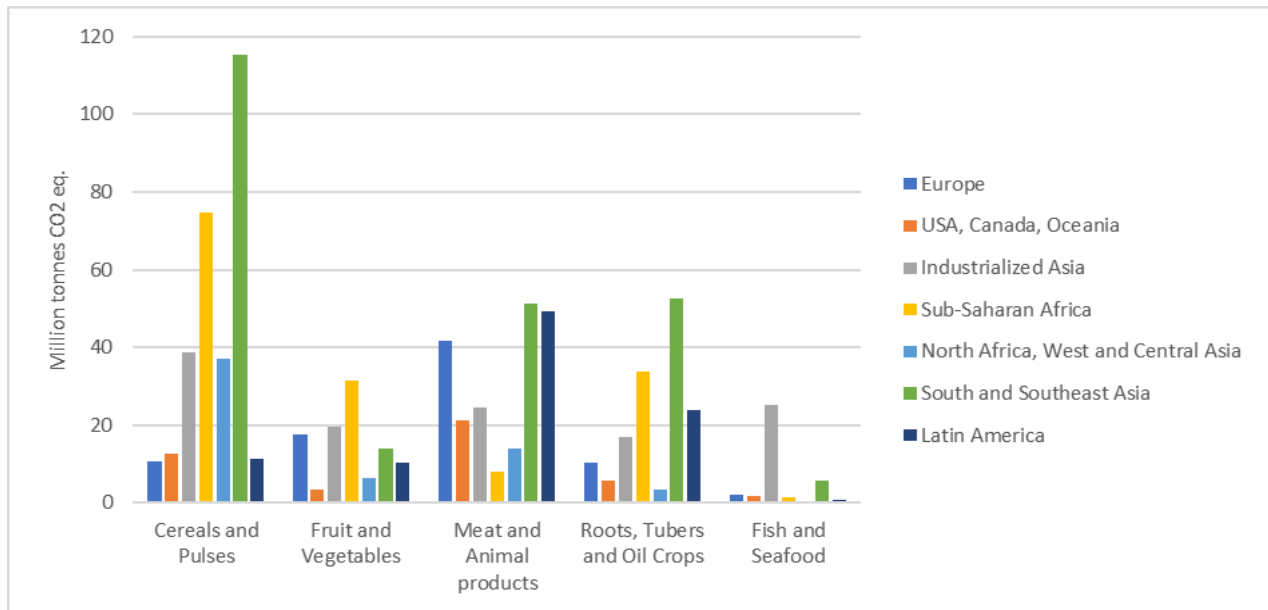


Figure 14 compares the proportion of total GHGs associated with food loss against the proportions of global food loss for each commodity group. Meat and animal products (40% emissions / 13% tonnage losses) and cereals and pulses (24% / 17%) have disproportionately high emissions compared with tonnage losses. This reflects the high greenhouse gas emissions associated with the production of meat and animal products. In contrast the low footprint of fruit and vegetables means that while they account for 38% of total tonnage losses, these only contribute 8% to the overall GHG emissions.

Figure 14: Percentage of food loss tonnage vs. associated % tonnes CO₂ eq. / year

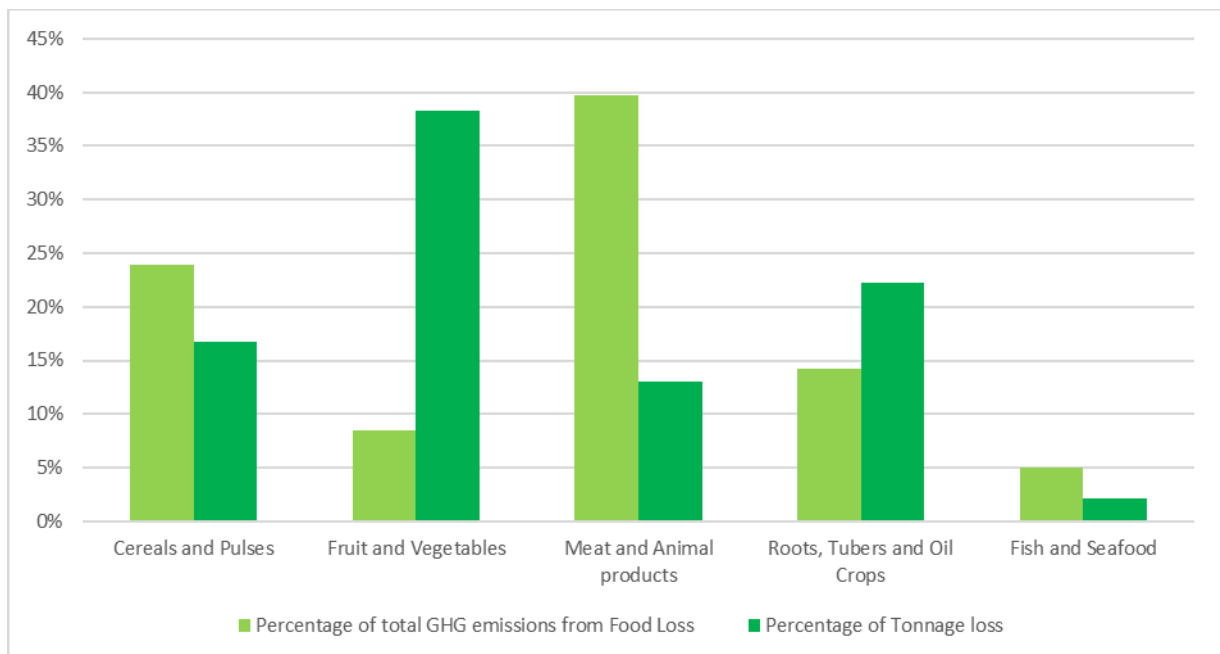
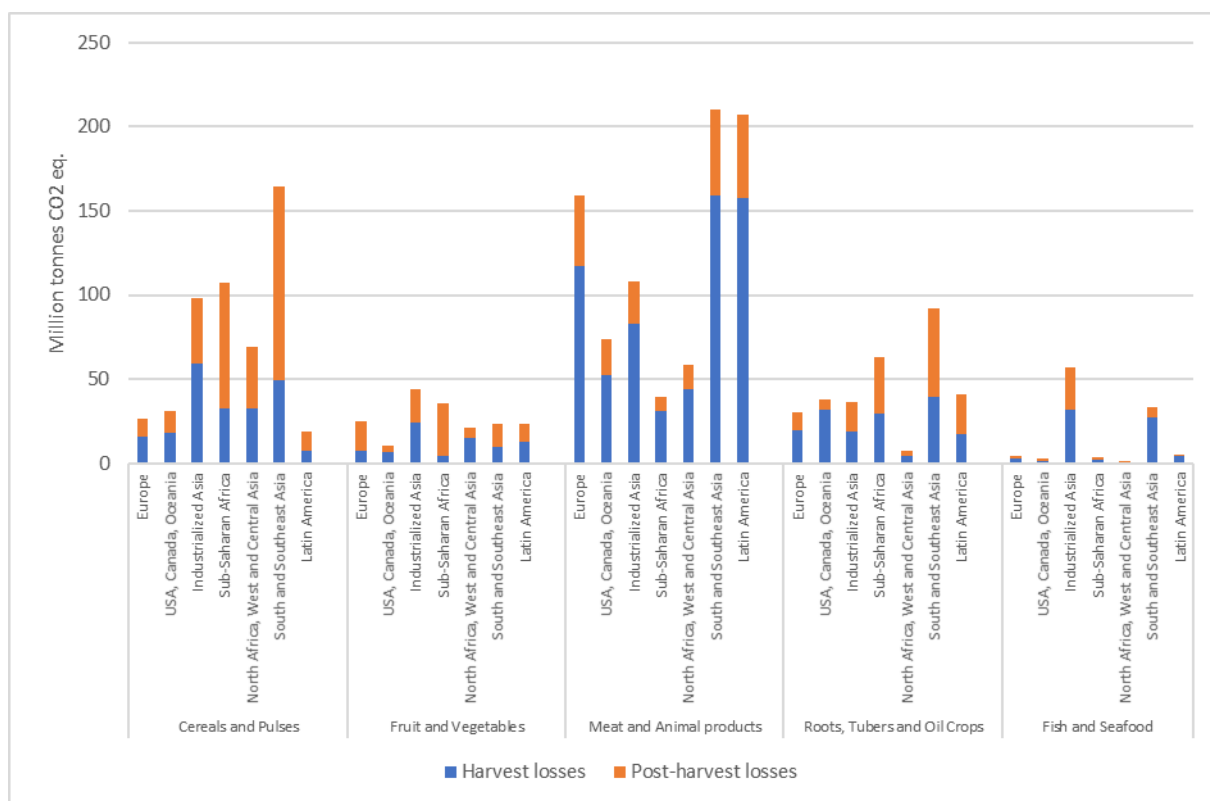


Figure 15 combines figures 12 and 13 and shows the contributions of commodity groups by region:

- Meat and animal products is the highest-ranking category in all regions apart from Sub-Saharan Africa and North Africa, West and Central Asia. In the latter two regions total CO₂ tonnes eq. is highest for ‘cereals and pulses.’
- Either fruit and vegetables or fish and seafood rank lowest within each region
- The highest post-harvest emissions associated with cereals and pulses are generated in South and Southeast Asia, followed by Sub-Saharan Africa and Industrialised Asia.
- Across all regions, livestock is associated with much higher GHG emissions due to animal losses (fallen stock and other losses) than due to post-harvest losses.

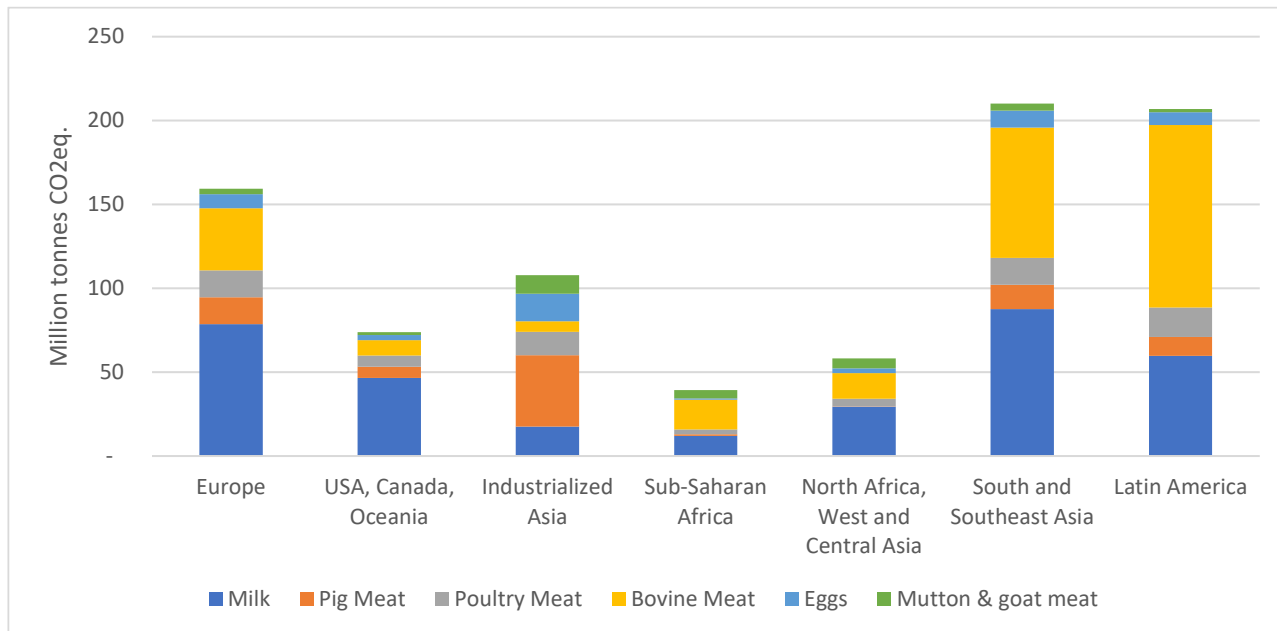
Figure 15: GHG emission by commodity group & region, million tonnes CO₂ eq. / year



Meat and animal products

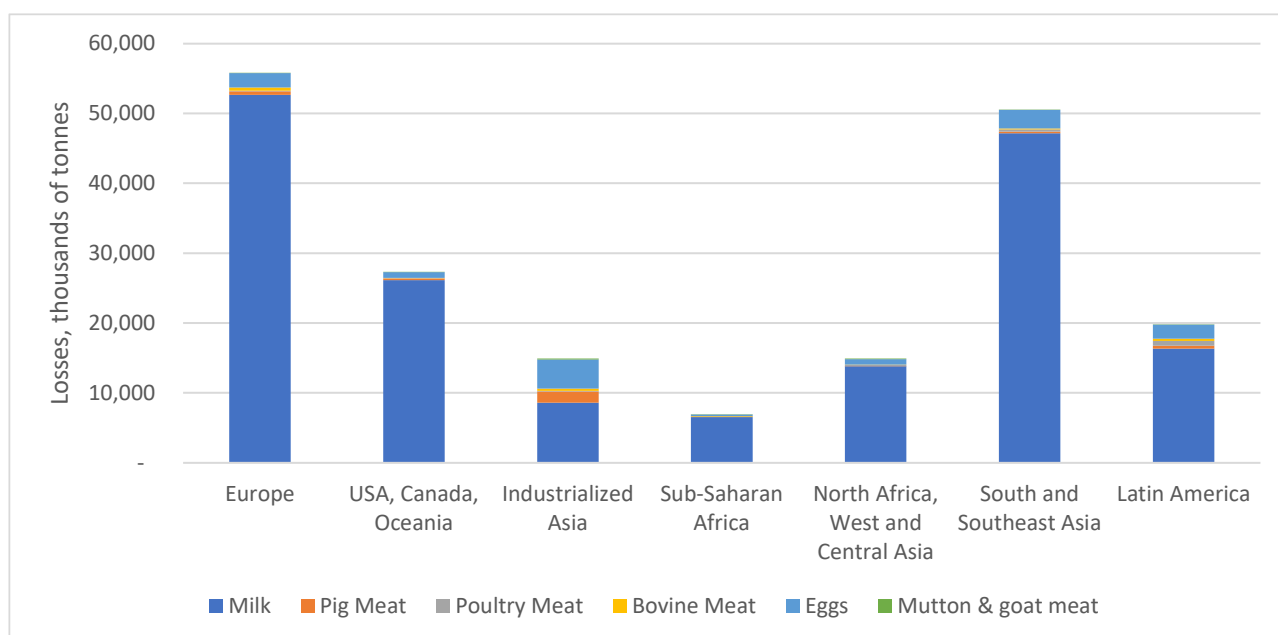
The high emissions from meat and animal products come mainly from enteric fermentation and manure management. The variation between regions mainly reflects the differences in absolute tonnages of food lost, which in turn reflect consumption patterns. See Figure 16 for a breakdown of emissions by region and product. Losses from milk form the largest share (39%) of emissions followed by bovine meat (32%). The relative contributions vary by region, with bovine meat dominating South and Southeast Asia and Latin America but pig meat dominating Industrialized Asia.

Figure 16: Emissions from meat and animal products by region



Milk’s contribution to emissions is due to the fact that it represents 90% of total losses (Figure 17) but has *relatively* low emissions per tonne. While bovine meat contributes about one-third of total emissions, it forms only 1 percent of food losses due to the fact that it has the highest emissions per tonne of any product in this report.

Figure 17: Meat and animal product food losses, thousands of tonnes



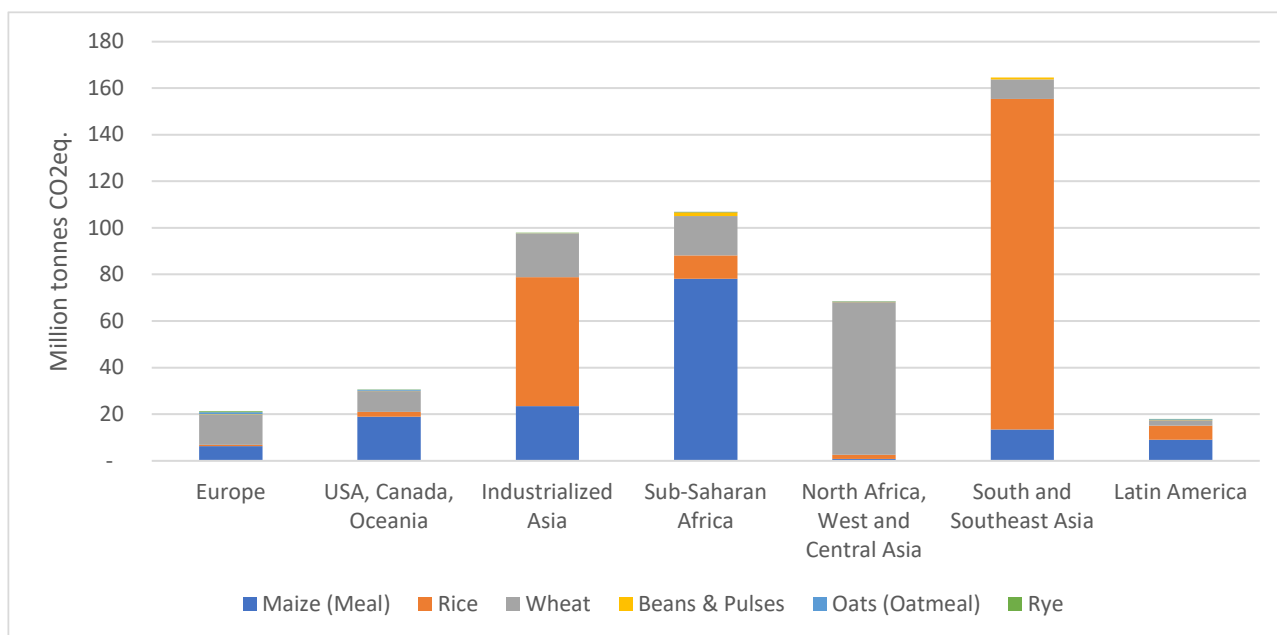
Some care must be taken in interpreting results between regions as the meat and animal products commodity group was not well represented in datasets available to this study, so some differences may reflect limitations in the data coverage (see Table 25: Number of farm stage studies included within final data compilation, by commodity (FAO 2011 classification) and region).

Cereals and Pulses

Cereals and pulses are the second highest contributor to greenhouse gas emissions. While the split of tonnage losses is roughly equal between harvest and post-harvest stages, the majority of emissions come from post-harvest losses as they already embody “harvest” emissions from growing and processing.

Rice contributes 43% of emissions from this category followed by maize (30%) and wheat (26%) – see Figure 18. The pattern of emissions largely follows the pattern of losses. Wheat in North Africa, West and Central Asia and maize in Sub-Saharan Africa have emissions out of scale to their losses as the average emissions intensity per tonne of production in the four LCAs used is heavily influenced by highly emissions-intensive production seen in the analysis of production in Mongolia.

Figure 18: Greenhouse gas emissions from cereals and pulses

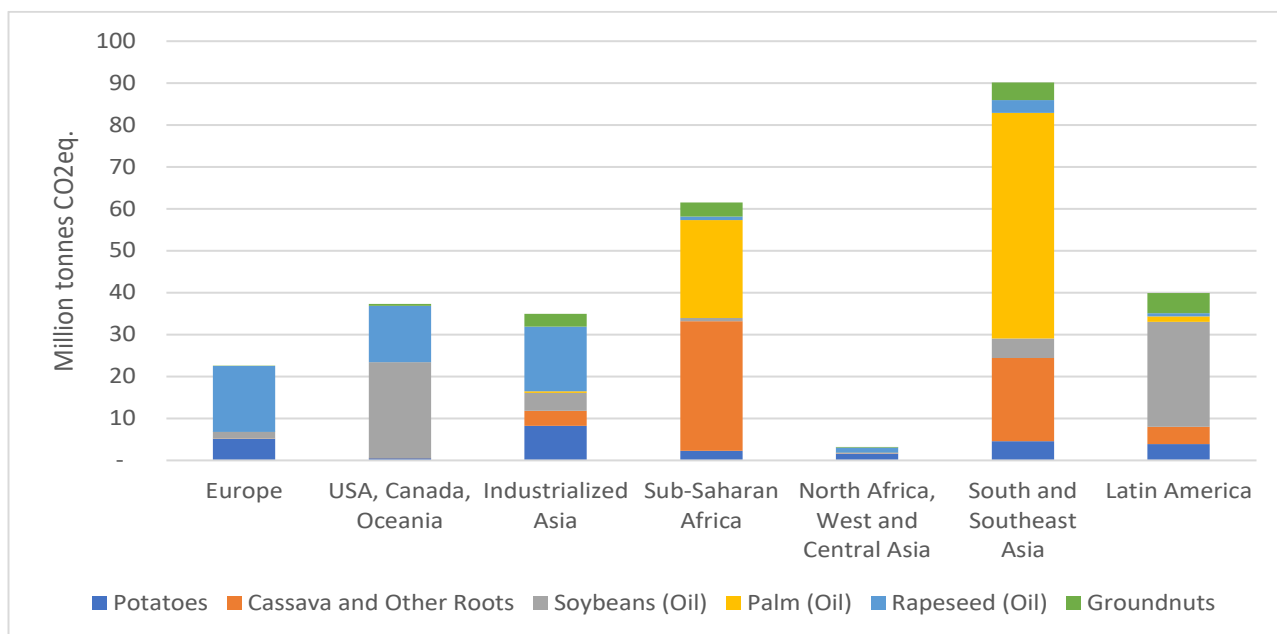


Roots, Tubers and Oil Crops

Emissions generated by farm stage losses of roots, tubers and oil crops are equally distributed between harvest and post-harvest food losses. The region contributing most to global CO₂ eq. emissions is South / Southeast Asia, while North Africa, West and Central Asia contributed the least (this commodity group does not contribute significantly to regional agricultural production compared with others).

The production of palm oil in Sub-Saharan Africa and South and South-East Asia dominates emissions (see Figure 19). This is due to the high per-tonne emissions associated with production (mainly from fertiliser production and use, and carbon stock changes to a varying degree).

Figure 19: Greenhouse gas emissions from roots, tubers and oil crops

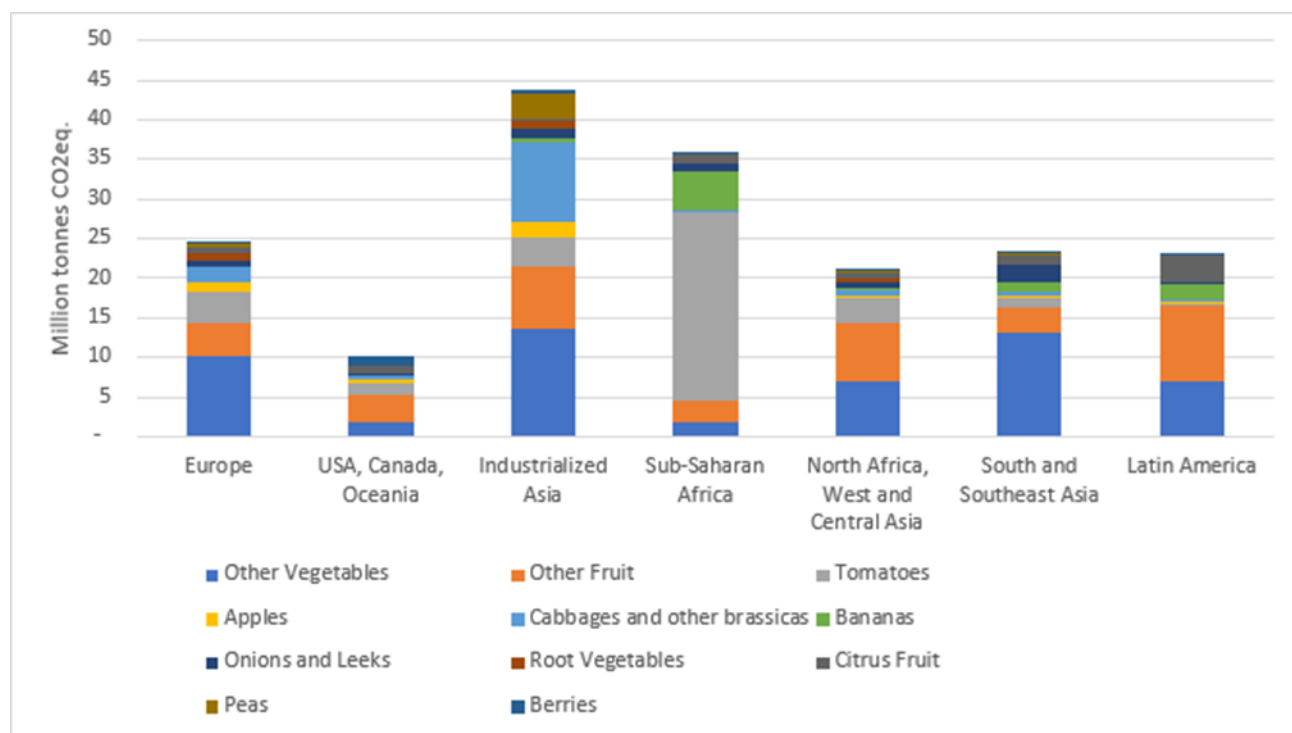


Fruit and vegetables

Fruit and vegetables losses form 8% of total greenhouse emissions, with only fish and seafood contributing less. The split between harvest and post-harvest losses is roughly equal overall.

“Other vegetables” forms the single largest category (30%) within this (see Figure 20)– it is mainly unspecified vegetables but also includes cucumbers, aubergines and spinach and anything not included in the other categories. “Other fruit” (mainly watermelons, tropical fruits and grapes) and tomatoes each form 21% of the total. Tomato production in Sub-Saharan Africa (principally Nigeria) forms 13% of the overall total making it the single biggest country / crop combination for fruit and vegetables. This is due to the large quantities of tomatoes being grown and high loss rates (about one-quarter) but also because the limited number of LCA studies underpinning this (from Benin) show extremely high emissions rates that are over 30 times the global average (due to land-use change and fertiliser use). Caution is therefore needed in interpreting these findings until further relevant LCAs are available to either support or refute these findings.

Figure 20: Greenhouse gas emissions from fruit and vegetables



Fish & Seafood

Total estimated emissions from fish and seafood harvest and post-harvest losses are 107 million tonnes. The majority of losses come from fishing activities rather than immediate post-capture processing, but the split is not straightforward and requires further explanation. Many of the relevant LCA studies (used only for aquaculture) combine emissions from fish capture and aquaculture with post-harvest stages. The split of two-thirds emissions from harvest losses and one-third post-harvest losses therefore largely reflects the split of tonnage losses.

Loss data for fish and seafood have significant regional gaps, so much of the analysis uses loss percentages from other regions. In particular, losses for Sub-Saharan Africa and Industrialised Asia use global-average harvest losses of 27% and post-harvest losses of 30% based on the FAO data for South and South-East Asia.

Table 3 shows greenhouse gas emissions from fish and seafood losses by region and FAO category and Table 4 shows tonnage losses (edible and inedible parts).

Table 3: Greenhouse gas emissions from fish and seafood losses, thousand tonnes CO₂ eq. / year

	Europe	USA, Canada, Oceania	Industrialized Asia	Sub-Saharan Africa	North Africa, West and Central Asia	South and Southeast Asia	Latin America	Total
Freshwater Fish*	959	289	23,845	1,895	554	10,970	1,071	39,583
Marine Wild Caught	2,733	1,176	12,095	1,316	399	7,317	1,339	26,376
Crustaceans	569	1,148	8,062	277	90	14,482	2,735	27,363
Molluscs, Other	262	286	12,572	13	10	366	220	13,729
Total	4,523	2,899	56,573	3,501	1,054	33,135	5,366	107,051

* includes farmed salmon and trout.

Table 4: Food losses (edible and inedible) thousands of tonnes

	Europe	USA, Canada, Oceania	Industrialized Asia	Sub-Saharan Africa	North Africa, West and Central Asia	South and Southeast Asia	Latin America	Total
Freshwater Fish*	491	93	6,669	704	141	5,318	512	13,928
Marine Wild Caught	2,010	584	4,494	1,005	247	4,517	2,068	14,924
Crustaceans	87	93	1,685	28	7	1,051	314	3,265
Molluscs, Other	153	107	3,905	6	3	194	146	4,515
Total	2,741	878	16,753	1,743	398	11,079	3,039	36,632

* includes farmed salmon and trout.

The main observations are:

- Emissions are closely correlated with loss tonnages.
- Industrialised Asia accounts for just under half of losses and just over half of emissions; this is because freshwater fish and crustaceans, associated with relatively high emissions, form a large share of total production.
- Europe has about 7% of losses but 4% of emissions due to the predominance of wild caught fish with relatively low emissions per tonne.

Different fish types have significantly varying relative emissions due to the different underlying sources and types of gases. Crustaceans (mainly shrimps and prawns) have the highest per-tonne emissions; for aquaculture these come mainly from methane emissions (and to a lesser extent nitrous oxide) arising from decomposition of excrement in the water and subsequent disposal. Fuel-use intensity for wild-caught crustaceans is also significantly higher than for other species groups. Methane also account for most of the emissions from other farmed fish (included within freshwater fish above).

Wild-caught marine and freshwater fish have the lowest relative impact; variations between regions reflects the types of fish caught (pelagic fish, such as mackerel, require significantly less fuel to catch than demersal species, such as cod) and fishing vessels used. Post-harvest operations and storage are not included in these numbers but are likely to be relatively small.

3.1.2 Eutrophication and acidification potential

To calculate the acidification potential from food losses, the emissions of SO₂, NH₃, NO_x to air are analysed and represented as sulphur dioxide equivalents (SO₂ eq.). The main sources for high acidification potential can be linked back to farming activities and to the production of key inputs, such as fertilisers and pesticides.

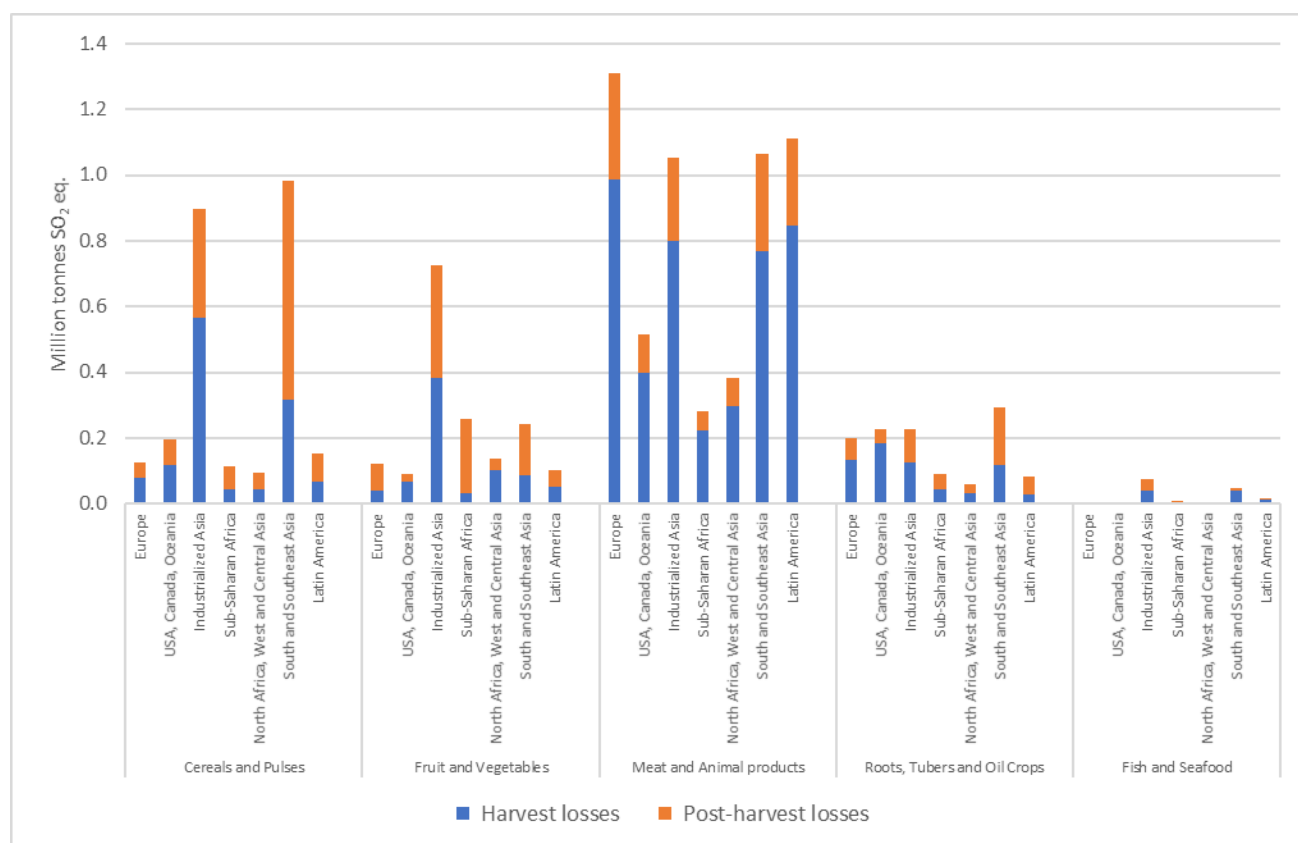
Eutrophication is the process whereby aquatic systems become over-enriched by nutrients, such as nitrogen and phosphorus, released through run-off from agricultural activities (such as fertilizer application) into lakes and rivers. Eutrophication potential encompasses multiple emissions to water as well as to air, including SO₂ and NO_x to air, and NO₃⁻, NH₄⁺, P and N to water. These different emissions are reported in a standardised way in this study as phosphate equivalents (PO₄³⁻ eq.).

Sulphur dioxide equivalents and phosphate equivalents associated with farm stage food losses follow similar patterns to those of greenhouse gas emissions across regions and commodities.

Total acidification potential associated with farm losses are 12 Mt SO₂ eq. and total eutrophication potential is 10 Mt of PO₄³⁻ eq. Meat and animal products form over 40% of each type of emissions followed by cereals and pulses at 20% and fruit and vegetables at 14%. Within meat and animal products the largest contribution is from milk losses.

Figure 21 illustrates the pattern for acidification potential across commodities and regions.

Figure 21: Acidification potential across all regions and commodity groups, tonnes SO₂ eq./year



Observations

Meat and animal products are associated with very high acidification and eutrophication potential due to the nature of their production – about four times higher than wheat. Fruit and vegetables have relatively low emissions so the spike in Industrialized Asia is due to absolutely high tonnage losses



(reflecting absolutely high production tonnages). The relatively low emissions from fish seafood reflect low tonnage losses rather than low impacts per tonne.

The origin for the different types of emission for cereals and pulses come mainly from rice (79% of the total acidification potential). The hotspot in South and Southeast Asia for acidification potential is due to a high tonnage of losses in the first place (with roughly 40 million tonnes) combined with the higher acidification potential for rice in this region (16kg SO₂ eq./ kg product) compared with other rice growing areas (e.g. Industrialised Asia, 8.6kg / kg of product). Other crops which contribute to high acidification potential are wheat and maize, while wheat shows high loss tonnages and similar acidification potential to rice, at (16kg SO₂ eq./ kg of product).

3.2 Water use

This report focuses on freshwater withdrawals, estimated through the LCA analysis. Water scarcity / stress is also noted for the 10 case study areas explored in Section 4.

Water withdrawals include irrigation withdrawals, irrigation withdrawals embedded in feed, drinking water for livestock, water abstracted for aquaculture ponds as well as processing water. In order to calculate water scarcity, it was assumed that all water irrigation is either evapo-transpired or embedded in the final product, but not returned to the watershed through percolation (*J. Poore and T. Nemecek (2018) supporting documentation*).^{xv}

The modelling estimates a total of 760 km³ of freshwater are withdrawn from nature for food lost at farm stage, equivalent to over 5 weeks' flow from the Amazon River into the Atlantic Ocean. This is significantly higher than the "blue water footprint" (consumption of surface and groundwater resources) of 250 km³ in the 2013 FAO report "Food wastage footprint - Impacts on natural resources". This difference is likely due to a combination of differences in food loss estimates, methodological differences in the way water use is estimated and the continued upward trend in water abstraction for agriculture since that study was carried out. While the total number is different, the pattern of waste between the two reports is very similar.

Figure 23 below shows that, regionally, South and South-East Asia dominates losses followed by Industrialised Asia and Sub-Saharan Africa – a pattern also seen in the FAO statistics. By crop, cereals and pulses dominate followed by meat and animal products and fruit and vegetables, also following the order of the 2013 FAO stats.

The main contributors to the water footprint in the form of freshwater withdrawal are cereals and pulses (37%) and meat and animal products (22%).

As seen in Figure 22, the split between freshwater withdrawal for harvest and post-harvest food losses shows differences between commodity groups. This largely reflects the differences in the harvest / post harvest split of losses; animal and harvest losses for meat and animal products are about 70% of total losses compared with about 50% for cereals and pulses. Post harvest losses include water used in production with additional losses of processing water; water used for processing tends to be much lower per tonne of commodity than production water use.

