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

WWF-UK (2021)
Driven to waste: The Global Impact of Food Loss and Waste on Farms. Woking.

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The farmers in the Korovatu area have traditionally farmed mostly sugar cane and rice. The seawall, built by the government to protect the farmland, is no longer sufficient to stop the incursion of seawater. Over the last years increasing saltwater intrusion on the farmland has caused many crops to fail and some farmers are harvesting now less than half of what they used to. Some of the land isno longer suitable for sugar cane farming and the farmers are struggling to make their ends meet. Many have left the area for alternative work.

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EXECUTIVE SUMMARY

In 2011 the UN Food and Agriculture Organization (FAO) estimated that one-third of all global food production is wasted, contributing to massive levels of environmental degradation and perpetuating food insecurity. This marked the launch of a global effort to accurately quantify the amount of food lost and wasted at all stages of the supply chain in order to monitor the impacts of food waste and progress achieved in reducing it. These efforts were given extra importance by the Sustainable Development Goal (SDG) 12.3, which in 2015 set the target to halve per capita post-retail global food waste by 2030 and achieve a reduction in pre-retailer losses. There has never been a more important time to redouble our efforts to reduce food waste in light of heightened awareness of our food system's impact on environmental health.

Despite this, food waste on farms remains neglected in comparison to efforts targeted at retail and households. This is due in part to the complexities in measuring farm stage waste, creating difficulty in measuring progress in reductions and an underestimation in the significance of its contribution to food waste levels. We challenge this status quo by presenting estimates of the scale and impact of global food waste on farms, demonstrating how imperative it is that this stage is no longer overlooked in efforts to keep global warming below 1.5 degrees, and slow biodiversity loss.

The relative lack of focus on farm-stage food waste also results from the perception that it is a more significant issue in lower-income countries, due largely to a lack of access to technology such as cooling facilities. Subsequently interventions in the past have tended to focus on technical solutions, addressing issues with farm technology or storage, whilst largely ignoring socio-economic and market factors that shape the agricultural system. Through case studies across a variety of regions and food commodity types, this research uncovers the impact of decisions made further downstream, in markets and even by the public, on the levels of food waste occurring on farm.

Historically, work in this field has termed food wasted at farm stage as 'loss', as opposed to 'waste' which is caused by retailers and consumer behaviours[ii] such as neglect, choice or error. This report, however, shows that food waste at farm level is driven by a multitude of human factors and decisions within the later stages of the supply chain – while waste in the supply chain is often driven by changeable factors at a farm level. Interventions targeted at the environmental and biological drivers of food 'loss' are unlikely to succeed until they are supported by changes to the human elements of the supply chain:[2]

1. **Markets and supply chains:**
   Current market structures separate farmers from their end market, making it difficult for farmers to take in to account the infrastructure and end market which can lead to mismatches in the volume of production, time of planting, cultivars planted and time of harvest, all of which influence food waste levels. Additionally, market practices frequently maintain asymmetric power balances which favour markets over farmers. In many supply chains this weakens farmers' abilities to negotiate and supresses their incomes, making it more difficult to break cycles of poverty and invest in training and technology to reduce food waste.

2. **National governments:**
   National governments play a key role in determining the importance placed on food waste work and the stages of the supply chain that are prioritised. Despite the massive contributions food waste makes to national carbon footprints, fewer than 6% of Paris Agreement signatories have included food loss and waste in their national carbon plans. Food waste on farms must take a higher position on policy agendas in the form of legally binding food waste reduction targets, policies which protect farmers from unfair trading practices, investment in infrastructure, R&D and training, and stronger animal welfare and fishery laws that reduce the volume of waste in livestock and seafood production. Governments also need to review farmer support practices that favour crops meant for export over those for domestic consumption.

3. **Multilateral Institutions & NGOs:**
   Globally, food waste initiatives must strive to make greater progress on measuring and reducing farm stage losses. This can be supported by future initiatives and programmes setting targets to reduce food waste by 50% from farm to fork, ensuring greater ambition and focus, and increasing funding available to programmes aiming to intervene at this stage of the supply chain. Additionally, exclusion of food diverted from the human food supply chain to animal feed due to overproduction or failure to meet specifications from food waste reporting masks the true extent and drivers of food loss on farms. This should be included in food loss reporting in order to increase the focus on reducing over production, the carbon footprint of agriculture and supply chain practices which drive food loss and waste.

4. **Citizens:**
   The public plays an active but thus far unaddressed role in driving food waste at the farm stage. Communicating this will enable them to become active food citizens and empower them to take control of their food choices. This can drive changes that support farmers in reducing food waste and promote greater environmental health.

[1] 'Industrialised Asia' refers to China, Japan and the Republic of Korea

[2] The drivers of food waste on farm vary depending on the region and culture, the crop and the farm e.g. smallholder farms' drivers will differ from larger farms), as such, on-farm interventions to target the drivers of food waste must be context specific.

1.2 BILLION TONNES OF FOOD, is wasted on farms each year – the weight of 10 million blue whales. This is significantly more than the 931 million tonnes wasted from retail, food service and households[i] and enough to feed to the world's 870 million undernourished four times over.

$370MILLION OF FOOD IS WASTED ON FARMS.
Reducing this could support significant progress towards the SDGs of 'No Poverty' and 'Zero Hunger', particularly in low-income countries where post-harvest waste amounts to 291 million tonnes each year.

58% OF GLOBAL HARVEST STAGE WASTE
occurs in the high -and middle-income countries of Europe, North America and Industrialised Asia[1] – despite these countries having higher on-farm mechanisation and only 37% of the global population.

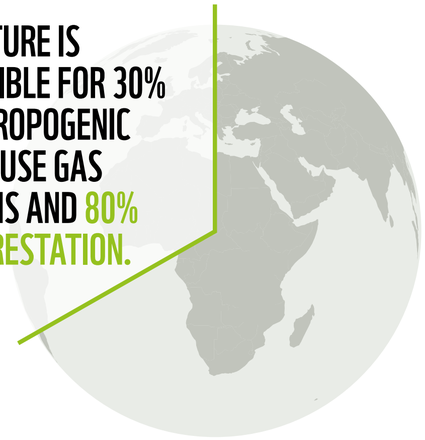
2.2 GIGATONNES CO_2 eq is the overall carbon footprint of farm stage food waste – approximately 4% of all anthropogenic greenhouse gas (GHG) emissions and 16% of agricultural emissions. This is equivalent to the emissions from 75% of all cars driven in the US and Europe over a year.

4.4 MILLION KM^2 OF LAND is used to grow food which is lost on farms each year – larger than the Indian subcontinent. This area of land could contribute significantly to rewilding efforts.

INTRODUCTION

Previous research, such as WWF-US No Food Left Behind[iii] initiative, has examined the country- and crop-specific scale of food waste on farms, providing examples of the significant extent and impact of food waste at this stage of the supply chain. However, farms largely remain a neglected hotspot of food waste. This is in part due to difficulty in measuring food waste at the farm stage, particularly that which remains unharvested for a variety of reasons. The lack of progress in high-income countries can also be attributed to the perception that post-retail waste is a greater priority in high-income countries, despite research finding that farm-stage losses exceed consumer food waste in both Europe and North America. Similarly, SDG 12.3 seemingly places greater importance on downstream food waste, setting a 50% reduction target for retail and consumer food waste, but only calling to "reduce" waste in the earlier stages of the supply chain. Champions 12.3, a coalition of executives supporting progress on SDG12.3, suggest that as it stands the target may reduce "both ambition and focus on an issue (food losses) that is important for many regions of the world"[viii]. While highlighting the problem of the lack of an explicit target for pre-retail waste reduction, this reinforces the idea that food waste on farms and in the supply chain is an issue only in specific regions.

AGRICULTURE IS RESPONSIBLE FOR 30% OF ANTHROPOGENIC GREENHOUSE GAS EMISSIONS AND 80% OF DEFORESTATION.



Despite already producing enough to feed 10 billion people, 1 in 9 are undernourished,[iv] whilst a previously suggested one-third of food produced is wasted.[ii] Research has suggested that reducing post-harvest waste by 50% in supply chains of high-income countries alone could decrease the number of undernourished people in low-income countries by up to 63 million.[v] It is clear that reducing food waste will play a significant role in improving global food security; however, the contribution that reductions in pre-harvest farm waste could make to this is as yet unaccounted for.

We begin this work by developing up-to-date estimates of the scale of global farm-stage food waste, both that which occurs post-harvest and at or around harvest. We also calculate the environmental impact of food waste occurring pre-farm gate, a significant but neglected contributor to the impacts of agriculture and the food system as a whole.

As we work towards rewilding, ending deforestation, reversing biodiversity loss and keeping global warming well below 1.5 degrees, minimising farm-stage food waste will play a pivotal role. Agriculture is responsible for 30% of all anthropogenic GHG emissions[vi] and 80% of deforestation. Food production results in large areas of land being cleared, contributing to biodiversity loss, extinctions and soil degradation. Soil is being lost up to a hundred times faster than it is being made, diminishing crop yields and in turn increasing pressure to convert more land to agriculture. When food is wasted, so are all the embedded emissions associated with the inputs to agricultural production, crop or livestock growth, harvesting and processing, while its disposal causes additional emissions.

We calculated global farm-stage waste from 2,172 farm-stage food loss and waste data points for different commodities and regions using online databases and literature reviews (academic and grey literature). The analysis of global farm-stage food waste environmental impacts was based on the scale of waste determined in the analysis described above, combined with emission factors derived from a model developed by Poore and Nemecek (2018), illustrating its importance in the sustainability agenda. In addition, we developed 10 case studies exploring waste across a range of food commodities and regions, drawing on 209 stakeholder interviews and relevant literature. These provide a sense check of estimates of food waste volumes and an in-depth look at the global, systemic drivers of food waste on farms. Key case studies have been included to illustrate the impacts and the role of actors and agencies beyond the farm gate in reducing farm-stage food waste.

WHAT IS 'FOOD LOSS'?

There is often a distinction made between *'food loss'* and *'food waste'*. The term 'food loss' is frequently used to refer to agricultural production that is lost unintentionally because of a variety of factors including market conditions, poor infrastructure, poor agricultural practices, pests, disease, natural disasters and weather events. By contrast, food waste is often perceived as being caused by negligence or a conscious decision to discard food, often at the retail or consumer stages.