Figure 22: Freshwater withdrawal associated with farm stage food losses, km³/year

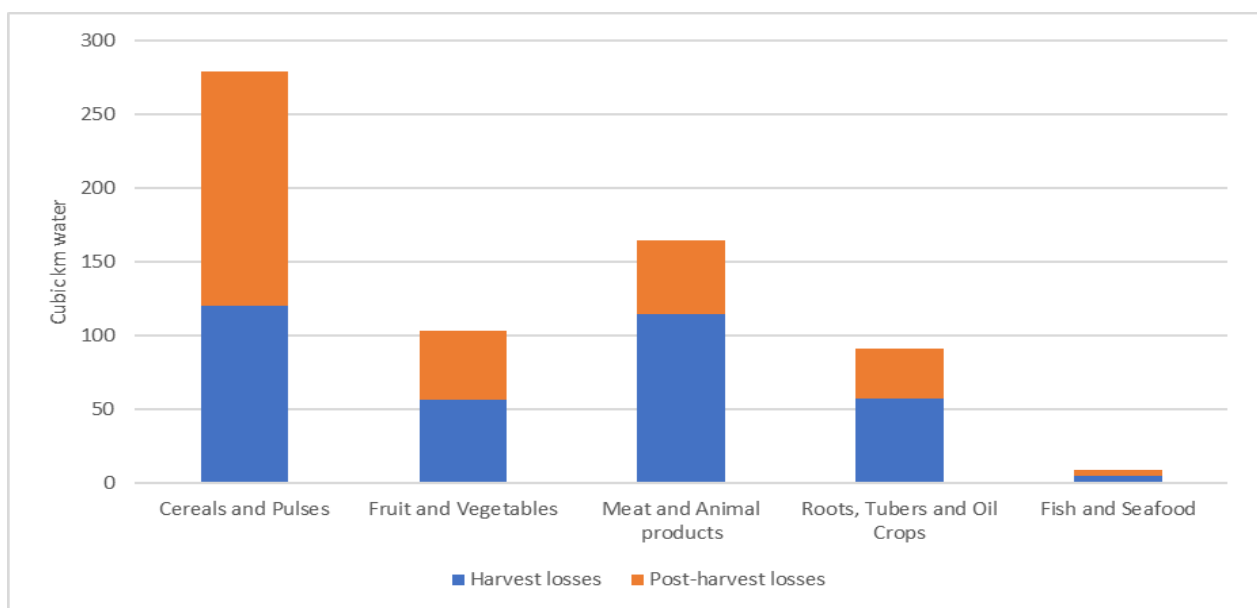
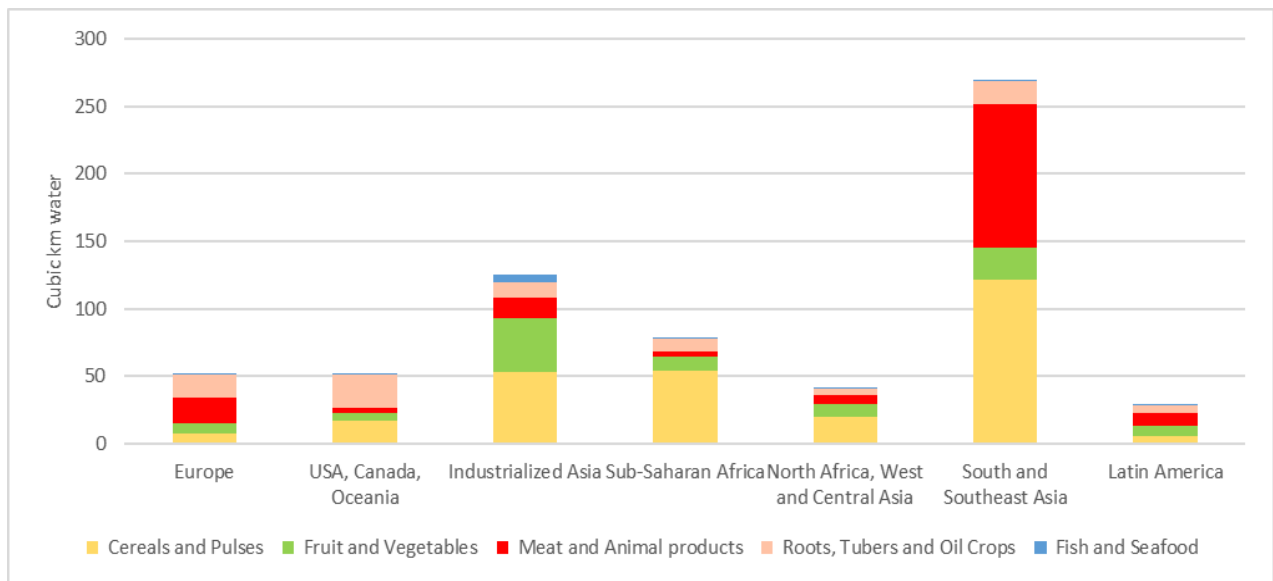


Figure 23: Freshwater withdrawal associated with farm stage food losses by region and crop type, km³ / year



See the case studies analysis in Section 4 for regional comments on water scarcity.

Cereals and pulses

Freshwater withdrawals vary significantly between regions and crops - European wheat and other cereal production is largely rain-fed with little water use whereas wheat production in Asia and the USA is much more dependent on irrigation systems.

Rice requires a large amount of water no matter where it is grown, although there is some variation between countries, with production in Japan showing relatively low use in the lifecycle analysis.

Fruit and vegetables

Figure 23 above shows that Industrialized Asia is associated with the largest quantity of water losses within the fruit and vegetable group. This is mainly driven by the huge tonnage losses – see Figure 7.

Meat and animal products

Commodities within this group have a high water footprint arising from crops grown for feed as well as water drunk by the animals during their lifetime; the water footprint therefore depends partly on the origin of the feed. Water losses are dominated by milk, which forms over 80% of the total for meat and animal products. Almost 80% of milk losses are in South and South East Asia and 8% in Europe. Pig meat forms 8% of the total, of which about one half comes from Industrialized Asia.

Comparison with tonnage losses

As noted above, water use varies by region and commodity group. Figure 24 shows that, globally, cereals and pulses and meat and animal products are particularly water-intensive. Cereals and pulses account for about 16% of total food losses but 37% of total water losses, for example. Fruit and vegetables generally use less water per tonne of production than other crops.

Comparison of the percentage global food loss tonnage for each commodity group versus the share of overall water withdrawal associated with food losses in Figure 24 highlights that cereals and pulses and meat and animal products are disproportionately responsible for freshwater withdrawal for reasons noted above.

Figure 24: Percentage of food loss tonnage vs. associated freshwater withdrawal

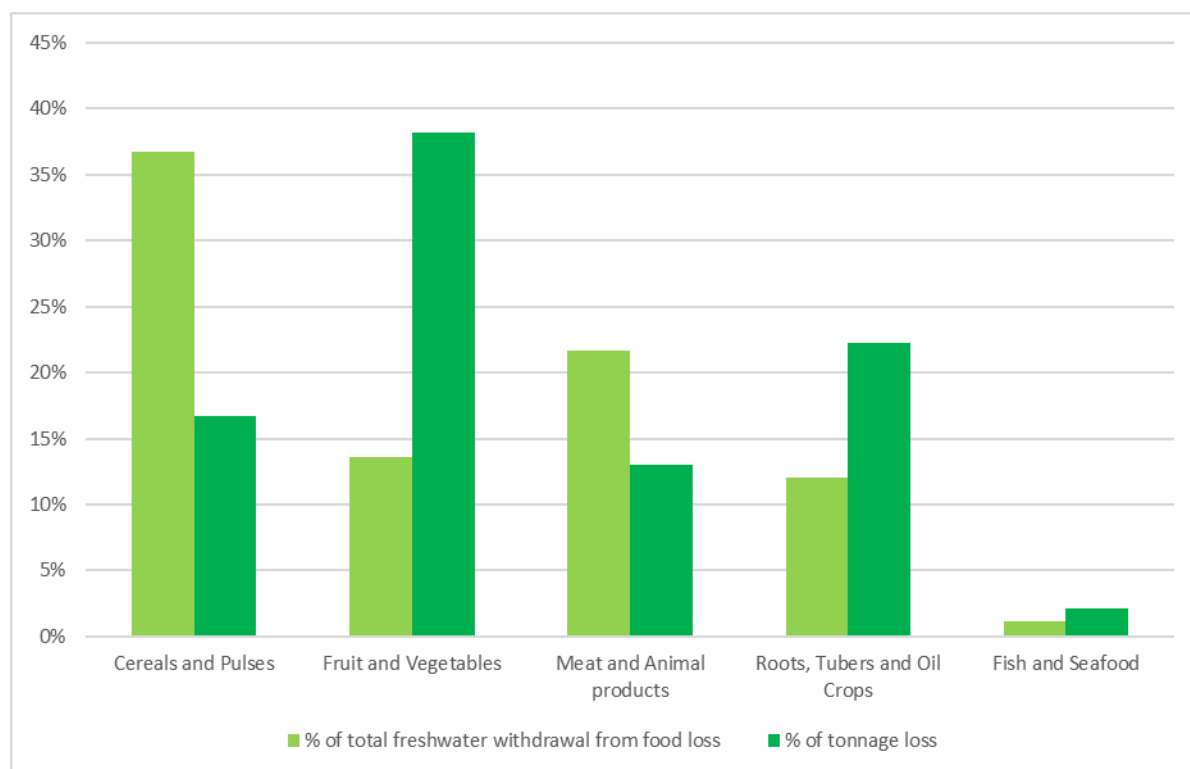
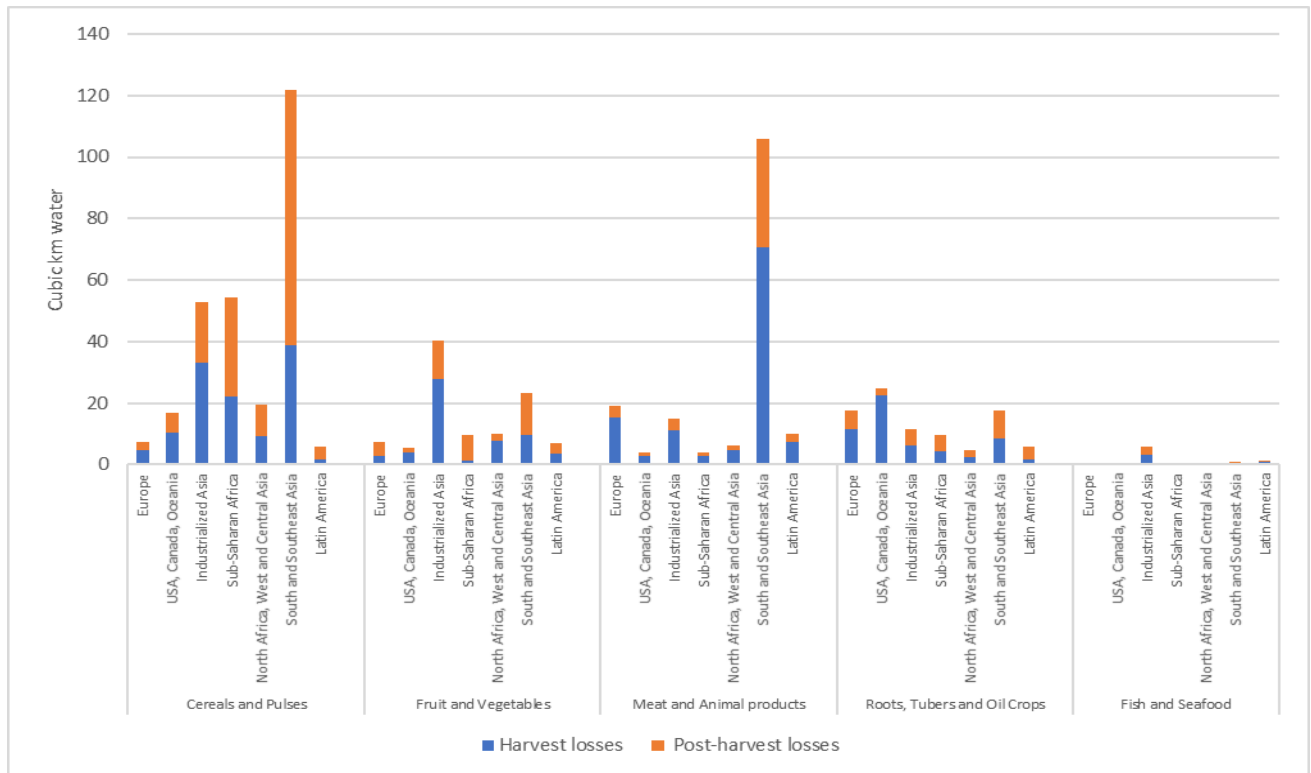


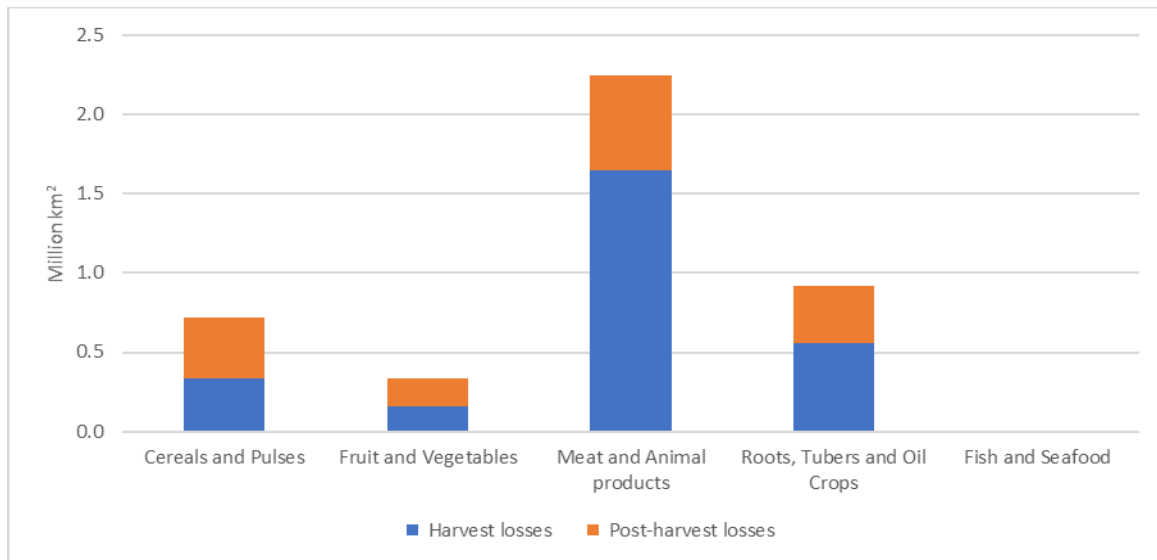
Figure 25: Freshwater withdrawal across all regions and commodity groups, km³ / year



3.3 Land use

Land use includes the land used during the occupation time from seed, on-and off-farm arable and permanent crops, fallow land, temporary as well as permanent pasture. Following the same approach as for other impacts, land use associated with food losses is the total land area that would be used to produce an amount of food equivalent to losses. Total land used to produce food that was lost on the farm is about 4.4 million km², a land area larger than India.

Figure 26: Land use associated with Food Loss, million km²/ year



Land use has not been estimated for ‘fish and seafood’ as marine fisheries do not “use” land as such, although trawling can be associated with significant damage to the seabed and subsequent biodiversity loss. Aquaculture may be in the sea, in freshwater lakes or in tanks on land; data to identify the split, land use for each is scarce. Some forms of aquaculture, in particular tiger prawn fisheries in SE Asia, are associated with significant impacts, such as mangrove destruction.

Meat and animal products

Meat and animal products are responsible for one-half of land use losses, at over 2.2 million km². This comes from grazing animals over a long period of time, until the end product can be produced (dairy or meat), as well as the land necessary for feed production to support livestock. There is significant variation between regions (Figure 30) with the lowest land use associated with animal losses from Sub-Saharan Africa and the highest land use in Industrialized Asia.

While the land use from harvest losses is high in multiple regions, the land use associated with post-harvest losses is considerably higher in Industrialised Asia than in other regions. This is associated with milk production in China, but this number is probably skewed upwards considerably by the inclusion of several extensive, low-yield farms within the LCA model.

Roots, Tubers and Oil Crops

Losses from this commodity group are associated with the second highest land use, being responsible for roughly 1.5 million km² / year.

Cereals and Pulses

Land use from cereals and pulses is evenly distributed between harvest and post-harvest losses. While the harvest losses are very similar in the different regions, ‘Sub-Saharan Africa’ and ‘South / Southeast Asia’ are commodity hotspots for post-harvest land use, being responsible for more than twice as much land as other regions.

Fruit and Vegetables

Whereas many commodity groups use proportionally more or similar land than their proportion of the total food loss, fruit and vegetables use much less land compared to their food loss volume. The total contribution to food loss tonnage is 38%, while their land use of 350,000 km² only contributes 8% of the total.

Figure 27: Land use by commodity group & region - animal and harvest losses, thousand km²/year

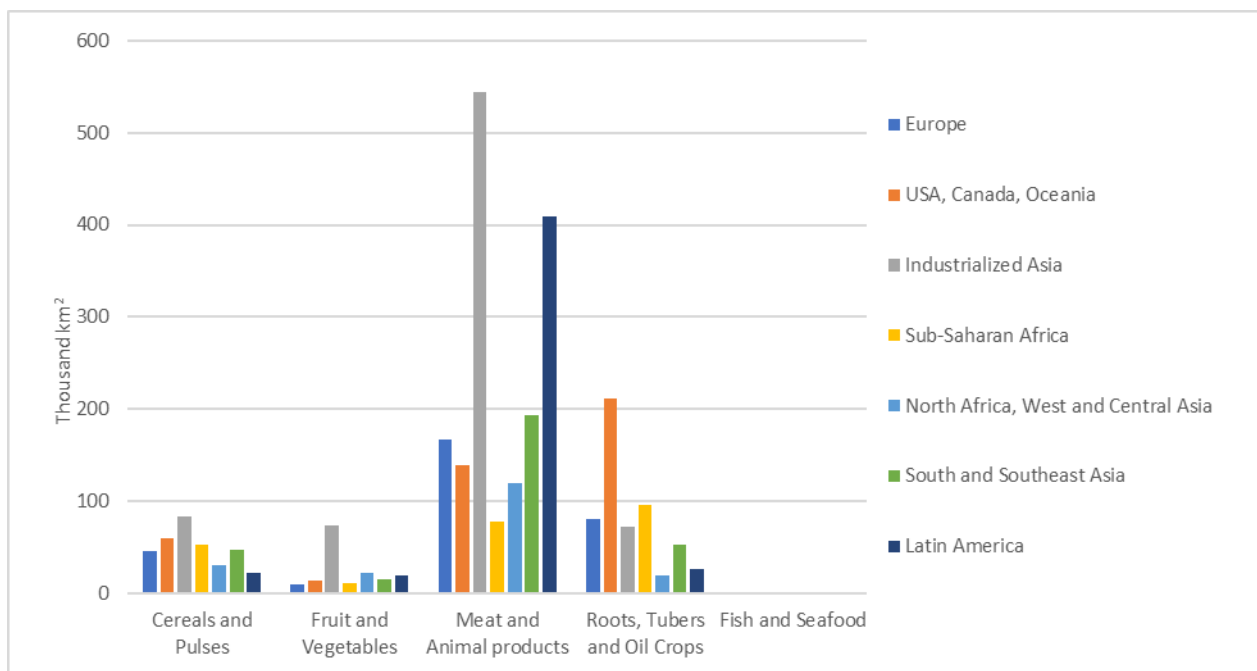


Figure 28: Land use by commodity group & region - post-harvest losses, thousand km²/year

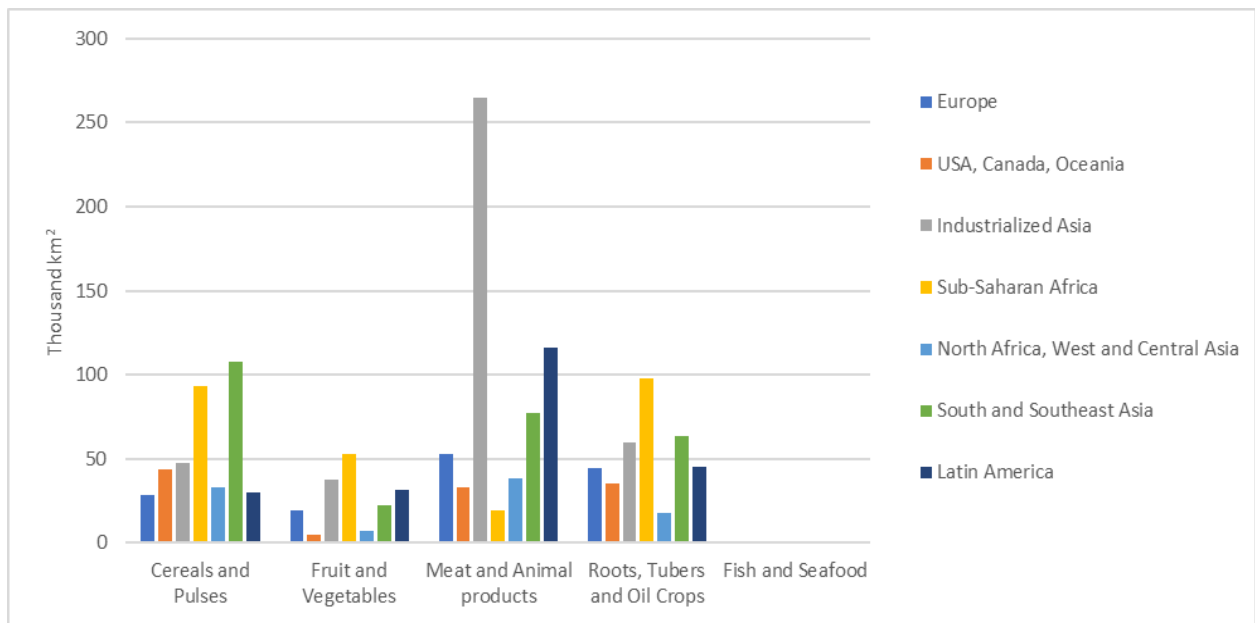


Figure 29: Percentage of food loss tonnage vs. % land use associated with food loss, km²/year

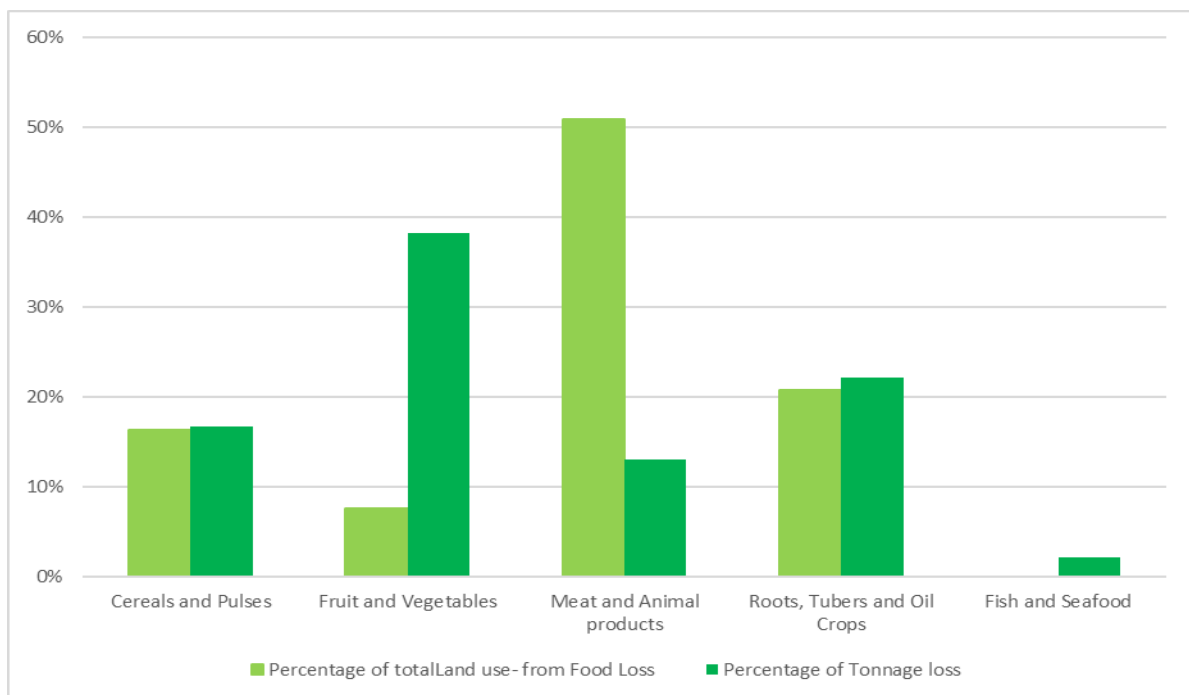
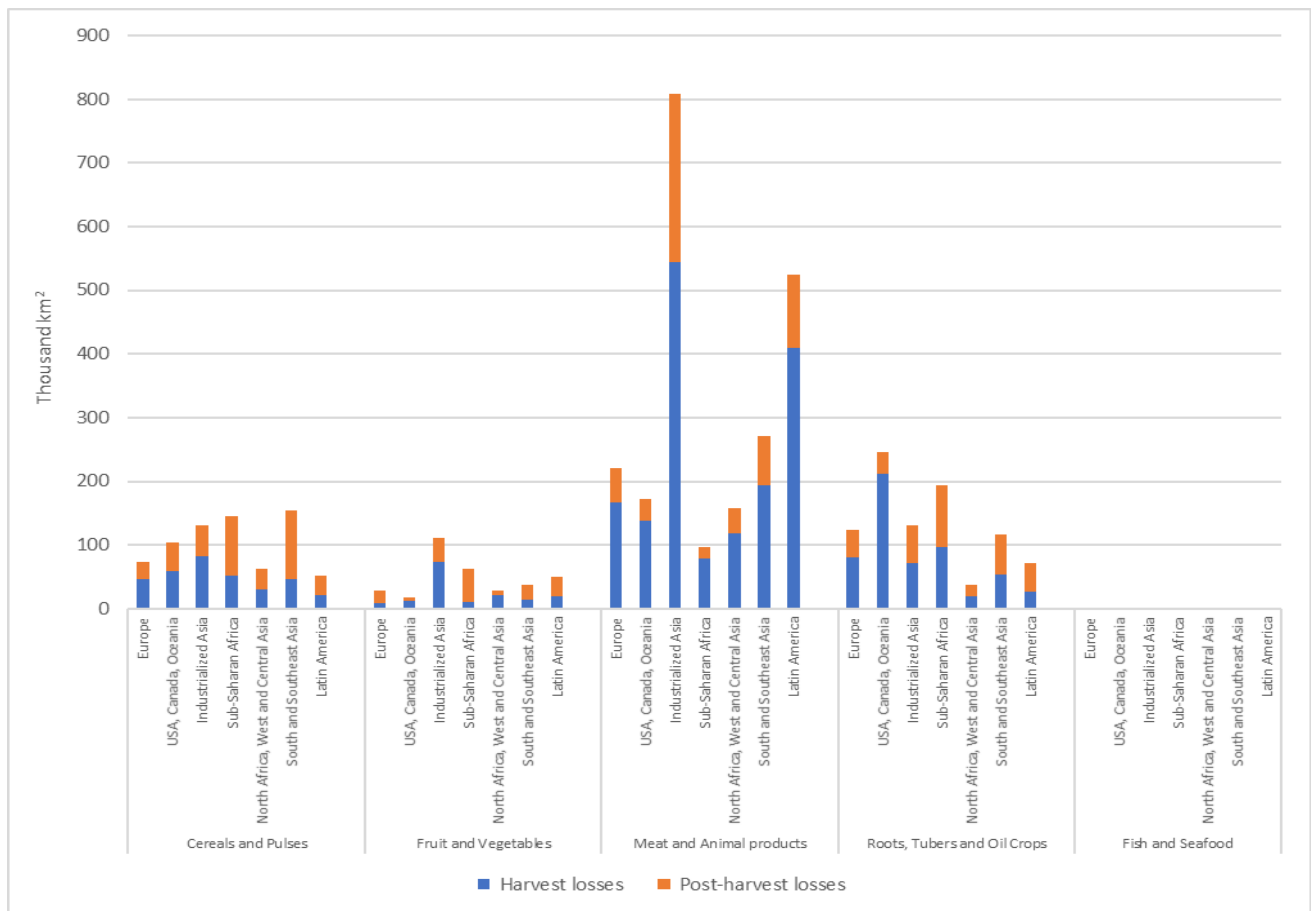


Figure 30: Land use across regions and commodity groups, thousand km²/year



3.4 Biodiversity loss

The biodiversity impacts of the agricultural production of lost food have been analysed for the 10 case studies described in Section 4 rather than for all commodities and all regions. This is because biodiversity impacts are much more location- and crop-specific and making generalisations is not possible. For each case study we have picked out the three or four countries with the largest losses to focus further on.

For the assessment of biodiversity impacts both quantitative and qualitative assessments have been carried out. The quantitative assessment was based on factors that may affect biodiversity, such as land-use change and water use, as well as country rankings for biodiversity and habitats and ecosystem services in the given case study areas. For the qualitative assessment, scientific papers and reports for the case study regions and commodities have been assessed (A2).

The quantitative assessment enables comparison between risks to biodiversity for each case study country or region. The qualitative assessment provides more insight into some of the impacts that specific food commodities might have on the country or region's biodiversity.

3.5 Socio-economic impacts

The total economic losses brought by food losses at the farm stage were estimated to be \$370 billion and were reported alongside the global food loss estimates in Section 2.4. Apart from these direct losses this section focuses on wider socio-economic impacts. These impacts have been assessed through



the lens of the identified case studies; an approach similar to that taken for biodiversity impacts. This leads to a direct assessment of different socio-economic impacts for each case study commodity and case study group.

With the direct assessment approach, no further externalities have been included in the assessment. The factors included were:

- the value loss (\$ loss per tonne and \$ loss from total case study),
- the proportion of food loss among the case study region and commodity group,
- the % contribution of agriculture, forestry and fishery to the country's GDP.
- The \$ losses per tonne and for the total case study were based on the average \$ / tonne of FLI basket group in the country.

In addition to these economic factors, the case study country's development towards certain SDG goals are included in the assessment. As these goals and the development to reaching these goals are globally monitored, a comparison across the regions was possible. This included the SDG goal 1 "No poverty" and SDG goal 2 "Prevalence of undernourishment".

Overall, areas where agriculture makes up a big proportion of the country's GDP, the performance against the SDG goals is generally poorer. This correlation can be seen across most of the case study regions, described in the next section. For example, from case study 4 focusing on fruit and vegetables in South and Southeast Asia, the economic loss associated with food waste at the farm stage is roughly \$15,000 million. India has one of the highest economic losses for this commodity group and also shows significant challenges remaining on the pathway to reach SDG goals 1 and 2. This correlates with the highest contribution to GDP from the agricultural sector for any country within the region, at 16%. In contrast, for Thailand, where agriculture only contributes only 8% to national GDP, only smaller challenges remain to reach "no poverty", whereas the goal of prevalence of undernourishment has already been reached.

4 Global food loss case studies

Case studies were conducted across each of the main commodity groups in order to ground-truth assumptions made on the scale of losses, to explore different viewpoints on food loss and waste definitions and collect more granular information on food loss drivers and mitigating actions.

4.1 Criteria for identification of case study region/ commodity pairs

Identification of 10 global food loss case study areas for further investigation involved different selection criteria across the 5 main commodity groups, given the uneven coverage of food loss data (see Appendix 1, Table 25) and the need for representation of different commodities/ regions.

For commodities and regions well represented within food loss datasets, the main factors taken into consideration were:

- Significance of production volumes or value within the region
- Commodities with data suggesting high rates of farm stage food losses
- The need to include a balance of food types/ nutritional values, in line with the FAO's basket of top 10 commodities that countries can select for monitoring under the Food Loss Index (see A4, Table 31 for detailed classification)
- Coverage of contrasting agricultural systems and levels of mechanisation.

For commodities with limited or no data but with significant production volumes or value, proxy values were calculated. Of particular interest were regions/commodities where production is likely to have significant environmental impacts and/ or areas of rapid change and nutrition transition.

4.2 Collection of evidence to support case study analysis

The 10 selected case studies are shown in Table 5, arranged by commodity group, with details of their focus and sources of information used, split between stakeholder interviews and relevant literature.

In total 20 interviews were conducted, 13 of which were specific to the case study commodity-regions and 7 relating to over-arching themes such as field measurement, whole chain initiatives, research into innovative solutions and economic drivers of farm stage losses. Expertise relating to farm stage losses is fragmented and not easily accessed, so it was not possible to complete interviews for all of the chosen case studies. Further evidence gathering involved an extensive literature review that located over 60 relevant sources (listed under case study in A5). The most valuable sources used to inform food loss drivers and mitigating actions are those that deployed the FAO's four elements approach to food loss analysis, part of the [Save Food](#) initiative:

1. screening (for known research literature and consultation with experts, to gain an approximate idea of the range of losses and main causes),
2. survey (including observational, group interviews, stakeholder interviews),
3. sampling (load tracking, field measurement, analysis of loss by activity) and
4. synthesis (involving root cause analysis and solution identification), FAO 2016.^{xvi}

Table 5: Case studies selected for further analysis, with listing of interviews and focus of literature review

Indicates in table below that references include studies using the FAO's four elements approach

10 Global Case studies	Evidence collected
Cereals & pulses	<p>1. European - wheat production in UK Interview with trade association, literature review -10 references</p> <p>2. South & SE Asia - rice production Interview with in-country experts with 14-15 years' experience working on rice crops(WWF team) and use of literature focussing on losses in India and Pakistan - 5 references #</p>
Fruit & vegetables	<p>3. Sub-Saharan Africa - citrus fruit, tomato + other vegetables 5 interviews covering different components of citrus production – growers, trade bodies, exporters and academic research sector. Literature review as primary source exploring losses for small-holder farms - 9 references #</p> <p>4. S&SE Asia - mango, guava, aubergine, onions + other vegetables Interview and literature review – mango in India and detailed mapping within Andhra Pradesh , 7 references #</p>
Roots, tubers & oil crops	<p>5. Industrialised Asia – potato + sweet potato SW China Interview - researcher with potato tuber expertise in Industrialised Asia working with farmers , 4 references</p> <p>6. Latin America - cassava, potato + sweet potato production Interview relating to losses within Peru, literature with a focus on Trinidad & Tobago + Guyana (cassava), Peru (potato), 3 references.#</p> <p>7. Europe - rape seed and sunflower seed France: oilseeds, 4 references.</p> <p>8. Sub-Saharan Africa - groundnuts Interview with researcher and groundnut co-ordinator for Ethiopia, additional literature from Malawi, 5 references #.</p>
Meat & animal products	<p>9. USA, Canada & Oceania – broiler chicken rearing/ slaughter Interview with meat sector expert/ consultant: USA, broiler chickens, 7 references</p>
Fish & seafood	<p>10. Sub-Saharan Africa - freshwater fisheries East Africa, Lake Victoria dagaa fishery, 11 references #</p>
Over-arching issues	<p>A series of interviews conducted to explore over-arching issues in relation to farm stage losses 7 interviews including an NGO working on farm stage losses associated with crops exported to UK from Africa and Latin America, 2 interviews with conservation charity policy officer working on food loss, academic expert on farm stage food loss measurement, retailer working on Champions 12.3 10*20*30 initiative, researchers developing food loss solutions for fruit and vegetables, researcher within government department responsible for food loss reporting.</p>

4.3 Cereals and pulses – case studies 1 and 2

- Data coverage: 1,619 observations assessed of which 1,238 were selected (85% related to Sub-Saharan Africa). Significant data gaps exist for Europe, North Africa, West and Central Asia and USA, Canada and Oceania.
- Harvest losses appear to be more significant than post-harvest losses in regions with more highly mechanised agricultural systems (i.e. those found within higher- and middle-income countries) This may also reflect different grain commodities grown in these regions (e.g. wheat and barley) compared with lower income regions.