However, this distinction can be misleading if it is taken to imply that much of the food loss and waste occurring in the early stages of the supply chain is not due to human decision or error. This report does not make this distinction between food loss and waste, as its findings illustrate that there are a multitude of human factors (conscious decisions or otherwise) that drive food waste at farm level and elsewhere within the supply chain. In turn, food waste in the supply chain may be driven by a variety of factors rooted at the farm level. As such, within this report, food leaving the human food supply chain at the farm stage, both around harvest and post-harvest, is viewed to be food **waste.**

Numerous food waste studies have been conducted since the FAO's 2011 report; however, the supply chain stages and parameters of each vary (See figure 1). This report considers the term food waste at the farm stage to apply to any outputs from primary food production that are, or were at some point, intended and suitable for human consumption but which end up either not being harvested or sent to one of a range of food waste destinations (see Appendices for more detail).

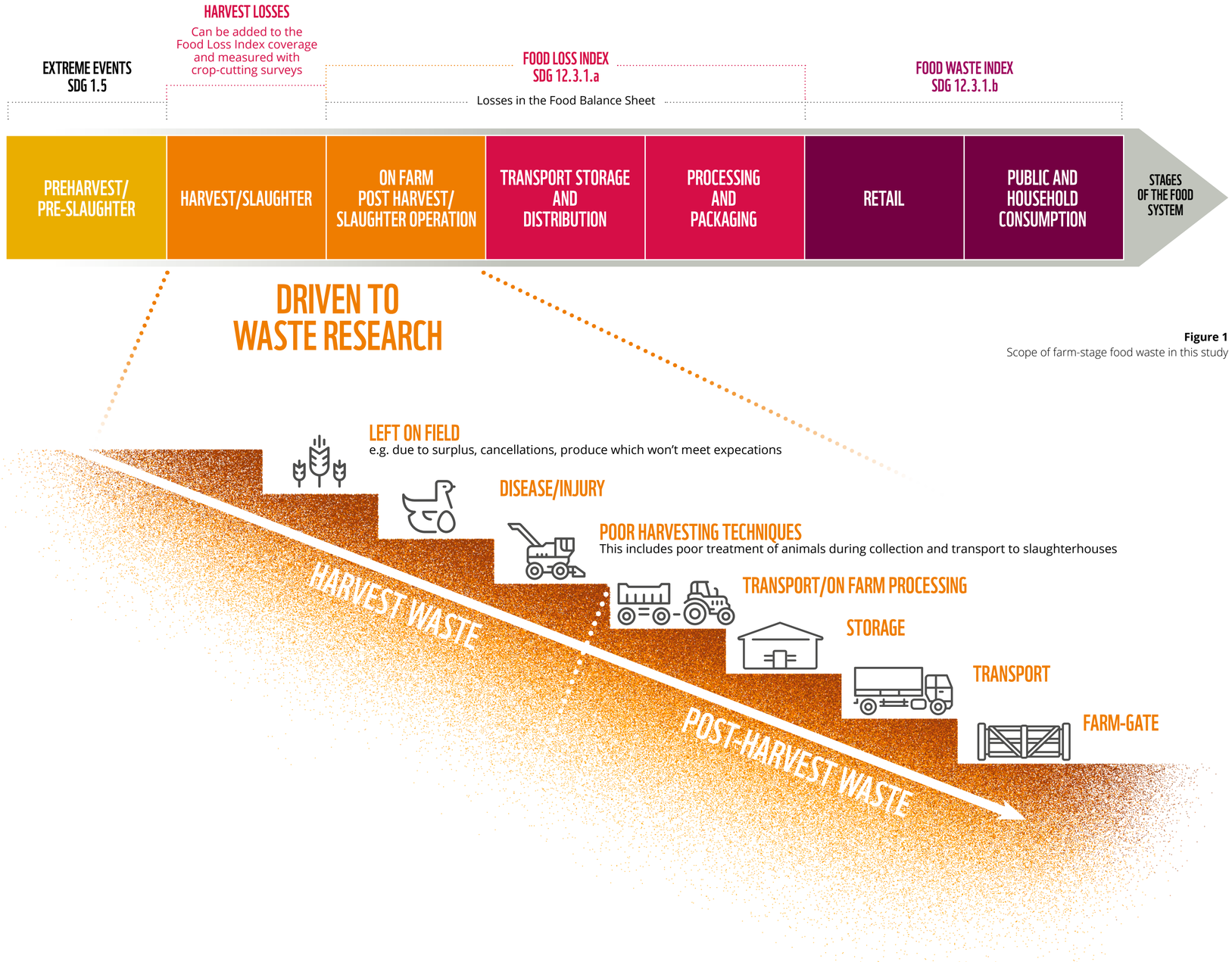


Figure 1
Scope of farm-stage food waste in this study

WHAT IS THE CURRENT SCALE AND VALUE OF FARM-STAGE FOOD WASTE?

15.3%
OF ALL FOOD PRODUCED GLOBALLY IS WASTED AT FARM STAGE. THIS SUGGESTS THAT SUBSTANTIALLY MORE THAN A THIRD OF FOOD PRODUCED IS BEING WASTED - POSSIBLY AS MUCH AS 40%, OR 2.5 BILLION TONNES.

This report estimates that global food waste on farms amounts to 1.2 billion tonnes per year, the equivalent weight of 10 million blue whales. This represents a waste of approximately 15.3% of food produced globally (table 4), with a total value of $370 billion (table 1). Recent estimates have placed post-harvest waste up to and including retail at around 14% of production,[vii] based on total harvest weight. As a result, food that remains unharvested due to the inability of farmers to fund harvesting labourers or as a result of market-based specifications, amongst other reasons, was not included in these estimations, resulting in the underestimation of the scale, impact and importance of farm-stage food waste. We estimate that 8.3% of food is wasted at or around harvest and 7.0% during farm-stage post-harvest activities. We cannot overlook the impact of the volume of harvest stage waste.

As well as including harvest waste, these estimations provide an up-to-date view of the potential scale of whole supply chain waste. The FAO's commonly cited 2011 report estimated whole supply chain food waste at 1.3 billion tonnes, based on production volumes at the time, or approximately one-third of food produced. Although it is not possible to combine harvest and post-harvest estimates from the research conducted in this study with the additional post-farm gate/pre-retail elements included within the FAO's more recent estimates (2019) due to differences in methodology (See Appendix 3 for more detail), the data suggests that 20-25% of global production may be lost across primary production and supply chain stages, up to but not including retail.

When viewed alongside the recent findings of the Food Waste Index,[i] which reports 17% of food produced is wasted from the retail to consumer stages of the supply chain, this suggests that substantially more than a third of food produced is being wasted – possibly as much as 40%.

Additionally, when viewed within the context of current production statistics and the recent FWI findings, it appears significantly more than 1.3 billion tonnes of food is currently wasted throughout the supply chain – as much as 2.5billion tonnes.

This estimate is based on the 1.2 billion tonnes of food loss on farms calculated within this research, the 931 million tonnes wasted in retail, food service and consumer homesi, and calculations based on the percentage of food loss occurring post-harvest up to but not including retail provided by the FAO[vii]. From the latter, estimates were drawn for losses occurring in the post farmgate transport, storage, manufacturing and processing stages[vii] which was taken to be in the region of 436 million tonnes *(See Appendix 3 for methods)*. Whilst 2.5 billion tonnes is an indicative estimate of whole supply chain losses, the methods used and assumptions made to reach this figure mean it is likely to be an underestimation. Additionally, given the prevalence of self-reporting rather than direct measurement within farm stage studies, loss rates are likely to be higher than those reported within this research due to the tendency of questionnaires and indirect measurement techniques to under-estimate actual harvest and post-harvest losses. Subsequently, 2.5 billion tonnes is a conservative estimation of the current levels of whole supply chain food loss and waste."

Commodity	Volume of waste *(million tonnes)*[3]	% of total production	Value of waste *($million)*[4]
Fruit & vegetables	449	26%	160,157
Roots, tubers & oil crops	261	15%	44,095
Meat & animal products	153	12%	99,738
Cereals & pulses	196	14%	56,199
Fish & Seafood	25	44%	-
Other	90	6%	8,930

Table 1
Contribution of food commodity types to production totals, total volume and value of waste

[3] Global farm stage loss and waste were calculated using a compilation of 2,172 farm stage food loss and waste data points. 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.

[4] These are farm gate prices: losses to farmers & prices that do not include the added value in the supply chain.

HOW IS FARM-STAGE FOOD WASTE PREVENTING US FROM MEETING MULTIPLE SUSTAINABLE DEVELOPMENT GOALS?

Continued overlooking of farm-stage food waste in the food waste agenda, including reduction targets, will prevent the achievement of SDG 12 on responsible consumption and production. Currently SDG 12.3, which focuses on food waste, excludes harvest stage waste entirely, a huge oversight when an estimated 8.3% of food produced is wasted at this stage. Undervaluing the scale and impact of farm-stage food waste and excluding it from the 50% reduction target contribute to the neglect of this body of work.

SDG 12.3:

"By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses"

Despite Champions 12.3[viii] guidance to interpret SDG 12.3 as covering the entire food chain, efforts continue to be centred around reducing waste at later stages of the supply chain. With farm-stage food waste accounting for 15.3% of food produced, more than any other stage of the food supply chain, this is hugely problematic in environmental, economic and food security work.

Progress towards SDG 12.3 is integral to achieving many of the other SDGs, including SDG 13 (Climate Action), SDG 14 (Life Below Water) and SDG 15 (Life on Land). Additionally, the case studies conducted in this research illustrate how food waste on farms hinders progress towards SDG 1 (No Poverty) and SDG 2 (Zero Hunger). Where agriculture forms a significant proportion of a country's GDP, performance against the SDGs is generally poorer. For example, when examining fruit and vegetables in South and Southeast Asia, the economic loss associated with food waste at the farm stage is roughly $15 billion/year. India has one of the highest economic losses for this commodity group and shows significant challenges remaining on the pathway to reach SDGs 1 and 2, while also having the highest contribution to GDP from the agricultural sector of any country within the region, at 16%. In contrast, for Thailand, where agriculture contributes only 8% to national GDP, smaller challenges remain to achieve the target of ending hunger and the target of "no extreme poverty" (based on people living on less than $1.25/day) has already been met.

Whilst there is an observable link between higher food waste rates and lower incomes for farmers, the link between agriculture and poverty rates also reflects the less noted systemic drivers of supressed farmer incomes. Market pricing, lack of investment and lack of access to funds drive a cycle of food and financial losses that is difficult to break, as farmers are unable to pay for farming technology or even labour to reduce levels of food waste. This in turn contributes to local undernutrition, as when food supplies are short, they are likely to be reserved for higher-income exports or domestic markets, over lower-income locals.

CASE STUDY

The role of Daaga Fish waste in preventing progress towards the SDGs (Tanzania and Uganda)

Food waste drives down farmer incomes to the point of poverty as well as limiting access to nutrition for locals, preventing regional progress towards achieving SDGs 1 and 2. FAO note that unwanted fish discarded by commercial fishing operations represent a loss of a rich source of dietary protein as well as to the stocks of those species that, even if they have low market value, may nonetheless be vital components of the marine ecosystem. This is seen clearly in the case of dagaa, a small pelagic species endemic to Lake Victoria which could be made available to locals to fill the fish nutrition 'gap' caused by a shortage of affordable fish and high local demand if waste rates were lower. In 20 African countries fish contributes more than 20% of protein, particularly in the diets of poorer households, as well as providing important income from both local fisheries and those exporting to international markets.

Dagaa waste levels were estimated to be 26-40% of landed catch in Uganda and 40% in Tanzania.[ix] As dagaa are eaten whole, the immediate processing stage for the dried fish market involves sun-drying on the ground near landing sites. During the rainy seasons, when proper drying is more difficult, post-harvest waste can be as high as 40%, with fish being washed away or rotting. This is a serious socio-economic problem leading to tonnes of highly nutritious fish being left to rot, contributing to food insecurity for locals and financial loss to fisheries. Although dagaa is a source of high-quality protein with potential to supply low-income families with food, the feed market currently pays higher prices, so less of the remaining catch is available to local people.

While the immediate cause of fish waste is the lack of suitable drying equipment and technology, this is driven by low market prices and a lack of access to funds or investment in infrastructure to improve the processes of the fishery. Improving the financial situation of fishers by paying higher prices for the fish or improving local micro-investment infrastructure could enable fishing communities to invest in simple technology such as raised platforms for drying the fish. This in turn could greatly reduce the volume of food waste as well as supporting countries around Lake Victoria in moving towards SDGs 1 and 2.

HOW DOES FOOD WASTE ON FARM COMPARE ACROSS LOW AND HIGH-INCOME COUNTRIES?

It has been a long-held belief that food waste on farms is largely an issue in less affluent regions with lower levels of industrialisation. Counter to this perception, a key finding of this report is that per capita farm-stage waste levels are generally higher in more affluent regions. Despite having higher on-farm mechanisation, high- and middle-income countries of Europe, North America and Industrialised Asia, with only 37% of the global population, contribute 58% of global harvest waste (368 million tonnes).

By comparison, low-income countries with 63% of the population have a 54% share of global post-harvest farm-stage waste (291 million tonnes).

When viewed as a percentage of total food production the difference in food waste between industrialised and developing countries may appear negligible in several categories; however, when examined on a per capita basis, farm-stage waste is far more significant in industrialised regions such as Europe, the US, Canada and Industrialised Asia (see figures 2 & 3).

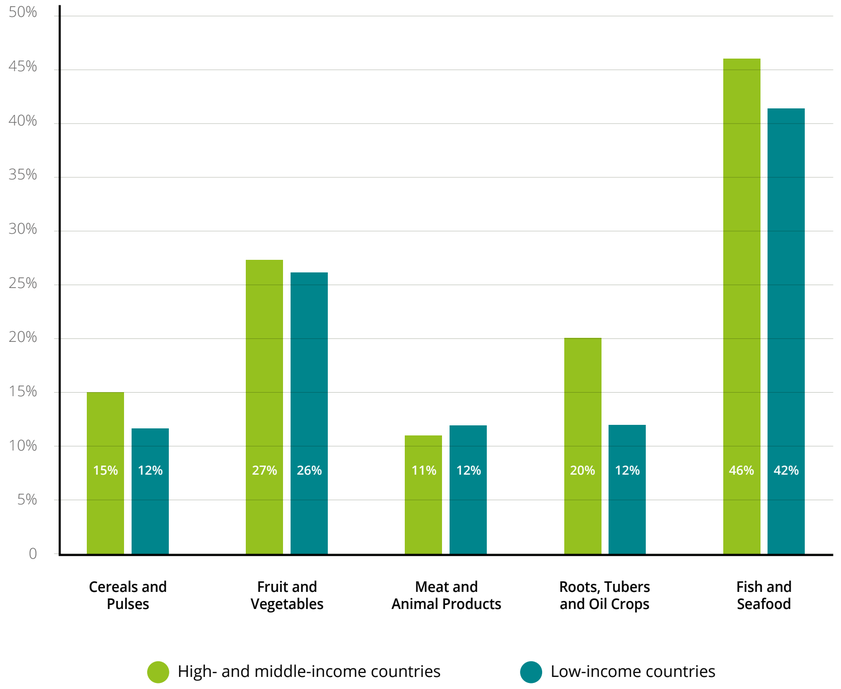


Figure 2
Farm stage food waste by commodity group as % total food production.

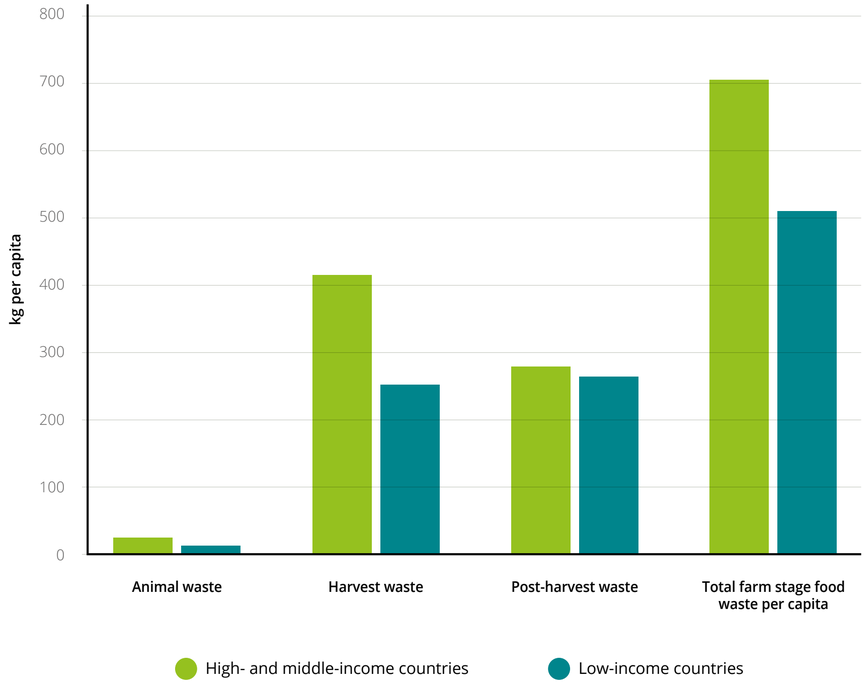


Figure 3
Per capita farm stage food waste by region (kg/year)

ENVIRONMENTAL IMPACTS OF FARM-STAGE FOOD WASTE

The assessment of global environmental impacts of farm-stage food waste included GHG emissions, eutrophication and acidification potentials, water abstraction and land use. This includes all the impacts of inputs to farming processes such as fertiliser used for crops and feed and manure management for livestock.

In terms of GHG emissions of on-farm food waste, the results exceed the scale of impacts found in other research, such as the widely quoted results from the FAO's Food Wastage Footprint report.[x] The most impactful commodity group was meat and animal products (including dairy), which accounted for 40% of CO_2 eq. emissions associated with global farm-stage food waste but only 13% of food waste tonnage. In addition, this commodity group was associated with a high proportion of global food waste's acidification and eutrophication potentials and half of land use associated with farm-stage food waste. This is explored further in the following sections.

IMPACT	DEFINITIONS
GHG EMISSIONS	GHG emissions resulting from farm-stage activities include 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 comprises of emissions to air from carbon dioxide, methane and nitrous oxide, expressed as CO_2 equivalent (CO_2 eq.).
WATER USE	Water used to grow crops and maintain livestock. Water withdrawals include irrigation withdrawals, irrigation withdrawals embedded in feed, drinking water for livestock, water abstracted for aquaculture ponds as well as processing water.
EUTROPHICATION	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 fertiliser application) into lakes and rivers. This alters the aquatic environment, placing local biodiversity at risk.
ACIDIFICATION	Acidification is the process in which the pH of soil or water environment becomes more acidic. 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. This can reduce the soils fertility, eventually meaning the land can no longer be used to grow crops, and adversely impact aquatic ecosystems.
LAND USE	The land use associated with food waste is the total land area that would be needed to produce an amount of food equivalent to that wasted.
BIODIVERSITY LOSS	Biodiversity refers to the genetic variability, number and variety of species in an area; it is essential to planetary functioning and even small losses can have catastrophic effects on ecosystem structure and functioning. The impact of farm-stage food waste on biodiversity is assessed based on factors that may affect or present risks to biodiversity, such as land-use change and water use.

CASE STUDY

How farm-stage rice waste is warming the planet (South and South East Asia)

Rice is a staple for 4 billion people, including 80% of world's undernourished. Some 144 million smallholder farms are engaged in cultivating rice paddies. With a production of 172 million tonnes, India is the second largest global rice producer, with a 26% share of the global rice export market.