Figure 31: Cereals and pulses - losses by region (million tonnes)

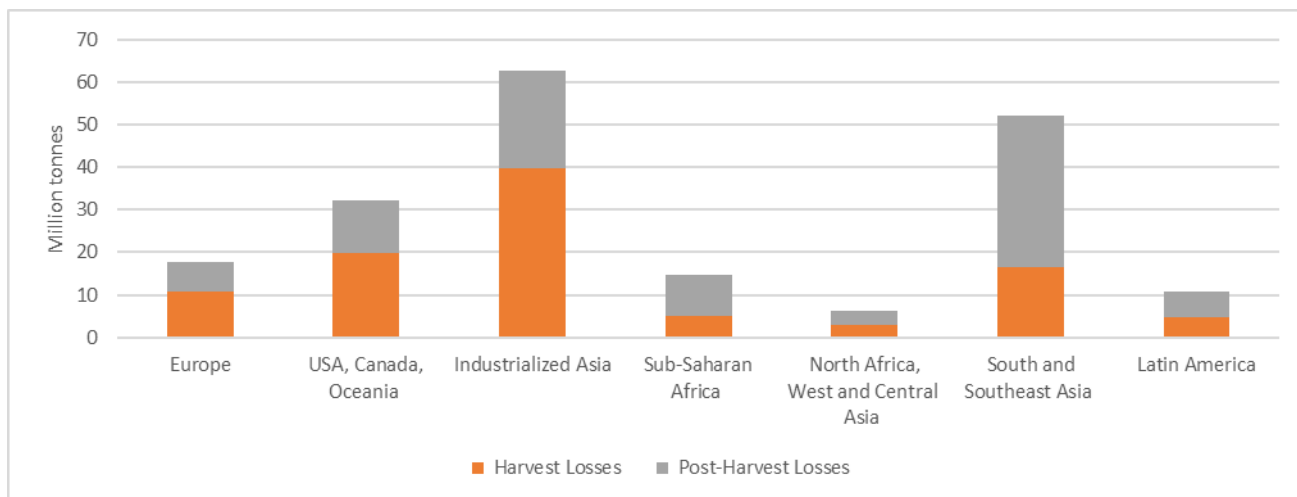
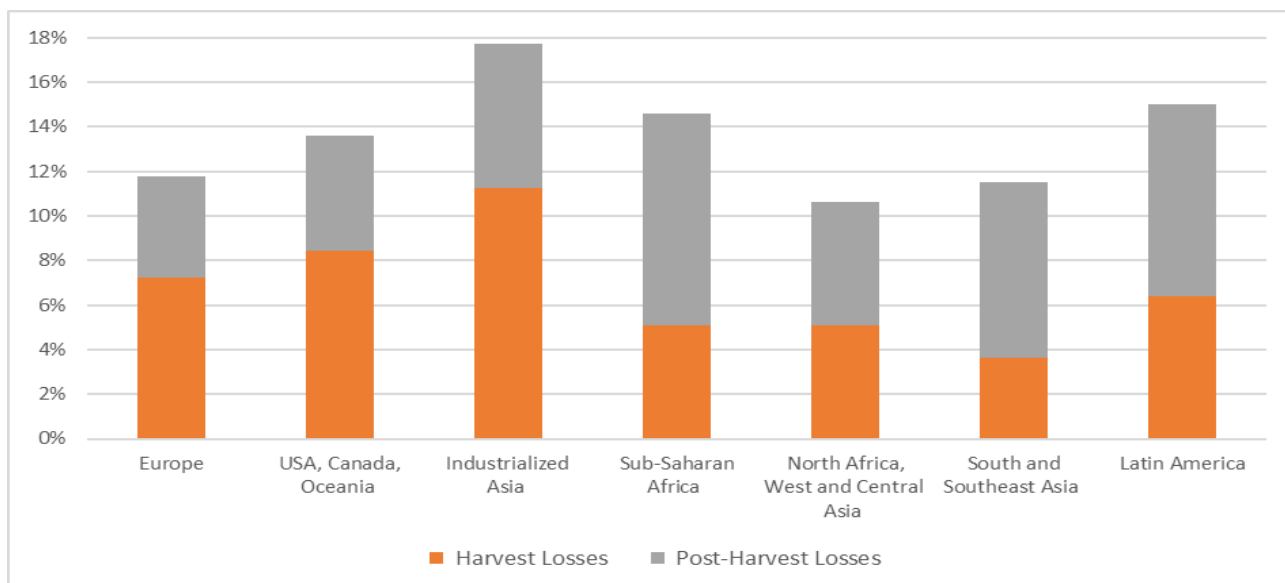


Figure 32: Cereals and pulses - % food production lost at farm stage



4.3.1 Case study 1 - European - wheat production

- Wheat is an important commodity within the region (both in terms of economic value and proportion global cereals and pulses production)
- For highly mechanised agricultural systems the losses implied by the available datasets require closer investigation as it is generally assumed that more highly mechanised grain harvesting would result in losses lower than 10%.
- Within the region, only 5 studies met the selection criteria for inclusion in food loss estimates.

Table 6: Case study 1 - European wheat production

European cereals & pulses production as % global production	11%	150 million
European wheat production as % European cereals & pulses production	49%	73 million
European farm stage losses of cereals & pulses as % global farm stage losses of cereals & pulses	9%	18 million
European farm stage losses of cereals & pulses as % European farm stage losses of cereals & pulses	40%	
% of European wheat production lost at farm stage (harvest and post-harvest)	10%	7 million
Estimated value of loss (million Int. \$)	\$2,521	
European farm stage wheat losses: kg per capita	9.26	

Case study 1 - Wheat in the United Kingdom

Sources: stakeholder interview and literature review

Wheat is one of the main arable crops in the UK with approximately 1.9 million hectares planted per year. East Anglia, the South East and East Midlands are the main growing regions.

Wheat - production statistics

The initial estimate for UK wheat production in 2020 was between 9.7 and 10.1Mt, the lowest for 40 years, the more typical range is between 11-16 million tonnes. This low level reflects the impact of extreme weather in autumn 2019, affecting winter wheat plantings and growth. Of the total of wheat varieties planted specifically as milling wheat for bread or biscuit making (Nabim Group 1 and 3 varieties),^{xvii} it is estimated that only 31% will meet the full quality specification in terms of nutritional value, grain kernel condition and moisture content (0.9Mt), 51% lower than in 2019 (Nabim, 2020)^{xviii}. Grain rejected for premium uses is diverted to animal feed, alongside grain from varieties of wheat grown to supply grain to feed markets (Group 2 and 4 varieties).

Wheat - market characteristics

The UK's wheat market production, with an average annual yield of 11-16 million tonnes, is mainly intended for the national market. Around 40% meets miller's requirements, with the remainder being used in animal feed.

Due to a high technological standard on UK farms, food loss rates are minimal, with the main loss driver being heavy weather events, especially heavy rain, which can lead to pest and diseases. Integrated Pest Management approaches can be used to improve natural pest control and crop varieties resistant to diseases.



The UK wheat market focuses mainly on national supply, with millers typically meeting 80-85% of their wheat requirements from within the UK. Wheat quality and suitability for baking is determined by a combination of grain weight, protein content and Hagberg Falling Number – a measure of quality damage caused by wheat kernel germination. In a typical year 40% of wheat grain meets milling grain requirements, with the remainder used in animal feed.

Wheat - farm systems

Wheat production in the UK is an intensive and highly mechanised system with relatively high cost inputs in terms of seed quality, fertilisers and agrochemicals used to control pests, disease, and weeds. After harvest, grain is stored on-farm, and if necessary, also dried, or watered, depending on the prevailing weather conditions during harvest.

Wheat - comment on the estimates from study

The wheat industry is an industrialised and technical industry, with very efficient processes. Losses are reduced and minimised where possible along the different farm stages. Different incentives lead towards low loss rates, such as a high cost if grain is lost at the end of the growing period, given the resources invested into its cultivation. Furthermore, losses away from the field can attract vermin, lead to the development of diseases.

As Europe's farmland is comparatively small-scale compared to other wheat growing regions such as in North America, a high field productivity and yield is necessary to make the farming process economically viable. This also incentivises the reduction of harvest and post-harvest losses, where possible.

According to a WRAP^{ix} study of England, food loss from wheat in the UK has an average annual loss rate of about 1.3%, with a range of 1 to 12.9%, (based on a Nordic Council study).^{xx} While food surplus was estimated at around 10.2%, which mainly included grain intended for human consumption used in animal feed, not one of the listed destinations classified as food waste within the SDG 12.3's definition. In conclusion, the estimate for farm stage losses from the data review are too high for this case study commodity, based on the stakeholder interview and more detailed review of the literature. Where higher estimates exist, it is likely that bread wheat varieties rejected from bread making but instead diverted to animal feed were included within food loss estimates.

Wheat - farm activities: breakdown of losses by activity, where available

The estimation of wheat grain losses associated with crops left unharvested or grain scattered during harvesting are difficult to establish, as residues and non-harvested grains are soon consumed by birds and other animals in the field.

Losses during storage on-farm are estimated to be around 0.1%, which is due to rodents, birds and insects, or due to storage failures. In some areas planned overproduction can also lead to losses, to meet changes in demand and to plan for unexpected weather events. This is when the decision is taken to plant more wheat than might be required as an insurance against lower yields. However, if there is a glut and grain prices fall, it may not be economically viable to harvest all of the crop.

In total, losses between 2-3% can be assumed to occur on the primary production stage in the UK, while losses in France are between 1-5% for wheat (Refresh, 2017).^{xxi} An overall loss of 3% for cereals is also assumed to occur in Denmark (Borum et al., 2018).^{xxii}

Wheat - connection to market

Most farmers in the UK store harvested grain on-farm, until they are directly transported to millers or other facilities for further reprocessing. In the UK millers are the biggest buyer of wheat.

Wheat - factors driving losses at farm stage

The main driving factors for grain losses at farm stage are abiotic factors, such as extreme weather events, and biotic factors that impact on wheat yields (pests, diseases and weed infestation). Weather conditions that cause loss include wet as well as dry conditions. However, the biggest impact on the grain quality comes from heavy rain events during harvest, as this can lead to diseases or premature sprouting and stem/root lodging (when stem or root system has insufficient strength to hold the plant upright), which can reduce grain quality and increase losses. According to the AHDB, every three or four years the interactions between wind rain and soil cause widespread lodging in UK winter wheat crops affecting 20% of the planted area.^{xxiii} In addition, humid conditions make grain more susceptible to mycotoxins (such as T-2 and HT-2), which can result in grain being rejected on food safety criteria.

Although modern harvesting techniques are highly sophisticated, careful management of grain moisture content and forward speed and cut height of the combine harvester are important factors in minimizing seed loss and seed breakage and shattering of heads during harvest. It is especially important to keep the harvesting and storage of grain from weathered or lodged areas of crop separate from other harvested crop (AHDB, *fusarium* and *microdochium* in cereals).^{xxiv}

Another driver for food losses can come from high food safety standards (specifically in relation to pesticide residues and mycotoxins) and quality criteria in relation to a range of milled products. Collectively these have a significant impact on the amount of harvested grain used in bread, cake, biscuits and other products for human consumption. However, grain failing to meet standards is mainly diverted to animal feed (provided that it meets feed hygiene and quality standards), which is not considered a food loss by the agricultural sector. Under some circumstances food safety regulations can reduce the amount of grain accepted for human consumption by up to 20%. These regulations apply for agricultural residues and mycotoxins.

Wheat - mitigating actions

A key aspect of mitigating against losses in the field includes improved agronomic techniques, reduction in grain rejected by mycotoxins and the treatment of crops against losses due to aphids, orange wheat blossom midge and slugs. There is general concern within the sector that the number of agrochemicals available to limit the losses caused by pests and diseases is being successively reduced by legislation (e.g. neonicotinoids, pyrethroids). As a counter to this, Integrated Pest Management approaches can be used to improve natural pest control and crop varieties resistant to diseases, such as Orange Wheat Blossom Midge.^{xxv}

A significant proportion of harvested wheat may therefore be excluded from the human grain market and human consumption as wheat not meeting the required quality for human consumption is diverted to other markets.



4.3.2 Case study 2 - South and SE Asia - rice production

- South & SE Asia Rice: accounts for a high proportion of global and regional losses associated with this commodity group. The value of losses within the region is estimated to be \$15 billion, based on FAO 2016 production values.
- Of the estimated 41 million tonnes of rice lost at the farm stage within the region, 68% occurs in immediate post-harvest activities carried out at the farm, such as drying, threshing, hulling, cleaning, storage at farm.
- Data coverage: 51 datapoints relating to the region.

Table 7: Case study 2 - South & SE Asia - rice

South & SE Asia cereals & pulses production as % global production	31.2%
South & SE Asia rice production as % regional cereals & pulses production	71.6%
South & SE Asia farm stage losses of cereals & pulses as % global farm stage losses of cereals & pulses	27.7%
South & SE Asia farm stage losses of rice as % regional farm stage losses of cereals & pulses	74.7%
South & SE Asia % of rice production lost at farm stage	13.1%
South & SE Asia estimate of total crop losses (tonnes)	40,587,489
estimated value of loss (million Int. \$)	\$14,914
regional farm stage rice losses: kg per capita	15.7

Case study 2 - Rice in Pakistan and India

Sources: stakeholder interview / literature review

Rice is the staple food for 4 billion people, including for 80% of the world's undernourished population. In total 144 million small-holder farms are engaged in growing rice on rice paddies often



no bigger than two hectares (CGIAR Research Programme on Rice)^{xxvi}. Most rice is grown for domestic consumption, with only 9.5% of production traded internationally.

Rice - production statistics

India is the second largest rice producer after China with 172,580,000 tonnes produced in 2018 from 44,500,000 hectares under cultivation (FAOSTAT 2018). Five states are responsible for over half the production: West Bengal, Uttar Pradesh, Punjab, Odisha and Andhra Pradesh. It is now the largest rice exporting country, with a 26% share of global rice exports at 10,044,804 tonnes (FAOSTAT 2018).

Pakistan's rice production is 10,802,949 tonnes with 2,810,030 hectares in cultivation (FAOSTAT 2018) and with 9% of global rice exports is the fourth largest exporter, exporting 3,827,937 tonnes of milled rice in 2018 (FAOSTAT 2018). Both Basmati and IRRI long grain rice are exported, with Basmati being the higher value product.

Rice is Pakistan's third largest crop in terms of area sown, after wheat and cotton, with 2.8 million hectares planted, mostly within Sindh and Punjab.

Over the last 10 years rice yields have fallen significantly in Pakistan, whilst the demand for rice exports has continued to rise. The higher value Basmati rice has become an important source of export revenue: compared with white rice.

Rice - market characteristics

Rice supply chains can be categorised into formal or informal systems. Informal arrangements exist where farmers sell their rice directly to the consumers, such as at the farm gate or in local markets. The formal rice supply chain involves farmers selling their paddy rice to processors or rice traders. The processed rice is then sold on to retailers.

In relation to the IRRI white rice and Basmati supply chains in Pakistan, the majority of growers are small-holders, with the traders who buy paddy rice to farmers performing the drying and husk removal (primary processing) and they then sell the rice onwards to rice millers.

Rice - farm systems

In Pakistan's Basmati rice belt, traditional methods of agriculture have been fully replaced by the use of tractors and harvesters. Supply chain analysis suggests that farmers often use machines designed for harvesting wheat, with implications for lower harvesting efficiency (BASIC, 2018).^{xxvii}

A detailed study of the Indian rice supply chain, focusing on two districts within Uttar Pradesh (FAO 2018)^{xxviii} found a highly organised supply chain with both publicly and privately run routes to market. The larger farmers supplied direct to the mills, reducing their costs, whereas small-holder farmers sold through village aggregators and middlemen.

Rice - comment on the estimates from study

The loss rate in rice differs by rice variety and along the supply chain in the range 25-30%, according to studies carried out in Pakistan. Although the farm stage losses are not always differentiated within the

With a production of 172 million tonnes of rice, India is the second largest global rice producer, with an export share of 26% of the global rice exports.

Although differing from region and farming system, an average of 10% loss rates at farm stage can be expected for rice in Pakistan and India. Basmati rice shows higher loss rates at the milling stage, due to higher quality standards.

The main driver for losses of rice in this regions include inappropriate choice of rice variety, use of poor quality of rice seed, factors relating to good agricultural practices and the timing and method of harvesting and threshing.

The main impact of losses falls on smallholder farmers, through losses during harvest and post-harvest operations. Some of the solutions involve technological improvements and investment, but without better farm prices and training, uptake will remain limited.

research, it is thought that losses at this stage are approximately 10% of production, similar to the central loss estimate of farm stage losses assumed from our work.

Loss rates are higher for Basmati rice varieties compared with coarse grained rice: mainly due to higher quality specifications in the length and shape of grain demanded by end markets. These losses occur mainly at the milling stage, where the market requires a more polished product.

Rice - factors driving losses at farm stage

The main factors driving losses at the farm stage include inappropriate choice of rice variety, use of poor quality of rice seed, factors relating to good agricultural practices and the timing and method of harvesting and threshing. In the case of FAO's case study, farm losses associated with harvesting and threshing ranged between 7 – 10%. The study identified higher loss rates at the farm stage where farm labourers had limited understanding of how harvest and post-harvest operations impact on the quality (and losses) of rice for subsequent stages of the supply chain. Labour factors also directly impacted on the losses at the farm stage through poor operation of combine harvesters, incomplete separation of panicles from rice straw, shattering of grains in dry conditions (or where non-shattering varieties not chosen) and poor drying practices. It was also found that when pesticides were applied excessively to crops, their residues may result in grain being rejected at later stages of the supply chain. The study recorded low storage losses because minimal quantities were stored on-farm and management practices in warehouses was generally good.

Underlying reasons that drive losses were identified by the FAO study through their field studies and stakeholder interviews. These included an increase in tenant farming (where investment is more problematic), rising labour costs and a general perception that losses were negligible (even though evidence suggested otherwise).

Rice - mitigating actions

The main impact of losses falls on small-holder farmers, through losses during harvest and post-harvest operations. Some of the solutions involve technological improvements and investment, but without better farm prices and training, uptake will remain limited.

Key actions to address losses identified by stakeholder interview included:

- Implementation of integrated pest control systems to address losses from rodents, birds.
- Need for training / education, with inputs from government sector and NGOs, training schemes need to acknowledge the key role played by women in planting and tending crops and at harvest and drying stages.
- Need for better/ more efficient irrigation systems.

Drying – The FAO study in India identified good practice in relation to the sun drying of paddy in the open fields, with the paddy spread on a plastic sheet for 2 to 3 days, depending on the weather. With wet weather, the plastic sheet is then folded over and covered with another sheet to protect the grains.

Timing of harvest - Higher storage losses result from harvesting in wet weather conditions, result in grains needing extra drying, hence it is crucial to harvest at the correct maturity for paddy and moisture content required for harvesting.

Improvements to harvesting machinery, combine harvester – Currently, the combine harvesters used in India's Andhra Pradesh region are not efficient and can only perform shallow cutting, which results in residual grains being wasted. They achieve poor separation of rice panicles from straw and much rice grain is scattered through their rough harvesting mechanism. The introduction of more advanced

combine harvesters would enable deeper cutting and help minimise harvest losses. Training would be needed to operate the improved machines.

Fair prices: rice farmers are at the bottom of the rice value chain and are in a weak position to negotiate for prices in their interactions with traders and millers. Research commissioned by Oxfam estimated that farmers in Nepal, Pakistan and Vietnam receive 4-17% of price paid by consumers for rice (Segal and Minh, 2019).^{xxix}

Paying a fair price to farmers for rice sold to export markets would encourage better handling and post-harvest care and improve the livelihoods of farmers. According to a study commissioned by Oxfam, Pakistani IRRI rice farmers typically earn 50% below the living income from selling their rice. Although they generally also grow other crops, in some seasons it may be difficult to cover their costs. As an indication of the distribution of value in relation to Basmati rice sold to European supermarkets, the Oxfam study found that Pakistani farmers received only 5% of the consumer price of their product sold in a Swedish supermarket. In contrast, the Swedish supermarket's share was greater than 50% (Alliot and Fechner, BASIC, Oxfam 2018).^{xxx}

Different contractual arrangements were identified as part of the solution to addressing rice losses (stakeholder interview, FAO 2018). Where farmers connect directly with markets, closer working with the customer results in better crop monitoring and the farmer has greater certainty of obtaining a good price compared with selling to brokers. This model is given extra momentum with the increased growth in the supply of branded rice products over recent years and could be facilitated by farmer associations and cooperatives.

4.3.3 Cereals and pulses - summary of environmental impacts from Section 3

- The main environmental impacts from losses associated with cereals and pulses are from greenhouse gas emissions and water abstraction.
 - GHG emission: losses from production within this commodity group is the second highest contributor, with the majority coming from post-harvest losses.
 - Rice contributes 43% of emissions from this category followed by maize (30%) and wheat (26%). The pattern of emissions largely follows the pattern of losses, although wheat in North Africa, West and Central Asia and maize in Sub-Saharan Africa have emissions that are disproportionately high in relation to losses due to the relatively high intensity of production in those regions.
 - Freshwater withdrawals vary significantly between regions and crops - European wheat and other cereal production is largely rain-fed with little water use, whereas wheat production in Asia and the USA is much more dependent on irrigation.
 - Rice requires a large amount of water no matter where it is grown although there is some variation between countries, with production in Japan showing relatively low use in the lifecycle analysis. Rice production also results in very high acidification and eutrophication potential.
-

4.3.4 Biodiversity and water impacts within case study 1 and 2 areas

The impact on biodiversity for cereals and pulses depends a lot on the crops type and growing region, besides the intensity of production and management system.

Countries in case study 2 (South and Southeast Asia) have low rankings for biodiversity and habitat as well as ecosystem services in the Yale EPI, implying that the state of biodiversity as well as framework



to protect it is relatively poor. Rice production losses may be linked to pressures on biodiversity through land-use change and high use of water in rice paddies. India is responsible for 37% of the food loss within this commodity group and region and suffers high water stress and land-use change.

Conversely, wheat production in Europe (case study 1) is not, overall, associated with significant potential impacts on biodiversity from land-use change though it varies by country (see below). The biodiversity and habitat rankings for the case study countries are all high (positive), although ecosystem services tend to be rated lower.

Due to chemicals used in crops, acidification and eutrophication potentials are a moderate impact from wheat. However, all main growing countries rank relatively well within the pollution emissions and sustainable agriculture ranking.

Water level change can be one effect of water irrigation in more arid and semi-arid regions, which can lead to further problems in the region for flora and fauna, due to fluctuations in the water table caused by water abstraction.

Besides having a negative impact on biodiversity, croplands in humid areas can however also maintain bio-diverse habitats, depending on the degree of management.

The potential impacts on biodiversity of increased wheat production in Europe vary by country – Russia grows about 30% of the region’s wheat and has a middle ranking (111 and 113 in the EPI’s Biodiversity & Habitat index and Ecosystem Services index respectively) for its biodiversity protection and historic biodiversity loss rates. Other large growers such as France and Germany have better rankings for these indicators, albeit in a region of comparatively low endemic species richness.

For Case study 1 - wheat, there remains very little scope for expanding the total area of cropland in Europe but some potential for intensification (i.e. growing more on the same land), based on biophysical and socio-economic factors (Zabel, F., Delzeit, R., Schneider, J. et al., 2019)^{xxxi}. This includes, amongst other factors, yield increases through better crop utilisation and food loss reduction actions, as discussed in case study 1 mitigating actions.

Eastern Europe and Former Soviet Union shows the greatest potential for intensification and in the scenarios modelled (Zabel, *op. cit.*), it makes a significant contribution to increased crop production (for all crops, not just wheat).

Most of Europe is relatively low in endemic species richness (the number of endemic species in an area weighted by the share of the range in that area). Intensification (or expansion) is therefore unlikely to result in a significant loss of endemic species.

For case study 2 -rice, much of South and South-East Asia has medium to high levels of endemism richness, with particularly high levels in Papua New Guinea and Indonesia. Rice fields represent 15% of the world’s wetlands.

The majority of the region also has potential for agricultural intensification and expansion with the exception of India, where socio-economic factors may limit expansion.

The overlap between biodiversity and increased production case studies is most clear for expansion rather than intensification, and particularly in areas of Myanmar, Thailand, Cambodia and Vietnam and a small area of Indonesia. If intensification reduces the need for expansion in this region then this could help reduce potential species loss. Intensification (which could include increased use of pesticides to reduce losses) is not such a risk to species in this region. To the extent that it could reduce expansion then there is the potential to avoid species loss.

Water stress



The WRI Aqueduct water stress baseline water stress varies significantly by country and within country by watershed and also by time with changes in demand and supply.

The LCA analysis uses a more granular measure “AWARE (available water remaining)”^{xxxii} which “quantifies the potential of water deprivation... based on the available water remaining per unit of surface in a given watershed relative to the world average, after human and aquatic ecosystem demands have been met.” It is “based on the inverse of the difference between availability per area and demand per area”.

The characterisation factor (w) ranges from 0.1 to 100 where a low number represents low stress and 1 is the global average.

European wheat

At a high level, the largest wheat producers in Europe are Russia all have low to medium stress, with the exception of France, which has medium to high stress. However, as noted, most wheat production within the region is rainfed, so water withdrawals are relatively low. Hence there is relatively little impact on water scarcity within the region.

Asia - rice

Rice production is very water intensive and most water comes from irrigation. Water stress in the main producing countries ranges from low (Vietnam and Bangladesh) to extremely high (India). The more granular AWARE factors also show correspondence between water use and water stress for different producers studied. The highest CFs are in India (Haryana state, 83) and Iran (91) where water use per kg of rice is particularly high whereas the lowest water-intensive production area of India (Andhra Pradesh) also has a low CF of 2.

4.3.5 Socio-economic impacts - case studies 1 and 2

Within this commodity group, rice grown in South and Southeast Asia generates the highest overall monetary loss across all case study areas and commodity groups, which was based on the average FLI basket group price. The lost value for rice in this region amounts to \$15,700 million, with an average value loss of \$355/ tonne of product. Within S&SE Asia the contribution to GDP of agriculture, fishery and forestry is around 15%, which indicates the vital role of this sector plays within the economy of the region.

While challenges remain for reaching both SDG goal 1 and 2 within the area, countries identified as the case study areas are generally on track for reaching the SDG goals by 2030.

Compared to the high losses from rice in Asia, wheat grown in Europe only generates low value losses in comparison, with a total value loss of \$1,900 million and an average loss per tonne of \$312. Across the European case study countries, the contribution to the individual country’s GDP is between 1% (France & Germany) and 12% in the Ukraine. The SDG goals have all already been achieved. A big contribution to the country’s food security cannot be directly linked to the food losses.

4.4 Fruit and vegetables – case studies 3 and 4

- Data coverage 1,360 observations were assessed of which 482 were selected, of these S & SE Asia accounted for 48% and Sub-Saharan Africa, 21%. Significant data gaps exist for North Africa /W & C Asia and Latin America, with less than 10 useable observations each.
- Two global regions, Industrialised Asia and S & SE Asia account for over 60% of global fruit and vegetable production. Industrialised Asia accounts for 43% of production and a similar proportion of global fruit and vegetables farm stage losses, whereas S & SE Asia accounts for 19% of production, with a proportionately lower share of global losses (15%).

- Post-harvest losses account for a significantly higher share of on-farm losses within Sub-Saharan Africa compared with other global regions. Conversely, data suggest that North America and Oceania losses are mostly associated with harvesting activities. This may partly relate to better post-harvest handling and infra-structure within this region.
- While greenhouse gas emissions from fruit and vegetables are relatively low compared with other commodities, there is a spike in eutrophication and acidification potential in Industrialised Asia associated with the global spike in fruit and vegetable losses within that region.
- Water impacts were far more significant, with Industrialised Asia also associated with the largest quantity of water abstraction losses, driven by the huge tonnage losses. Within this case study, Chinese watermelons are particularly water-intensive and make up only 9% of the tonnage losses but account for 27% of freshwater withdrawal impacts. Pears and peas also have a high water impact, making up 2.6% and 1.6% of the loss tonnages and with each accounting for approximately 9% of freshwater abstraction associated with regional losses.

Figure 33: Food Losses -fruit and vegetables, (million tonnes)

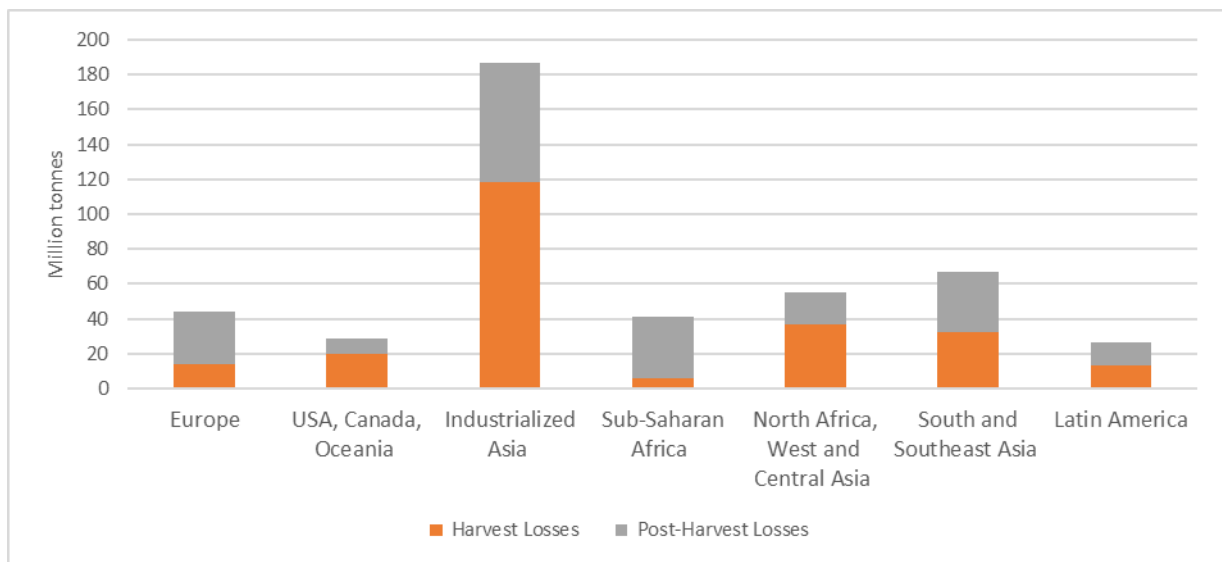
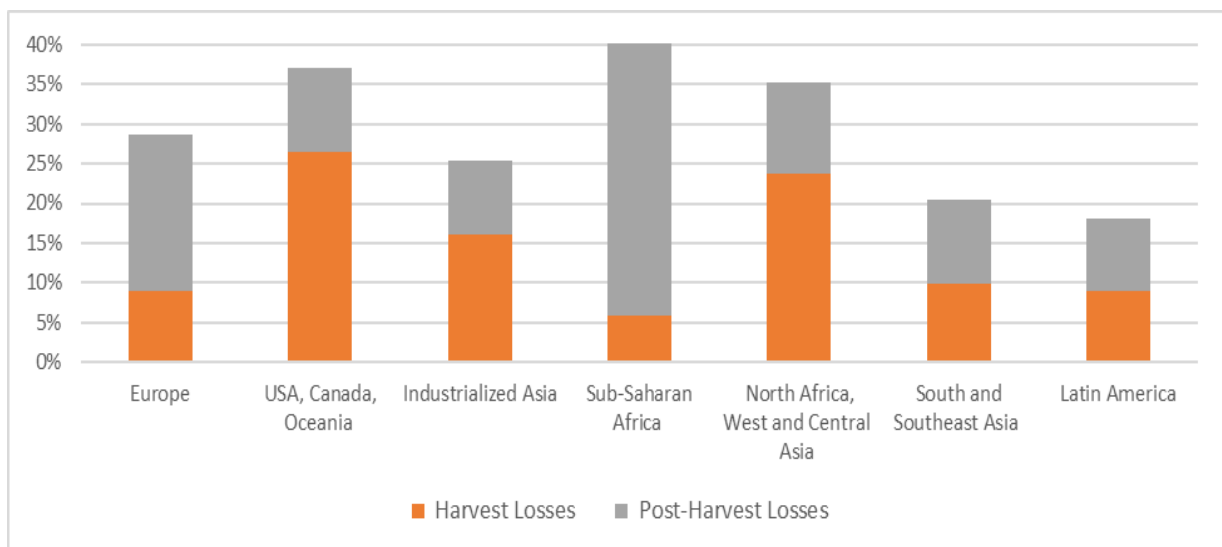


Figure 34: Fruits & Vegetables % food production lost at farm stage





4.4.1 Case study 3 - Sub-Saharan Africa - citrus fruit, okra and other vegetables

- Analysis was based on 103 datapoints with citrus, aubergine and other vegetables identified as having particularly high loss rates.
- The region grows a very wide variety of fruit and vegetables, including many tropical varieties and is a major exporter of grapes, citrus, apples and other produce.
- High farm stage loss rates for citrus production were found in the available data (31.5%) and the FAO category 'other vegetables' (48%) mainly associated with immediate post-harvest activities,
- High economic value of losses of these commodities within region,
- WWF work already underway looking at fruit & vegetable production in Kenya and South Africa.

Table 8: Case study 3 - Sub-Saharan Africa - citrus fruit, aubergine + other vegetables

Sub-Saharan Africa fruit & vegetable production as % global production	6.0%	Sub-Saharan Africa estimate of total citrus losses (tonnes)	2,621,291
Sub-Saharan Africa citrus fruit production as % regional fruit and vegetable production	8.3%	Estimated value of citrus loss (million Int. \$)	\$909
Sub-Saharan Africa aubergine & other vegetable production as % regional fruit and vegetable	13.9%	Sub-Saharan Africa farm stage citrus losses: kg per capita	2.5
Sub-Saharan Africa farm stage losses of fruit & vegetables as % global farm stage losses of fruit & vegetables	9.2%	Sub-Saharan Africa estimate of aubergine & other vegetable losses (tonnes)	6,694,246
Sub-Saharan Africa farm stage losses of citrus as % regional farm stage losses of fruit & vegetables	6.4%	Estimated value of loss (million Int. \$)	\$1,398
Sub-Saharan Africa farm stage losses of aubergine & other vegetables as % regional farm stage losses of fruit & vegetables	16.3%	Sub-Saharan Africa farm stage aubergine & other vegetable losses: kg per capita	6.3
% of citrus production lost at farm stage	31.5%		
% aubergine & other vegetable production lost at farm stage	48.0%		

Case study 3

Citrus fruits, tomato, okra in Sub-Saharan Africa- focus on the case study commodity within region

Sources: stakeholder interviews and literature review

Interviews were conducted amongst citrus growers, trade bodies and exporters within South Africa. Evidence was also gathered from a literature review that included citrus production in South Africa, tomatoes and okra in Ghana (Vowoter et al., 2013)^{xxxiii}, farm stage losses amongst small-holder farmers in South Africa^{xxxiv} and in Benin^{xxxv},

South Africa is the biggest citrus fruit exporter, with Europe as main destination.

Large scale exporting citrus farms are not expected to have high loss rates, due to high utilisation either in the intended form, or by processing so fruit juices.

The loss rates for other vegetables in Sub-Saharan Africa look very different, as these are mostly based on small-scale farming, with low technological standards. For these, the main drivers for losses are limited storage and cooling facilities, inadequate transit packaging (boxes, bags) and general low levels of technological knowledge.

Improving storage, transport and cooling facilities is one step to reduce food losses, with the overall need for more training and knowledge transfer.

South Africa is amongst the 10 largest citrus growing countries globally, and the second largest fresh fruit exporting country, with an exporting volume of over 2 million tonnes of fresh citrus fruits in 2018/19, second only to Spain. The total land area used for citrus production in South Africa is 88.5k hectare, with Limpopo being the largest production area, followed by the Eastern Cape (Citrus Growers' Association of South Africa, 2020).^{xxxvi}

Citrus fruit, tomato, okra - market characteristics

65% of South Africa's production is exported (Citrus Growers' Association of South Africa, 2020), with individual producers exporting up to 90% of their crop. Volumes not exported are sold in local markets or processed into fruit juices or other products. Residues, such as peel or low-quality fruit unsuitable for processing is mostly diverted to animal feed.

The main export destination for citrus fruits is Europe (33%), followed by the Middle East (19%) and South East Asia (16%) (Citrus Growers' Association of South Africa, 2020).

For small-holder farms, representing 80% of all farms within Sub-Saharan Africa^{xxxvii}, the route to market is shorter and may include transport to local markets, selling direct from the farm: either to the community or to traders (wholesalers or retailers).

Citrus fruit, tomato, okra - farm systems

As one of the world leaders in growing and exporting citrus fruits, South Africa's technological standards for commercial-scale farms is very high, with new technologies being tested and invested in. Furthermore, many farms make significant R&D investments to optimise production processes and reduce inefficiencies.

In contrast to the highly industrialised farms in parts of South Africa, the majority of farms across Sub-Saharan Africa are small-holder farms. In Ghana the technological standard for growing fruit and vegetables is rather low at the farm stage, with low practices of pre-cooling of tomatoes before transportation. The farm system at commercial farm level still involves a high proportion of manual harvesting, for instance in the cultivation of tomatoes.

Citrus fruit, tomato, okra - comment on the estimates from study:

On-farm losses of around 30% for citrus fruits for Sub-Saharan Africa seem too high in relation to South African citrus production (stakeholder interviews). This is explained by a combination of the citrus export production being atypical of a region dominated by small-holder agriculture and food waste definitional issues. Most of the citrus fruits are intended for export, with most export rejects being used for fruit juices and for animal feed, if all other options fail. Furthermore, a distinction should be made between South Africa and other Sub-Sahara African countries, as the level of farm technology is very different as is the level of farm level food loss.

Low loss rates from the citrus industry are emphasised in other studies, as fruit unsuitable for export are processed into fruit juice, fruit salad, canned or jam. Out-graded fruit that has not met supermarket specifications in relation to UK and US supermarkets have been estimated to be around 2-3% (Jenkin, 2016).^{xxxviii}

The food loss estimates for vegetables from small-holder farms in Ghana look very different to citrus losses in South Africa, albeit looking at other crops. Tomatoes grown in Ghana have post-harvest losses of between 20-50%, while Okra has losses of around 20-30% (Vowoter et al., 2012)^{xxxix}. Loss rates for other vegetables in South Africa from small-holder farmers have been reported within a typical range of 5-25% during handling, 1-10% storage losses, 5% for packaging and 1-3% transport to market. Around 1-5% of the products is returned from market unsold. Overall, higher loss rates are noticed in the summer months (South Africa) of November – February, with lower loss rates being between June and July.

In Ghana, around 18% of vegetables at farm level are sold at discounted prices due to defects, decay and damages. These vegetables are often used for the preparation for soups and stews (Vowoter, *op. cit.*).

Citrus fruit, tomato, okra - farm activities: breakdown of losses by activity

The losses from citrus fruits have been assessed in Benin (Affognon, H. *et al.*, 2014)^{xl}, where most losses occur during harvest and marketing activities. Roughly 20% of losses are estimated on-farm due to damage and decay, with another 51% at wholesale. This leads to a total of 84% of products having to be sold at discount prices at retail stage due to quality losses.

The average value loss across Sub-Saharan Africa for fruit and vegetables in total are estimated to be 10% from production, and 9% during post-harvest handling processes.