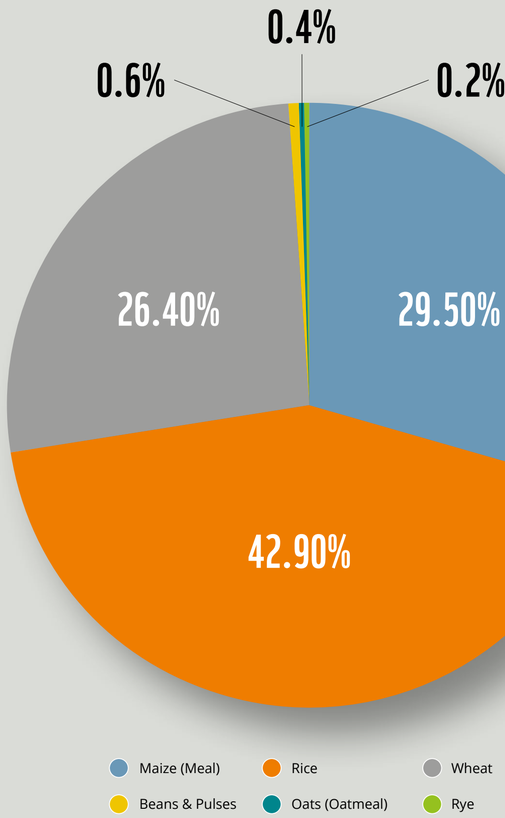
Although rates vary across regions and farming systems, the case study research observed an average of 10% waste rate at the farm stage in Pakistan and India. Taking this as representative, this equates to over 41 million tonnes of rice waste each year in South and South East Asia alone. This level of waste is driven by numerous on-farm practices such as choice of rice variety, use of poor quality of rice seed, poor agricultural practices and the timing and method of harvesting and threshing. However, this in turn is driven by market demands and behaviours: for example, choosing cultivars that are better suited for the region or land could drive down waste rates, but farmers' selections are influenced by financial necessity and market demand for specific types of rice, such as basmati.

Despite lower yields and higher waste rates, farmers are able to secure better prices for more popular variants of rice, so in order to turn a profit they must plant cultivars that produce greater volumes of waste.

Rice waste has a huge environmental impact, contributing 43% of GHG emissions associated with waste from the cereals and pulses category (see figure 4). The largest impacts come from methane emissions from rice paddies. Rice paddies are a significant source of global GHG emissions, contributing an estimated 19% of methane and 11% of nitrous oxide emissions.[xii]

A 2007 study found that rice paddies were responsible for 35% of India's total methane emissions and 9.8% of its total GHG emissions.[xiii] As such, there is significant environmental benefit in reducing the number of rice paddies needed to produce current volumes of rice through farm-stage waste reduction.

Figure 4:
Greenhouse gas emissions from cereals and pulses



GREENHOUSE GAS EMISSIONS

The overall carbon footprint of farm-stage food waste amounts to 2.2 gigatonnes CO2 eq; this is equivalent to the emissions from 75% of all cars driven in the US and Europe over a year. Of these, 55% came from harvest sources and 45% from post-harvest sources, again highlighting the importance of including harvest-stage food waste in reduction initiatives. The total GHG emissions from global agriculture inclusive of food waste are estimated to be 13.7 gigatonnes/year.[xi] This suggests that food waste occurring at farm level is responsible for in the region of 16% of all agricultural emissions and approximately 4% of total anthropogenic GHGs, based on the Poore and Nemecek study.

Harvest-waste GHG emissions have a variety of sources across the different commodity types, including enteric fermentation and manure management in livestock, methane emissions from rice paddies and the production and use of artificial fertilisers. Post-harvest emissions take into account the GHG levels created in the production of the wasted food as well as harvest, storage and processing undertaken on the farm.

Meat and animal products (40% emissions/13% tonnage waste) and cereals and pulses (24%/17%) have disproportionately high GHG emissions compared with tonnage waste. This reflects the high GHG emissions associated with the production of these commodity groups. In contrast the low footprint of fruit and vegetables means that while they account for 38% of total tonnage waste, they only contribute 8% to the overall GHG emissions associated with global waste on farm.

Commodity	Greenhouse Gas Contributions *(Million tonnes, CO_2 equiv.)*	% of GHG contributions from food waste	Commodity as a % of overall tonnage waste	Biggest contributors
Meat and animal products	856Mt	40%	13%	Milk & Bovine meat
Cereals and pulses	515Mt	24%	17%	Rice & Maize
Roots, tubers and oil crops	307Mt	14%	22%	Palm oil
Fruit and vegetables	182Mt	8%	38%	More highly perishable fruit & vegetables (e.g. tomato, watermelon)
Fish and seafood	107Mt	5%	2%	Shrimps & prawns *(highest per tonne)*

Table 2
Contribution of food commodities farm-stage waste to GHG emissions and overall tonnage waste

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Woman planting rice paddy, Assam, India.

WATER WASTAGE

Our modelling estimates a total of 760km3 of freshwater is withdrawn from nature for food lost at farm stage, equivalent to over five weeks' flow from the Amazon River into the Atlantic Ocean or 304,000,000 Olympic swimming pools' worth of water. This is significantly higher than previous estimates such as the "blue water footprint" (consumption of surface and groundwater resources) of 250km3 in the 2013 FAO Food wastage footprint report.

The main food types contributing to the water footprint associated with food waste in the form of freshwater withdrawals are cereals and pulses (37%) and meat and animal products (22%). Freshwater withdrawals vary significantly between regions and crops. European wheat and other cereal production is largely rain-fed with little abstracted water use, whereas wheat production in Asia and the US 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.

Meat and animal products have a high water footprint, arising from crops grown for feed as well as water drunk by the animals; 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 waste is in South and South East Asia and 8% in Europe. Pig meat forms 8% of the total, of which about one half comes from Industrialised Asia.

EUTROPHICATION AND ACIDIFICATION

Total acidification potential associated with farm waste is 12 Mt sulphur dioxide equivalent (SO2 eq.) and total eutrophication potential is 10 Mt of phosphate equivalent (PO43- eq.). Meat and animal products form over 40% of each, followed by cereals and pulses at 20% and fruit and vegetables at 14%. Within meat and animal products the largest contributors are milk and bovine meat

Eutrophication is the process whereby aquatic systems become over-enriched by nutrients such as nitrogen and phosphorus through run-off from agricultural activities (such as fertiliser application) into lakes, rivers and the sea. Eutrophication potential encompasses multiple emissions to water as well as to air, including SO2 and nitrogen oxides (NOx) to air, and nitrates (NO3-), ammonium (NH4+), phosphorous and nitrogen to water. These different emissions are reported in a standardised way in this study as phosphate equivalents (PO43- eq.). To calculate the acidification potential from food waste, the emissions of SO2, NH3 and NOx 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. Sulphur dioxide equivalents and phosphate equivalents follow similar patterns to GHG emissions across regions and commodities.

LAND USE

The total area of land used to produce food that was lost or wasted on farms globally equates to about 4.4 million km2, an area larger than the Indian subcontinent. Meat and animal product waste levels are responsible for half of this land use, at over 2.2 million km2. This comes from grazing animals over a long period of time, until the end product (dairy or meat) can be produced, and the land necessary for feed production to support livestock. Waste from roots, tubers and oil crops is associated with the second highest land use, being responsible for roughly 1.5 million km2 per year. Where many commodity groups use proportionally more or similar land areas in proportion to their contribution to total food waste, fruit and vegetables use much less land compared to their food waste volume: they contribute 38% of food waste tonnage at the farm stage but this equates to only 8% of land use, or 350,000km2. Increased land use in order to grow food which is ultimately lost or wasted is a significant issue due to its impact on deforestation and habitat conversion, biodiversity loss and soil erosion.

THE TOTAL AREA OF LAND USED TO PRODUCE FOOD THAT WAS LOST OR WASTED ON FARMS GLOBALLY EQUATES TO ABOUT 4.4 MILLION KM2, AN AREA LARGER THAN THE INDIAN SUBCONTINENT.

BIODIVERSITY LOSS

The case studies found extremely high biodiversity impacts from the volume of extra livestock reared to account for waste in meat and animal systems. Threats to biodiversity from meat and animal production are numerous: including land-use change (destruction of habitats), increase of invasive alien species (including feral livestock), persecution of livestock predators, habitat degradation from overgrazing, as well as pollution both from the livestock directly and due to manure management. The feed system required to sustain animal agriculture presents an additional threat to biodiversity, including habitat loss to provide land for feed crops such as soy and the conversion of forests and other natural land to pasture.

A significant but under-researched area is waste and degradation caused by fishing practices. Trawling is associated with significant damage to the seabed and subsequent biodiversity loss. Fishing also threatens biodiversity through bycatch of non-targeted species, which will be caught and discarded before the catch is landed. However, due to failures in effective monitoring the impact on biodiversity can only be estimated. Additionally, 34% of all fisheries are reportedly being overfished[xiv] which can drive biodiversity loss, a figure which could potentially be reduced by minimising waste levels.

With regards to arable farming and horticulture, the impact of farm-stage food waste on biodiversity depends significantly on the crop type, growing region and intensity of the production and management system.

Under our current wasteful food system, increased demand is typically met either by intensifying farming practices or expansion of land used for agriculture, both of which have significant biodiversity impact:

1. Intensification – growing more on the same land – This includes yield increases through better crop utilisation. This may impact biodiversity as a result of habitat homogenisation, increased water use for irrigation and higher inputs of agrochemicals, such as fertilisers and pesticides. However, this depends on the production system and commodity.

2. Expansion – extending cropland into uncultivated natural ecosystems or on to degraded agricultural land – may threaten biodiversity through habitat conversion and fragmentation, particularly where agriculture encroaches into remaining biodiverse areas.

If intensification reduces the need for expansion of cropland into natural ecosystems, then this could help to reduce potential species loss. In most case study areas, intensification did not present as significant a risk to species. Although certain intensification practices can contribute to a reduction in food waste, such as increased use of pesticides and other agrochemicals, these still present a threat to biodiversity as a result of toxicity in the local environment.

Reducing waste presents a third option for increasing food production. Interventions that reduce waste, such as upskilling farm workers and using of more appropriate cultivars, can provide the same outcomes as intensification, without the adverse implications for biodiversity. Nor do they require increasing the area of farmland, an important factor in nature restoration.

FISHING PRACTICES THREATEN BIODIVERSITY THROUGH BYCATCH OF NON-TARGETED SPECIES, WHICH WILL BE CAUGHT AND DISCARDED BEFORE THE CATCH IS LANDED.