For tomatoes grown in Ghana, the loss rates can be broken down into the different handling steps from farm to market. Higher losses occur during the minor season rather than the major season. The following breakdown shows the loss rates at each stage during major season and minor season, with overall losses between 20-30%.

- Harvesting operations - 3.4-4.2%
- Assembly at farm – 2.-1.4%
- Grading and sorting – 5.5-2.6%
- Transport – 3.1-3.6 %
- Store at home / farm – 3.9 – 3.3%

Okra grown in Ghana has an overall loss rate of around 20-30% at farm stage, with a relatively short shelf life. Unsold okra at the local market is mostly discarded, as return transportation to the farm would not be feasible. The split of losses is 16.6% at farm level, 2.3% at wholesale level and 6.3% at retail level.

Citrus fruit, tomato, okra - connection to market

Big supermarket chains in South Africa often have direct contract with large farms, who then transport their produce to regional distribution centres, for onward delivery to stores. Distribution centres carry out quality checks on the produce received. Large-scale farms are responsible for supplying three-quarters of the fresh produce market within South Africa. The routes to market include direct sale to retail and wholesale, fresh produce markets, hawkers, processors and consumers.^{xli} Small-holders are responsible for less than 10% of the market and mostly sell to local markets or via traditional street stalls.

For small-holder farmers in Ghana, the harvest is either transported by vehicle to the closest market, or it is carried as head load to market. The latter is still a very common transportation technique for harvest in many parts of Ghana.

Citrus fruit, tomato, okra - factors driving losses at farm stage

Losses can occur due to extreme weather events, such as droughts, hail, as well as pests and diseases. Another factor which can influence fruit being left in the field are supermarket specifications and consumer expectations of the appearance.

Drivers for tomato losses at farm stage in Ghana can be multiple:

- Low levels of technical knowledge / no technical knowledge
- Poor handling in field and in post-harvest stages
- Lack of storage facilities which preserve the products or extend shelf life

- Lack of processing capacity within the region to provide alternative markets for surpluses
- No pre-cooling of products after harvest
- Droughts causing harvest losses.

Citrus fruit, tomato, okra - mitigating actions:

One of the first steps to mitigate food losses at the farm stage, is a more rigorous measuring and monitoring process. This is currently not done on any scale in South Africa. Currently there is no formal reporting system within the sector, not even amongst the large citrus growers. The development of such a system must be in tandem with training of farmers in measurement and recording of losses.

Other general innovations and approaches towards reducing post-harvest losses include improved handling, transport and shipping containers to reduce damage during these supply chains. Furthermore, having low energy cool storage available for post-harvest steps through to end markets. Depending on the scale of the farm, implementation of on-field packing systems and limiting the direct sunlight on the product after harvesting can also reduce the volumes of fruit and vegetables lost at the farm stage (Kitinoia, 2013).^{xlii}

Other potential mitigation actions to reduce losses, especially for small-holder farmers would be:

- Better storage and transportation containers, such as sturdy boxes instead of plastic bags where produce often gets crushed
- Better field packing methods during harvest to reduce damage and reduce the handling of produce between harvest and market
- Improved pest management
- Low-cost cooling and storage methods and cool transporter to markets
- Small-scale food processing – low-cost technologies to be adopted by a greater number of farmers or as food innovation hubs within farming areas
- Better water management systems in water stressed areas, mulching and drip irrigation
- Training to improve post-harvest handling and harvest management
- Harvesting practices to identify proper harvesting time and maturity level of fruit and vegetables
- Small-scale efforts have proven to be more successful in rural areas of Ghana/ Africa than high-tech solutions, as the solutions have to be low-cost and easy to handle due to lack of training
- Especially for Okra, drying of the vegetable before marketing can reduce decay and food loss.

4.4.2 Case study 4 - South and Southeast Asia - mango, guava, aubergine, onions and other vegetables

- This region is second only to Industrialized Asia in volume of fruit and vegetable produced and accounts for 19.3% of global production.
- Farm stage loss rates were particularly high for the selected fruit and vegetables at farm stage (29% for the selected vegetables, 17.2% for mango and guava),
- These crops account for 48% of the fruit and vegetable losses within the region.
- The value of lost mango/ guava and mangosteen and of the selected vegetables is high at over \$8 billion per year, based on farm gate prices.

Table 9: Case study 4 - South and Southeast Asia - mango, guava, aubergine, onions & other vegetables

S & SE Asia fruit & vegetable production as % global production	19.3%	S & SE estimate of total aubergine, onion + other vegetable losses (tonnes)	32,267,443
S & SE aubergine, onion + other vegetable production as % regional fruit and vegetable production	33.9%	estimated value of aubergine, onion + other vegetable losses (million Int. \$)	\$5,207
S & SE mango + guava production as % regional fruit and vegetable production	7.6%	S & SE farm stage aubergine, onion + other vegetable losses: kg per capita	12.5
S & SE farm stage losses of fruit & vegetables as % global farm stage losses of fruit & vegetables	15.0%	S & SE estimate of mango + guava losses (tonnes)	4,297,226
S & SE farm stage losses aubergine, onion + other vegetables as % regional farm stage losses of fruit & vegetables	48.0%	estimated value of mango + guava losses (million Int. \$)	\$3,016
S & SE farm stage losses of mango + guava as % regional farm stage losses of fruit & vegetables	6.4%	S & SE farm stage mango + guava losses: kg per capita	1.7
% of aubergine, onion + other vegetable production lost at farm stage	29.0%		
% of mango + guava production lost at farm stage	17.2%		

Case study 4 -

Mango production in India - focus on the case study commodity within region

Mango accounts for 21% of all fruit production in India, with 20.4Mt produced in 2019-20

Currently exports account for 36 kt of fresh and 128 kt of mango pulp. Over a thousand mango varieties are grown in India, with about 30 grown commercially, including early, mid- and late- season varieties.

Overall losses within region vary greatly by variety, season (3 seasons for mango, with different varieties), maturity of orchard (taller trees more difficult to harvest).

Losses may result from broken and damaged fruit, fruit dropped directly on the ground and diseased fruit with stem-end rot. Qualitative losses relate to immature, irregular and bruised fruit caused by improper handling. Harvesting taller trees may involve climbing into trees and harvesting using 'pick and throw' method (uncaught fruit may crack when it falls to the ground). This can result in 5% damaged fruit.

Losses at the production stage are highly dependent on climatic conditions, careful handling and the presence of pest and diseases: these factors determine a large part of the losses at the farm stage and at subsequent stages of the supply chain. Pre-harvest infections greatly impact post-harvest decay and losses throughout all subsequent supply chain stages.

Some technological mitigation actions can include:

- Introduction of drip-irrigation, fertigation to improve yields.
- Evaporative cooling chambers for use in field to reduce field heat in mango.
- Mango de-sapping techniques: e.g. destemming with lime wash, use of racks to hold inverted fruit.

Sources: stakeholder interview and literature review

India is the second largest producer of fruit and vegetables in the world only surpassed by China and has increased production between 2007-2017. During this period, the area under horticulture grew 2.6% per annum and total production grew 4.8% per annum. This trend was driven by the dietary shift in the population away from staple starchy foods towards more diversified food, included more fresh produce. Within this context, mango is India's national fruit and accounts for 50% of global production of tropical fruits (Ministry of Agriculture, 2013).^{xliii}

Mango production statistics

Mango accounts for 21% of all fruit production in India, with 20.4Mt produced in 2019-20 (Area and Production of Horticulture Crops).^{xliv} Currently exports account for 36 kt of fresh and 128 kt of mango pulp. Over a thousand mango varieties are grown in India, with about 30 grown commercially, including early, mid- and late season varieties.

Extensive mango cultivation occurs across a number of states, with Andhra Pradesh having the largest area under cultivation. This was the location of an extensive field studies carried out by the FAO as part of the Save Food initiative (Case study on the mango value chain in the Republic of India, FAO 2018).^{xlv}

Mango market characteristics

A large share of fresh and processed horticultural exports from India are sold to major Near East and European markets. The main mango markets include raw green mango (2%), fresh (> 80%) and mango for pulp processing (16%). Cottage industries also process small quantities into other processed products (e.g. jams and jellies).

Mango farm systems in Andhra Pradesh State

Three-quarters of Andhra Pradesh's mango farmers cultivate small and marginal land holdings of not more than two hectares, the remainder are medium (4 ha) to large farms (10 ha) of approximately. For small-holder farmers the mango crop may contribute 30-40% of their annual income.

Mango - connection to market

A distinction between farmers supplying for pulp and export markets versus those selling to fresh markets is that pulp suppliers have direct links to the processing plants. These farmers generally have a better understanding of post-harvest handling and quality requirements than those supplying fresh mango markets. They are also more likely to be governed by Good Agricultural Practices, with guidelines developed in relation to soil testing, integrated pest and nutrient management, application of agrochemicals and post-harvest handling procedures. These are all key factors in improving the quality of mango and reducing losses at all stages of the supply chain.

Those supplying fresh – sell through traders, some via pre-harvest contracts or sell direct to market. The main markets for fresh are mostly distant from farm (68.6%), with 5% produced for export.

Mango - farm stage loss rates

Loss rates are highly varied across growing regions in India, depending on climatic factors, different harvesting campaigns and a range of factors relating to orchard type, mango cultivar, harvesting techniques, skill of farmer in judging fruit ripeness. The extent to which there are a range of markets available for different mango qualities also influences losses. Where Good Agricultural Practices (GAP) are followed, losses are lower than on farms where factors that influence mango loss and quality are only poorly understood.

Jha *et al.*,^{xlvi} report a downward trend in mango losses when comparing 2013/14 data against an earlier study for (2005/7); FAO 2018 harvesting losses (10-15%).

The FAO study differentiated losses by mango supply chain type, with losses at orchards supplying fresh mango markets higher at the harvest stage (10-15%) compared with pulp suppliers (5-10%). This difference was offset by higher grading losses in the pulp supply chain compared with fresh.

As with other highly perishable produce, a glut in the mango market increases losses, as the incentive to harvest and supply is reduced.

Detailed research in Andhra Pradesh (FAO 2018) provides evidence that quality losses are very significant through damaged fruit (physical damage during harvest and sap damage, when resinous sap exuded from the cut or broken fruit pedicel burns into the skin of the fruit).

Mango - losses by farm activity

During harvest, losses relate to harvested fruit being immature, sap damage, mechanical damage during harvesting in the orchard and subsequent handling, diseases from such as stem-end rot and pest infestations. Sap damage reduces consumer acceptance and the storage life of the fruit.

During the mango harvesting, quantitative losses may result from broken and damaged fruit, fruit that is dropped directly on the ground and diseased fruit with stem-end rot. Qualitative losses relate to immature, irregular and bruised fruit caused by improper handling. Harvesting technique and height of the orchard canopy are important factors. In younger plantations with medium tree height are easier to harvest whereas in taller trees harvest may involve climbing into trees and harvesting using 'pick and throw' method (uncaught fruit may crack when it falls to the ground). This can result in 5% damaged fruit. When harvested mango is then placed directly onto the ground it can become infected if the skin has become damaged. Careful removal of fruit from trees is also required to avoid sap damage.

For the fresh mango chain, grading losses are typically 5% of harvested fruit and once all damaged, spotted and diseased fruit have been removed, the remainder is graded into top grade and second grade. The graded fruit are packed into boxes for transportation. There are no major exports from this region and hence no further grading standards have been adopted.

Mango - factors driving losses at farm stage

Losses at the production stage are highly dependent on climatic conditions, careful handling and the presence of pest and diseases: these factors determine a large part of the losses at the farm stage and at subsequent stages of the supply chain. Pre-harvest infections greatly impact post-harvest decay and losses throughout all subsequent supply chain stages.

Mango losses - mitigating actions

Initiatives in place to address farm stage losses:

In Andhra Pradesh, the horticulture department has provided limited subsidies to support mango canopy management, rejuvenation of senile orchards and for integrated pest management. Support was extended to improve post-harvest practices by providing plastic crates, and the establishment of grading, packing and processing units.

- The introduction of drip irrigation for mango has increased yields from 50 to 70% and improved water management is particularly important where water tables are low and water scarcity is a problem.
- Further potential exists for promotion of precision farming through micro-irrigation, fertigation (injection of fertilizers into irrigation system), greenhouse cultivation, mulching for better water conservation and quality of production. Encouragement in the use of modern farm machinery and tools to save time and labour and to improve the harvested fruit quality.
- Promotion of post-harvest management practices and GAPs, through the establishment of pack houses, cold storage, ripening chambers and the reduction of post-harvest losses
- Application of hot water treatment to fruit within 36 hours of harvesting can be used as a treatment to minimise post-harvest decay and reduces post-harvest losses.^{xlvii}
- Improving marketing facilities through farmers' markets, vegetable markets, and collection centres and refrigerated vans so that farmers can obtain better prices for their produce.
- Processing companies play a crucial role in building farmer awareness of the factors that are important in post-harvest handling. Losses are minimised if fresh fruit is handled gently and transported in plastic crates. With more distant markets, the return of the plastic crates is an issue as their transportation may not be economically viable.
- The importance of ripening chambers is well understood by all levels of processors who have upgraded their technology through the scheme provided by the Agriculture and Processed Foods Export Development Authority (APEDA) or National Horticultural Board.

Mango losses - mitigating actions needing more attention.

- More emphasis is needed on initiatives that focus on appropriate time and method of mango harvest as a means of addressing both quantitative and qualitative food losses in the subsequent stages can be greatly reduced (FAO, 2018b).^{xlviii}
- Improvements to harvesting practices: need to be effectively communicated to farmers to ensure that they understand the impacts on later stages of the supply chain. GAPs adopted by

local progressive farmers (such as those supplying the pulp sector) and the benefits derived should also be included in the content of the training programmes.

- Mango de-sapping techniques have potential to reduce losses. These include short-stemming at harvest, inverting the fruit and placing on racks for a couple of hours and de-stemming in lime wash (Malik *et al.*, 2017).^{xlix}

Appropriate technology applied to mango production: the evaporative cooling chamber is a low-cost technology that can be deployed in remote rural areas at farm level to reduce the field heat in mango after harvest. The 2018 FAO study identified the need to promote this technology to extend mango shelf life. Units can be constructed using locally sourced materials and where adopted can reduce mango losses particularly for fresh supply chains that involve transport over longer distances.

Encouragement of entrepreneurs: to increase potential to produce value-added products from surplus mangoes that might otherwise be lost or fed to livestock.

4.4.3 Fruit and vegetables – summary of environmental impacts from Section 3

- Fruit and vegetable production is generally much less carbon-intensive than other crops such as cereals, accounting for only 8% of overall GHG emissions from farm stage losses, but for 38% of total tonnage losses.
 - The main sources at the farm stage were fuel use and embodied emissions in machinery, with important but lesser contributions from nitrous oxide from fertiliser and fruit and vegetable crop residues.
 - Emissions associated with losses within FAO’s “other vegetables” category forms the single largest source (30%)– it is mainly unspecified vegetables but also includes cucumbers, okra and spinach and anything not included in the other categories.
 - Tomato production in Sub-Saharan Africa (principally Nigeria) forms 13% of the overall GHG total making it the single biggest country / crop combination for fruit and vegetables.
 - While greenhouse gas emissions from fruit and vegetables are relatively low, there is a spike in eutrophication and acidification potential in Industrialised Asia attributable to high tonnage losses.
 - Fruit and vegetables generally use less water per tonne of production than other crops.
 - Industrialized Asia is associated with the largest quantity of water losses within the fruit and vegetable group. This is mainly driven by the huge tonnage losses
 - Whereas many commodity groups use proportionally more or similar land than their proportion of the total food loss, fruit and vegetables use much less land compared to their food loss volume. The total contribution to food loss tonnage is 38%, while their land use of 350,000 km² only contributes 8% of the total.
-

4.4.4 Biodiversity and water impacts within case study 3 and 4 areas

As for other case study areas, land use change from forest to agricultural farmland is one of the main drivers for biodiversity change and potentially loss from fruit and vegetable production.

The case study area of Sub-Saharan Africa ranks medium to low for ecosystem services, while the scores for land use change and acidification / eutrophication are overall scored good. As the impacts of land use change are not very high, the risk of impacting the biodiversity based on this factor in the region is not significant at present.

The water stress situation varies widely across the different countries, with India suffering under high water stress, where different fruits are grown. India is simultaneously responsible for around 70% of



the food losses within the case study, which increases the negative impact of water stress for food which is not consumed.

South and South-East Asia

Much of South and South-East Asia has medium to high levels of endemism richness, with particularly high levels in Papua New Guinea and Indonesia.

The majority of the region also has potential for agricultural intensification and expansion, with the exception of India where socio-economic factors may limit expansion.

The overlap between biodiversity and increased production case studies is most clear for expansion rather than intensification, and particularly in areas of Myanmar, Thailand, Cambodia and Vietnam and a small area of Indonesia.

Intensification (which could include increased use of pesticides to reduce losses) is not such a risk to species in this region. To the extent that it could reduce expansion, then there is the potential to avoid species loss.

Sub-Saharan Africa

Sub-Saharan Africa covers a huge area, and the majority has medium to high levels of species endemism richness, with particularly high levels on the Nigeria / Cameroon border, the region around Lake Tanganyika and Rusizi River on the DRC's Eastern border. Madagascar is also home to many unique species.

There is significant potential for expansion of the area planted with horticultural crops and to improve productivity across the region. However, expansion and intensification would increase the potential for biodiversity loss across much of the region.

Water stress

Water stress in the main countries ranges from Extremely High in India (a large producer of fruit and vegetables) to High in South Africa and Low to Low / Medium in the remaining Sub-Saharan African countries.

The largest freshwater losses are in India due mainly to the underlying tonnage losses, which corresponds with a country with overall high water stress.

4.4.5 Socio-economic impacts – case studies 3 and 4

The economic loss from fruits and vegetable food loss in South and Southeast Asia is roughly \$30,000 million, with an average of \$446 lost per tonne of produce. The high per tonne price shows that the products grown and lost in this region are high value crops, including products such as mangos, guavas and aubergines.

The country with the highest losses is India, which also shows significant challenges remaining on the pathway to reach SDG goals 1 and 2. This correlates with the highest contribution to GDP from the agricultural sector of 16%. In comparison Thailand, where agriculture only contributes 8% to national GDP, and only smaller challenges remain to reach “no poverty”, whereas the goal of prevalence of undernourishment has already been reached.

For most countries within the case study area challenges still remain for both SDG goals, while all but one is on track of reaching the goal. Only Iran is stagnating to reach the goal to reduce the prevalence of undernourishment.

Compared to the high total losses from South and Southeast Asia, the losses in the same commodity group are much lower in Sub-Saharan Africa, where a total value of \$3,500million is lost. The products lost are not as high value as in Asia, with mainly citrus fruits and a range of vegetables generating a value loss of around \$325 per tonne.

While the overall value losses in this region have lower rates than in Asia, the development to reach the different SDG goals shows remaining challenges across the countries in Sub-Saharan Africa, with some countries also still facing significant challenges. Especially the prevalence of undernourishment remains a (significant) challenge in all countries. Having high food loss rates from farm stage, while simultaneously still facing undernourishment in the same region suggests that food losses could contribute directly to increasing the food security in this case study area, should mitigating actions be taken and better connection to markets be established.



4.5 Roots, tubers and oil crops – case studies 5 to 8

- Data coverage 618 observations assessed of which 279 were selected, of these S & SE Asia accounted for 60%. Only 4 data points were available for Industrialised Asia and 7 for North America/ Oceania.
- The main crops included in this category are cassava (dominant in Sub-Saharan Africa, S & SE Asia, and Latin America) and potato (North America, Central Asia, and along with sweet potato in Industrialised Asia, S & SE Asia, Latin America).
- Harvesting losses are generally a higher share of total farm stage losses, except for cassava in Sub-Saharan Africa and cassava/ potatoes in Latin America, where post-harvest farm losses predominate.
- For the oil crops: soybean is the predominant crop in North America, S&SE Asia, and Latin America. Groundnut is the dominant oil crop in Sub-Saharan Africa.
- Across North America and Oceania, Industrialised Asia, and S& SE Asia the main losses occur at the harvest stage.

Figure 35: Food Losses - Roots, tubers & oil crops, (million tonnes)

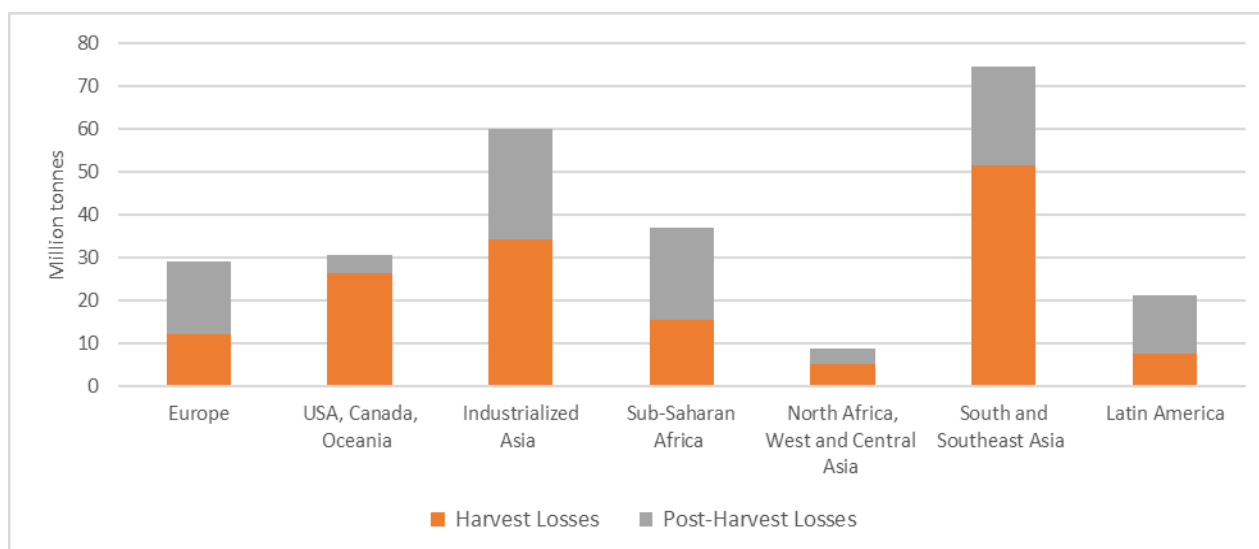
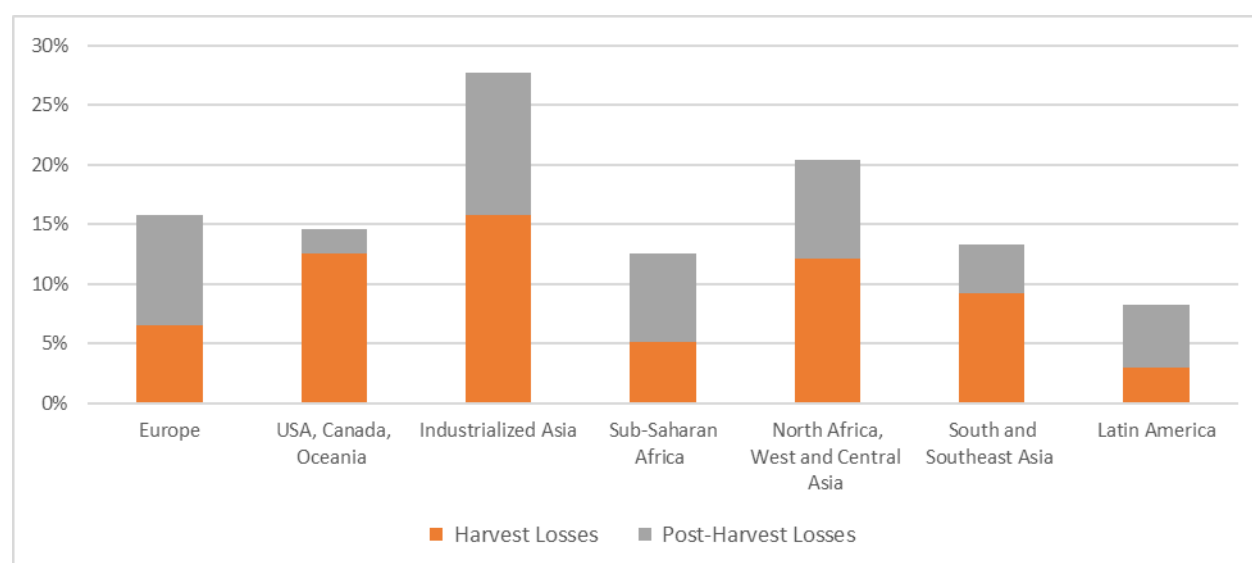


Figure 36: Roots, tubers & oil crops - % food production lost at farm stage



4.5.1 Case study 5 - Industrialised Asia – potato + sweet potato

- Coverage: estimates are based on only 4 studies, so requires further investigation, given the global significance of production within the region
- The region accounts for 25% of global farm stage losses for this commodity group, reflecting both the scale of production, but also higher loss rates than other regions
- Losses are also significant on a per capita basis, at 31 kg per capita/ year.
- The estimated economic value of the losses is over \$5 billion.

Table 10: Case study 5 - Industrialised Asia – potato + sweet potato

Industrialised Asia roots tubers & oil crops production as % global R + T & O production	12.3%
Industrialised Asia potato/sweet potato production as % regional roots, tubers & oil crops production	66.5%
Industrialised Asia farm stage losses of roots, tubers & oil crops as % global farm stage losses of R, T&O	25.4%
Industrialised Asia farm stage losses of roots, tuber & oil crops as % regional farm stage losses of roots, tubers & oil crops	83.2%
Industrialised Asia potato/ sweet potato % of production lost at farm stage	34.7%
Industrialised Asia estimate of total potato/ sweet potato crop losses (tonnes)	49,932,014
Estimated value of loss (million Int. \$)	\$5,476
Industrialised Asia farm stage potato losses: kg per capita	30.9

Case study 5 - Potatoes grown in SW China

Sources: interview with academic expert, South West China Region and literature relating to Asian potato production (Scott u. Suarez, 2012)¹

Potatoes grown in the developing countries of Asia, including amongst others China and India, has increased the yield / hectare and calories per hectare compared to the mainly cereal based agriculture in the area. Furthermore, potatoes are a very profitable crop for small-holder farmers. Overall, potatoes contribute to Asian food security.

The average yield per hectare is around 16.4 t, which has increased by around 1.4% annually over the last half century (yields as high as 70 t/ha have been reported in New Zealand).

China became the world leader in potato production in 1993, with a steep increase in yield productivity. The majority of the yield is consumed regionally, with only 3% export rates.

The main driver for food losses include poor handling and packing methods, limited storage facilities. In addition to this, the weather plays an important role, as too high moisture content can increase the risk of mould, pest and diseases.

Technical training in one of the key mitigation actions against food loss rates for potato production at farm stage.

Potato-Chinese production statistics

In 1993 China became the world's largest potato producer, with the developing countries in Asia producing a total of 46% of the global output of potato production. This is roughly twice the production volume of Europe.

Across the developing countries of Asia, potato production averaged at around 144.6 Mt per year between 2008-2010, with a steep increase in productivity. This was especially the case in China, where production areas decreased while yield increased.

China and India are the largest contributors to potato production in the region, together producing 74% of the regional output, and using 77% of the areas managed for potato production. According to FAO, potato production in China was 99 Mt in 2017, of which 62 Mt was used directly as food, 6 Mt went into processing, 19 Mt was used as animal feed and 7 Mt was reported as losses (FAO New Food Balance Sheet, 2017 data).

Potato – market characteristics

As potatoes grow in a short vegetative cycle, and are high yield crops, potato cultivation in Asia is mainly for commercial purposes and as a cash crop, which also applies to small-holder farmers. However, the majority is consumed regionally and not exported out of the region. In China and West Asia, only around 3% of annual production is exported.

Potato – SW China farm systems

In the Southwestern region of China, potato crops take up around 70% of the cultivation land area. This is mainly for national use, as potatoes are a big contributor to the national food security. The technological standard in harvesting and managing the crop and the field is very low in Southwestern China, where farmers have to rely more on the weather and natural conditions than on the management methods in the field.

Potato - comment on the regional estimates from study

Food loss values are not expected to be as high as the study data used in the global calculations suggest (34.7% of production lost) and are assumed to be under 5% at farm stage, according to the expert interview, with an additional 15-20% being lost during storage and transportation processes. It is not clear whether or not the 34.7% losses included the route to animal feed, which may explain the wide difference between the assumed loss rate and expert opinion. As wider context, according to FAO's



Food Balance Sheet for China, potato losses during storage and transportation accounted for 7.5% of potato production, with 19% of China's potato production used to feed animals.^{li}

Potato- farm activities: breakdown of losses by activity

According to findings from the interview, mechanical lifting of potatoes results in a loss / leakage rate of around 3% in the field, with an additional 15-20% losses occurring at storage and during on farm transportation .

Potato- factors driving losses at farm stage

The factors driving losses include lack of appropriate storage facilities, poor handling and packaging system. Of prime importance is the weather, as high moisture during the growing process can result in higher disease incidence. Pests and diseases often include late blight (*Phytophthora infestans*), which can be an important factor in reducing yields and quality of tubers.

There is a need to improve the quality of seed potatoes and to store freshly harvested potatoes in good condition to maintain tuber quality and obtain better prices (Ilangantileke, S., FAO, undated).^{lii}

Potatoes that cannot be used for human food are fed to animals or left in the field (e.g. to feed chickens or used as fertilizer for soil), with this unofficial route not contributing to FAO's statistics on harvested potato product used as animal feed. Potato farms in China are often located in poorer mountainous areas, where the utilisation rate of the grown food is high, due to cost of growing and need for food.

Potato - mitigating actions:

In order to mitigate potato losses, but also to increase yields, technical training should be available to farmers. This could be done within government schemes, or university collaborations, such as the current 'Science and Technology backyard' scheme. This Chinese government scheme has been designed to empower small-holder farmers with sustainable intensification of agriculture. This is a route that small stakeholders stand to greatly benefit from and which they would like to see in the future, to improve their practices leading to increasing yield, reduce losses, and ultimately improve their economic benefits. As such, the mitigating actions that local farmers would benefit from are mostly training and knowledge transfer in relation to cultivation, soil and pest management, harvesting and postharvest storage. On the other hand, the big potato company has largely invested *to 'rectify the land, purchase machinery, and prevent diseases and pests.'* However, they will benefit from *'government incentives and/or investing programmes'* for them to improve their facilities and expand to other areas where potato tubers are not currently cultivated, maybe because of less favourable elevation and growing conditions.

It is also the industry's view that national and local policies and regulations are key to improve the cultivation of potato tubers in industrialised Asia and to reduce food waste; yet the leader of the company will eventually have a key role in the successful implementation of technology and management of the crop. All in all, a better link between researchers, policy makers and government funding is needed to directly support both small farmer and bigger potato companies to develop and adopt technology.

Key areas that can help to reduce potato losses in China include the development of cultivars resistant to late blight and improvement in seed potato quality (Wageningen, 2017).^{liii}

4.5.2 Case study 6 - Latin America - cassava, potato + sweet potato production

- Latin America: cassava, potato, and sweet potato: 3 crops account for 95% of production roots and tubers, with cassava accounting for 54% of total volume.
- High loss rates (26.4%) at the farm are mainly due to post-harvest activities rather than harvest losses.

- The economic value of losses is significant (over \$1.2 billion) as is the loss per capita (20 kg).

Table 11: Case study 6 - Latin America - cassava, potato + sweet potato production

Latin America roots & tubers production as % global	2.8%
Latin America potato/sweet potato/ cassava production as % regional roots & tubers production	94.8%
Latin America farm stage losses of roots, tubers & oil crops as % global farm stage losses of roots & tubers	10.8%
Latin America farm stage losses of roots, tuber & oil crops as % regional farm stage losses of roots & tubers	58.3%
Latin America potato/sweet potato/ cassava % of production lost at farm stage	26.4%
Latin America estimate of total potato/ sweet potato/ cassava crop losses (tonnes)	12,372,261
Estimated value of loss (million Int. \$)	\$1,221
Latin America farm stage potato/ sweet potato/ cassava losses: kg per capita	19.6

Case study 6 - Focus on cassava grown in Trinidad & Tobago and Guyana and potatoes grown in Peru

Sources: Literature review – FAO reports using four elements approach Cassava losses in Trinidad & Tobago^{liv} and Guyana^{lv} and stakeholder interview

Cassava is a commonly grown and eaten root in Latin America, where it is used as a staple food in different forms, in this example grown in Trinidad and Tobago. As another example, potatoes grown in Peru. Potatoes have been an important component of Peruvian diets for millennia.

Cassava and potatoes - production and market characteristics

Cassava, Guyana = 7,335 tonnes

Potatoes, Peru: total production of 4.8 Mt, 475 kt used as feed, 1.1 Mt losses, 257 kt other uses and 2.5 Mt used as food.

Cassava, Trinidad and Tobago= 1,950 tonnes

Cassava grown in Guyana are mainly grown by small-holder farmers, covering a wide range of different soil types in all regions of the country.

In both areas the industry is characterised by a diverse range of producers and traders

Cassavas are commonly eaten in Latin America / Caribbean, where it's mostly grown by smallholder farmers.

Loss rates are reported to be lower than estimated within this study, with loss rates of around 7%.

Losses occur mostly due to poor harvesting techniques, transportation, as well as heavy weather events.

By changing the harvesting and transport method and increasing care, loss rates could significantly decrease.

Cassava and potatoes - farm systems

In Trinidad and Tobago, as well as in the Andean highland region of Peru, the cultivation of cassava and potatoes is mainly based on small-scale farms. Cassava grown in Trinidad and Tobago is mainly grown for wholesale markets or processing into other products such as frozen logs. The roots can be harvested and marketed over a staggered period of between 7 to 15 months (after which they might become



fibrous and some varieties bitter and woody), but once the root has been lifted it is highly perishable under ambient conditions and only marketable for around 2 days after harvest (FAO).

After harvesting, which is mainly done by manual labour and often involves spading forks, the harvested roots are packed in plastic bags and transported to markets or further production.

Peru has a diverse farming system, with a mix of small and large-scale farms. The small-scale farms in the highlands of the Andean region are mostly managed in a very traditional way, with much manual labour involved. Farms are mostly not directly linked to markets, with high dependency on middlemen to transport harvested goods to market locations. This dependency can lead to problems and losses, if planned transports are delayed or cancelled (which was the case during COVID-19 disruptions in 2020).

In comparison to the small-holder farms in the highlands, the lowlands of Peru have many large-scale farms with land holdings of 2,000-3,000 hectares. These farms are highly industrialised, with little manual labour or external dependencies.

Cassava and potatoes - comment on the estimates from study

Farm losses of potato in Peru are expected to occur at a higher rate on small-scale farms than on the industrialised farms.

In Trinidad and Tobago (FAO), the cassava loss rates are estimated to be lower than those used in the global food loss calculations, (7% losses at farm stage compared with 26%). Possible factors contributing to this difference, apart from geographical and methodological differences, include the use of lower grade cassava roots for use in animal feed possibly included as food waste within studies contributing to the higher estimate and the relative diversity of end markets found in Tobago (enabling greater crop utilisation).

Cassava and potatoes - farm activities: breakdown of losses by activity

The loss rates from cassava grown in Trinidad and Tobago at the production stage mainly occur during harvesting and at the pack-house. During both stages, the loss rates are estimated to be around 3.5%. The losses during harvesting mainly occur due to punctures or abrasions on the root itself, which happens through contact with the spading fork used to loosen the soil. This can lead to breaking the distal ends, which becomes a point of potential decay through micro-organisms being able to enter the root (FAO).

Losses during packing occur through physical damage to the root during the packing and transportation handling process. This damage happens as the roots are often packed in plastic bags and transported in multiple layers on the vehicles.

Although out of scope for this report, losses at further stages in the supply chain can mostly be traced back to damages due to harvesting and transportation stages and result in further losses at the market stage. Hence, the cumulative damage to the root must be considered throughout the supply chain, with the lowest losses occurring at earlier stages, and the highest loss rates at market stage.

Guyana shows higher loss rates than Trinidad and Tobago. The losses during harvest are around 6.5%, due to similar reasons such as punctures on the roots and damage to the skin through the spading fork.

Losses during packaging / transport are slightly lower in Guyana, with roughly 2% losses at this stage.

Total losses (including losses at market stage) are around 23%, which is very similar to the estimated loss rate for this commodity group across Latin America estimated by this study (Table 11).

Cassava and potatoes - connection to market

In Trinidad and Tobago, the cassava farmers are directly linked to the markets and responsible for the transportation of the goods to the market or further processing.



In both Guyana and Peru's small-scale farms the farmers are reliant on middlemen for transportation, which can both increase losses and reduce the quality.

Cassava and potatoes - factors driving losses at farm stage

There are different factors driving losses for the different products. For cassava grown both in Trinidad and Tobago and Guyana losses occur mostly due to poor harvesting techniques and transportation. Traditional harvesting of cassava is a labour-intensive activity that involves manual lifting of the stem and pulling the roots out of the ground. This is particularly hard work during the dry season when lifting can cause the roots to break off in the ground. A range of semi-mechanised and fully mechanised harvesting options have been developed, but more work is needed to make these technologies appropriate to different growing conditions and scales of farming (Amponsah, S., Addo, A. and Gangadharan, A., 2017).^{lvi}

Furthermore, the roots are mostly packaged in plastic bags for transport, without further protection, which can lead to damage from other roots in the vehicle, or through careless handling during loading and unloading.