Forest cut down to make way for cattle farming, Atlantic Forest, Brazil

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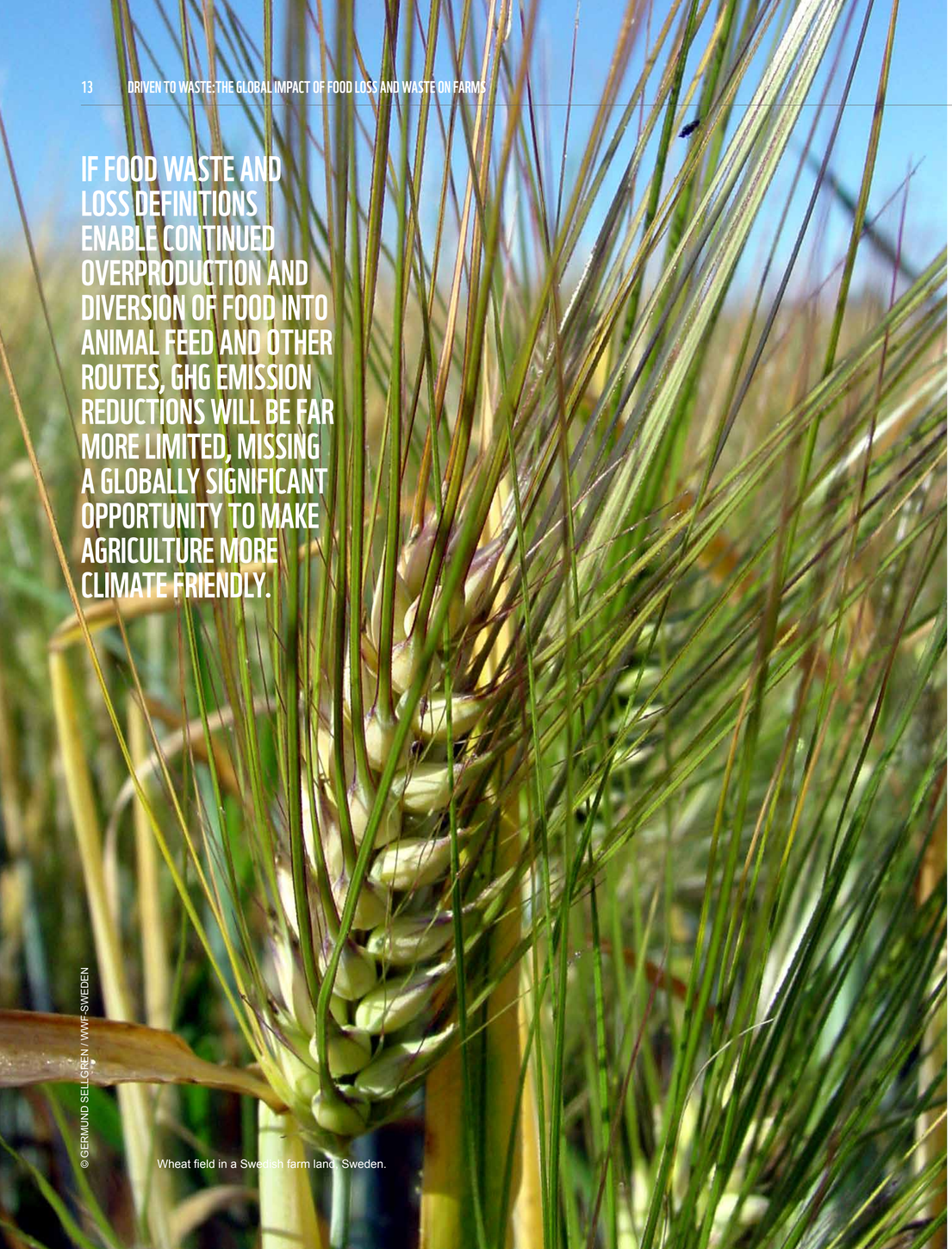

IF FOOD WASTE AND LOSS DEFINITIONS ENABLE CONTINUED OVERPRODUCTION AND DIVERSION OF FOOD INTO ANIMAL FEED AND OTHER ROUTES, GHG EMISSION REDUCTIONS WILL BE FAR MORE LIMITED, MISSING A GLOBALLY SIGNIFICANT OPPORTUNITY TO MAKE AGRICULTURE MORE CLIMATE FRIENDLY.

Wheat field in a Swedish farm land, Sweden.

THE FOOD-TO-FEED SYSTEM: ARE WE MASKING THE EXTENT OF THE PROBLEM?

Current definitions of food 'loss' and waste present three key issues:

i. They exclude a significant part of farm-stage food waste, contributing to an underestimation of the extent and severity of the issue in relation to food security and the wider sustainability agenda.
ii. They may disincentivise food waste reduction efforts and drive overproduction.
iii. In some cases, markets outside the food supply chain, such as diversion to animal feed, may pay better than providing nutrition to locals, undercutting food security and access.

There are a number of ways in which food intended for human consumption may leave the food system as either 'food surplus' or 'food loss/waste'. Within the definitions used to assess progress towards SDG 12.3, animal feed and some applications that are considered to 'valorise' food waste (e.g. as industrial products other than biofuels) are not regarded as food loss or waste. These are excluded on the basis that these uses have better environmental outcomes than food waste sent to incineration or landfill.

However, Feedback's 2020[xv] report found that whilst using food waste as animal feed saves on average three times more emissions than sending it to anaerobic digestion, preventing the waste in the first place saves nine times more compared to anaerobic digestion. This reinforces the need to prioritise reduction of food 'surplus' or food waste over the ability to divert it to 'less harmful' destinations than landfill. The current food waste definitions used are, therefore, counterproductive to the core objectives of SDG 12 targeting responsible consumption and production. SDGs 1,2 and 12 will not be achieved while we continue to divert edible food, intended for human consumption, to animal feed or valorisation options. If food waste and loss definitions enable continued overproduction and diversion of food into animal feed and other routes, GHG emission reductions will be far more limited, missing a globally significant opportunity to make agriculture more climate friendly.

Additionally, the alternative routes labelled as valorising often mask the full extent to which edible crops, livestock and fish are being underutilised as food. This undermines efforts to address underlying issues, such as specifications, which perpetuate edible food being diverted from the food system to the feed system. Where food surplus or that which is deemed unfit for market can be diverted into the feed system without being considered waste, there is little incentive to address the issues driving overproduction and food waste. Within this research, this was seen in a case study exploring the UK wheat industry, where on average only 40% of crops meet specifications and yet 'loss' rates are reported at approximately 1.3%. This is because close to 60% of these crops, grown for human consumption, are redirected into the feed system, taking massive amounts of embedded carbon and environmental degradation with them.

While diversion to animal feed and other uses may provide a better option than incineration or landfill, the priority objectives of improved food security and nutrition may be undermined in the process. The study of such flows is a neglected dimension of food access and security issues, as well as distorting the understanding of the scale of food waste and its associated environmental impacts. Where the extent of food waste is masked by rejects used as animal feed, the scale of loss to the human food chain is unseen. Greater support to food markets over those in the feed sector would be required to address this issue.

CASE STUDY

How animal welfare issues drive farm-stage food waste (United States)

The poultry industry is the largest user of crop-based feed in Asia-Pacific, Europe and North America, accounting for 41.5% of global feed use in 2009.[xvi] There has been a huge increase of poultry consumption globally in recent history, with its production increasing from 15% of global meat production in the mid-1960s to 32% by 2012. Growth has been particularly marked in higher-income regions such as Europe and North America. Currently, 40% of meat and animal production occurs in Europe, North America and Oceania, regions containing only 15% of the global population. In the United States, chicken is the number one dietary protein source; with more than 44kg per capita consumed in 2019, it has the highest level of chicken consumption of any country. To support the high level of consumption of chicken products, the US has the largest broiler chicken industry in the world, with about 16% of production exported to other countries. A total of 9.2 billion broiler chickens are processed each year, weighing 26 million tonnes.[xvii]

In order to keep up with this level of demand, unsustainable practices are being employed at the cost of animal welfare and increased waste. 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 90-100g per day. While this development over the last few decades has changed the economics of the poultry industry, such fast growth rates have brought welfare issues [xviii] and waste levels reaching 637,000 tonnes per year, or 6.5% of total farm-stage waste from meat products within the region. Waste levels are significantly linked to animal welfare and handling, with poultry health, accidents, equipment failures and welfare problems contributing to unnecessary waste. Disease outbreaks, such as avian influenzas in 2015, have caused catastrophic levels of waste; these too are linked to poor animal welfare. Poultry transport conditions cause additional waste as a result of broken wings or legs or suffocation.

Animal welfare is no longer a matter of ethics alone – it is an environmental necessity. To reduce waste, it is imperative that we enable farmers to increase animal welfare by implementing best practice from other regions, reducing injuries and mortality. This is likely to require the introduction of slower-growing varieties of broiler chicken, which would lead to lower mortality rates and better animal welfare scores.

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DRIVERS OF FARM-STAGE WASTE

The case studies conducted in this research illustrate the direct drivers of food waste occurring on-farm, including lack of technology, pests and disease, and poor agronomic practices. In addition, the case studies provided evidence of the indirect systemic drivers of on-farm waste from the wider food supply chain (from processing, retail and consumer stages), governance and cultural factors (see figure 5). Although direct drivers can be targeted through ground-level solutions, such as new technologies, education and training, these efforts are significantly less likely to have lasting and meaningful impacts on food waste levels without simultaneous adjustments to underlying factors further along the food supply chain.