Weather and temperature are a cause of losses for both cassava and potatoes. Potatoes grown in Peru can be under high weather stress, as the seasons are greatly influenced by El Nino / La Nina weather events. These weather events lead to extreme rain fall and higher moisture content in the air, which impacts storing capacity. Moreover, heavy rain events can destroy storage facilities and infrastructure necessary for transport to markets, which can make the harvest unusable and lost. Depending on the time of the rain falls, the root systems can also be destroyed during the growing process.

Cassava and potatoes - mitigating actions:

The mitigation actions can be very specific to the different crops and farming systems.

For cassava, a change in the harvesting technique can bring the biggest reduction in losses. A change in the cutting method of the root during the harvesting process can make it more resilient to decay. This aligns with the overall need to increase the care when harvesting the roots, to prevent damage to the root skin that would accelerate microbial activity and decay.

As a lot of loss occur due to the packaging prior to transportation, plastic crates instead of plastic bags are preferred as a means of limiting damage during transportation and handling processes.

An overall mitigating action to reduce losses is to ensure rapid post-harvest packing and transportation to market, as cassava root condition deteriorates the longer the exposure to sunlight directly after harvest. Ideally, the root should be packed for transportation between 1-2 hours after harvesting.

Adequate field drainage in cassava production and overall field sanitation and management can reduce the occurrence of pests and diseases.

Field drainage is also a component of mitigating actions in Peruvian potato production, though for a different reason. On large-scale farms, drainage and channels are constructed to lead excess water away from the fields during in extreme weather events to protect the growing crop. If necessary, greenhouses are also used to protect the crops during late frost periods.

To prevent losses in small-scale potato farming in Peru, more emphasis has to be put on increasing the independence of the farmers to transport their harvest to market, as the dependency on middlemen increases the risk of food losses.

An overall problem in Peru in tackling food losses at farm stage is the missing governmental agenda to tackle this topic. Much priority is put on support given to export goods, while locally consumed produce is lower down the list of government priorities.

4.5.3 Case study 7 - Europe - rape seed and sunflower seed

- Rape seed and sunflower are the dominant oilseed crops in Europe, accounting for over 70% of oilseed production volume.
- Losses are large in tonnage as well as having a high farm stage loss rate (12.7%)
- The economic losses are estimated to be \$1.7 billion.

Table 12: Case study 7 - Europe - Rape seed and Sunflower seed

Europe - oilseed production as % global	9.0%
Europe rape seed/ sunflower production as % regional oilseed	70.6%
Europe farm stage losses of oilseed & pulses as % global farm stage losses of oilseed	13.5%
Europe farm stage losses of rape seed / sunflower as % regional farm stage losses of oilseed	74.2%
% of rape seed/ sunflower production lost at farm stage	12.7%
Europe estimate of total rape seed/ sunflower losses (tonnes)	8,032,631
Estimated value of loss (million Int. \$)	\$1,732
Europe farm stage rape seed/ sunflower losses: kg per capita	10.5

Case study 7 - Focus on the case study commodities within region – oilseeds in France

Sources: Literature review

Oilseed - production statistics

The total production volume of oilseeds within the EU was 32.8 million tonnes in 2018, which was a decline of around 6% compared to the previous year ^{lvii}.

France is one of the main growers of oilseeds in Europe, with the main crops being rapeseed/mustard, soybeans and sunflower. According to FAOSTAT in 2017 production of rapeseed/mustard was 5.3Mt, sunflower 1.6Mt and soybean 415kt.

Oilseed - market characteristics

Rapeseed was originally grown to be processed into edible oil for human consumption and for use in the manufacture of oilcake in animal feed. Today it also has a market in biofuel and faces strong competition in animal feed markets from imported soybean meal, and from soybean and palm oil within the edible oil market. A higher proportion of French soybean production is used in animal feed (22% of production) than is the case for oilseed rape (0.6%) or sunflower (13%) (FAO New Food Balance Sheet).^{lviii}

Oilseeds - comment on the estimates from study

Losses from oilseeds and vegetable oils in France are estimated to be around 71.4Kt per annum, including on farm harvest, storage and transport and processing stages. These losses are equivalent to 10% of the total consumption of these commodities in France, with just under half of losses occurring at the harvesting stage.

The loss rates across all three stages differ slightly between the different oil seeds. The rapeseed oil sector has the highest loss rates with 9.8%, followed by sunflower seeds of 7% and soybeans of 6%. These losses equivalent to value losses of up to €50M for rapeseeds alone (Fine *et al*, 2015).

These loss rates are very similar to the loss rates estimated in this study, where the overall loss rate for rapeseed and sunflower was 12.5% at the farm stage.

For soybean used in French tofu production, the harvesting step is the most impacting on losses, while the total losses are equivalent to 8.2% of the total production

Oilseed - farm activities: breakdown of losses by activity

Across different oil seeds the highest loss rates occur during harvesting, with loss rates between 2% (sunflower), 5% (rapeseed) and 6% (soybean & tofu). During transport and storage, the loss rates are 1.5% for all seeds. Losses occurring during processing are 3.7% for rapeseeds, sunflower and soybean, but only 1.1% for tofu. The maximum seed losses during harvest can be as high as 18% for soybeans, 15% for sunflower seeds and 13% for rapeseeds (Fine *et al.*, 2015).

Oilseed - factors driving losses at farm stage

The main drivers for losses at farm stage occur during harvesting, with further losses occurring during refining. Field losses can be driven by various factors, such as the tendency of oilseed pods to dehiscence (or 'shatter') prior to or during harvest and poor choice of harvesting time.

Fully mature oilseed pods naturally shatter as a means of seed dispersal. This may result in a 10-25% loss of seeds and during extreme weather events at harvest time (hail and heavy rain) 70% of the crop may be lost. Seeds scattered on the ground where they germinate to become weeds that infest the following crop (Pari *et al*, Journal of Agricultural Engineering 2013).^{lix} It is very difficult to measure the level of losses due to the small diameter of the seeds and their dark colour (Fine *et al*, 2015, *op. cit.*).

Harvesting of soybeans can incur additional losses when pods grow too close to the ground and remain in the stubble after harvest, being too close to the soil for being mechanically harvested. These losses can be greater for particular cultivars as well as a result of poor cultivation methods and adverse weather conditions.

Oilseed - mitigating actions:

The EU had a total of 32.8MT production of oilseeds in 2018, with France being the main oilseed producer.

Losses in France are estimated to be around 10% of the total annual consumption. The main driver for losses are seen in the highly heterogeneity fields, and too inflexible reapers.

Flexible reaper and more optimised harvesting methods can reduce losses. Furthermore, the high consumer standards also produce losses. This requires a rethink in consumers and high standards in appearance for food products.

In order to reduce losses during harvest, the design of combine harvesters can be improved through use of on-board technologies and more flexibility in the height of the cut - such as camera systems linked to flexible reapers. Such systems can optimize harvesting to respond to the heterogeneity of the crop to reach more seeds and thereby improve yields.

In addition to harvester design, rapeseed losses can be made through the development of cultivars that produce pods that are more resistant to shattering and for soybean, the selection of varieties less prone to producing pods close to the ground.

Losses due to disease and pests are very significant factors amongst oilseeds: slugs and pigeons can result in very high losses or total crop failure and insect pests are a major threat (Zheng, X et al, 2020).^{ix} Use of trap crops to attract pests (e.g. pollen beetles and seed weevils) away from main crops can be used as a method of reducing insect damage.



4.5.4 Case study 8 - Sub-Saharan Africa - groundnuts

- Data coverage: based on 12 studies.
- Estimated a high rate of loss, mainly associated with post-harvest manual processing of groundnuts: shelling, stripping.
- Groundnut losses represent 27% of oil crop losses within the region and an economic loss of \$0.5 billion.
- These losses are likely to be concentrated in relatively few countries in Nigeria, Sudan, Chad, Cameroon, and Senegal, which account for over two-thirds of production within the region.

Table 13: Case study 8 - Sub-Saharan Africa - Groundnuts

Sub-Saharan Africa oilseed production as % global	4.8%
Sub-Saharan Africa groundnut production as % regional oilseed production	26.9%
Sub-Saharan Africa farm stage losses of oilseed % global farm stage losses of oilseed & pulses	6.9%
Sub-Saharan Africa farm stage losses of groundnut as % regional farm stage losses of oilseed	26.9%
% of groundnut production lost at farm stage	11.7%
Sub-Saharan Africa estimate of total groundnut losses (tonnes)	1,489,983
Estimated value of loss (million Int. \$)	\$593
Sub-Saharan Africa farm stage groundnut losses: kg per capita	1.4

Focus on the case study commodities within region -groundnuts in Ethiopia and Malawi

Sources: Interview with Ethiopian expert and literature review, Malawi (FAO 2018) ^{lxii}

Groundnuts are a significant subsistence and food crop in Sub-Saharan Africa, providing an important source of protein, cooking oil and vitamins. By-products from oil extraction can also be used as a source of animal feed (groundnut meal) as can groundnut haulms.^{lxiii} Crops can be grown in semi-arid areas over a growing season of 75-150 days and as a leguminous crop, help to improve soil fertility.

Groundnut - production statistics

Total production Ethiopia = 130 kt (2016, FAOSTAT) groundnut is predominantly grown in Hararge, Metekel, Wolega and Gojam and totals

Malawi, Sudan and Nigeria are major groundnut exporting countries, although declining due to increasing regulations by export countries.

Average losses at farm stages can be between 50-60%, with extreme years having 100% loss rates. abiotic as well as biotic factors, with fungal and nematode losses being the dominant source and driver for food loss. Poor handling techniques in lifting, drying, stripping, shelling and storage can also increase losses.

Mitigation actions can include good agronomic practices, which includes adequate drying of the harvest to the right moisture level, advanced storage structure, sanitation and good storage practices.

Malawi = 275,000 tonnes (2016 FAOSTAT), Sudan and Nigeria are the main producers within the region, each with nearly 3 Mt production and major exporters of shelled groundnuts.

Groundnut - market characteristics

Both countries have been hard hit by the stringent aflatoxin regulations imposed by export markets, in particular EU and Japan. Malawi was formerly one of the major exporters of groundnuts to Europe, but this was reversed due to aflatoxin concerns and falling productivity.

Groundnut - farm systems and supply chain

The supply chain can vary between that supplying the formal sector into export markets and the informal market. In both Malawi and Ethiopia, groundnut cultivation is by small-holder farmers under rainfed conditions. Cultivation requires high labour inputs and low levels of mechanisation. Most of the labour-intensive activities, such as picking, drying, threshing and shelling, are performed by the farmwomen. Use of fertilizers, herbicides and pesticides is limited and crops suffer from pests and disease as well as water scarcity and the impacts of extreme weather events.

It is one of the crops most cultivated by small-holder farmers in Malawi, and it is an important source of income to smallholders supplying to informally operating supply chains (i.e. those lacking formal rules, regulations and market specifications). However, in Malawi the formal groundnut sector that supplies both domestic and export markets receives much backing from the Government and represents the majority of the country's production. There are two main systems within the informal supply chains, depending on whether not the farmer has access to farm storage:

- Short chain: the crop is harvested, dried for a week and then directly supplied to the market. Stripping of pods from hulms is often carried out inefficiently by under-age child labour. This is a highly unmechanised system with high potential for farm losses as as the crop is dried out in the open and more susceptible to insect and animal damage and on-farm processing is carried out manually. The sprinkling of water to soften the pods make manual shelling easier results in loss of quality and may encourage aflatoxins. The advantage of the rapid supply of harvest to market is that labour costs are covered by the immediate sale of the groundnuts, although there is less potential to wait for better prices in the marketplace at times of glut..
- Long chain: a more capital intensive approach operating within the informal supply chain involves harvesting followed by a week's drying (ideally covered for protection) and 3-4 month's storage (mainly as pods still within their shells) before going to market. In this more capital intensive system the farmer has adequate cash flow to cover harvesting costs as well as infrastructure to store the groundnuts until the market prices are favourable.

In Ethiopia both short and long supply chains also operate, again with higher losses expected in the shorter supply chain.

Groundnut - comment on the estimates from study:

Four critical loss points were identified by FAO's study of the informal groundnut supply chain in Malawi. These were the drying, stripping, shelling and storage stages. The combined quantitative and qualitative losses for the different critical loss points were estimated at 17.8%. Lower levels of loss were expected for the more formal supply chain, which is more highly organised and regulated.

For the Ethiopian stakeholder -the impact of weather and disease were key aspects of losses, particularly during critical periods such as pod development and maturity. The main groundnut diseases are fungal (e.g. Fusarium, Alternaria and Aspergillus), bacterial (e.g. bacterial wilt), virus or parasitic nematodes.

Groundnut - factors driving losses at farm stage

Drivers of farm level food loss in groundnuts include abiotic as well as biotic factors, with fungal and nematode losses being the dominant source and driver of food losses. Poor handling techniques in lifting, drying, stripping, shelling and storage can also increase losses.

The Ethiopian stakeholder stated average losses of 50-60 % at farm level but on occasions 100% production can be lost in cases of extreme weather. In 2018, 100% of the harvest was lost when a salty lake flooded into the groundnut fields at Werer Agriculture Research Center. In 2015, 80 - 100% of the harvest was lost due to complex root rot and rust disease.

The FAO study in Malawi provided details of losses associated with harvest and post-harvest stages:

- Lifting hand hoes; manual lifting of haulms, these are stacked in the field with pods facing up (to reduce potential for mould growth). Careful lifting is needed, otherwise the pods are left in the ground (FAO Malawi study estimates 3% loss).
- Drying in the field may result in more significant losses than the lifting stage, due to pest damage (rodent, groundnut weevil and birds). There is also the risk of losses in quality and quantity from aflatoxins if drying conditions are too humid (depending on weather at harvest). Slow drying after rain during harvest also increased fungal attack, compared with rapid drying.^{lxiii}
- Stripping pods from haulms: small-holders may carry out this operation manually in field stripping operations and pods may be left on the haulms, resulting in further losses.
- Shelling: losses are both qualitative and quantitative if shelling is carried out by hand.
- On-farm storage losses
- Groundnut that is unfit for human consumption is fed to animals

Groundnut - mitigating actions

In the case of Ethiopia, mitigation actions have already been established to reduce losses, including increased training for farmers, which addresses issues along the different stages from field to post-harvest stages. Some of these include the development and application of Good Agricultural Practices, which includes adequate drying of the harvest to the right moisture level, advanced storage structure, sanitation and good storage practices.

Furthermore, the technological standard of groundnut harvest is very low, which can also lead to increased food losses.

- Farmers have applied lime (acidic soil) to reduce root rot diseases incidence
- Harvest groundnut crop at full maturity and avoid drought stress and mechanical damage during harvesting
- Inter cultivation is ploughing or cultivating between groundnut plots or between rows to avoid weeds and losing the soil, these measures result in better pegging (the connection between the nut pod and stem) and pod development.^{lxiv}
- Training to address sorting and removal of infected groundnuts to reduce aflatoxin levels in final product.

In Ethiopia, there is a need for a country led policy for groundnuts, as it is the case for cereals like wheat. Since it's a lowland crop in Ethiopia and planted in remote areas, less attention is paid to it from the government, at the same time it is not officially an exportable crop, due to the detection of aflatoxin levels in groundnut seed above the threshold set by various international market.

There is also a need for farmer training focusing on groundnut production, aflatoxin avoidance and good handling practices. All of these skills and knowledge are important factors in increasing the quality of product. Provided that the market responds with better prices, this will increase farm revenue.

- Groundnut harvesting and shelling technology is urgently needed to reduce groundnut loss in Ethiopia. Rotary shellers produce very little damage to seeds, improving the quality of the product and reducing risk of fungal infections.
- Research centres are in contact with farmers. At national level there is no good attention to on-farm losses.
- Use of A-frames to dry plants/ pods.
- Purdue Improved Crop Storage bags (or PICS) to minimize post-harvest losses during storage caused by aflatoxin and weevil infestation.
- Aflasafe,^{lxv} a biocontrol, was introduced into Malawi to prevent aflatoxin contamination in groundnut and to minimize losses in the field and during storage.
- There is a need for groundnut cultivars that are better suited to rain-fed systems where water stress and high temperatures cause losses.
- Improvements to seed quality purchased by farmers.

Based on the interview, the potential key players identified for changing or mitigating groundnuts food loss rates in Ethiopia include government, research institutions and including NGO's, which should be coordinated and involved in different aspects, such as funding, training, distributing machinery (viz. groundnut harvester and seller).

4.5.5 Roots, tubers and oil crops- summary of environmental impacts from Section 3

-
- GHG emissions associated with farm losses from this commodity group are low compared with meat and meat products, cereals and pulses, but higher than for fruit and vegetables and fish.
 - The production of palm oil in Sub-Saharan Africa and South and South-East Asia dominates global emissions from this category. This is due to the high per-tonne emissions associated with palm oil production (mainly from fertiliser production and use, and carbon stock changes to a varying degree).
 - Emissions generated by farm stage losses of roots, tubers and oil crops are equally distributed between harvest and post-harvest food losses.
 - Roots, tubers and oil crop losses result in low eutrophication and acidification potential and generally less water is abstracted per tonne of production than with other commodity groups.
-

4.5.6 Biodiversity and water impacts – case studies 5 - 8

The biodiversity and ecosystem service rankings are 'medium-to-good' for most countries, while China shows a low ranking for biodiversity and habitat. The eutrophication and acidification potential is medium across the case study countries, as is the overall pollution ranking for most of the countries, with some countries rating slightly lower.

The main impact on biodiversity for this commodity group in South America is based on the big expansion of agricultural land and land use changes encroaching on forested areas. Especially the Andean region is a very biodiversity rich area, with high risks of degradation from higher land use changes. This effect is mainly driven by expansion of small-scale farming in the Andean region.

Oilseeds grown in Europe contribute to the single biggest impact factor to biodiversity in Europe, which is agriculture. This effect is mainly driven by land-use change, which can lead to habitat fragmentation or degradation. Furthermore, climate change and invasive species are driving a change in biodiversity in Europe. Especially energy crops lead to a big land use change, with the intensity depending on the special scale, geographic region, type of crop and the initial land use, determining the scale of impact on the local biodiversity. Most of the European regions within the hotspots do not suffer under extreme water stress.

In common with other case study regions, the potential for increased production varies by crop and region. Increasing global production by intensification in Europe is less likely to lead to significant biodiversity loss (specifically loss of endemic species) than expansion and intensification in other regions.

Water stress

Roots and tubers have a relatively low water-use intensity compared with the other commodities. Water stress, as for other commodities, varies by region and it is difficult to draw any firm conclusions.

4.5.7 Socio-economic impacts

The region growing roots, tubers and oil crops with the highest total value loss is industrialized Asia (China) with a total value loss of \$10,000 million, and an average value loss per tonne of \$150. This value per kg is the lowest across all case study regions and commodities. While the SDG to reduce undernourishment has been reached, challenges remain to reach the goal of no poverty.

Roots, tubers, and oil crops have an overall much lower socio-economic impact in Latin America, where the total value loss is \$2,700 million, with an average loss per tonne of \$180. According to the development towards the SDG goals, many of the case study countries in Latin America have overcome poverty, while undernourishment remains a challenge in most of the region's case study countries.

Although both Industrialised Asia and Latin America show different socio-economic situations, the contribution to GDP from agriculture is similar for both regions, with around 7-8% of GDP coming from agricultural activities.

Oilseeds grown in Europe, which include rapeseeds and sunflowers, generate a total value loss of \$1,150 million, and an average of \$181 / kg. Oilseeds in the form of groundnuts grown in Sub-Saharan Africa show much higher per tonne losses with \$320/tonne.

While across the European countries agriculture only contributes 4% to the total GDP and all the SDG goals have already been reached, the average contribution to GDP from agriculture in Sub-Saharan Africa is 31%, with major challenges remaining to reach SDG goals 1 and 2.

4.6 Meat and animal products, including dairy and eggs – case study 9

- Data coverage: 104 of 184 observations compiled by this study had adequate data, 58% of these related to Europe. Significant data gaps exist for Industrialised Asia and S&SE Asia.
- The pattern of meat and animal product losses across global regions largely reflects the differential between richer to poorer areas. 40% of production of meat and animal products occurs in Europe and North America/ Oceania, regions containing only 15% of the global population.
- The data are distorted by differences between studies in what is included within the definition of 'food loss'. The disposal of fallen stock and animals rejected at slaughter can result in significant quantities of animal tissue directed towards rendering, alternative markets (e.g. pet

food) and non-food uses. Many of these destinations would not necessarily be included within the scope of food loss/ waste definitions but may contain an element of loss to the food supply chain.

Figure 37: Food Losses - Meat and animal products -including dairy & eggs (million tonnes)

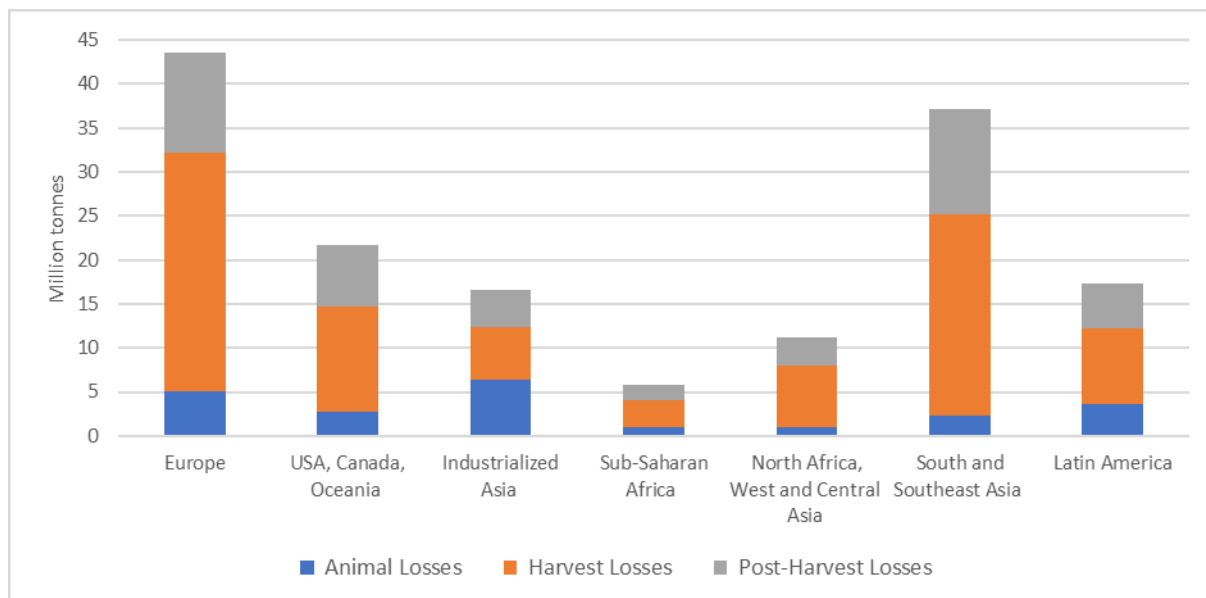
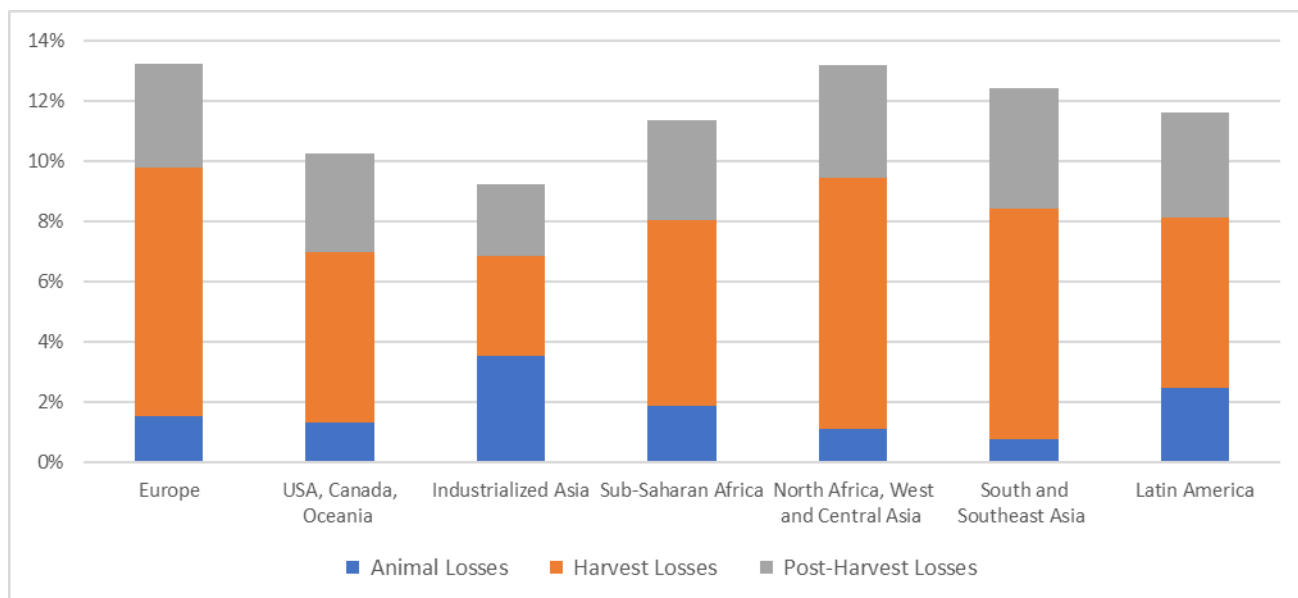


Figure 38: Meat and Animal Products -including dairy and eggs % Food production lost at farm stage



4.6.1 Case study 9 - USA, Canada & Oceania – broiler chicken rearing/ slaughter

- Coverage: only 6 studies were available for the region that included farm stage and pre-slaughter losses in poultry production and of these only one dataset estimated loss at slaughter.
- In relation to North America/Oceania and Europe, the 2011 FAO study concluded that losses and waste was relatively low at the agricultural production and post-harvest stages due to relatively low mortality during rearing, breeding and transportation to slaughter.

- High rate of chicken mortality during rearing according to the available data needs to be explored, given the scale of poultry production within the region and the high value of the losses, if the 6.2% loss rate is indeed appropriate for the region.
- Losses from poultry production on this scale would account for 6.5% of total farm stage losses from meat products within the region.
- The estimates are based on birds that are lost at rearing, death on delivery at slaughter and condemned carcasses. Mainly these are sent to rendering and therefore are not within scope of the SDG12.3 interpretation of farm stage food losses.

Table 14: Case study 9 USA, Canada & Oceania broiler chicken rearing/ slaughter

USA, Canada & Oceania meat/ animal + eggs + dairy products production as % global production	16.2%
chicken rearing/ production as % regional meat products	38.4%
USA, Canada & Oceania meat/ animal products farm stage losses as % global farm stage losses meat products	14.1%
USA, Canada & Oceania farm losses - chicken rearing/ production as % regional farm stage losses meat + eggs +dairy products	6.5%
% of chicken production lost at farm stage: (6.0% loss on-farm, 0.2% reject at slaughter)	6.2%
USA, Canada & Oceania estimate of total farm stage chicken production losses (tonnes)	1,402,139
estimated value of farm stage chicken losses (million Int. \$)	\$1,854
USA, Canada & Oceania farm stage chicken losses: kg per capita	3.5

Focus on the case study commodity broiler chickens in the United States –

Sources: interview with United States meat sector expert and literature review

Chicken is the number one dietary protein source in the United States, with more than 44 kg per capita consumed in 2019. The United States has the highest level of chicken consumption of any country and double the per capita consumption levels of 1970.

Broiler chicken - production statistics

To support the high level of consumption of chicken products, the United States has the largest broiler chicken industry in the world, with about 16% of production exported to other countries. 9.2 billion broiler chickens are processed each year, equivalent to 26 Mt (USDA, 2020)^{lxvi}.

Broiler chicken - market characteristics

The USA has the highest chicken consumption globally, with around 44kg / person consumed in 2019 and the largest broiler chicken industry in the world.

It is uncertain how much of the food loss associated with chicken rearing and slaughter would fit within the SDG 12.3 standard definition of food loss.

Fast growing of the chicken, as well as poor handling are one of the drivers for animal loss rates at farm stage.

Increased animal welfare to reduce injuries of animal and reducing the speed to growth can decrease losses of chicken during production processes.

Broiler production is concentrated in 5 states that account for half of the national production: Georgia, Alabama, Arkansas, North Carolina, and Mississippi. A small number of large processing businesses dominate the market, sourcing birds from a network of approximately 25,000 independent family-run farms rearing broilers and/or producing eggs. These farms source chicks from hatcheries and breeder farms (United States National Chicken Council, 2019).^{lxvii}

Broiler chicken - comment on the estimates from study and definition of food loss

It is uncertain how much of the food losses associated with chicken rearing and slaughter would fit within the SDG 12.3 standard definition of food loss. This is due to the variety of pathways that carcass disposal may take and the extent to which these destinations fall within food loss definitions. The options that fall within the SDG 12.3 food loss definition include waste treatment (AD/ composting), energy from waste, landfill or land-spreading. These are not the main routes used for chicken carcass disposal as the rendering route is generally used. In addition, as with all livestock, aquaculture and poultry systems that involve intensive rearing systems, the losses associated with animal feed that were found to be such an important element within the wider environmental footprint of these commodities in Section 3, are not included within SDG 12.3.

Disposal of carcasses is a problem for poultry producers, with many states requiring stricter disposal precautions for diseased animals to control the spread of disease outbreaks. The following routes may be used: burial, landfill, composting, incineration or rendering (University of Georgia Cooperative Extension, 2009).^{lxviii}

No information sources were located that could provide a current breakdown of routes used for farm stage poultry losses, but a stakeholder interview confirmed that rendering was the main route for disposal of carcasses from large processing plant. Information from the United States Environmental Protection Agency in response to livestock and poultry sector needing to 'depopulate by euthanizing animals' at closed processing facilities suffering from Covid-19 outbreaks, suggests that the cheapest option for farmers is burial on-farm (USEPA, undated).^{lxix}

Without any official national statistics on current practices in relation to carcass management, it is not possible to interpret the food loss aspect of United States poultry production in terms of the SDG 12.3 food loss definition. Rendering is the main route traditionally used for the management of carcasses (not SDG 12.3 food loss), with outputs have a range of food industry and industrial end markets. The rendering markets include poultry meal/ poultry by-product meal, blood meal, feather meal into aquaculture, livestock feed and pet food. Poultry fat is used in biofuel, as livestock or poultry feed and in pet food. Uses outside of the food chain involve production of oleic acid, glycerine, stearic acid and linoleic acid.

The rendering market in the US has changed over recent years because the price of meat and bone meal has declined and the use of many of the by-products from rendering have been eliminated due to concerns related to transmissible bovine spongiform encephalopathies (BSE or mad cow disease). Farmers now have to pay for fallen stock to be removed.

Broiler chicken - farm activities: breakdown of losses by activity

Nature of losses: routine losses are mainly a function of poultry health, accidents, equipment failures and welfare problems and thresholds set by food safety and quality control measures. Catastrophic losses relate to significant disease outbreaks, such as avian influenzas in 2015, or natural disasters. Typical mortality rates are 4.9% for broilers, resulting in 637,000 tonnes per year at current production levels.

Main aspects of loss relate to the conditions of poultry harvesting and transport (broken wings or legs or suffocation) and bird diseases at farm level. Additionally, birds that are under or oversized or

struggling are rejected. Broilers that are insufficiently bled or birds damaged at the first stages of the slaughter-line and are also discarded.

Losses on-farm include wing or leg fractures, suffocation, and bird diseases. A recent study published by KFC, as part of European Chicken Commitment, looked at all aspects of chicken welfare (annual progress report on chicken welfare, July 2020)^{lxx} and measured a mortality rate of 4% on-farm, including deaths from culling, disease, injury or lameness.

- In addition to farm losses, pre-slaughter mortality includes birds condemned prior to their arrival at slaughter or 'dead on arrival', caused by deaths in transit and birds rejected post-slaughter by inspectors.

- Condemned birds, pre-slaughter, following inspection: in US Federal statistics, rate in 2019 was 0.24% of live weight inspections (USDA 2020, *op. cit.*).
- Birds inspected for general health, abnormalities in structure, behaviour, colour, cleanliness.
- Post-mortem condemnations: carcasses or parts condemned by the inspector because of disease or mishandling and removed from the slaughter line and destroyed:
 - EPA report 0.77% of weight inspected birds.
 - main reasons included *septicaemia*, *airaccutis* (inflammation of the air sacs in a live chicken).

Broiler chicken - factors driving losses at farm stage

Mortality levels on-farm are an indication of the breed of chicken and how the environment and health of the birds are managed. Broiler chickens have been selected for rapid growth, with some breeds gaining as much as 90g/day and at over 35 days more than 100g/day. Whilst this development over the last few decades has changed the economics of the poultry industry it has brought with it welfare issues associated with such fast growth rates (Compassion in world Farming, 2013).^{lxxi}

- Method of catching and crating causes stress if multiple birds are caught at a time and held by their legs before being placed in a transport crate. Rough handling at this stage causes stress and injury to the birds.
- Dead-on-arrival: strongly influenced by stocking densities during transport and duration and environmental conditions of transport from farm to slaughter.
- Slower growing chickens, with need to introduce new varieties and monitor on-farm welfare (Dixon, 2020, research for RSPCA Broiler Welfare Protocol).^{lxxii}

Broiler chicken - mitigating actions:

- Increase animal welfare by implementing best practice from other regions for animal welfare, reduce injuries of birds and mortality.
- Improved temperature/ humidity and ventilation management in the rearing sheds (reduced death in early stages, also reduced death caused by smothering in colder conditions).
- In the case of chicken this would include slower growing varieties of broiler chicken, which would lead to lower mortality rates and better animal welfare scores.

4.6.2 Meat and animal products- summary of environmental impacts from Section 3

- The carbon footprint of losses associated with meat and meat products accounted for 40% of CO₂ eq. emissions from global farm stage losses, derived from only 13% of global food loss tonnage. These emissions were mainly from ruminant livestock enteric fermentation and manure management from the rearing of livestock and keeping of dairy cattle.
 - Losses associated with poultry and pork production has a relatively low carbon footprint compared with dairy and bovine meat production.
 - Losses from milk form the largest share (39%) of emissions followed by bovine meat (32%). The relative contributions vary by region, with bovine meat dominating South and Southeast Asia and Latin America but pig meat dominating Industrialized Asia.
 - In addition, this commodity group was associated with over 40% of global food losses' contribution to acidification and eutrophication potentials. Again, mainly associated with losses from dairy production.
 - The land area used for meat and dairy production accounted for over half of the global land area used to produce food losses – The land area associated with losses from this commodity group was equivalent to half the land area of India.
 - Commodities within this group have a high water footprint arising from crops grown for animal feed as well as water drunk by the animals during their lifetime. Water losses are dominated by milk, which forms over 80% of the total for meat and animal products, mainly resulting from dairy losses in South and South East Asia.
-

4.6.3 Biodiversity and water impacts – case study 9

The biodiversity impact of meat and animal products is very high, as many biodiversity drivers are impacted either directly or indirectly by this commodity group. The main drivers for biodiversity change or loss from meat and animal products are land-use change (destruction of habitats), climate change, increase of invasive alien species, overexploitation through extensive grazing of livestock, as well as pollution both from the livestock directly and due to manure management. These factors act both on a local level, as well as on a global level. The quantification of the biodiversity change from meat and animal products is very difficult, as the drivers and impacts come from a diverse web of different factors.

Some of the major threats to biodiversity overall include the conversion of natural land to pasture (including deforestation), planting of soy for animal feed, persecution of livestock predators and feral livestock. The highest land use impacts are in the USA, which is also responsible for 88% of the overall food losses for this commodity group in the case study region. The countrywide ecosystem ranking for all three regions is medium.

Water stress

Water stress for livestock in the USA and Canada is “Low to Medium” and in Australia it is “Medium to High”. Whilst freshwater withdrawals per kg of product are globally high, they are much lower in the three regions highlighted within the case study. Milk in the USA uses about 146,000 litres of water per tonne of product – less than half the global average. Beef in Canada uses about 169,000 litres per tonne which is about 12% of the average.

4.6.4 Socio-economic impacts – case study 9

The total value lost from meat and animal products within the case study region of USA, Canada and Oceania is \$15,000 million, with the value loss of \$677 per tonne, reflecting the relatively high cost of poultry/ livestock rearing (e.g. cost of feed) compared with production costs associated with other commodities.

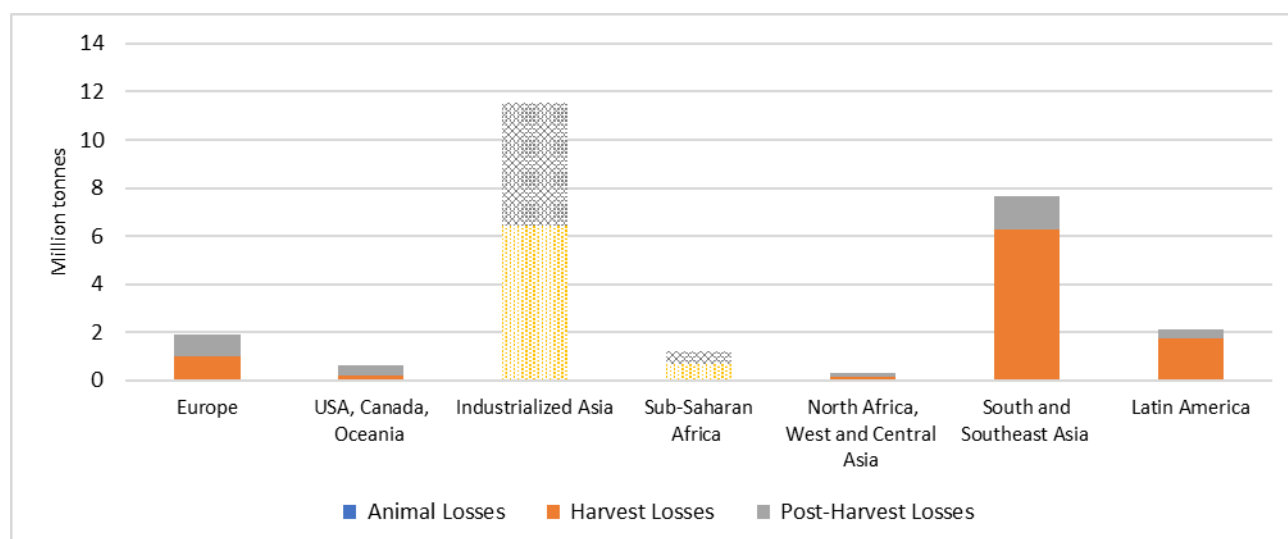
The case study regions do not show any challenges and have already reached the SDG goals, except for Canada, where challenges remain to overcome undernourishment. The contribution to the country's GDP from agriculture is low, with a contribution of around 2%.

Overall, the food losses do not indicate to directly impact the food security of the case study countries.

4.7 Fish and fish products – case study 10

- Data coverage: limited availability of primary data points globally, with many studies reiterating the same few observations relating to by-catch and post-harvest losses. Of 37 observations compiled by this study 22 had adequate data, mostly focused on marine fisheries, with three-quarters relating to just two regions: North America/ Oceania and S&SE Asia. No data were located for Industrialised Asia or Sub-Saharan Africa, which account for 41% and 4% of global production, respectively. No data were identified for by-catch associated with freshwater capture fisheries from any global region.
- Measurement of fish losses is a particularly challenging area as there are no consistent methodologies and the dearth of good data may result in extrapolations made from single studies that are likely to be unreliable (Kruijssen et al., 2020)^{lxxiii}
- As a result of the poor data coverage, it is difficult to provide reliable interpretation of differences between global regions. It is likely that more industrialised fisheries tend to discard fish at sea at higher rates than elsewhere, particularly under the landing restrictions imposed by quota systems, and that in developing countries losses on landing and immediate processing are likely to be higher. However, this is not reflected in the available data.

Figure 39: Food Losses - Fish and Fish Products (million tonnes). Shaded indicates estimated % losses were used.

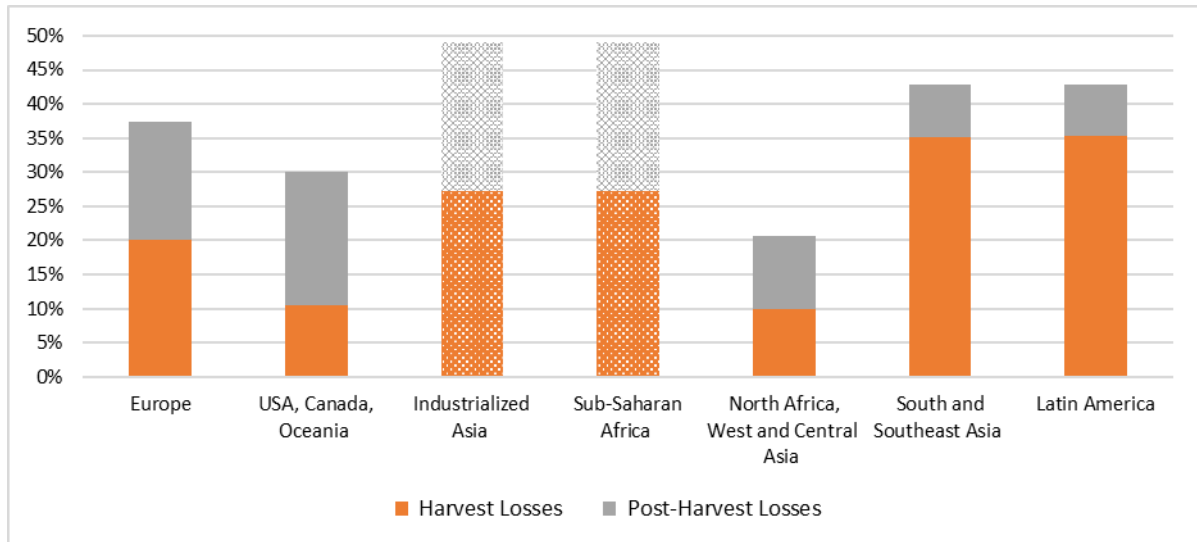


Note that the loss numbers above (and throughout the report) for Industrialized Asia (region 3) and Sub-Saharan Africa (region 4) use the global average of 27% Harvest losses and upper-end 30% (from Latin America) immediate post-harvest losses, due to lack of data. The chart below shows the ranges of losses – from 10% harvest in North Africa, West and Central Asia to 35% harvest losses in South and

Southeast Asia and post-harvest losses are 10% for North Africa, West and Central Asia, 7% for South and Southeast Asia and Latin America and 22% for Europe, USA, Canada, Oceania.

Figure 40: Food losses - Fish & Seafood, % Fish production lost during capture, landing, and immediate processing.

[Industrialised Asia and Sub-Saharan Africa use global average harvest losses and upper-end (based on Latin America) post-harvest losses].



4.7.1 Case study 10 - Sub-Saharan Africa - freshwater fisheries

- Data coverage: No general data points were located for freshwater fisheries in Sub-Saharan Africa, although data were located for a limited number of species, with one example (dagaa) reviewed here.
- Inland fisheries are an important element of fisheries within the Sub-Saharan Africa, accounting for 40% of the tonnage of live fish from capture fisheries or aquaculture, but there is likely to be significant under-reporting of wild-caught artisanal fisheries within the region, an important fishery for low-income communities for livelihoods and as a source of dietary protein.

Table 15: Case study 10 - Sub-Saharan Africa - inland fisheries

Regional fisheries as % global fisheries capture/ aquaculture (tonnes live weight)	4%
inland fisheries as % regional fisheries capture/ aquaculture (tonnes live weight)	40%
regional fisheries by-catch/ processing losses as % global fisheries by-catch/ processing losses (tonnes live weight)	5%
regional inland fisheries by-catch/ processing losses as % regional fisheries by-catch/ processing losses (tonnes live weight)	40%
% fisheries capture/ aquaculture production losses at capture/ processing (tonnes live weight)	49%
regional estimate of inland fisheries capture/ processing losses (tonnes live weight)	486,011

Focus on the case study Lake Victoria dagaa fishery (*Rastrineobola argentea*)

Main sources: Literature review including East African Community, Lake Victoria Fisheries Organization, 2016^{lxxiv}, Kolding *et al.*, 2019^{lxxv}, Akanda and Diei-Ouadi, 2010.^{lxxvi}

In 20 African countries fish contributes more than 20% of protein, diet transition has added to demand for fish. Fish contribute to the diets of poorer households within the region as well as providing income from commercial fisheries and export markets. However, fish consumption in Sub-Saharan Africa is approximately 8.6 kg per capita, compared with the global average of 20kg per capita. Much of this consumption consists of freshwater fish, especially low value pelagic species. As a result of rapid growth of landings over the last few decades, small pelagic species now account for 75% of total inland fish catch in Africa, and the majority of the catch in most African lakes.

A high proportion of fish consumption in Sub-Saharan Africa comes from freshwater fish.

Post-harvest losses can be as high as 40%, with fish being washed away or rotting. In small-scale fisheries, quality losses can account for more than 70% of total losses.

The main drivers for losses are lack of investment in infrastructure to improve the value of the fishery and quality of product supplied to market. Open air operations at landing sites are exposed to the weather, predators and insects.

The losses can be reduced through early landing of catches, salting and improved handling, processing and packaging. Value can be enhanced with improved support to the dagaa trade, especially for women actors of the value chain.

Lake Victoria is the largest lake in Africa and second largest in the world. The fishery is today dominated by three fish species: Nile perch, Nile tilapia and dagaa. Nile Perch is mainly caught for export whereas Tilapia is primarily used for domestic consumption. Dagaa, a small pelagic species endemic to the lake, is currently mostly used for animal feed but has a high potential to be used to address the fish nutrition 'gap' between a shortage of affordable fish and high local demand.

The impact of the introduction of the Nile Perch species on the endemic fish stocks has been much studied and an extreme case of biodiversity loss caused by an alien species. The decline of the lake's endemic haplochromine species (more than 500) has been attributed mainly to Nile Perch predation (Njiru *et al*, 2018).^{lxxvii} Lake Victoria fisheries: outlook and management, Lakes & Reservoirs Research & Management, 2018).

Dagaa - production statistics

The Lake Victoria fishery currently supports more than 220,000 fishers, artisanal and commercial (Lake Victoria Fisheries Organisation (LVFO), 2014)^{lxxviii}, on which an estimated 35 million people depend for a living, either directly or indirectly (Weston, 2015).^{lxxix} The estimated fish catch for all species is 876 547 tonnes with Dagaa representing 65% of the catch (Lake Victoria Fisheries Organization Catch Assessment Report, April 2016). The dagaa fishery ranks as one of the largest single species small-scale fisheries in the world.

Wild-caught fish in freshwater fisheries are likely to be under-estimated in official fish production statistics due to incomplete or ineffective monitoring of artisanal and subsistence fisheries (Fluet-Chouinard *et al*, 2017).^{lxxx} Furthermore, there has been a lack of measurement of by-catch in freshwater fisheries, with studies mainly focused on marine fisheries (Raby *et al*, 2011)^{lxxxi}.

Dagaa - market characteristics

The main product from dagaa is sun-dried fish sold locally. More highly processed dagaa are also sold in the form of salted, smoked, deep-fried or milled/powdered products. In the region, only about 30% of the dagaa is utilized as human food (Uganda Department of Fisheries)^{lxxxii}, the remainder is processed into poultry, fish and livestock feed.

Fishing systems in Lake Victoria

Within the last 50 years, the Lake Victoria fishery has transformed from a mainly subsistence-led fishery operated by local communities to a system dominated by commercial fisheries exporting Nile Perch to Europe, USA and Middle East. The Nile Perch fishery has declined as a result of over-fishing and climate change. Since Nile perch is the main predator on dagaa, numbers of dagaa have increased.

Dagaa is now an important fishery targeted by 32% (70,513) of the fishers. Fishing for dagaa is done at night using lamps to attract the fish and deploying manually operated and labour-intensive purse-seine methods, often from non-motorized vessels fishing a few kilometres from the shore. Traditional scoop-nets, artisanal lift-nets are also used.

Comment on the estimates from study:

In Uganda post-harvest losses were estimated to be 26-40% of production and in Tanzania estimated at 40% of landed catch (Lake Victoria Fisheries Organisation Secretariat, 2016). No by-catch statistics were available, although it was noted that fishing further from the shore was advised to avoid excessive by-catch than close to shore.

For a fishery that is mainly supplying animal feed, the concept of food loss is somewhat different to the accounting of food loss within fisheries predominantly supplying fish to people. However, there is a strong case for supplying greater quantities for human consumption based on nutritional value: high-



quality protein and important micronutrients. This is important within a region with a high burden of hunger and micro-nutrient deficiencies.

Fishery activities: breakdown of losses by activity

As dagaa are eaten whole, the immediate processing stage for dried fish market involves sun drying on the ground near landing sites. During the rainy seasons when proper drying is more difficult to achieve, post-harvest losses can be as high as 40%, with fish being washed away or rotting. In small-scale fisheries, quality losses can account for more than 70% of total losses (FAO, 2014). Losses also occur through contamination with sand whilst drying, fish breaking up into pieces too small to market.

Dagaa- connection to market

The dagaa trade is currently limited by the lack of conformity with fish quality standards, limiting the access to high value dagaa markets. Much of the fish is sold from the beaches at low prices.

Dagaa - factors driving losses within the fishery

As dagaa is perceived as a low value fish, compared with larger species such as Nile Perch. Losses are driven by a lack of investment in infrastructure to improve the value of the fishery and quality of product supplied to market. Open air operations at landing sites are exposed to the weather, predators and insects. Furthermore, the dagaa for human consumption competes with the aquaculture industry's growing demand for fishmeal within in the region. A trade-off exists between providing high quality protein to low income families and high-value aquaculture products destined either for domestic middleclass, or for export markets In the United Republic of Tanzania and Uganda the dagaa fishery requires an immediate technical intervention. Losses are a serious socio-economic problem leading to tonnes of highly nutritious fish being left to rot, thus contributing to food insecurity (Kaminski et al., 2018).^{lxxxiii} .

Dagaa - mitigating actions

The losses can be reduced through early landing of catches, salting and improved handling, processing and packaging. Value can be enhanced with improved support to the dagaa trade, especially for women actors of the value chain.

Processing of dagaa on beaches can be greatly improved by using raised platform for drying the fish.

This called for alternative approaches such as solar drying, smoking or deep frying of the dagaa and better connection with distant consumer end-markets.

There is a general need for governments that share Lake Victoria to create awareness of the trade-off between the use of "low-value" but highly nutritious fish as animal feed or human food and prioritize direct human and support infrastructure and marketing.

4.7.2 Fish and seafood - summary of environmental impacts from Section 3

- Industrialised Asia accounts for just under half of losses and just over half of emissions; this is because freshwater fish and crustaceans, associated with relatively high emissions, form a large share of total production.
 - Different fish types have significantly varying relative emissions due to the different underlying sources and types of gases. Crustaceans (mainly shrimps and prawns) have the highest per-tonne emissions; for aquaculture these come mainly from methane emissions (and to a lesser extent nitrous oxide) arising from decomposition of excrement in the water and subsequent disposal. Fuel-use intensity for wild-caught crustaceans is also significantly higher than for other species groups, such as pelagic fish species. Methane also accounts for most of the emissions from other farmed fish (included within freshwater fish above).
 - Wild-caught marine and freshwater fish have the lowest relative carbon impact; with variations between regions reflecting the types of fish caught and vessels used (pelagic fish, such as mackerel, require significantly less fuel to catch than demersal species, such as cod and halibut).
-

4.7.3 Biodiversity impacts – case study 10

When assessing the biodiversity impact of fish and seafood, a distinction is made between wild caught fish and freshwater fish. Inland and therefore freshwater fishery can be a big threat to wild animals, due to land use change from aquaculture and therefore habitat degradation. Other driving factors for a change in biodiversity are overharvesting, an unbalanced waste utilisation and pollution. In the case of Lake Victoria and other lakes in East Africa, the introduction of the Nile Perch for purposes of improvement of commercial fishing potential has had the most severe impact on fish biodiversity in the region.

Overall, the impacts on the different impact assessments and rankings are medium.

4.7.4 Socio-economic impacts – case study 10

Compared with other case study commodities, freshwater fish and seafood from Sub-Saharan Africa only generate a low overall loss value of under \$900 million. However, the value per tonne of product is by far the highest across all case study areas and commodities, with a value of \$2,600 / tonne of final product. The high value of fisheries contributes to the high proportion that agriculture, forestry and fish contribute to the national GDP within this case study region, which ranges from 21% (Nigeria) to 27% (Tanzania). Significant challenges remain for all the countries on their path to meet the SDG goals of no hunger and to reduce undernourishment.

4.8 Comparison between food loss rates used in study with case study findings

The case studies have enabled the ground-truthing of assumptions underlying the quantification of global food loss and waste presented in Section 2.3. The 10 case studies contained 12 distinct supply chains (case studies 3 and 4 having two each), providing an assessment of farm stage losses for their respective commodities, as summarised in Table 16. These were cross-checked against the relevant mean rates of food loss applied within in the global food loss calculations. The assessment also considered the relative availability of datasets (column 3 in Table 16), ranging from ‘very poor’ (with few/no data points available for the case study commodity within region) to ‘very good’ (a large number of data points). Only two regions had cases that scored ‘very good’ for any of the relevant commodities: S & SE Asia and Sub-Saharan Africa, covering rice, fruit/ vegetables, and groundnuts. Scores did not take account of the farm level methodologies used to collect primary data as it was established in the review of datasets that most measurement involved self-reporting and expert opinion, rather than more robust in-field measurements (see Appendix 1, Figure 44).

Table 16: Comparison of % food loss used in global food loss and waste estimates with findings of case study analysis

Case study commodity-region	Commodities covered	Relative availability of datasets	Food loss % mean value derived from available data	Case study evidence supports lower loss rates	About right	Case study evidence supports higher loss rates
1 Europe - cereals + pulses	UK wheat	very poor	10.00%	1.30%	Inclusion of grain to animal feed within source studies?	
2 S & SE Asia - cereals + pulses	Pakistan + India Rice	very good	13.10%		10.00%	
3 Sub-Saharan Africa - citrus + vegetables	S-S Africa small-holder farms citrus + veg.	very good	48.00%	11-40%	Wide range of values: case study focus too broad	
	South Africa citrus export growers		31.50%	<5%	South Africa not typical of Sub-Saharan Africa	
4 S&SE Asia – mango, guava, onions + other vegetables	India fresh mango	very good	17.20%		20.0%	
	India mango pulp				15.0%	
5 Industrialised Asia roots & tubers	SW China potatoes	poor	34.70%	5% (15-20% storage +	Inclusion of potatoes to feed animals as FW?	
6 Latin America - roots & tubers	Latin America: cassava + potatoes	neither poor nor good	26.40%	7.0%	Inclusion of potatoes to feed animals as FW?	
7 Europe - oilseeds	France: oilseeds	good	12.70%		6%-10%	
8 Sub-Saharan Africa - groundnuts	Ethiopia + Malawi groundnuts	very good	11.70%	Manual production % loss, mechanised systems lower		17.8%
9 USA, Canada & Oceania - chickens	USA: broiler chickens, rearing + slaughter	poor	6.20%		5.2-5.7%	
10 Sub-Saharan Africa - freshwater fisheries	S-SA Africa: Lake Victoria dagaa fishery	very poor	49.00%		26-40% for PHL only	

Half of the case study supply chains endorsed the relevant loss rates used in the global estimates presented in Section 2. Of the remainder, 5 cases provided research evidence which supported lower

loss rates than those assumed in this study. For potatoes in Industrialised Asia, potatoes and cassava in Latin America and UK wheat - the differences may be partly explained by the inclusion of food losses fed to animals within food waste definitions. Many of the source studies focused on food availability and on-farm loss reduction rather than recording destinations relevant to the World Resources Institute and SDG 12.3 definitions, which exclude the route to animal feed. The relationship between food loss definitions and drivers and the use of food surplus to feed animals is discussed in more detail in Section 5. For citrus production in South Africa, divergence from the values used to represent Sub-Saharan Africa were due to the citrus industry in that country having levels of food loss that were atypical of the region, with a highly developed sector driven by export markets and low loss rates.

For the Sub-Saharan groundnut case study, higher losses were reported within the case studies than the loss value used in the study. However, the case study areas in Malawi and Ethiopia focused on smallholder systems with highly manual cultivation techniques, whereas elsewhere in Sub-Saharan Africa lower loss rates are apparent in more mechanised systems (e.g. within the major groundnut producing countries that are major exporters, such as Nigeria and Sudan).

No adjustments were made to the global food loss calculations on the basis of the case study findings, but the uncertainties in relation to food loss definitions and loss estimates were noted and are discussed further in Section 5.2.



5 Global food loss drivers and mitigating actions

5.1 Food loss and waste drivers

5.1.1 Overview

The drivers of farm stage food losses and solutions to address them are diverse and inter-connected, as demonstrated by the case studies. The drivers vary at different spatial and temporal levels by commodity type and cultivar, by region, climatic factors, agricultural system and by stage of harvesting campaign. A detailed understanding of the local context is of prime importance in understanding drivers in linking the visible reasons for loss with deeper underlying drivers operating at a macro-level. Wider factors include price volatility, market/ information failures, inadequacy of investment and lack of market access. For instance, where market prices are below the labour costs of harvesting or processing, crops may remain in the field.

The case studies also illustrate how a lack of focus on farm level factors can limit the understanding of losses further along the supply chain. Post-harvest losses are often a consequence of poorly executed actions at the farm stage, some originating from decisions made pre-harvest, coupled with conditions within the supply chain. Conversely, the case studies provide instances where decisions made within the supply chain drive losses at the farm stage, such as poor availability of transport to market.

These conclusions support the view that the distinction made between ‘food losses’ (predominantly unintended losses in the early part of the supply chain, driven by factors beyond human control) and ‘food waste’ (driven by negligence or a conscious decision to discard food at retail or consumer stages) is misleading. This distinction does not shed light on the nature of factors driving losses nor the identification of solutions. This distinction originates from an observation by Parfitt *et al*, 2010^{lxxxiv} that the research literature generally applies the term ‘food loss’ to earlier stages of the supply chain and ‘waste’ to later stages. However, this source was not advocating a distinction between loss and waste in relation to food waste drivers and reasons for loss. Similarly, the approach taken here does not make such a distinction and regards the terms as inter-changeable. Factors that originate from the pre-harvest stage have also been included here, as another important component of understanding drivers at the farm stage.^{lxxxv}

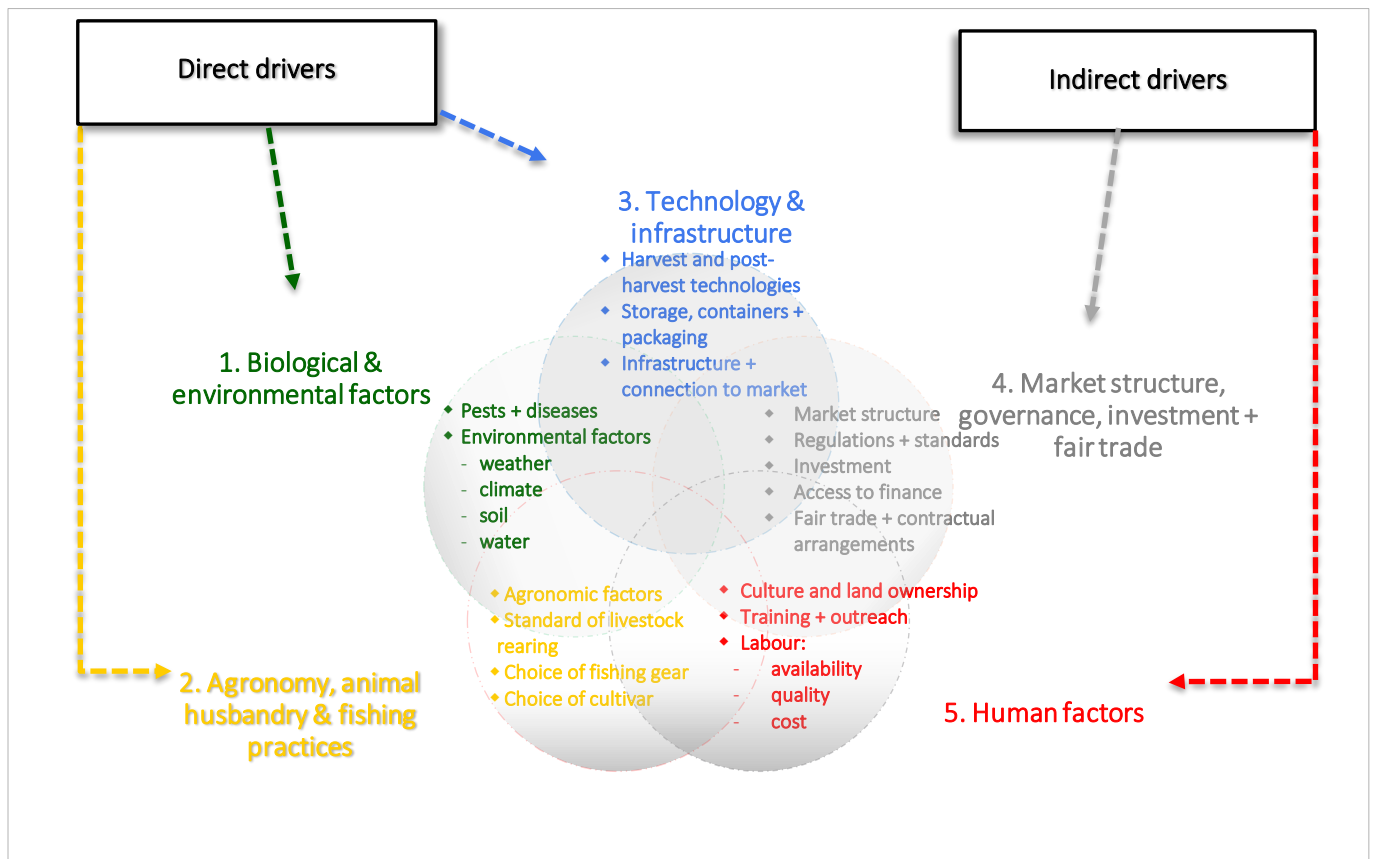
Error! Reference source not found. provides a summary of food loss and waste drivers at the farm stage, as evidenced by the case studies analysed in Section 4 and a review of key publications on the subject.^{lxxxvi, lxxxvii, lxxxviii, lxxxix, xc} These factors have been arranged into 5 inter-connected groups that are split into direct and indirect drivers.

5.1.2 Direct drivers - observable at the farm stage

- **Biological and environmental factors** - examples include drivers that cause damage or biological spoilage to crops, pests/ diseases attacking crops, factors linked to weather, climate and soil, water availability, extreme weather events and natural disasters.
- **Agronomy, animal husbandry and fishing practices** - examples include factors linked to decisions (or indecisions) at the farm stage e.g. poor harvesting and handling techniques, inadequacy of inputs to production: nutrients, water, pest control, choice of variety appropriate to growing/ rearing conditions, quality of seed purchased, judgement of crop maturation and timing of harvest. Poor sanitation during milking leading to diseases (e.g. mastitis) and poor standards of animal husbandry resulting in high livestock mortality rates. Fishing techniques that result in significant by-catch and damage to fish.
- **Technology and infrastructure**, examples include the inadequacy of storage/ containers for harvested produce, poor harvesting technology, lack of temperature management of produce at harvest, inefficient threshing and drying technologies and routes to market that lack adequate infra-structure, inappropriate fishing gear and lack of chilling of landed catch. Supply

chains in higher income regions generally have well-established cold storage, whereas this is not the case in lower income countries. Without adequate storage of more perishable crops, producers are forced to sell their produce regardless of market prices, or risk losses if transport to market is unreliable.

Figure 41: Summary of direct and indirect factors driving food loss and waste at farm level.



5.1.3 Indirect drivers - relating to underlying factors

- **Market structure, governance and investment:** market conditions that prevail will determine farm prices and the ability to invest to reduce losses, and will influence whether crops are left unharvested when prices are too low or there is a glut in the market. Market structure determines how close the linkages are between primary producers and the markets that they supply. In supply chains with multiple intermediary stages (e.g. India rice), linkages are generally weaker. Where suppliers work in step with markets, Good Agricultural Practices (GAPs) are more likely to be in place. Regulatory influences include formal regulations (such as food standards, permitted uses), the availability of support and finance to farming/ fishing, regulation and standards applied to production, by-catch and fishing quota, whether or not market induces over-production. Contractual arrangements between farmers and markets can also be a factor: where prices are guaranteed and a proportion of the crop has a guaranteed market, the risks of losses associated with over-production are reduced.
- **Human factors:** these factors include farm culture, nature of land holding (tenancy/ ownership, size of holding), demographics, literacy, gender issues (particularly in relation to division of farm labour), labour-intensity of harvest and post-harvest operations, labour costs and availability, level of training and skills in relation to food losses, perceptions of extent of food losses and

understanding of market requirements (quality, causes of post-harvest losses, implications of poor harvesting/ handling techniques).

Effective interventions to reduce farm stage food losses involve multiple elements rather than single solutions. Interventions in the past have tended to focus on discrete technical solutions addressing issues with farm technology or storage, whilst largely ignoring socio-economic and market factors that shape the agricultural system. Crucially, these wider influences involve actors and agencies beyond the farm gate. Although technological solutions remain an important component of interventions to reduce losses, they need to be suitable for the given region and culture and be affordable. If a predator control fence defending a rice paddy or a cool store for harvested mango is too expensive in relation to farm income, adoption rates will be low.

Sections 5.1.4 to 5.1.8 provide summaries that link the 5 sets of drivers to mitigating actions drawn from the case study analysis. For the direct drivers, examples are drawn from each of the 10 case studies alongside mitigating actions. In the case of the indirect drivers, which are less specific to a commodity type, coverage of factors and solutions for each case study are summarised overall, rather than for each case study individually.

5.1.4 Biological and environmental factors

Table 17: Drivers of biological and environmental factors causing food loss and waste in primary production, examples by case study

1. Biological and environmental factors	Summary of main drivers identified in case studies	Mitigations/ interventions - Examples
Summary	<p>Pre-harvest pest infestations may become apparent later in storage + supply chain losses. Although these may be classified as losses from natural causes, the failure to treat pests and diseases exacerbates losses, particularly in fruit.</p> <p>Weather conditions at harvest is a key factor: losses may be driven by extreme heat, sun damage, conditions that are too wet favour moulds/ rust formation that may cause direct losses or later during storage and supply chain.</p> <p>Natural disasters and extreme weather events / climate change - cause direct losses and damage to crops and livestock.</p>	<p>Improved agronomic practices are required to address these drivers: integrated pest management, protection of produce from climate extremes, protection against flooding, water conservation measures in water stressed environments.</p> <p>The added pressures of climate change and water stress will require more resilient cultivars to be selected if losses are to be minimised.</p>
Case study 1: Wheat, UK	<p>Extreme weather events in UK, poor harvest conditions, and biotic factors that impact on wheat yields (pests, diseases and weed infestation).</p> <p>Stem and root lodging caused by rain, wind and soil conditions in winter wheat is an</p>	<p>Prevention of grain rejects caused by mycotoxins and the treatment of crops against losses due to aphids, orange wheat blossom midge and slugs. Integrated pest management approaches can be used to improve pest control. Wheat varieties resistant</p>

	important factor. In certain years lodging may affect up to 20% of the UK winter wheat crop, reducing grain quality and increasing losses.	to diseases, such as OWBM. Timing of planting – late planting of winter wheat to reduce lodging, lower planting density to reduce root lodging,
Case study 2: Rice, S&SE Asia	Wet weather resulting in higher losses, shattering of rice grains in dry conditions.	Implementation of integrated pest control systems to address losses from rodents, birds. Avoidance of excessive use of pesticides as residues may cause grain to be rejected at later stages of supply chain.
Case study 3: Citrus, South Africa + fruit/vegetables Ghana + Benin	Droughts, hail, extreme weather events, pests and disease. Citrus Black Spot disease: danger to export crops. Damage to crop if over-exposed to strong sunlight in the field.	Limiting exposure to direct sunlight of produce after harvesting, reduces the volumes of fruit and vegetables lost at the farm stage. Post-harvest hot water treatments to reduce spoilage.
Case study 4: Mango, S&SE Asia	Losses at the production stage are highly dependent on climatic conditions, water stress/ scarcity, and the presence of pest and diseases. These factors determine a large part of the losses at the farm stage and at subsequent stages of the supply chain. Pre-harvest infections greatly impact post-harvest decay and losses throughout all subsequent supply chain stages. Anthracnose and stem end rot are two important diseases that may not be detected before the fruit ripens.	Catch and treat mango stem-end rot and pest infestations early. Improved water management through drip-irrigation, mulching. Integrated pre- and post-harvest disease management in mango to control anthracnose and stem end rot
Case study 5: Potato, SW China	High moisture during the growing process can result in higher risk of disease affecting tubers. Pests and diseases often include late blight (<i>Phytophthora infestans</i>), which can be an important factor in reducing yields and quality of tubers.	Removal of infected/ damaged roots and tubers from harvested crop as part of GAP.
Case study 6: Cassava, potato, Trinidad + Tobago, Guyana, Peru	Weather and temperature are a cause of losses for both cassava and potatoes. Potatoes grown in Peru can be under high weather stress, as the seasons are greatly influenced by El Nino / La Nina weather events. Depending on when the rain falls, root systems can also be destroyed during the growing process.	Development of potato cultivars resistant to late blight and improvement in seed potato quality. Reduce soil erosion from extreme rainfall through cutting ditches and improvements to field drainage.