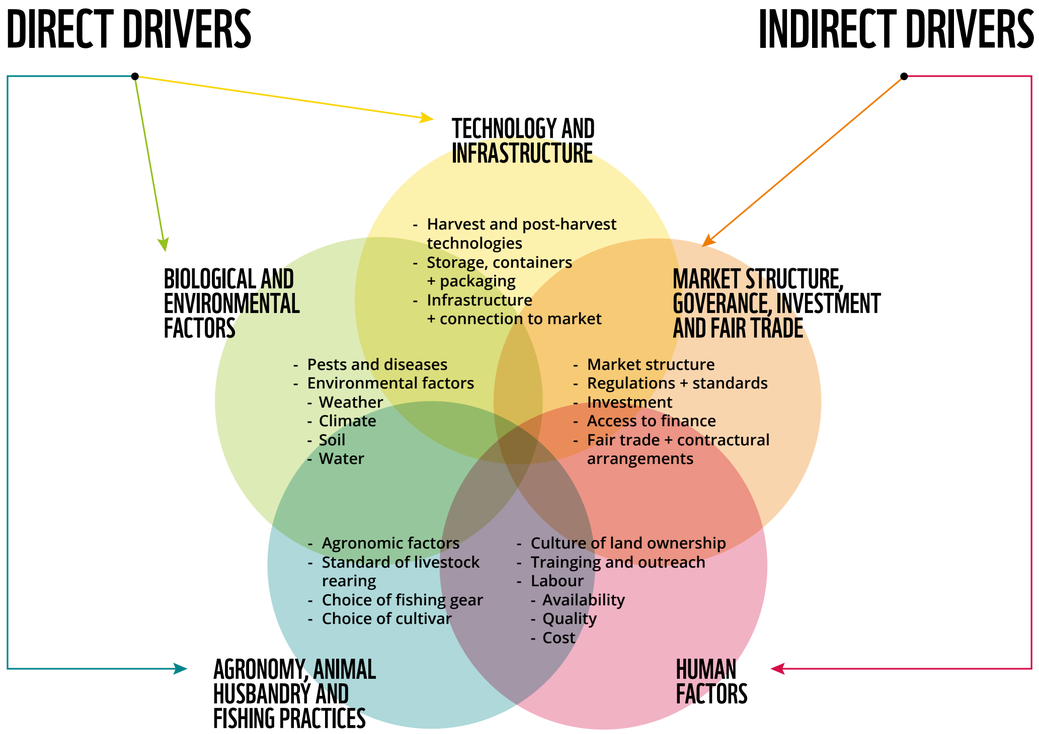

Figure 5:
Summary of direct and indirect factors driving food waste at farm level

For instance, farmers' ability to afford training or on-farm technologies to reduce waste is limited by the asymmetric power balance in the food supply chain, which leaves farmers unable to negotiate fair prices and subject to last minute cancellations which may mean farmers cannot afford to harvest surplus food. However, adjustments to this structure must be made alongside the delivery of training which highlights the importance and methods of reducing waste to farmers to provide incentive for farmers to target food waste reductions with the increase in income. The lack of whole chain thinking in interventions partly explains why so many solutions that address waste have not been more widely adopted. A detailed appreciation of the local context is therefore of prime importance in linking the most visible reasons for waste at farm level with the deeper underlying drivers operating at a macro-level.

Farm-stage factors also influence food waste occurring at subsequent stages of the supply chain. Downstream waste often results from a sequence of poorly executed actions at the farm stage, some originating from decisions made pre-harvest, coupled with conditions within the supply chain. For example, current market practices may keep farmers at a distance from their end markets where brokers and intermediaries operate. The lack of direct connection may cause farmers to misjudge the demand for commodities and the timing of harvest (creating unwanted surplus), or reduce their awareness of farm-stage factors that increase spoilage in the supply chain.

DIRECT DRIVERS

Biological and environmental factors that cause damage or biological spoilage to crops include pests/diseases, factors linked to weather, climate and soil, water availability, extreme weather events and natural disasters. While some of these factors are beyond the control of primary producers, others are more controllable, including through choice of resilient/appropriate cultivars, better protection from extreme weather events, early treatment of pests and disease and improved water management. This requires technological, financial and education intervention in many areas.

Agronomy, animal husbandry and fishing practices include factors linked to decisions (or indecisions) at the farm stage, such as poor harvesting and handling techniques, choice of variety appropriate to growing/rearing conditions, judgement of crop maturation and timing of harvest. Within animal agriculture, drivers of waste include poor sanitation during milking leading to diseases (e.g. mastitis), poor standards of animal husbandry resulting in high livestock mortality rates, and fishing techniques that result in significant bycatch and discards. Such practices may be caused by a lack of knowledge or training in better methods.

Technology and infrastructure examples include inadequate storage for harvested produce, poor harvesting technology, lack of temperature management of produce at harvest, and inappropriate fishing gear and lack of chilling of landed catch. Supply chains in higher-income regions generally have well-established cold storage, which 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 waste if transport to market is unreliable.

Mitigating action against the direct drivers of food waste include agronomic training and education for farmers, technological interventions and financial support to allow investment in training and technology. However, aside from the need to address the underlying systemic issues which hinder the implementation of these solutions, as highlighted above, there is also a need to see these areas of intervention as interconnected in order to improve effectiveness. For technology options to be effective, they need to be implemented alongside better agronomic/handling practices, which would entail increased access to training and awareness of harvest and post-harvest waste.

INDIRECT DRIVERS

As illustrated in figure 5, the direct drivers of food waste at farm stage are influenced by wider, indirect drivers in the food supply chain. Effective interventions to reduce farm-stage food waste 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 which farmers and farm-stage interventions have little influence over.

Although technological and training-based solutions remain an important component of interventions to reduce waste, the success of food waste reduction initiatives often depends on synchronising a raft of interventions that include both farm-stage and post-farm-gate actions and stakeholders. There is a need for more holistic solutions that balance actions that address biological and environmental drivers with initiatives covering combinations of direct and indirect actions: no single intervention is likely to succeed unless also it also addresses other factors simultaneously. The case studies explored illustrated the need to continue existing actions as well as develop additional interventions to address biological and environmental threats to crops, livestock and fisheries, but alongside these, changes are needed within the wider food system. Issues include imbalances of power between farmers and retailers; market structures that keep farmers separated from the end consumer; and a lack of governmental support or policy to drive change. These keep farmer incomes supressed and maintain the status quo, which perpetuates waste. Without considering change at this level, reducing waste at the farm stage is difficult to achieve.

Based on the case studies, we have derived a number of recommended actions for various actors within the food system which target the indirect drivers of food waste on farms. These actions are outlined in table 3 and explored in further detail in the following section.

Table 3
Mitigating actions targeting the indirect drivers of food waste on farms

Actors	Actions
NGOs and Multi-lateral institutions	• **Review the definitions and parameters used for measuring progress towards SDG 12.3** - Extend the scope of required measurement and reporting in the Food Loss Index to include harvest waste - Review the exclusion of animal feed from definitions of food loss and waste • **Integrate 50% reduction target from 'Farm to Fork' in future food waste initiatives, goals and programmes** • **Establishment of micro-finance initiatives to support investment in food waste reduction initiatives** • **Ensure interventions are developed with the local context in mind**
Markets and supply chain actors	• **Support growers to implement food waste measurement and reporting which moves towards reducing overproduction and carbon impacts as well as food waste** - Support growers in implementing measurement and reporting of food waste - Adopt a stretched target in food waste reporting under SDG 12.3 • **Support initiatives looking for greater crop varieties** - Consider product portfolios and source a greater variety of crops - Starting dialogues with customers on agri-biodiversity • **Expand quality specifications** • **Contract practices** - Payment of fair prices to enable farmers to improve their harvesting and field management techniques - Risk sharing - Contractual protections • **Facilitate discussions with co-operatives and farmer associations** • **Review the role of brokers and the traditional market structure** • **Develop a larger number of alternative markets for surplus**
Governments	• **Set national targets to reduce food waste from farm to fork by 50% by 2030** - Introduce legally binding stretched national targets for food waste reduction - Make food waste and surplus measurement and reporting mandatory & provide support to enable implementation • **Integrate food waste into agricultural policy and support** - Establishment of Good Agricultural Practices (GAPs). - Incorporate waste reduction incentives within agricultural subsidies. • **Redevelop animal welfare policy to reduce the causes of livestock waste** • **Greater regulation of fishery practices including reporting of by-catch** • **Development of fair-trade laws to reduce unfair trading practices between farmers and supply chain** • **Development of infrastructure, R&D and education:** ***particularly for domestic crops***
Citizens	• **Increasing the variety in our diets** • **Adjust the frequency with which we eat meat** • **Challenging our beliefs about how food 'should' look**

CHANGES NEEDED TO SUPPORT REDUCTIONS IN FARM-STAGE FOOD WASTE

MULTILATERAL INSTITUTIONS, THE UN, FAO AND EU.

NGOs and multilateral institutions, such as the UN and FAO, are pivotal in setting the narrative for the future of food production and environmental and food security work. As organisations which often transcend country and continental borders, they are able to support change on a wider scale and are therefore essential in setting expectations and providing support for food waste reduction globally. They are also well placed to address the cultural and human factors that drive food waste on farms.

1 **Review the definitions and parameters used for measuring progress towards SDG 12.3**

a. **Extend the scope of required measurement and reporting in the Food Loss Index to include harvest waste.** In order to work towards reduction it is essential to first establish an accurate baseline of food waste occurring at the early stages of the supply chain. Whilst there are difficulties in measuring and reporting losses occurring at or around harvest, this report finds that an estimated 8.3% of food production is lost at this stage, making it too significant to sustainable production and consumption to not ensure inclusion in reporting.

b. **Review definitions of food loss and waste used in SDG 12.3.** Current definitions of food loss and waste present a blind spot in food waste reporting, making it difficult to measure the scale and impact of edible food being diverted to animal feed at the farm stage. Introducing more granular reporting of food waste and surplus on farms can support a body of work targeting a reduction in the volume of food diverted to animal feed and other uses, supporting more sustainable production.

2 **Integrate 50% reduction target from 'Farm to Fork' in future food waste initiatives, goals and programmes:** Specific and ambitious targets are needed in order to motivate action to reduce the hugely impactful level of loss experienced pre-retail. These should be integrated into food system initiatives in order to motivate action and ensure access to funding for interventions and work on farm losses as well as those occurring post farm-gate.

3 **Ensure interventions are developed with the local context in mind.** Outreach work and innovations to reduce losses need to be developed within the local cultural context and address gender issues if they are to be successfully adopted. Although technological solutions remain important, they need to be suitable and affordable for the given region and culture. Additionally, failure to consider local culture may impede the success of educational interventions. For example, in Pakistan while the majority of planting and harvesting work is conducted by women, food waste reduction training is largely attended by men.

4 **Establish microfinance initiatives.** A lack of access to finance prevents uptake of innovations that could drive down waste rates. In many regions smallholder farmers are tenants rather than landowners, making investments to reduce losses more difficult to secure. Additionally, lenders are often reluctant to finance farmers on favourable terms. Without access to finance, smallholder farmers may rely heavily on traders for financing. This takes away their independence in negotiating a fair price, as these are set by the lenders, who also control access to the markets.

People working with WWF plant mangroves in the western coastal region of Madagascar. A mangrove, a shrub or small tree that grows in coastal saline or brackish water, are key to a healthy marine ecology, providing shelter to crabs and shrimps, and reducing soil erosion. Birds, sea turtles, and dugongs. The landsea barrier is also an extremely efficient way to retain CO2, thus contributing to climate protection, says WWF.

Yet, rising sea levels, human activities, and cyclones, have harmed these valuable ecosystems, leading to decline everywhere in Madagascar. The community of Ambakivao works daily, with the support of WWF, for the sustainable management of nearly 3,000 hectares of mangrove forests. WWF teaches fishermen, who hunt for crabs living in the mangrove, to maintain or increase their food production without destroying the delicate habitat.

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MARKETS AND SUPPLY CHAINS ACTORS

Some of the key underlying drivers of food waste on-farm stem from current market structures and practices which supress farmers' incomes and negotiating power and keep them distanced from the end market. In order to support a reduction in food waste on-farm, fundamental shifts in the system are necessary:

1. **Support growers to implement food waste measurement and reporting which moves towards reducing overproduction and carbon impacts as well as food waste:**
   a. **Support growers in implementing measurement and reporting of food waste.**[5]
   b. **Adopt a stretched target in food waste reporting under SDG 12.3** Food businesses can support their growers in implementing food waste reporting which goes beyond SDG 12.3 requirements and includes measurement of all streams intended as food that do not leave the farm in the human food supply chain, including food diverted to animal feed. Food businesses can also adopt these stretched targets in relation to their own operations. Adoption of a stretched target could also support food businesses with ambitious climate action through the Science-Based Targets initiative and to reduce their scope 3 carbon emissions.

2. **Support initiatives looking for greater crop varieties in order to reduce the prevalence of farmers planting less suited cultivars with high waste rates due to market popularity:**
   a. **Retailers should consider their product portfolios.** Try to limit the percentage of produce which comes from the majority crops and instead include and increase alternatives.
   b. **Start dialogues with customers on agri-biodiversity.** Communicate the reasoning behind any stock changes with customers, including the environmental significance and aspects that support farmers to grow more resilient cultivars on their land.

3. **Expand product specifications.** By specifying high standards in shape and appearance, especially for fruit and vegetables, produce out-graded from the intended market may command lower prices. Where prices do not cover harvesting and other farmer costs, produce may be left unharvested, culled during harvest or used in low-value applications, such as animal feed. Widening specifications can help reduce this.

4. **Address contract practices which suppress farmers' incomes and power to negotiate:**
   a. **Pay fair prices to enable farmers to improve their harvesting and field management techniques.** Where investments are needed to improve farming practices and target the direct drivers of farm-stage food waste, better prices are required to provide the farmer with a return on investment. To this end, paying fair prices to farmers is an integral element of reducing food waste at the farm stage.
   b. **Introduce contractual arrangements that share risks more equitably between producers and markets.** This is necessary to boost farm incomes and provide enough financial security to allow farmers to invest in food waste reduction techniques. This includes contract types (e.g whole crop purchasing and flexible production targets) that protect farmers from the financial losses associated with both gluts (e.g. additional harvesting labour) and underproduction (e.g. cancelled contracts if predicted yield is not delivered).
   c. **Introduce contractual protections from unfair trading practices which drive up food waste at farm stage from the retail end of the supply chain.** Farmers are often subjected to last-minute cancellations and changes to orders due to issues in retail operations such as forecasting changes. These behaviours may leave farmers unable to fund harvest labour, or without time to find a second market to sell the produce.

5. **Facilitate discussions with cooperatives and farmer associations.** The case studies illustrate that cooperatives and farmers' associations empower farmers with price-setting and bargaining which improves their economic situation, allowing greater financial security for investment in food waste reduction.

6. **Review the role of brokers and the traditional market structure in driving food waste on farms.** Where farmers supply through brokers there is a weaker connection between farmers and end-market requirements. The lack of a strong feedback loop on product quality reduces the suppliers' understanding of food waste drivers and quality issues further down the supply chain, such as knowing at what stage of ripeness to harvest to allow enough time to reach the market. Additionally, weak market links supress farm incomes: farmers cannot command a higher price for quality and are more often 'price takers' than 'price makers'.

7. **Develop a larger number of alternative markets for surplus.** Gaining access to alternative markets for food which cannot be sold for its primary function is also an important aspect of reducing waste, for example, through food processing and preservation industries.

GOVERNMENTS

Governments play a critical role in setting the agenda and priorities for environmental work. It is imperative therefore that national governments begin to prioritise the development of policy and infrastructure to reduce food waste on farms. Governments should be ambitious in their targets for food waste reduction and support of innovation in order to assist farmers in implementing sustainable agricultural practices.

1. **Set national targets for food waste reduction from farm to fork by 50% by 2030:**
   a. **Introduce stretched national targets for food waste reduction.** Nations should set targets for a 50% reduction in food waste, including harvest and post-harvest waste in primary production.
   b. **Make food waste and surplus measurement and reporting mandatory and provide support to enable implementation.** National governments should generate robust baseline measurements for food waste across all sectors. To do so states need to provide support and training, particularly for small businesses, including many farmers, to implement measurement and reporting systems.

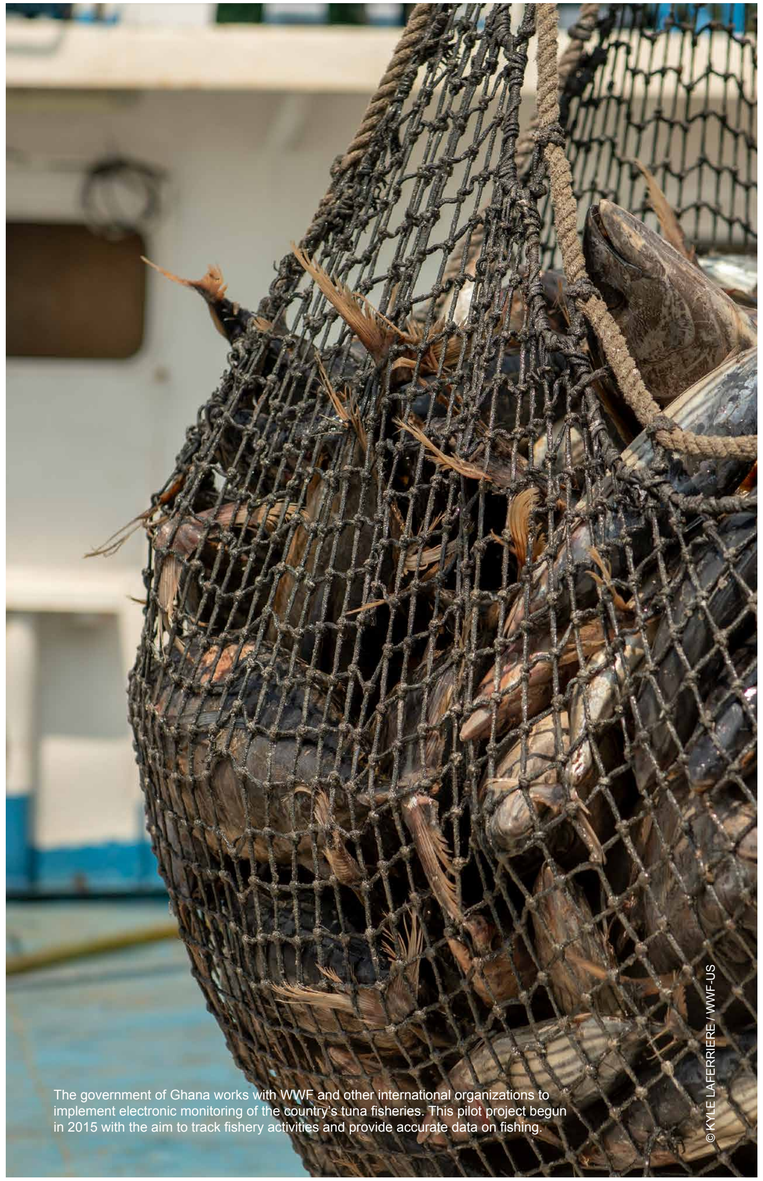
2. **Integrate food waste into agricultural policy and support**
   a. **Establish of Good Agricultural Practices (GAPs).** In previous cases where the food industry has become involved in the development of GAPs, farmers have benefited through improved agronomy, access to technology and training. This could take the form of specific GAP measurements as a prerequisite for imported or domestic goods.
   b. **Incorporate waste reduction incentives within agricultural subsidies.** By ensuring all agricultural subsidy scheme design has an increased emphasis on reducing farm-level food waste, both food waste volumes and the previously targeted impacts (e.g. carbon emissions) can be integrated and targeted simultaneously.

3. **Increase animal welfare standards.** Improved animal welfare standards in relation to rearing and slaughter, which includes improved transportation from farm to slaughter, could reduce farm-stage waste and therefore the amount of livestock that needs to be produced. This is particularly important given the extent of environmental damage caused by food waste in animal agriculture.

4. **Strengthen regulation of fishery practices and monitoring of bycatch levels.** Governments must regulate use of equipment and practices known to increase bycatch and mandate the monitoring of bycatch. While there is an awareness of bycatch as an issue in terms of both food waste and impact on biodiversity, very little data exists in this area on which to build targets and plan for reduction.

5. **Implement fair trade laws to protect farmers from unfair trading practices which drive up food waste.** There is a need for greater policy globally to protect farmers from unfair trading practices. Measures include prohibiting short-notice cancellations of perishable agri-food products and unilateral contract changes by the buyer, which transfer the risk of waste and deterioration to the supplier.