<p>Case study 7: Rape seed and sunflower, France</p>	<p>Wet harvesting conditions can contribute to shattering of seed pods, during extreme weather events at harvest time (hail and heavy rain) 70% of the crop may be lost. Losses due to disease and pests are also very significant: slug and pigeon attack can result in very high losses or total crop failure.</p>	<p>Use of oilseed and soybean cultivars that are less susceptible to pod dehiscence/ shatter. Use of trap crops to attract pests (e.g. pollen beetles and seed weevils) away from main crops.</p>
<p>Case study 8: Groundnuts, Ethiopia + Malawi</p>	<p>Extreme weather events in Ethiopia can on occasions result in total loss of the crop. Fungal and nematode losses are a dominant driver of food loss. In 2015, 80 - 100% of the harvest was lost due to complex root rot and rust disease. Significant losses also occur at the lifting stage, due to pest damage (rodent, groundnut weevil).</p>	<p>Reduction in aflatoxin B1 concentrations through careful sorting and drying of groundnuts to eliminate infected pods. During pod drying and sorting - avoidance of direct contact with ground. Application of lime (acidic soil) to reduce root rot diseases.</p>
<p>Case study 9: Broiler Chickens, USA</p>	<p>Diseases in poultry: linked to environmental conditions and stocking densities, including <i>septicaemia</i>, <i>airacculitis</i>.</p>	<p>Reduction in stock-density and use of slower growing chickens combined with better monitoring of on-farm welfare.</p>
<p>Case study 10: Dagaa Fishery, Lake Victoria</p>	<p>During the rainy seasons when proper drying is more difficult to achieve, post-harvest losses can be as high as 40%, with fish being washed away or rotting. Predation of landed fish by birds and animals is also a factor in driving losses.</p>	<p>Use of raised platforms for drying fish reduces losses and predation.</p>

5.1.5 Agronomy + animal husbandry + fishery practices

Table 18: Drivers of food loss and waste due to factors related to agronomy, animal husbandry and fishery practices, examples by case study

2. Agronomic factors	Summary of main drivers identified within case studies	Mitigations/ interventions - Examples
Summary	<p>Crop production is affected by poor farm practices such as control of irrigation practices/ water stress, nutrient management, orchard pruning and inappropriate choice of cultivar for prevailing conditions. Poor field sanitation can leave harvest more susceptible to decay and pests, where infected or rotting produce is not separated out. These drivers are closely linked to pressures from the environment and biological drivers.</p> <p>Timing of harvest is a key factor. If there is a poor understanding of market requirements or of reliable identification of crop maturity / suitability for harvest, losses either at farm or in supply chain will increase. Many subsequent losses result from poor timing decision in terms of crop maturity and suitability of harvest conditions. Appropriate level of ripeness of fruit and vegetables is important: tomatoes may be harvested green and ripens in transit. If produce is too ripe at harvest it will spoil before it reaches the market.</p>	<p>Mostly through improved agronomic practices: integrated pest management systems, protection of produce from climate extremes, protection against flooding, water conservation measures in water stressed environments.</p> <p>Improvements to agronomic practices also include choice of most suitable cultivar for the growing conditions, as also mentioned in relation biological and environmental factors (see above). For better adoption of the most suitable cultivars, policies also need to encompass seed quality/ variety certification as well as awareness raising through training and development of GAPs.</p> <p>Understanding and use of maturity indices to accurately judge the timing of harvest.</p>
Case study 1: Wheat, UK	<p>Seed breakage and shattering during harvest. Timing of wheat harvest in relation to crop maturity. For cereals and pulses harvesting during dry conditions is crucial to reduce drying after harvest and potential losses due to inefficient drying methods and development of moulds.</p>	<p>Management of grain moisture content and forward speed and cut height of the combine harvester are important factors in minimizing seed loss and seed breakage and shattering of heads during harvest.</p>
Case study 2: Rice, S&SE Asia	<p>The timing and method of harvesting and threshing. Higher storage losses result from harvesting rice in wet weather conditions, resulting in grain needing extra drying, hence it is crucial to harvest at the correct maturity for paddy and moisture content required for harvesting.</p>	<p>Training in identification of maturity of crop and choice of harvesting time</p> <p>Introduction of mechanical drying to reduce losses compared with field drying.</p> <p>Need for better/ more efficient irrigation systems.</p>

	<p>Field drying and stacking of rice prior to threshing – increased losses, breakage and aflatoxin contamination.</p> <p>Choice of rice varieties in relation the ability to separate panicles (top section of plant carrying the grain) from rice straw and their resistance to shattering of grains in dry conditions.</p> <p>Poor water management may drive crop losses as rice requires very wet conditions to grow (3,000 to 5,000 litres per kg of rice).</p>	
<p>Case study 3: Citrus, South Africa + fruit/veg Ghana + Benin</p>	<p>Losses due to poor handling of tomatoes in field and subsequent post-harvest stages. {Ghana}</p>	<p>Training, small-holder farmers: improved harvesting practices to identify proper harvesting time and maturity level of fruit and vegetables.</p>
<p>Case study 4: Mango, S&SE Asia</p>	<p>Harvesting technique and handling: ‘pick and throw’, results in high losses/ damage.</p> <p>Judgement of mango ripeness and level of ripeness appropriate to end market requirements.</p> <p>The significance of sap damage / sap burn through poor handling in orchard, reducing quality and shelf-life.</p>	<p>More emphasis is needed on initiatives that focus on appropriate time and method of mango harvest as a means of addressing both quantitative and qualitative food losses in the subsequent stages can be greatly reduced</p>
<p>Case study 5: Potato, SW China</p>	<p>Poor handling of tubers at harvest. Poor quality of seed potatoes.</p>	<p>Development of cultivars resistant to late blight and improvement in seed potato quality and certification of quality.</p>
<p>Case study 6: Cassava, potato, Trinidad + Tobago, Guyana, Peru</p>	<p>For cassava grown both in Trinidad and Tobago and Guyana, losses occur mostly due to poor harvesting techniques and handling after harvest.</p>	<p>A change in cassava harvesting technique can bring a significant reduction in losses. Use of digging tools that reduce harvest damage and encourage a change in cutting method of the root during the harvesting process can make it more resilient to decay.</p> <p>Adequate field drainage in cassava production and overall field sanitation and management can reduce the occurrence of pests and diseases.</p>
<p>Case study 7:</p>	<p>Shattering of pods prior to and during the harvest process. Choice of crop varieties and judgement of timing of harvest, as the oilseed crop tends not to mature evenly.</p>	<p>Search for varieties that produce pods that are more resistant to shattering and the development of improved combine harvester design to minimise field losses.</p>

<p>Rape seed and sunflower, France</p>		
<p>Case study 8: Groundnuts, Ethiopia + Malawi</p>	<p>Poor handling techniques in lifting, drying, stripping, shelling and storage can also increase losses. Drying in the field may result in more significant losses than the lifting stage, due to pest damage (rodent, groundnut weevil). There is also the risk of losses in quality and quantity from aflatoxins if drying conditions are too humid (depending on weather at harvest). Stripping pods from haulms: smallholders may carry out this operation manually in field stripping operations and pods may be left on the haulms, resulting in further losses.</p>	<p>Careful lifting is needed, otherwise the pods are left in the ground. {FAO Malawi study estimates 3% loss}. Aflasafe, a biocontrol agent that grow and spread across the crop to outcompete aflatoxin producing fungi, was introduced into Malawi to prevent aflatoxin contamination in groundnut and to minimize losses in the field and during storage.</p>
<p>Case study 9: Broiler Chickens, USA</p>	<p>Mortality levels on-farm are an indication of the breed of chicken and how the environment and health of the birds are managed. Method of catching and crating chickens causes stress if multiple birds are caught at a time and held by their legs before being placed in a transport crate. Rough handling at this stage causes stress and injury to the birds. Dead-on-arrival: strongly influenced by stocking densities during transport and duration and environmental conditions of transport from farm to slaughter.</p>	<p>Improvements to animal welfare standards and reduced stocking densities. Slower growing chickens, with need to introduce new varieties & monitor on-farm welfare</p>
<p>Case study 10: Dagaa Fishery, Lake Victoria</p>	<p>Losses linked to delays in landing and processing catches. Poor management of landing beaches results in loss to predators and exposure to weather.</p>	<p>The losses can be reduced through early landing of catches, washing before drying, salting, and improved handling.</p>

5.1.6 Technology and infrastructure

Table 19: Drivers of food loss and waste due to factors related to technology and infrastructure, examples by case study

3. Technology and infrastructure	Summary of main drivers identified within case studies	Mitigations/ interventions - Examples
Summary	<p>Harvesting technologies and techniques may contribute to food losses if they result in damage to the crop (e.g. fruit, cassava) or incomplete harvesting (e.g. grain, oilseed, potato, groundnut). This can be either from manual harvesting (particularly in relation to fruit and vegetables) or using some level of technology (with grain being more conducive to mechanised approaches).</p> <p>Post-harvest technologies include the use of different storage technologies to reduce losses (grain, oilseed and groundnuts in relation to long-term storage). For roots, tubers, fruit and vegetables, there is more focus on containers and packaging to protect produce and short-term storage and pre-cooling technologies.</p> <p>In relation to fisheries, the use of inappropriate fishing gear for target species increases by-catch, particularly in relation to capture fisheries targeting larger species (e.g. Nile Perch, rather than dagaa).</p>	<p>A key focus of the literature on interventions to reduce harvest and post-harvest losses has focused on improvements to technologies in harvesting, storage, processing and transporting of produce.</p> <p>Interventions include greater mechanisation of harvesting, drying and processing stages, development of better tools for harvesting, improved storage (hermetic containers) and packaging.</p> <p>For technology options to be effective, they need to be implemented alongside better agronomic/ handling practices, training and awareness of harvest and post-harvest losses, as well as more supportive market conditions and involvement of other stakeholders later in the supply chain.</p>
Case study 1: Wheat, UK	Harvesting technology -if operated at the wrong forward speed and cut height may result in loss of grain through shatter of wheat heads.	Appropriate adjustment of harvester settings to reduce grain losses.
Case study 2: Rice, S&SE Asia	Poor combine-harvester design or technology not suited to rice, combines used are not efficient and can only perform shallow cutting, which results in residual grains being wasted. They achieve poor separation of rice panicles from straw and much rice grain is scattered through the rough harvesting mechanism	<p>The introduction of more advanced combine harvesters would enable deeper cutting and help minimise harvest losses. Training would be needed to operate the improved machines.</p> <p>Drying of rice – on plastic sheets for multiple days, as this enables to easily cover the grains in case of rain.</p>
Case study 3: Citrus, South Africa + fruit/	<p>No pre-cooling of harvested produce after harvest, to reduce field temperature and extend shelf-life.</p> <p>Lack of storage facilities which preserve the products or extend shelf life</p>	<p>Implementation of on-field packing systems and improved post-harvest handling practices by providing plastic crates.</p> <p>Low-cost cooling and storage methods and cool transporter to</p>

veg Ghana + Benin	Poor arrangements for sorting, grading of produce.	markets: e.g. low-cost evaporative cooling chambers can be deployed in remote rural areas at farm level to reduce the field heat in mango after harvest.
Case study 4: Mango, S&SE Asia	Traditional methods of harvest, post-harvest handling on-farm (collection in baskets and packaging in wooden crates) and in transfer to market result in high levels of loss. Over-packing in wooden crates results in compression damage.	Use of drying: Especially for Okra, drying of the vegetable before marketing can reduce decay and food loss. Use of harvesting poles for mango, to replace 'pick and throw'. Mango de-sapping: inverting the fruit and placing on racks for a couple of hours and de-stemming in lime wash, reduces problem of sap-burn.
Case study 5: Potato, SW China	Lack of appropriate storage facilities and packing systems to store and transport freshly harvested potatoes in good condition to maintain tuber quality	A range of semi-mechanised and fully mechanised harvesting options have been developed for cassava, but more work is needed to make these technologies appropriate to different growing conditions and scales of farming.
Case study 6: Cassava, potato, Trinidad + Tobago, Guyana, Peru	Cassava roots packaged in plastic bags for transport, without further protection. Damage caused in lifting cassava manually, which is a very labour-intensive activity. Technologies need further research, but cassava is a relatively neglected crop. Poor storage arrangements.	Use of improved storage containers, ventilated storage, evaporative cool storage, cold storage. Plastic crates instead of plastic bags are preferred as a means of limiting damage during transportation and handling processes. Storage improvements for potatoes tubers include improved storage pits, Cold/ storerooms or use of evaporatively cooled or stores with improved ventilation.
Case study 7: Rape seed and sunflower, France	The main losses during harvesting relate to the crop moisture content being too high causing the threshing and cleaning of the crop to become less efficient and seed is lost.	In the case of oil seeds, the harvesting method is too static to allow to harvest all the grains, due to high heterogeneity of the oil seed fields. In this instance, a more flexible reaping technology would be needed to increase the harvesting efficiency and to reduce losses during harvest.
Case study 8: Groundnuts, Ethiopia + Malawi	In the areas covered by the case study analysis, the level of technology applied to weeding, harvesting and processing of groundnut was very low, with highly labour-intensive manual operations.	Groundnut harvesting and shelling technology is urgently needed to reduce groundnut losses within smallholder systems. Purdue Improved Crop Storage bags (or PICS) can be used to minimize

		post-harvest losses during storage caused by aflatoxin and weevil infestation.
Case study 9: Broiler Chickens, USA	No specific technology drivers noted in case study.	
Case study 10: Dagaa Fishery, Lake Victoria	Processing of landed fish on the beaches results in high losses and contamination of drying fish with sand. The technology and cool chain are lacking to supply fresh fish, drying of fish is carried out with a low level of technology. The fish are perceived as a low value commodity (despite their high nutritional content), so technological investments will only be made in conjunction with better marketing.	Fishery requires basic technical interventions to reduce losses and to move away from processing on the bare ground to raised platform for drying the fish. Cool chain, alternative preservation and processing techniques resulting in higher value products: smoking, use of sieves and solar dryers.

5.1.7 Market structure, governance: & investment

Table 20: Drivers of food loss and waste due to market structure, governance, investment, fair trade and contractual factors

4. Market structure, governance, investment and fair trade	Summary of main drivers identified	Mitigations/ interventions - Examples from case studies
Market structure and connection to market	<p>Farmers and fishers, especially small-holders, are often not well connected to end markets due to limitations in transport infrastructure but also through deeper structural issues relating to how markets operate, the transactional costs involved and how prices are set by the market.</p> <ul style="list-style-type: none"> • Where small-holder farmers supply through brokers there is a weaker connection between farmers and end market. The lack of a strong feedback loop between farmer and product quality reduces the suppliers' understanding of food loss drivers and quality issues further down the supply chain. • Where links are weaker, farm incomes are depressed, where farmers cannot command a higher price for quality and are more often 'price takers' than 'price makers.' • The role of brokers and middlemen may result in multiple handling between farm and end markets, further increasing losses. <p>Gaining access to alternative markets for food which cannot be sold in its primary function is also an important aspect of reducing losses. For example, through food processing and preservation industries.</p>	<p>Reduce dependency on brokers to transport goods to market. Higher independence can increase the farmer's profit, and bring closer understanding of consumer demand. Control over transport also gives greater choice over timing and conditions of transport: such as transit packaging and environmental conditions. {Potatoes – Peru}</p> <p>Where farmers connect directly with markets, closer working with the customer results in better crop monitoring and the farmer has greater certainty of obtaining a good price compared with selling via brokers. This model is given extra momentum with the increased growth in the supply of branded rice products over recent years, where large food producers, their mills and supply chains, procure rice from farmers to meet their 'brand' requirements. This necessitates closer cooperation between farmers and rice brands. Such efforts can be mediated through farmer associations and cooperatives. {Rice, Pakistan}</p> <p>Improving marketing facilities through farmers' markets, vegetable markets, and collection centres and refrigerated vans so that farmers can obtain better prices for their produce. {Mango, India}</p>

<p>Investment in agricultural sector and market diversification, governmental involvement</p>	<p>Governmental sector investment in food security, agricultural development, sequential investment in infrastructure (such that improvements in one element do not then hit severe constraints at the next), bulk storage facilities and processing industries., bulk storage facilities and processing industries.</p> <ul style="list-style-type: none"> • R&D in post-harvest research • Investment in extension services • Subsidy for farm improvements, to lift farmer incomes <p>A number of commodities were identified as being neglected by government, as higher priority was given to cash crops for export: groundnuts in Ethiopia, dagaa fishery on Lake Victoria, potatoes in Peru. Without greater commitment to these commodities at governmental level, training and investment is likely to be held back.</p>	<p>There is a need to develop added value end markets for wasted mango, such as Amchur (dried and powdered raw mango). These markets require investment in machinery and labour. {Mango, India}</p> <p>There is a trade-offs between low value dagaa fish as a protein source for poor households, for use as animal and fish feed and in the development of higher value fish for domestic middle class / export markets. Lack of investment in the sector has resulted in relatively low utilisation for human consumption, despite the dietary protein deficit in poorer households. {Dagaa fishery, Lake Victoria}</p> <p>The lack of processing technologies for tomatoes too damaged to be sold greatly limits the extent to which alternative uses can be made of surplus tomatoes. {Tomatoes, Ghana}</p>
<p>Regulation and standards within food & agriculture sector: food, seed, GAPs, animal welfare policies</p>	<p>The framework of food regulations and standards within a country, designed to protect consumers from unsafe, adulterated, or contaminated food can also be an influence on farm stage losses. Regulations and guidance may exist, but not be implemented.</p> <ul style="list-style-type: none"> • Food safety standards (e.g. aflatoxin levels in groundnut) • Animal feed regulations • Fish by-catch policies & enforcement • Animal welfare standards • Certification of seed quality • Good Agricultural Practices to address standards in on-farm production and post-production processes. 	<p>In relation to case studies, a range of very specific and more general reforms were identified:</p> <p>Improved animal welfare standards in relation to rearing and slaughter, which includes improved transportation from farm to slaughter to reduce 'dead on arrival'. {Broiler Chickens, United States}</p> <p>Regulation of fishing gear designed for the target species to reduce by-catch.</p> <p>Introducing designated fenced-off beach landing area & raised drying racks. Most dagga fisheries carry out their processing on the beaches and do not comply with health and fish quality standards and therefore</p>

	<p>Food losses at the farm stage do not necessarily depend on the nutritional quality or lack of physical damage but may also be influenced by cosmetic standards (colour, shape, size) required by end markets. By specifying high standards in shape and appearance, especially fruit and vegetables, produce out-graded from the intended market may result in reduced prices in secondary markets. However, if harvesting and other farmer costs are not covered by prices, produce may be left unharvested, culled during harvest or used in low value applications, such as animal feed.</p> <p>Consumer choice not only directly impacts food loss through cosmetic standards, but also indirectly through consumer preference for varieties that may be more difficult to grow. For example, premium basmati rice varieties that are grown for export may be less well suited to the growing conditions in displacing more traditional rice crops. Despite lower yields and higher losses, these basmati might still be more profitable to the farmer than more productive alternatives that have lower consumer demand.</p>	<p>cannot access higher value markets in which to sell their fish. {Dagaa fishery, Lake Victoria}</p> <p>A number of crops were perceived as being neglected by policy makers with greater priority given to support for export crops over crops for local consumption. Examples include Lake Victoria's dagaa fishery, groundnut production in Ethiopia and Malawi and Peruvian potato farming.</p> <p>In Ethiopia, there is a need for country-led policy for groundnuts, as it is the case for cereals like wheat. Since it's a lowland crop in Ethiopia and planted in remote areas, less attention is paid to it from the government, at the same time it is not officially an exportable crop, due to the detection of aflatoxin levels in groundnut seed above the threshold set by various international market. {Groundnuts, Ethiopia}</p> <p>Where the food industry has become involved in the development of Good Agricultural Practices, farmers have benefitted through improved agronomy, access to technology and training. Examples include mango pulp producers and rice farmers growing crops for branded rice producers.</p> <p>A case in point is the development of Good Agriculture Practices in mango cultivation in Andhra Pradesh by the mango pulp processing sector. This model needs to be replicated across the fresh mango producers who don't currently receive the same level of support. {Mango, India}</p>
<p>Lack of access to finance/ support for investment</p>	<p>Although there are many solutions to addressing post-harvest losses, adoption may be at a low level. An important factor is lack of access to finance the investments needed, where farmers may be reluctant to take on</p>	<p>Organisation of farmers into co-operatives and farmer associations can improve access to finance to help with paying for inputs to production.</p>

	<p>more debt in the face of price volatility and other risks/ market failures. Lenders are often reluctant to finance farmers on favourable terms.</p> <p>Without access to finance, small-holder rice farmers in Pakistan may rely heavily on traders or millers for financing inputs to production, such as for seeds and fertiliser. This takes away their independence in negotiating a fair price, as these are set by the lenders, who also control access to the markets. {Rice, Pakistan}</p>	<p>Establishment of micro-finance initiatives. {Rice, Pakistan}</p>
<p>Fair trade practices and contractual arrangements</p>	<p>The distribution of added value along the supply chain often leaves the farmer with a very small share of the profit compared with other players in the supply chain, even in cases where the product is exported into high value end markets. This is especially the case for farmers that are not well connected to either processing or retail stages. Unless mechanisms are found to lift farm incomes, small-holder farmers, who produce the majority of the world's agricultural products, will not have the means to invest in ways that reduce harvest and post-harvest losses. If investment are made, these can only be justified through better prices paid. To this end paying fair prices to farmers is an integral element of reducing food losses at the farm stage.</p>	<p>Payment of fair prices – to enable farmers to improve their harvesting / field management techniques.</p> <p>Contractual arrangements that share risks more equitably between producers and the markets: with agreements to purchase a proportion of the crop in advance, at a set price.</p> <p>Improved bargaining power and price setting through collective organisation of farmers. {Rice, India}</p>

5.1.8 Human factors

Table 21: Drivers of food loss and waste due to human factors

5. Human factors	Summary of main drivers identified within case studies	Mitigations/ interventions - Examples from case studies
Farming culture and land ownership	<p>Demographics and gender balance in division of labour, strength of farming traditions and use of traditional crops, farming methods and practices.</p> <p>The unintended consequences of technical and market changes on food culture and traditions need to be considered. For example, in many regions women play a pivotal role in food production and post-harvest activities. It often involves arduous and repetitive work carried out in and around the home (e.g. shelling of groundnuts), coupled with a social component, childcare and other tasks. Although such systems may be inefficient and result in high losses, any changes need to be considered within this context and widely consulted on if innovations are to be adopted. Interventions may even exacerbate gender inequalities if they are developed without reference to wider cultural and social issues.^{xci}</p>	<p>Including women more into training initiatives, as women contribute highly during farming stages, but are often excluded from training schemes. Outreach work and innovations to reduce losses need to be sensitive to cultural and gender issues if they are to be successfully adopted.</p> <p>Land ownership is a significant factor, with an increase in tenant farming, making investments to reduce losses more difficult to secure. {Rice, S Asia}</p>
Level of skills and training	<p>The interventions that address 'agronomy' and 'technology' drivers require training and support services to help with up-skilling, the establishment of GAP programmes, training for improved technologies and the marketing of produce. Outreach work and training is needed to help farmers and farm labourer better understand food losses and the factors causing them and the impacts on later stages of the supply chain.</p> <p>This work may be led by NGOs, UN FAO, government agencies, farmer organisations, academic institutions, or the private sector food businesses.</p>	<p>Labourers had limited understanding of how harvest and post-harvest operations impact on the quality of food at later stages of the supply chain. There is a need for training / education, with inputs from government sector and NGOs, training schemes need to acknowledge the key role played by women in planting and tending crops and at harvest and drying stages {Rice, India and Pakistan}</p> <p>Processing companies play a crucial role in building farmer awareness of the factors that are important in post-harvest handling. For farmers supplying the mango pulp sector, GAPs are well established, but not so for the fresh mango farmers.</p>

	<p>Similarly, the development of better connections between farmers and markets can unlock an array of alternative and added value markets, pushing up crop utilisation and farm incomes.</p> <p>Effectiveness of outreach schemes that address food losses may not reach those that would benefit most. For instance, where key tasks are carried out by women, but outreach training is attended primarily by men, or where the farm owners attend the training with no representation from the workforce.</p>	<p>{Mango, India}</p> <p>Technical training should be made available to farmers. This could be done within governmental schemes, or university collaborations, such as the currently running scheme 'Science and Technology backyard'.</p> <p>{Potatoes, SW China}</p>
<p>Availability & cost of farm labour</p>	<p>Labour shortages/ high labour costs: directly impact harvesting, particularly in relation to fruit and vegetables, may impact on unharvested crop/ left in orchard/ field. Bumper crops that require hand harvesting, also may suffer high loss rates due to lack of available labour.</p>	<p>Increased mechanisation can address high labour costs or shortages. However, there is often a trade-off in that increased mechanisation may result in higher losses and damage to crops compared with more labour-intensive approaches.</p> <p>{Rice, India, and Cassava, Latin America}</p>
<p>Consumer / market expectations</p>	<p>Consumer preferences can be a factor in driving food losses at the farm stage, through the choice of varieties grown, or the grading of products to meet standards of appearance.</p> <p>To reduce losses, consumer must get used to "imperfect" goods. This applies to a variety of products, such as fruit and vegetables, oilseed (oil), roots and tubers.</p>	<p>For varieties of rice demanded by export markets: consumer preference is for long and slender-grained Basmati rice compared regular brown rice, resulting in higher losses at the farm and milling stages. Farmers might choose to grow Basmati varieties, even though they tend to be lower yielding with higher field and post-harvest losses, but command a better price compared with shorter grained varieties. A wider understanding of environmental implications and losses associated with supply chains associated with imported rice products would help to better inform consumer choice.</p> <p>{Rice, Pakistan}</p> <p>Modern consumer preferences for low cost, white poultry meat in the United States has led to lower levels of carcass utilisation compared with previous generations that mainly cooked whole birds as an occasional roast meal. The development of fast-growing broiler chicken varieties has led to flocks that are more susceptible to disease and are</p>

		<p>often reared at high stock densities. A switch in consumer preference for higher welfare, slower growing varieties would contribute to reduction in these losses but would also result in higher food prices.</p> <p>{Broiler Chickens, USA}</p>
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5.2 Priority actions and interventions by case study

Based on the cross-section of global commodities provided by the case studies analysis, it can be concluded that individual measures to address food loss and waste at farm stage are difficult to prioritise, as success often depends on synchronisation of a raft of interventions that include both farm stage and post-farm gate actions and stakeholders. Tackling farm stage losses is a multi-dimensional challenge that involves multiple stakeholders and different disciplines, as well as the primary producers themselves.

Limited data are available by which to assess the effectiveness of different interventions, except in cases where field trials have explicitly focused on technological, storage or crop handling improvements. For a holistic picture, empirical evidence is lacking to assess the effectiveness of farm stage interventions working with wider measures, such as training, improvements to finance, contractual arrangements, and the introduction of Good Agricultural Practices (GAPs). It is not possible to set priorities based on such a limited evidence-base, instead, Table 22 presents a qualitative assessment of priority areas of work within each case study. For each of the 12 supply chains, scores were assigned from 'higher' to 'lower' priority for the main types of interventions described in Section 5.1.

For the direct drivers of farm stage losses, account was taken of the split in food losses between different on-farm activities and the balance between harvest and post-harvest losses. In the case of indirect drivers, scoring was based on examination of the market/ governance and training/human contexts of each case study and their potential to support food loss reduction.

Higher priority actions are those where:

- change is likely to be most effective in reducing losses.
- actions previously neglected or where established actions need far greater uptake/ support.

These priorities acknowledge that levels of activity associated with lower priority actions need to be maintained as part of holistic strategies to reduce farm stage losses.

Without exception, all case study systems require continuation of existing actions as well as additional interventions to address biological and environmental threats to crops, livestock and fisheries. Although biological and environmental drivers of food loss include many factors beyond the control of primary producers (such as 'natural disasters'), there are losses that are more controllable. These include choice of resilient/ appropriate cultivars, better protection from extreme weather events, early treatment of pests and disease and improved water management, as illustrated by the examples given in Table 17.

For less mechanised or partially mechanised farm systems (most of the case study supply chains), priorities to address biological/ environmental drivers need to be balanced equally with initiatives covering combinations of direct and indirect actions. These include technological and agronomic improvements (Table 18 and Table 19) combined with adequate training of farm workers/ fishers that take account of the gender and demographic division of farm labour (Table 21). In order to sustain improvements and investments, work is also needed to secure more direct connection to markets – particularly where this might support higher farm incomes and result in closer partnership arrangements between primary producers and their customers within the processing and retail sectors (Table 20). There is also the need to develop a cascade of secondary markets to accept a greater range of food qualities for production that would otherwise be wasted and to increase food utilisation, this is illustrated schematically in Figure 42 for the case of perishable fruit and vegetables.

Table 22: Case studies analysis - qualitative prioritisation of mitigation actions to drive further farm stage food loss reductions

Case study	1.Actions on biological & environmental pressures	2.Improved farming / fishing practices	3.Technology & infrastructure improvements	4. Actions to address market, governance, and regulatory failures	5.Outreach, training, support services in support of interventions	Food utilisation: reduce risks posed by non-food uses (animal feed, biofuels etc.,)
1 UK Wheat	XXX	XX	X	X	X	XXX
2 S+SE Asia Rice	XXXXX	XXX	XXXX	XXX	XXXX	XX
3 Sub-Saharan Africa citrus + vegetables	XXXXX	XXX	XXXX	XX	XXXX	XXX
3 South Africa citrus	XXX	XX	XX	X	X	XX
4 India fresh mango	XXXXX	XXXXX	XXX	XXX	XXXXX	X
4 India mango pulp	XXXXX	XXX	XX	X	XX	X
5 SW China potatoes	XXXXX	XXXXX	XXXX	XX	XXXXX	XXXX
6 Latin America: cassava + potatoes	XXXXX	XXXXX	XXX	XXXXX	XXXX	XX
7 France: oilseeds	XXX	XX	XX	X	X	XXX
8 S-S Africa groundnuts	XXXXX	XXXXX	XXXX	XXXXX	XXXXX	XXXX
9 USA: broiler chickens	XXX	XXX	X	XXX	XX	XXX
10 S-S Africa: L. Victoria dagaa fishery	XXX	XXXX	XXXXX	XXXXX	XXXX	XXXXX
KEY	Mitigating Actions	Improved Food Utilisation				
Higher priority	XXXXX	XXXXX				
Lower priority	X	X				

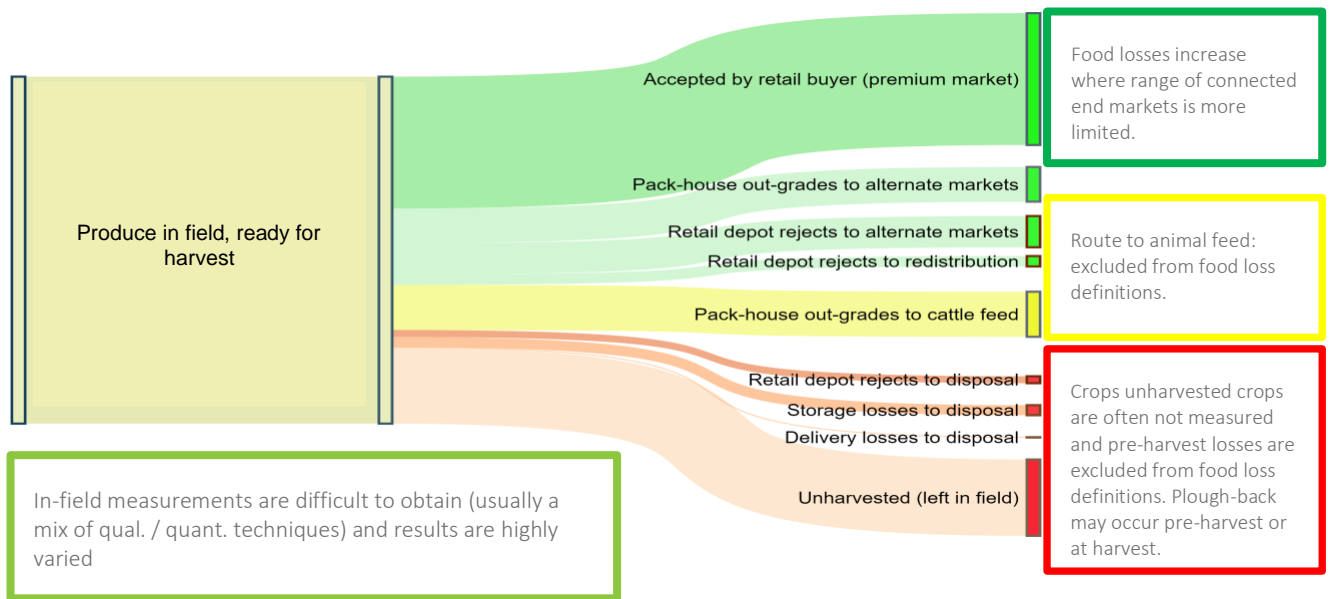
5.3 Competition between food supply and feed supply

Food utilisation: reduction in the risks posed by non-food uses (Table 22, column 6): outside the scope of SDG 12.3 food loss definitions are non-food uses for food surplus/ waste in animal feed and applications that valorise food waste (e.g. biofuel production or another higher value product). Such uses have the potential to undermine food loss initiatives or reduce food access or nutrition within local populations. Diversion to animal feed was identified as a factor behind some of the discrepancies between food loss rates used in Section 2.3 calculations when sense checked against case study findings in Section 4.8. In order to assess priorities for improved food utilisation each case study was scored in a similar way to the food loss intervention headings, taking account of the scale of non-food uses and more qualitative aspects revealed by the case studies.

Although valorisation routes and diversion to animal feed may provide greater market diversity and access, thereby reducing food losses, the higher objectives of improved food security and nutrition may be undermined in the process. Where the extent of food loss is masked by rejects used as animal feed, the scale of loss to the human food chain is unseen. Again, the case of fruit and vegetables illustrates this in Figure 42 (yellow = route to feed, red includes proportion of crop left unharvested in the field). Other examples of non-food routes include the competition between dagaa fish supplied for human consumption and use as fishmeal within livestock and aquaculture, edible chicken losses to rendering and pet food (e.g. chicken liver) and oilseed for biofuel/ feed. These routes often 'mask' the full extent to which crops/ livestock/ fish are being under-utilised as food and differ by commodity, farm system and level of mechanisation. Whilst alternate markets can act as a sink for what might otherwise be counted as food loss, larger farms are also more likely to dedicate a higher proportion of their production to feed and processing uses, compared with small-holder farms (< 2ha), where growing crops for food predominates (Ricciari, V., et al., 2018).^{xcii}

This is a complex area involving diversion of agricultural production to non-food uses as a planned farming activity (e.g. growing of wheat varieties intended for feed production) as well as an unintended consequence of poor growing conditions or last minute order cancellations. However, this is a significantly neglected dimension of food access and security issues, reduction of food losses and in the wider environmental impacts of agriculture. Greater support to food markets over those in the feed sector is required to address this issue, but this is counter-acted by the buoyant growth in diet transition towards dairy, fish and meat consumption in lower and middle income countries.

Figure 42: Relationship between farm stage produce losses, diversity of end- markets and whether fruit and vegetable out-grades are fed to cattle



6 Summary and conclusions

The main findings and conclusions are summarised below in relation to each of the main study objectives.

Objective 1: *Collate food loss data from various regions across the globe to understand where these losses are occurring, and which crop and country hot spots exist across both developed and developing economies. Utilise existing literature to map out these hot spots, data availability and measurement/data collection tools being used.*

Global farm stage losses were calculated using a compilation of 3,816 farm stage food loss and waste data points, of which 2,172 were suitable for use. These data were obtained for different commodities and regions using online databases and literature reviews (academic and grey literature). Data availability was unevenly spread across commodity group and global region, with cereals and fruit and vegetables better represented than others (particularly in Sub-Saharan Africa and S and SE Asia) and fish and dairy products having the fewest data points.

- Total farm stage losses were estimated at 1.2 billion tonnes per year, equivalent to 15.3% of total production (including harvest losses), with a total value of \$370, based on farm gate prices (excluding fishery losses).
- The high- and middle-income countries, with 37% of the global population, were estimated to contribute 58% of global harvest losses (368 million tonnes). Conversely, low-income countries with 63% of the population had a 54% share of global post-harvest harvest farm stage losses (291 million tonnes). The profiling of these estimated overturns the assumption that farm level losses are more significant in low-income countries and that in middle- and high -income countries, consumer stage food losses are more significant.

The compiled loss data for harvest and post-harvest stages provided inputs into the socio-economic and environmental modelling and were used to inform the selection of global case studies for further analysis.

Objective 2: *Using the data gathered, analyse the environmental, social and economic impacts resulting from the losses. Where possible estimate environmental impacts e.g. GHG emissions, land use/land conversion, water use, excess agri-chemical use etc. at sub-national, national and global scales. Furthermore, seek to provide a sense of the scale of the social impacts in terms of potential lost livelihoods, economic burden and impacts on food security.*

The global analysis of food loss and waste impacts was based the outputs from Objective 1, combined with emission factors derived from a model developed by Poore and Nemecek (2018) *Reducing food's environmental impacts through producers and consumers*. This study had the advantage of providing a large number of farm level studies (38,700) with global coverage for the key impact categories: GHG emissions (kg CO₂ eq.), freshwater withdrawal (L), water scarcity (L eq.), acidification potential (g SO₂ eq.) and eutrophication potential (g PO₄³⁻ eq.). A separate analysis was carried out for wild-caught fish, as these were not represented in the Poor and Nemecek model.

Outputs from the modelling of the environmental impacts associated primary production resulted in revised global estimates for the impacts associated with food loss and waste in terms of GHGs emissions, eutrophication, water abstraction, acidification and land use.

Other impacts were looked at on a case study basis, including the wider socio-economic impacts, biodiversity impacts and water scarcity, as these aspects were more difficult to generalised across each global region and commodity group.

- Overall, it was found that the carbon footprint of farm stage food losses amounted to 2.2 gigatonnes CO₂eq., of which 55% came from harvest sources and 45% from post-harvest sources. This was equivalent to 16% of the estimated 13.7 gigatonnes/ year associated with global agriculture year.
 - Meat and animal products form the largest contribution from a single commodity group (40% of global carbon dioxide eq. emissions associated with all losses from only 13% of tonnage losses), followed by cereals and pulses (24%, 17%). Meat and animal product losses from Europe, Asia and Latin America dominated harvest stage losses – mostly associated with enteric fermentation and manure management, followed by cereals and pulses in Asia.
 - Post-harvest losses were dominated by cereals and pulses, with South/Southeast Asia (rice paddies) and Sub-Saharan Africa (maize) contributing the most.
- Patterns of acidification and eutrophication potential mostly mirrored those of greenhouse gas emissions across regions and commodities.
 - Milk production were found to be a significant component of acidification and eutrophication potentials from meat and animal products.
 - While greenhouse gas emissions from fruit and vegetables are relatively low, a spike in eutrophication and acidification potential was identified in Industrialised Asia, associated with high tonnage losses.
 - An acidification potential hot spot was identified in South and Southeast Asian rice production, due to a combination of high tonnage losses and the higher acidification potential for rice in this region (16kg SO₂ eq./ kg product) compared with other rice growing areas (e.g. Industrialised Asia, 8.6kg / kg of product).
- Water withdrawals for agricultural production associated with global food losses were estimated to be 760 km³ of freshwater, equivalent to over 5 weeks' flow from the Amazon River into the Atlantic Ocean.
 - South and South-East Asia dominated water losses followed by Industrialised Asia and Sub-Saharan Africa, with cereals and pulses having the highest global water footprint, followed by meat and animal products and fruit and vegetables.
 - The study found much variation by crop type across regions, for instance wheat in Europe had a lower water footprint (largely rain-fed) than North America and Asia, the latter regions having high irrigation dependency.
- The land areas used to produce food losses was estimated for all commodities apart from fisheries, taking account of the occupation time from seed, on-and off-farm arable and permanent crops, fallow land, temporary as well as permanent pasture. Total land used to produce food that was lost on the farm was estimated to be 4.4 million km², a land area larger than the Indian sub-continent.
 - Over half of the 'lost' land use was associated with meat and animal products. This was due to grazing animals over long periods of time, until the end product can be produced (dairy or meat), as well as the land used for feed production to support livestock (cattle feed, feed supplements).
 - The study found significant variation between regions with the lowest land use associated with animal losses from Sub-Saharan Africa and the highest land use in Industrialized Asia.
 - Overall, fruit and vegetable losses were responsible for 8% of the total food loss land use, while being responsible for 38% of food loss tonnage. Conversely, meat and animal products were responsible for 50% of the land use, but only 13% of the food loss tonnage.



In conclusion, the work clarified the overall pattern of environmental impacts across commodities and regions for the main impact categories. These were found to be most significant for losses associated with meat and animal products. This commodity group had a disproportionately high environmental impact in relation to its share of global food loss tonnage.

Objective 4: *Summarise the key reasons for the losses occurring e.g. product quality, strict specifications, poor management practices, market dynamics, etc. and provide an overview of the actions being taken by different countries/blocs.*¹ *Propose a range of mitigation actions (e.g. on-farm management practices, technological fixes, supply chain interventions, including possible alternative supply chains/options, policy levers) that can be adopted by different actors (companies in different sectors, countries, NGOs, blocks like the EU, farmers, policy makers etc). Where possible, provide further detail on specific mitigation actions relevant to specific crop/country case studies.*

A five-part classification was constructed as a framework for understanding food loss and waste drivers, based on evidence gained from the case study analysis combined with wider literature sources. These included three categories of direct drivers that were apparent on the farm (or fishery):

- Biological and environmental factors
- Agronomy, animal husbandry and fishing practices
- Technology and infrastructure.

Two indirect, or systemic groups of drivers were identified as:

- Market structure, governance and investment
- Human factors

For the limited literature that provided cases where detailed holistic assessment of drivers had been carried out, such as those using the FAO's four elements approach, it was apparent that synchronized interventions were required to address farm stage losses, with no single action effective on its own. In the past there has been a tendency to focus on technological solutions to reduce losses during harvesting, processing or storage, without taking account of the wider socio-economic context represented by the indirect drivers.

Due to the lack of systematic evidence to assess the effectiveness of mitigating actions, this study attempted a qualitative scoring of relative priorities across the case study supply chains.

- All case studies involved actions to address biological and environmental drivers of food loss, with no distinction between case studies in high-/ middle-income areas or low-income areas.
 - Examples of mitigations to address biological environmental pressures included integrated pest management systems (UK wheat), better water management and orchard mulching (Mango, India) and removal of damaged or infected potato tubers from the harvested crop (SW China, potato).
- For less mechanised or partially mechanised farm systems (most of the case study supply chains), there was a need to balance actions to address biological/ environmental drivers with initiatives covering combinations of direct and indirect actions.
 - Agronomic, animal husbandry and fishery practices - choice of more appropriate/ robust cultivars to suit environmental conditions (SW China, potatoes), appropriate use of ripening indices (India, mango) and use of biocontrol agents against aflatoxins (Malawi, groundnut)
 - Technological improvements to harvesting – such as the use of more efficient rice harvesters specifically designed for producing a deeper cutting action (India, rice), improved field packing systems (Ghana + Benin, fruit and vegetables), drying platforms to replace beach drying (Lake Victoria, dagaa fishery)
 - Organisational, market and governance failures relating to market access, food regulation, weak linkages between primary producer and end markets – examples are very varied and specific to country and supply chain. In markets where there are multiple stages between farmer and market, for instance through brokers and middlemen, losses are higher as there

are greater uncertainties for the farmer in supplying the market and a more limited understanding of what the market requires and the factors that driver down product quality and increase losses in the supply chain. Examples include fresh mango producers in India with poor linkage to end markets compared with mango pulp producers, inability of dagaa fishery to supply fresh fish to markets, as perceived as a low value product.

- Government support for agricultural improvement in low income countries are more likely to favour cash crops linked to export markets and higher value crops (e.g. neglect of Peruvian potato farming and Ethiopian groundnut).
- Human and cultural factors that case studies identified included the need to ensure that outreach and training programmes addressed the gender balance of activities undertaken on farms, for example the planting and post-harvest processing of rice in India and Pakistan is carried out by women but training to reduce losses is attended by men.
- Most of the direct interventions identified to address losses in less mechanised systems involved elements of training and support services to succeed.
- Private sector food businesses can play an important role in linking to farmers to improve understanding of market requirements and develop Good Agricultural Practices (e.g. India, mango pulp processing firms working with producers).



A1 Methodology used to compile farm stage global food losses

A1.1.1 Overview

A four-stage process was used (Figure 43) to combine the best selection of existing datasets relating to on-farm losses, with high-level estimates for global regions and commodity groups based on the FAO 2011 methodology, with a spotlight on more qualitative and granular data for case studies identified.

Figure 43: Steps in the food loss quantification methodology.



Step 1: To make the best use of existing global data and identify new sources, we collated on-farm loss studies using existing databases and literature searches. The core component of the analysis involved use of the FAO's open-access online database,^{xciii} containing 18,000 observations relating to food loss and waste, which was downloaded, edited and de-duplicated for the purposes of this study.

A literature search was conducted to identify additional data sources. The search included peer-reviewed journals, reports (consultancy + 'grey literature', governmental/NGOs, trade bodies), PhD/MSc theses, conference papers and book chapters.

Overall, 20,000 observations were compiled, but many were found to be out of scope, mainly through their focus on whole supply chain food loss and waste estimates, lack of coverage of primary production stages or not containing any useful primary data sources.

A1.1.2 Selection criteria

- methodology and study context
- timeliness: how recently the primary data were collected
- balance between data from mechanised/ industrialised systems and low/tech small-holder systems
- significance of the crop type within the region: nutritional value, volume on the market, socio-economic factors
- whether or not data from a crop-country-supply chain combination that is significant to UK imports
- alignment with WRI FLW Standard

Where available, qualitative data were also extracted on topics relevant to other aspects of the project, such as food loss drivers, any information on interventions to reduce losses, market destinations and losses/ waste along supply chains. For the 'deeper dive' stage into the case studies and crop-country-supply chain combinations significant to UK imports, data were coded to enable greater granularity in the analysis by commodity, geographical area (see Appendices A3 and A4).

Data collation focussed on up-dating farm stage losses, whilst recognising that activities associated with harvesting, processing, grading, packing and storage do not neatly fall within 'on-farm' and 'off-farm' stages (e.g. grading may be carried out in-field, off-farm, or both).

In addition to collecting improved loss data, new sources of information was sought on the conversion factors that determine the part of agricultural production that is edible, and the proportion allocated for human consumption versus non-food uses (including feed). These factors are important to the understanding of the impact of food losses on access to edible food for human consumption.

A1.1.3 Food Losses: activities within scope

The scope of the study includes the farm stage of agricultural production. Studies included within the data compilation were classified according to a set of harvest and immediate post-harvest activities carried out at the farm stage. This section describes activities within scope for vegetal and animal/ fishery systems.

A1.1.4 Agricultural production of vegetal commodities

Losses due to mechanical damage and/or spillage during harvesting operations in field. Also includes estimates of crops not harvested or ploughed back into the field. Although the objective was to maintain a distinction between losses at harvest and those associated with immediate post-harvest activities carried out on-farm, there are likely to be overlaps, depending on the commodity type. For instance, the preliminary grading of vegetables within the field may have been included within total harvest losses by one study but separated as a post-harvest activity in another.

A1.1.5 Postharvest handling and storage of vegetal commodities

A wide range of activities are associated with farm stage losses, broadly grouped into harvest/ harvest losses and immediate post-harvest losses. FAO’s online food loss and waste tool lists 20 different activities associated with the farm stage (Table 23), with many overlapping with subsequent supply chain stages beyond the farm gate. These boundaries in part relate to crop/ commodity types and their perishability, but also follow a gradient between small-holder farmers in poorer economies versus larger scale, more highly industrialised agricultural systems.

Table 23: Activities associated with post-harvest losses recorded at the farm (FAO’s food loss online database)

Collection from field	Lifting (e.g. cassava)	Transport on-farm
Drying (e.g. rice, fish)	Milling on-farm	Winnowing
Drying Before Storage	On-farm assembling	Cleaning
Drying Before Threshing	On-farm storage	Sorting/Grading
Farm storage	Packaging on-farm	Stacking
Grading	Piling	Stooking
Grading & Sorting	Platform drying	Storage
Handling	Preliminary Processing	Storage, handling
Harvesting	Processing on-farm	Stripping
	Removing cobs from stalks	Threshing
	Shelling (e.g. groundnuts)	

A1.1.6 Agricultural production of animals, milk and fish

For bovine, pork and poultry meat, losses refer to animal death during breeding. For fish, losses refer to discards during fishing. For milk, losses refer to sickness (mastitis) for dairy cows and other dairy livestock, as well as fallen stock.

A1.1.7 Post-harvest handling and storage of animals, milk and fish

For bovine, pork and poultry meat, losses refer to death during transport to slaughter and condemnation at the slaughterhouse, following veterinary inspection). For fish, losses refer to spillage and degradation during dry/ preserving, icing, packaging, storage and transportation after landing. For milk, losses refer to spillage and degradation during transportation between farm and distribution.

A1.1.8 Definitions used in compilation of estimates

Food losses refer to a decrease in food quantity or quality in the early stages of the food supply chain, before the food products reach their final stage, reducing the amount of food suitable for human consumption. The concept of food losses at primary production are often related to agronomic, technology and infrastructure deficiencies a (Parfitt, Barthel et al. 2010) and a distinction is often made between food losses as 'unintended' and food waste being as a conscious decision to discard. Although studies may include loss of food quality that may not also result in a reduction in food weight, the main purpose of quantification of the scale of food losses has necessarily focussed on the proportion of the total weight of food lost. There are few datasets that consistently measure the loss in food quality and this category of loss may also relate to standards set by markets.

Food loss does not apply to inedible food stuffs such as peels, and skin etc., which generally are not consumed. However, unless a study has separately identified the edible fraction within total food losses, it is difficult to interpret this issue. Losses and waste of meat is however reported in carcass weight (including bone). The idea was to report losses and waste of meat in carcass weight so that these volumes would be comparable to other volumes (e.g., production volumes), often reported in carcass weight.

A1.1.9 Practicalities of applying definitions to studies of harvest and post-harvest losses

Definitions are sometimes difficult to apply to studies that did not have food loss definitions as a primary focus. For instance, when a crop is ploughed-in before it is ready for harvest, this would formally be counted within the pre-harvest stage (i.e. not a food loss/waste), even though the drivers might be the same as those that result in a crop that is ready for harvest being abandoned (i.e. unharvested crop that is mature is a food loss/waste). So, in the real world these definitional distinctions are not easily up-held. Although there is a need for consistency, the datasets and studies available to the review were not specifically designed with food waste definitions in mind.

World Resources Institute Food Loss and Waste Protocol definitions require one or more of 8 destinations (see below) to be recorded in order to determine whether or not a loss is to be counted within food loss/ waste definitions. As food loss studies in regions such as India and Sub-Saharan Africa have been conducted with the specific purpose of improving food access and security, the question of the 8 food loss destinations has not been a feature of the compiled data. So, they cannot be formally aligned with WRI requirements. The reality on the ground may also be ambiguous when destinations are known: potatoes left in the field that happen to be eaten by livestock may be counted as 'not harvested' (therefore food waste) or may equally be recorded as 'animal feed' (therefore not food waste).

A1.1.10 Definition of geographical groupings

For the analysis, the same regions were used as that of FAO study: “Global Food Losses and Food Waste - extent, causes and prevention”- FAO, 2011

Medium and higher income countries were divided into three world regions. All countries included in the medium and high-income regions are listed in Appendix A3.

Lower income countries were divided into four world regions. All countries included in the low-income regions are listed in Appendix A4.

A1.1.11 Classification of commodity groups

Three classifications of food commodities have been applied by the UN FAO on their work on global food losses:

1. The basket of different commodities used by countries adopting the Food Loss Index (with FAO asking countries to select the top 2 commodities from the main 5 groups for tracking purposes)
2. Classification applied to FAO’s Food Balance Sheets
3. Grouping chosen for FAO 2011 study.

For data compilation all three classifications were applied, for the main analysis and reporting commodities were grouped and analysed based on the FLI Commodity Baskets in the SDG 12.3.1: Global Food Loss Index.

A1.1.12 Results of literature review and data selection process

Of the 20,000 observations processed during the data and literature review, only 3,816 focused on farm stage losses, of these 2,172 provided usable datapoints for the study. These are split by commodity group in Table 24 and by region in Table 25. The main reasons for rejecting studies were that they repeated data already included or provided no estimates of the proportion of food lost at the farm stage.

Table 24: Number of farm stage studies included in the data/literature review by commodity and whether selected for further analysis

Commodity	Used	Rejected
Cereals	1,238	381
Roots and Tubers	117	58
Oilseeds and Pulses	162	281
Fruit and Vegetables	482	878
Meat and Poultry	82	65
Fish and Seafood	29	6
Dairy Products	22	15
Sugars and Syrups	14	9
Other	26	39
Total	3,816	1,732

Table 25: Number of farm stage studies included within final data compilation, by commodity (FAO 2011 classification) and region

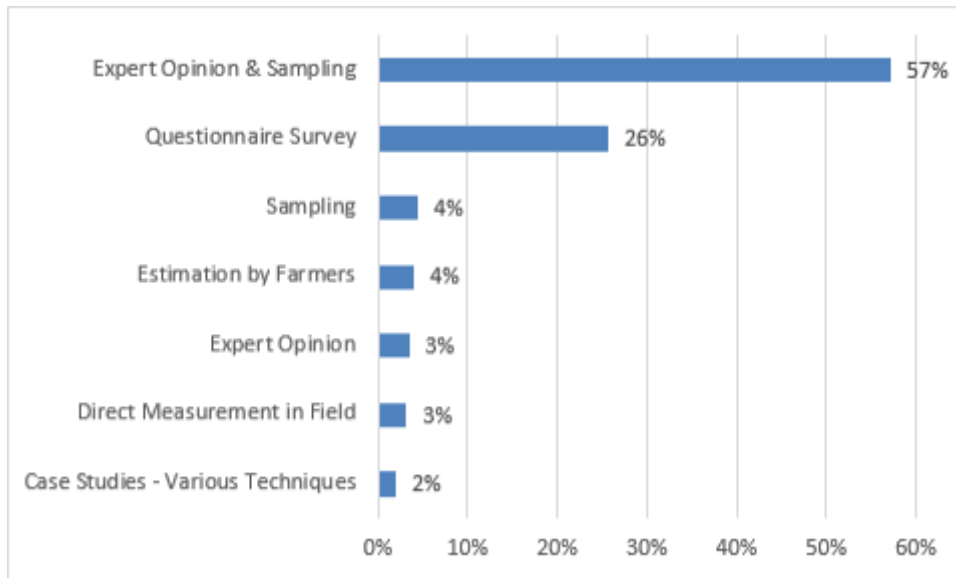
	Cereals	Roots & Tubers	Oilseeds & Pulses	Fruit & Veg.	Meat & Poultry	Fish & Seafood	Dairy	Sugars & Syrups	Other	Total
Europe	5	30	12	66	54	2	6	-	-	175
North America & Australasia	2	5	2	27	5	10	-	-	-	51
Industrialised Asia	15	4	-	38	1	-	-	-	-	58
Sub-Saharan Africa	1,059	34	1	103	4	-	1	-	-	1,202
Northern Africa & Middle East	6	4	7	8	3	1	4	-	-	33
South & South East Asia	133	34	132	231	13	11	8	14	26	602
Latin America	18	6	8	9	2	5	3	-	-	51
Total	1,238	117	162	482	82	29	22	14	26	2,172

Two global regions accounted for over 80% of the usable datapoints: 55% of observations related to Sub-Saharan Africa, 28% to South and South East Asia. In the matrix of 63 cells, 17 commodity-region cells had no available data.

Cereals accounted for 57% of datapoints (86% of these related to Sub-Saharan Africa) and fruit/vegetables 22% (48% from South and South East Asia)

Wide range of different measuring methods were apparent in the data sources reviewed, Figure 44. Most involved mixed methods of measurement (e.g., 57% used both in-country expert opinion and an element of sample surveys), with heavy reliance on surveys using interviews and questionnaires. Due to the expense of conducting on-farm measurements – only 3% of datapoints were based solely on this technique. Methodology has important implications for the consistency of loss estimates obtained, with self-declared losses generally under-reporting losses compared with data obtained from direct measurement in the field.

Figure 44: Methodologies used to compile primary data relating to food loss estimates at farm stage.



A2 Methodology used to model environmental and socio-economic impacts

Two approaches have been taken to estimate the environmental impacts associated with agricultural losses:

1. The main environmental impact factors have been mapped at a global level to each region and commodity using a comprehensive 2018 study (see below). Where impacts data are not easily available (for marine fishing), a simplified approach has been taken.
2. Biodiversity indicators derived from the Yale Environmental Performance Indicators set have been applied to the ten case studies.

A2.1.1 Global analysis

The global analysis is based on impact factors derived from *J. Poore and T. Nemecek (2018): Reducing food's environmental impacts through producers and consumers*^{xciiv} for the different commodities and in the different regions. The study covered a total 5 environmental indicators, 38,700 farms and 1,600 processors, packaging types, and retailers to assess the environmental impacts of diverse producers all over the world.

The impacts in the referenced study as well as the following study include:

- GHG Emissions (kg CO₂ eq.)
- Freshwater withdrawal (L)
- Water scarcity (L eq.)
- Acidification potential (g SO₂ eq.)
- Eutrophication potential (g PO₄³⁻ eq.)

The *J. Poore and T. Nemecek (2018)* model categorises LCAs by product and by country. The LCA results are standardised to be per kg of final product impacts and where possible are split into the different stages of the life cycle of the product (e.g. feed, farm, processing, transport and storage, packaging and retail). The impacts of per kg of final product are based on the total volume of products leaving the farm; harvest losses are not factored in. To estimated impacts for this report we took the pre-farm and farm level impacts from the model and adjusted the product weights to reflect the gross weight of harvested product where applicable.

A2.1.2 Fish and seafood

A different approach was taken for fish due to the lack of LCA data for wild-caught fish. Land use is not estimated as it is either not applicable or there is no split in the loss data between marine farming, freshwater farming in lakes and farming on land.

Wild-caught impacts are limited to greenhouse gas emissions from fishing vessels as land-use, eutrophication and acidification are not applicable.

For farmed fish, molluscs and crustaceans, LCA data from the main study are used. There are no data in the model on molluscs so only greenhouse gas emissions (taken from freshwater fish farmed) are estimated.

A weighted average of the wild-caught impacts (fuel use) and farmed impacts (from LCA) is used with weighting by the estimated percentage of fish from each source.

Table 26 shows the estimated proportion of each type of fish that are wild caught. All other types (demersal fish, pelagic fish, other cephalopods) are assumed to be 100% wild caught. Note that farmed

salmon and trout are counted as “freshwater” within the FAO stats. This is consistent with the table below, which shows that the majority of such fish are farmed.

Table 26: Proportion of fish caught wild versus (farmed)

% of fish wild caught (aquaculture)	Freshwater Fish	Crustaceans	Molluscs, Other
Europe	18% (72%)	2% (98%)	11% (89%)
USA, Canada, Oceania	18% (72%)	45% (55%)	11% (89%)
Industrialized Asia	18% (72%)	45% (55%)	11% (89%)
Sub-Saharan Africa	18% (72%)	45% (55%)	11% (89%)
North Africa, West and Central Asia	18% (72%)	45% (55%)	11% (89%)
South and Southeast Asia	18% (72%)	45% (55%)	11% (89%)
Latin America	18% (72%)	45% (55%)	11% (89%)

The freshwater fish split comes from FAO capture data from 2016 – 63 million tonnes of inland production, of which 12m tonnes (18%) was wild and 51m tonnes (72%) was aquaculture.

The split for crustaceans comes from a WWF article about Shrimp, with production in Europe assumed negligible. The split for molluscs comes from *Wijsman J.W.M. et al (2019)*.^{xcv}

All impact estimates are made using regional averages, weighted according to production tonnages per country.

Carbon dioxide emissions for marine vessels (wild caught, based on fuel use) comes from *Parker et al (2018)*.^{xcvi} Regional rather than species group data were used for most species types as these better reflect the mix of catch by region. However, the impacts for crustaceans and molluscs were used as these are separately identified and the impacts for crustaceans are particularly high.

Table 27: CO₂e emission for marine vessels

Region	kg CO ₂ eq. per kg
Europe	1.7
USA, Canada, Oceania	2.25
Industrialized Asia	3.7
Sub-Saharan Africa	1.8
North Africa, West and Central Asia	1.8
South and Southeast Asia	2.5
Latin America	1
Species group	
Crustaceans	7.9
Demersal molluscs	2.4

A2.1.3 Calculating the impacts for the agricultural stages

In order to find the impacts specific to the agricultural stage of the supply chain, LCA's were identified within *Poore and Nemecek* (2018) that included farm and feed stages split from other supply chain stages. One study was excluded as the impacts from feed, farm, processing and transportation were combined. For the relevant stages of feed and farm, the impacts per kg of raw material commodity (removing any processing conversion factors) were compiled and weighted averages for each impact were calculated for each raw material by country, using the model's allocation of the LCAs coverage, resulting in the following coverage:

- each raw commodity by region.
- each Food Balance Sheet (FBS) group by region
- each Food Loss Index (FLI) Basket group by region (global average applied if no specific regional data available)

Based on the available LCA data it was possible to generate impact values (per kg of raw material) for both harvest losses and post-harvest losses.

A2.1.4 Applying these impacts to the tonnage loss data (extrapolated from FAO production data)

Environmental impact factors were then applied to food loss data arranged by FAO commodity through mapping these to the products listed within as reported in the LCA model. In instances where there was no direct match between FAO commodity description and those within the model, proxies were used and matched (this was the case for 47 commodities, which represented 3.2% of the total food loss by tonnage). The appropriate emission factors were then applied to the calculated tonnage losses for each commodity and scaled-up to provide overall impact estimates for the following:

- By commodity and country
- By commodity and region
- FBS group and region
- FLI based and region.

A2.1.5 Case studies analysis - environmental impacts

For case studies we put the LCA impacts from the above analysis in the context of national indicators from the Yale Environmental Performance Index (EPI) and WRI. This is complemented by insights from a study on endemic richness and agricultural expansion and intensification.

The following indices are used:

Table 28: Indices used in the environmental impact assessment

LCA impact	Yale EPI / WRI	Components
Eutrophication potential	Agriculture (AGR)	Sustainable Nitrogen Management Index
Acidification potential	Pollution Emissions (APE)	Adjusted emission growth rate for sulphur dioxide Adjusted emission growth rate for nitrous oxides
Land use	Biodiversity & Habitat (BDH) Ecosystem Services (ECS)	Terrestrial biome protection (national weights) Terrestrial biome protection (global weights) Marine protected areas

		Protected Areas Representativeness Index Species Habitat Index Species Protection Index Biodiversity Habitat Index Ecosystem Services Tree cover loss Grassland loss Wetland loss
Freshwater withdrawals	WRI Water Stress indicator	Aqueduct baseline water stress (low – extremely high)

Due to the difficulties in aggregating country indicators into meaningful regional indicators, a country-based approach is used for the case studies. For each region, the three or four countries with the largest tonnage losses were chosen for review.

A2.1.6 Case studies analysis - biodiversity – endemic richness

A recent paper in Nature Communications (*Zabel et al, 2019*)^{xvii} provides a detailed analysis of endemic richness at a granular level around the globe. This is compared with the potential for agricultural expansion or intensification.

The results of this paper are summarised for each case study to illustrate how land use might impact on biodiversity.

A2.1.7 Case studies analysis - social context

Sustainable development goals SDG 1 (No poverty) and SDG 2 (Zero hunger) were selected to put food waste into context. They were chosen because of their relative simplicity, availability and reliability of data. A broad range of other indicators were considered (e.g. wages, governance, female participation) but the links between these and food waste were complex and generalising to very different case study contexts is difficult given the many local factors in play.

A3 Geographical groupings used in food loss database

Table 29: Countries included in medium and high-income 'industrialised' regions.

Europe		
Albania	Georgia	Netherlands
Armenia	Germany	Norway
Austria	Greece	Poland
Azerbaijan	Hungary	Portugal
Belarus	Iceland	Romania
Belgium	Ireland	Russian Federation
Bosnia & Herzegovina	Italy	Serbia
Bulgaria	Latvia	Slovakia
Croatia	Lithuania	Slovenia
Cyprus	Luxemburg	Spain
Czech Republic	Macedonia	Sweden
Denmark	Malta	Switzerland
Estonia	Moldova	Ukraine
Finland	Montenegro	United Kingdom
France		
North America & Oceania (NA&Oce)		Industrialized Asia (Ind. Asia)
Australia	USA	Japan
Canada		China
New Zealand		Republic of Korea

Table 30: Countries included in low-income regions

Sub-Saharan Africa		North Africa, Western & Central Asia	South & Southeast Asia	Latin America
Angola	Malawi	Algeria	Afghanistan	Argentina
Benin	Mali	Egypt	Bangladesh	Belize
Botswana	Mauritania	Iraq	Bhutan	Bolivia
Burkina Faso	Mozambique	Israel	Cambodia	Brazil
Burundi	Namibia	Jordan	India	Chile
Cameroon	Niger	Kazakhstan	Indonesia	Colombia
Central African Rep	Nigeria	Kuwait	Iran	Costa Rica
Chad	Rwanda	Kyrgyzstan	Laos	Cuba
Dem Rep of Congo	Senegal	Lebanon	Malaysia	Dominican Republic
Cote d'Ivoire	Sierra Leone	Libya	Myanmar	Ecuador
Equatorial Guinea	Somalia	Mongolia	Nepal	El Salvador
Eritrea	South Africa	Morocco	Pakistan	Guatemala
Ethiopia	Sudan	Oman	Philippines	Guyana
Gabon	Swaziland	Saudi Arabia	Sri Lanka	Haiti
Gambia	Tanzania	Syria	Thailand	Honduras
Ghana	Togo	Tajikistan	Vietnam	Jamaica
Guinea	Uganda	Tunisia		Mexico
Guinea-Bissau	Zambia	Turkey		Nicaragua
Kenya	Zimbabwe	Turkmenistan		Panama
Lesotho		United Arab		Paraguay
Liberia		Emirates		Peru
		Uzbekistan		Suriname
		Yemen		Uruguay
				Venezuela

A4 Commodity groupings used in food loss database

Table 31: Classifications of food commodity groups used by FAO Food Loss Index, FAO Food Balance Sheet and FAO 2011 food loss study

FLI Commodity Group	Food Balance Sheet Groups	Grouping used in FAO 2011
Cereals and Pulses	Cereals	Cereals
	Pulses	Included within Oilseeds
Fruit and Vegetables	Fruit	Fruit and Vegetables
	Vegetables	
Roots, Tubers and Oil Crops	Oil Crops	Oilseeds and Pulses
	Roots and Tubers	Roots and Tubers
Meat and Animal Products	Animal fats	Meat and Poultry
	Eggs	
	Meat	
	Milk and Dairy	Dairy Products
Fish & Fish Products	Fish	Fish and Seafood
Other	Spices	Miscellaneous
	Stimulants	
	Sugars and Syrups	Sugars and Syrups
	Tree nuts	Included within oilseeds and pulses

Table 32: Full listing of FAO commodities

Item	FBS	FAO 2019	FAO 2011
Eggs, hen, in shell	Eggs	Meat and Animal products	Meat and Poultry
Fat, camels	Animal Fats	Meat and Animal products	Meat and Poultry
Fat, cattle	Animal Fats	Meat and Animal products	Meat and Poultry
Fat, goats	Animal Fats	Meat and Animal products	Meat and Poultry
Fat, sheep	Animal Fats	Meat and Animal products	Meat and Poultry
Honey, natural	Sugar and Syrups	Other	sugars and syrups
Meat, camel	Meat	Meat and Animal products	Meat and Poultry
Meat, cattle	Meat	Meat and Animal products	Meat and Poultry
Meat, chicken	Meat	Meat and Animal products	Meat and Poultry
Meat, game	Meat	Meat and Animal products	Meat and Poultry
Meat, goat	Meat	Meat and Animal products	Meat and Poultry
Meat, sheep	Meat	Meat and Animal products	Meat and Poultry
Milk, whole fresh camel	Milk and Dairy	Meat and Animal products	Dairy Products
Milk, whole fresh cow	Milk and Dairy	Meat and Animal products	Dairy Products
Milk, whole fresh goat	Milk and Dairy	Meat and Animal products	Dairy Products
Milk, whole fresh sheep	Milk and Dairy	Meat and Animal products	Dairy Products
Offals, edible, camels	Meat	Meat and Animal products	Meat and Poultry
Offals, edible, cattle	Meat	Meat and Animal products	Meat and Poultry
Offals, edible, goats	Meat	Meat and Animal products	Meat and Poultry
Offals, sheep, edible	Meat	Meat and Animal products	Meat and Poultry
Eggs, other bird, in shell	Eggs	Meat and Animal products	Meat and Poultry
Fat, pigs	Animal Fats	Meat and Animal products	Meat and Poultry
Meat nes	Meat	Meat and Animal products	Meat and Poultry
Meat, pig	Meat	Meat and Animal products	Meat and Poultry
Milk, whole fresh buffalo	Milk and Dairy	Meat and Animal products	Dairy Products
Offals, pigs, edible	Meat	Meat and Animal products	Meat and Poultry

Meat, horse	Meat	Meat and Animal products	Meat and Poultry
Meat, rabbit	Meat	Meat and Animal products	Meat and Poultry
Meat, turkey	Meat	Meat and Animal products	Meat and Poultry
Meat, duck	Meat	Meat and Animal products	Meat and Poultry
Meat, goose and guinea fowl	Meat	Meat and Animal products	Meat and Poultry
Fat, buffaloes	Animal Fats	Meat and Animal products	Meat and Poultry
Meat, buffalo	Meat	Meat and Animal products	Meat and Poultry
Offals, edible, buffaloes	Meat	Meat and Animal products	Meat and Poultry
Meat, other camelids	Meat	Meat and Animal products	Meat and Poultry
Meat, other rodents	Meat	Meat and Animal products	Meat and Poultry
Item	FINAL FBS	FAO 2019	FAO 2011
Meat, ass	Meat	Meat and Animal products	Meat and Poultry
Meat, bird nes	Meat	Meat and Animal products	Meat and Poultry
Meat, mule	Meat	Meat and Animal products	Meat and Poultry
Snails, not sea	Meat	Meat and Animal products	Meat and Poultry
Almonds, with shell	Tree Nuts	Other	Oilseeds and Pulses
Anise, badian, fennel, coriander	Spices	Other	Miscellaneous
Apples	Fruit	Fruit and Vegetables	Fruit and Vegetables
Apricots	Fruit	Fruit and Vegetables	Fruit and Vegetables
Barley	Cereals	Cereals and Pulses	Cereals
Berries nes	Fruit	Fruit and Vegetables	Fruit and Vegetables
Cottonseed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Figs	Fruit	Fruit and Vegetables	Fruit and Vegetables
Fruit, citrus nes	Fruit	Fruit and Vegetables	Fruit and Vegetables
Fruit, fresh nes	Fruit	Fruit and Vegetables	Fruit and Vegetables
Fruit, stone nes	Fruit	Fruit and Vegetables	Fruit and Vegetables

Grapes	Fruit	Fruit and Vegetables	Fruit and Vegetables
Linseed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Maize	Cereals	Cereals and Pulses	Cereals
Melons, other (inc. cantaloupes)	Fruit	Fruit and Vegetables	Fruit and Vegetables
Millet	Cereals	Cereals and Pulses	Cereals
Nuts nes	Tree Nuts	Other	Oilseeds and Pulses
Olives	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Onions, dry	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Oranges	Fruit	Fruit and Vegetables	Fruit and Vegetables
Peaches and nectarines	Fruit	Fruit and Vegetables	Fruit and Vegetables
Pears	Fruit	Fruit and Vegetables	Fruit and Vegetables
Pistachios	Tree Nuts	Other	Oilseeds and Pulses
Plums and sloes	Fruit	Fruit and Vegetables	Fruit and Vegetables
Potatoes	Roots and tubers	Roots, Tubers and Oil Crops	Roots and Tubers
Pulses nes	Pulses	Cereals and Pulses	Oilseeds and Pulses
Rice, paddy	Cereals	Cereals and Pulses	Cereals
Sesame seed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Spices nes	Spices	Other	Miscellaneous
Sugar beet	Sugar and Syrups	Other	sugars and syrups
Sugar cane	Sugar and Syrups	Other	sugars and syrups
Sunflower seed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Item	FINAL FBS Match	FAO 2019	FAO 2011
Vegetables, fresh nes	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Walnuts, with shell	Tree Nuts	Other	Oilseeds and Pulses
Watermelons	Fruit	Fruit and Vegetables	Fruit and Vegetables
Wheat	Cereals	Cereals and Pulses	Cereals

Beans, dry	Pulses	Cereals and Pulses	Oilseeds and Pulses
Beans, green	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Broad beans, horse beans, dry	Pulses	Cereals and Pulses	Oilseeds and Pulses
Cabbages and other brassicas	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Carrots and turnips	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Cauliflowers and broccoli	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Cherries	Fruit	Fruit and Vegetables	Fruit and Vegetables
Cherries, sour	Fruit	Fruit and Vegetables	Fruit and Vegetables
Chestnut	Tree Nuts	Other	Oilseeds and Pulses
Chillies and peppers, green	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Cucumbers and gherkins	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Dates	Fruit	Fruit and Vegetables	Fruit and Vegetables
Eggplants (aubergines)	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Garlic	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Leeks, other alliaceous vegetables	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Lemons and limes	Fruit	Fruit and Vegetables	Fruit and Vegetables
Lettuce and chicory	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Mushrooms and truffles	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Oats	Cereals	Cereals and Pulses	Cereals
Okra	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Onions, shallots, green	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Peas, green	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Pumpkins, squash and gourds	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Quinces	Fruit	Fruit and Vegetables	Fruit and Vegetables
Rye	Cereals	Cereals and Pulses	Cereals
Sorghum	Cereals	Cereals and Pulses	Cereals

Soybeans	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Spinach	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Strawberries	Fruit	Fruit and Vegetables	Fruit and Vegetables
Tangerines, mandarins, clementines, satsumas	Fruit	Fruit and Vegetables	Fruit and Vegetables
Item	FINAL FBS	FAO 2019	FAO 2011
Tomatoes	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Vegetables, leguminous nes	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Vetches	Pulses	Cereals and Pulses	Oilseeds and Pulses
Artichokes	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Bananas	Fruit	Fruit and Vegetables	Fruit and Vegetables
Carobs	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Chickpeas	Pulses	Cereals and Pulses	Oilseeds and Pulses
Chillies and peppers, dry	Spices	Other	Miscellaneous
Fruit, tropical fresh nes	Fruit	Fruit and Vegetables	Fruit and Vegetables
Grapefruit (inc. pomelos)	Fruit	Fruit and Vegetables	Fruit and Vegetables
Groundnuts, with shell	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Lentils	Pulses	Cereals and Pulses	Oilseeds and Pulses
Peas, dry	Pulses	Cereals and Pulses	Oilseeds and Pulses
Rapeseed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Triticale	Cereals	Cereals and Pulses	Cereals
Cassava	Roots and tubers	Roots, Tubers and Oil Crops	Roots and Tubers
Cocoa, beans	Stimulants	Other	Miscellaneous
Coconuts	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Maize, green	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Pineapples	Fruit	Fruit and Vegetables	Fruit and Vegetables
Taro (cocoyam)	Roots and tubers	Roots, Tubers and Oil Crops	Roots and Tubers

Yams	Roots and tubers	Roots, Tubers and Oil Crops	Roots and Tubers
Cashew nuts, with shell	Tree Nuts	Other	Oilseeds and Pulses
Castor oil seed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Coffee, green	Stimulants	Other	Miscellaneous
Oil palm fruit	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Oil, palm	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Palm kernels	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Sweet potatoes	Roots and tubers	Roots, Tubers and Oil Crops	Roots and Tubers
Mangoes, mangosteens, guavas	Fruit	Fruit and Vegetables	Fruit and Vegetables
Asparagus	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Avocados	Fruit	Fruit and Vegetables	Fruit and Vegetables
Canary seed	Cereals	Cereals and Pulses	Cereals
Cereals nes	Cereals	Cereals and Pulses	Cereals
Lupins	Pulses	Cereals and Pulses	Oilseeds and Pulses
Matã©	Stimulants	Other	Miscellaneous
Item	FINAL FBS	FAO 2019	FAO 2011
Oilseeds nes	Oil Crops	Roots, Tubers and Oil	Oilseeds and
Papayas	Fruit	Fruit and Vegetables	Fruit and
Peppermint	Spices	Other	Miscellaneous
Safflower seed	Oil Crops	Roots, Tubers and Oil	Oilseeds and
String beans	Vegetables	Fruit and Vegetables	Fruit and
Tea	Stimulants	Other	Miscellaneous
Tung nuts	Oil Crops	Roots, Tubers and Oil	Oilseeds and
Hazelnuts, with shell	Tree Nuts	Other	Oilseeds and
Blueberries	Fruit	Fruit and Vegetables	Fruit and
Cow peas, dry	Pulses	Cereals and Pulses	Oilseeds and
Currants	Fruit	Fruit and Vegetables	Fruit and
Kiwi fruit	Fruit	Fruit and Vegetables	Fruit and
Mustard seed	Oil Crops	Roots, Tubers and Oil	Oilseeds and
Persimmons	Fruit	Fruit and Vegetables	Fruit and
Raspberries	Fruit	Fruit and Vegetables	Fruit and
Buckwheat	Cereals	Cereals and Pulses	Cereals

Gooseberries	Fruit	Fruit and Vegetables	Fruit and
Grain, mixed	Cereals	Cereals and Pulses	Cereals
Poppy seed	Oil Crops	Roots, Tubers and Oil	Oilseeds and
Cranberries	Fruit	Fruit and Vegetables	Fruit and
Pigeon peas	Pulses	Cereals and Pulses	Oilseeds and
Plantains and others	Fruit	Fruit and Vegetables	Fruit and
Areca nuts	Tree Nuts	Other	Oilseeds and
Ginger	Spices	Other	Miscellaneous
Sugar crops nes	Sugar and Syrups	Other	sugars and
Fruit, pome nes	Fruit	Fruit and Vegetables	Fruit and
Chicory roots	Vegetables	Fruit and Vegetables	Fruit and
Vanilla	Spices	Other	Miscellaneous
Roots and tubers nes	Roots and tubers	Roots, Tubers and Oil	Roots and
Yautia (cocoyam)	Roots and tubers	Roots, Tubers and Oil	Roots and
Fonio	Cereals	Cereals and Pulses	Cereals
Karite nuts (sheanuts)	Oil Crops	Roots, Tubers and Oil	Oilseeds and
Kola nuts	Tree Nuts	Other	Oilseeds and
Melon seed	Oil Crops	Roots, Tubers and Oil	Oilseeds and
Pepper (piper spp.)	Spices	Other	Miscellaneous
Nutmeg, mace and cardamoms	Spices	Other	Miscellaneous
Brazil nuts, with shell	Tree Nuts	Other	Oilseeds and
Item	FINAL FBS Match	FAO 2019	FAO 2011
Pyrethrum, dried	Spices	Other	Miscellaneous
Quinoa	Cereals	Cereals and Pulses	Cereals
Cashew apple	Fruit	Fruit and Vegetables	Fruit and Vegetables
Cassava leaves	Vegetables	Fruit and Vegetables	Fruit and Vegetables
Hempseed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Bambara beans	Pulses	Cereals and Pulses	Oilseeds and Pulses
Cinnamon (cannella)	Spices	Other	Miscellaneous
Cloves	Spices	Other	Miscellaneous
Tallowtree seed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Kapok fruit	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
Kapokseed in shell	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses



Jojoba seed	Oil Crops	Roots, Tubers and Oil Crops	Oilseeds and Pulses
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A5 References

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Section 2

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