6. **Develop infrastructure, R&D and education, particularly for domestic crops.** Governments need to invest in food security, agricultural development. Sequential improvements in infrastructure (such that improvements in one element do not then hit severe constraints at the next), transport, bulk storage facilities and processing industries. In particular, a number of commodities were identified as being neglected by governments (e.g. groundnuts in Ethiopia), as higher priority was given to cash crops for export over crops for local consumption. Without greater commitment to these commodities at governmental level, training and investment is likely to be held back.



The government of Ghana works with WWF and other international organizations to implement electronic monitoring of the country's tuna fisheries. This pilot project begun in 2015 with the aim to track fishery activities and provide accurate data on fishing.

CITIZENS

Several of the case studies illustrate how citizens' choices can affect farm-stage food waste, highlighting a new role for active citizenship in their food choices. The main roles that citizens can play in reducing food waste on farms is through what they choose to buy and eat:

1. **Increase the variety in our diets.** Farmers are often driven to select less suited cultivars (plant varieties) for their region or cropland, because of the popularity of that type of food. Despite higher waste, the crop might still be more profitable than more productive alternatives that have lower consumer demand. By increasing the variety of the foods that we eat we can encourage markets to sell a greater variety, reducing the need for farmers to select less fitting plant types for their land.

2. **Adjust the frequency and way we eat meat.**[5] A switch to higher welfare meats, as well as reducing how frequently we eat meat, would contribute to reducing waste driven by current intensive production methods. This would significantly reduce emissions related to food waste, because meat carries a disproportionate part of food waste's climate impact.

3. **Challenge our beliefs about how food 'should' look.** Our preferences can affect the types of food planted and whether foods are even harvested at the farm stage. The cost of harvest labour can make it unprofitable to harvest food which is unlikely to sell due to aesthetics. Supporting initiatives like retailers selling 'wonky veg' is a great way to encourage change.

5 For guidance on nutritious, low impact, plant based foods see WWF & Knorr's Future 50 Foods: Report available at: https://www.wwf.org.uk/sites/default/files/2019-02/Knorr_Future_50_Report_FINAL_Online.pdf

CONCLUSIONS

This report presents clear evidence that farm-stage food waste is a significant but overlooked food waste hotspot. As work continues globally to stabilise climate change, slow and reverse biodiversity loss and increase food security, it has never been more evident that moves towards sustainable agriculture are imperative. With food waste on farms contributing 16% of all agricultural emissions, driving land-use change and contributing to environmental degradation, targeting a reduction in the 1.2 billion tonnes of food wasted at the farm stage can no longer be overlooked. Additionally, with 15.3% of food production being lost pre-farm gate, this is a significant area of concern in the goal of halving food waste levels by 2030.

Farm-stage interventions can no longer be focused on technology alone. Effective interventions to reduce farm-stage food waste must involve multiple elements rather than single solutions, and must address the 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 waste, they need to be suitable for the given region and culture and be affordable.

The case studies explored in this research highlight the need for changes within the food system and its governance. Paramount is driving policy and market changes to give farmers greater price-setting and bargaining power, which improves their economic situation and allows greater financial security to invest in food waste reduction. Changes in market structure are also necessary to allow farmers to connect directly with markets, facilitating better crop monitoring, understanding of the market and infrastructure to safely deliver produce.

Alongside these changes, there is further work needed to enable better measurement and reporting in order to reduce food waste on farms and in fisheries. This is necessary to ensure transparency and progress.

The steps that must be taken to achieve these goals include:

i. Developing ambitious targets for pre-retail food loss and waste and more granular reporting of food waste on farms.

ii. Integrating farm-stage food waste reduction initiatives into policy, such as mandatory reporting of harvest waste and fisheries bycatch.

iii. Addressing market drivers of farm-stage food waste which suppress farmer incomes, maintain asymmetric power balances and distance farmers from their end markets.

iv. Developing region- and culture-specific ground-level interventions to target the direct drivers of farm-stage food waste.

APPENDICES

1. METHODS

Global farm stage loss and waste 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 (including sources from 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) with fish and dairy products having the fewest data points.

Data collation focused on updating farm stage losses, while 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. As such, estimations of inedible food stuffs were removed during the estimation of the scale of food waste on farms and did not contribute to the 1.2 billion tonne estimate, however were included in the environmental impact assessments as they're existence still contributes to environmental degradation.

The global analysis of food loss impacts was based on the scale of food loss determined in the analysis described above, 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 CO_2 eq.), freshwater withdrawal (L), water scarcity (L eq.), acidification potential (g SO_2 eq.) and eutrophication potential (g PO_{43-} eq.). A separate analysis was carried out for wild-caught fish, as these were not represented in the Poor and Nemecek model.

The 10 selected case studies are shown in Appendix 4, 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 overarching 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.

Identification of 10 food loss case studies for further investigation involved different selection criteria across the main commodity groups, given the uneven coverage of food loss data and the need for a mix of different commodities/regions. 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.

Within the deep dives interviews were conducted to sense check the global estimations of food loss, to determine overarching themes relating to farm stage waste and to develop a deeper understanding of drivers and possible mitigating actions. In addition, farm loss literature was identified that placed an emphasis on direct field studies along the lines of the FAO four elements used for food loss analysis: screening (for known research literature and consultation with experts, to gain an approximate idea of the range of waste and main causes), survey (including observational, group interviews, stakeholder interviews), sampling (load tracking, field measurement, analysis of loss by activity) and synthesis (involving root cause analysis and solution identification), FAO 2016.[xix]

2. SCOPE

This report considers the term food waste at the farm stage to apply to any outputs from primary food production that are, or were at some point, intended for human consumption but which ends up either not being harvested or sent to one of a range of food waste destinations. This starts by defining the point at which the food chain begins, when the outputs from primary production can be regarded as 'food'. For crops and produce this is defined in terms of crop maturity and being 'mature and ready for harvest'. For livestock and fisheries, although a similar definitional principle is applied (i.e. based on maturity, slaughter weight or when wild caught animals/fish are harvested) it is far more problematic to interpret. Fallen stock in the field or poultry 'dead on arrival' at slaughter may be recorded by studies, but the question of animal 'maturity' and whether the loss would count as 'food' remains largely theoretical.

The case studies explored in this research highlighted this issue and the need for more consistent measurement and reporting of food waste and destinations at the farm level. A major uncertainty identified in many of the case studies was that of inconsistent application of food loss and waste definitions when measuring and reporting food loss and waste. Few studies at the agricultural stage have been designed using the SDG 12.3 definitions of food waste and surplus based on their destinations. Farm waste research generally has a different focus to supply chain and consumer studies, with more emphasis on improved yields, and as a result waste destinations are often a secondary consideration. Subsequently, there is a lack of consistent measurement which prevents the full extent of food waste from being captured.

While food waste research frequently divides waste between that which is edible and inedible (e.g. bones), at primary production the distinction is more difficult to make as many of the products from primary production require processing which in part determines the edible/inedible fraction. Within this research estimations of inedible food stuffs were removed during the estimation of the scale of food waste on farms and did not contribute to the 1.2 billion tonne estimate, however were included in the environmental impact assessments as they're existence still contributes to environmental degradation.

3. COMPARISON OF FINDINGS TO RECENT RESEARCH

The most recently published assessment of global food lossesv 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 4. 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% total losses at farm stage when harvest losses are 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. This percentage was calculated along with the estimated 2.5billion tonnes of food lost or wasted throughout the supply chain using the following methods and assumptions.

The 1.2 billion farm stage losses from this research were split into the post-harvest losses and in field losses and then, using the percentage of post-harvest losses on farm and in the supply chain provided in the FAO State of Food & Agriculture report (2019), post-harvest losses on farm were subtracted from FAO 2019's estimate of post-harvest losses up to but not including retail. These figures were derived from the appropriate FAOSTAT production numbers. This created an indicative estimate of 436mt for losses occurring in the post farmgate transport, storage, manufacturing and processing stages. This figure is uncertain due to differences in calculation method and assumptions made in FAO 2019's primary production estimates against those used in the current study.

	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]

Table 4
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

4. CASE STUDIES

	10 Global Case Studies	**Evidence Collected**
Cereals and pulses	1. European - wheat production in UK	Interview with trade Association, literature review -10 references
Fruit and vegetables	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 #
Roots, tubers and oil crops	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 #
	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 #
	5. Industrialised Asia – potato + sweet potato SW China	Interview - researcher with potato tuber expertise in Industrialised Asia working with farmers , 4 references
	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 #
	7. Europe - rape seed and sunflower seed	France: oilseeds, 4 references
	8. Sub-Saharan Africa - groundnuts	Interview with researcher and groundnut co-ordinator for Ethiopia, additional literature from Malawi, 5 references #
Meat and animal products	9. USA, Canada & Oceania – broiler chicken rearing/ slaughter	Interview with meat sector expert/ consultant: USA, broiler chickens, 7 references
Fish and seafood	10. Sub-Saharan Africa - freshwater fisheries	East Africa, Lake Victoria dagaa fishery, 11 references #
Over-arching issues	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

5. RESOURCES FOR MEASURING FOOD WASTE ON FARMS

Resource	**Description**	**Location**
FAO's Case Study Methodology of Food Loss analysis	Support on measurement protocols and analysing the multidimensional causes of loss in various supply chains. In particular the Commodity System Assessment Methodology (CSAM) can be used to include pre-harvest waste in measurements.	http://www.fao.org/food-loss-reduction/resources/flaelearning/en/
WRAP's guidance for measurement	**Farm adviser guidance** on how to deliver a project, how to engage and recruit farmers, through to analysing data and identifying opportunities to improve, and all the key steps in between. **Farm adviser slide deck** which advisers can use during meetings with farmers at key stages. **Farm adviser data collection templates** which provide useful examples to support measurement.	https://wrap.org.uk/resources/tool/farm-adviser-resources
Stewardship Index for Specialty Crops (SISC) Food Loss Metric	A metric tool for measuring waste on-farms for fruit and vegetable crops as well as waste at other stages under a farmers operation, and includes qualitative data collection on the reasons and destinations for waste.	https://www.stewardshipindex.org/working-metrics

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Woman dehusking and seperating various grains such as millet, maize and sorghum along the road to Niassa Game Reserve from Marrupa, Mozambique, Africa.

(GERMUND SELLGREN/WWF-SWEDEN)

A gate to a pasture in Gryt archipelago, Sweden.