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FINAL REPORT

THE IMPACT OF REDUCING FOOD LOSS IN THE GLOBAL COLD CHAIN

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1. Executive summary

A third of all food produced globally is lost or wasted. Given the many starving people and poor levels of nutrition around the world, reducing this waste would appear to be a key global priority. By 2050, the global population will reach 9 billion. If current levels of food loss and waste are maintained, food production will need to increase by as much as 70% in developing countries alone, requiring investment of $83 billion a year[1].

Reducing the levels of loss and waste will have a large impact on food security, nutrition, rural income and the environment. Dealing with hunger though is not just a matter of increasing availability of calories; increased availability for consumption of micronutrients is also important to combat hidden hunger. This can be addressed through loss reduction targeted at key food groups such as fruit and vegetables.

In this report we focus on perishable food loss, from harvest or slaughter through to retail. The findings draw on a literature review but more centrally from a survey of a number of experts from different geographical regions and areas of expertise to enable us to produce a more accurate picture of where food is lost in the supply chain and what measures can be implemented to reduce this loss.

Our aim in producing this report is to raise awareness of the impact and scale of food loss around the world, to highlight the many approaches that can be used to reduce perishable food loss and suggest what might be the next steps in understanding this area.

Key Observations

- The major causes of food loss in developing countries include: poor harvesting practices; lack of access to cold chains and reliable energy sources required to power them; market conditions; inadequate infrastructure; design of government policies.
- Due to advanced cold chains and supply chain practices the levels of food loss are generally much lower in developed countries. The major causes of food loss in developed countries include: field losses; out-grading; uncertainties in demand; improper handling; breaks in the cold chain. Much of the total wastage in developed countries is due to consumer behaviour.
- By weight, fruit and vegetables have the highest levels of loss and waste globally at 44% of the total, yet account for just 13% of total loss and waste in terms of energy content[2].
- The total calorific content that could potentially be saved if fruit and vegetable loss was reduced by 25% in the four countries we investigate (China, India, Pakistan and Kenya) would be the equivalent of enough energy to satisfy the requirements of up to 22 million people for a year.
- The impact of the micronutrient content of the fruit and vegetables is even greater, having the equivalent iron content for up to 66 million people and vitamin A content

for up to 70 million people. This highlights the pressing need to reduce global perishable food loss.

- Reducing food loss could be achieved by: implementing or improving the cold chain; better packaging; food processing; improved farming practices; upgrading infrastructure; utilising new information technologies; increased access to credit; better regulations; more and better education.
- Some solutions to reduce loss can be implemented at specific sectors in the supply chain (farm or retail level) such as the use of better types of packaging, while others are more generic including large infrastructure projects. A broad range of stakeholders, from smallholder farmers to national governments, need to mount a concerted effort to reduce these huge levels of loss.
- Next steps in understanding this area point to better and more comprehensive data to assess the amount of food loss and the micronutrient impact of this food loss. Additional data is also needed on the impact on rural income, the most effective types of education, especially using new technologies such as mobile services, the amount of out-grading and what happens to food waste.

2. Introduction

According to the Food and Agriculture Organisation (FAO) of the United Nations there are 805 million people who are chronically undernourished[3], around 2 billion people who are affected by micronutrient deficiencies, also known as hidden hunger[4,5], and more than 100 million children under the age of 5 who are underweight[6]. The global population is expected to grow to 9 billion by 2050[7], with much of the growth occurring in Sub-Saharan Africa and rapidly industrialising nations in Asia, which will substantially increase the demand for food[8]. To combat malnutrition there are many challenges that have to be overcome such as climate change[9], water scarcity[10], energy requirements and reducing the huge amount of food loss and waste.

Undernourishment – a definition
"A state, lasting for at least one year, of inability to acquire enough food, defined as a level of food intake insufficient to meet dietary energy requirements." FAO (2000)[11].

The FAO estimates that almost a third by weight (1.3 billion tonnes) or a quarter, in terms of calorific content, of all food produced globally is lost or wasted every year[12,13]. Food loss is defined by HLPE (2014)[14] as "*a decrease, at all stages of the food chain prior to the consumer level, in mass, of food that was originally intended for human consumption*," while food waste refers to "*food appropriate for human consumption being discarded or left to spoil at consumer level*" and generally relates to behavioural issues.

To meet the growing food demand the global crop production will have to increase. Tilman, *et al.* (2011) have shown that the increase in global crop demand could increase by 100-110% from 2005 to 2050[15]. If current agricultural trends continue, this would have a large environmental impact, with 1 billion hectares (2.5 billion acres) of land being cleared globally by 2050, greenhouse gas emissions from agricultural activities reaching 3 billion tonnes per year and nitrogen use could be as high as 250 million tonnes per year. Reducing the levels of food loss and waste would have a significant impact on the number of people that could be fed as well as minimising the amount of land, water and energy required for agriculture. However, only about 5% of international agricultural research funding goes towards minimising postharvest losses, with 95% of the funds aimed at increasing yields[16]. In addition, only a small fraction of development projects in developing countries have focused on reducing postharvest losses[17].

Although there have been a number of studies that have investigated the extent of food loss, due to the high variability in methodologies they are often difficult to compare[18]. Due to the serious lack of data, which will be discussed further in Section 10, many of the regional and global estimates of food loss rely on small scale studies or anecdotal evidence that is then extrapolated to produce figures for entire regions or product categories[12].

Whilst these estimates should be taken with caution, they nonetheless demonstrate the huge quantities of food and particularly perishable food that is being lost around the world.

Fruit, vegetables, meat, fish and dairy are inherently perishable and without proper transport and storage their usable life is dramatically decreased. The level of perishable food loss is therefore much greater when compared to cereals[12,19]. By weight, fruit and vegetables have the highest levels of loss and waste globally at 44% of the total, followed by roots and tubers (20%)[2]. In many developing countries, fruit and vegetable losses are between 20-50%[16,20-22], with some studies reporting losses as high as 80%[17]. Meat, seafood and dairy have similar levels of loss, but due to their much lower levels of production, the overall loss is much lower than fruit and vegetables[2].

There are many interconnected causes of food loss along the entire food supply chain. Some of the major causes in developing countries include:

- poor harvesting practices
- the lack of access to cold chains and reliable energy sources required to power them
- poor market conditions
- insufficient infrastructure
- inappropriate government policies.

Due to advanced cold chains and supply chain practices the levels of food loss are generally much lower in developed countries, however, contribution to food loss includes:

- field losses
- out-grading – the rejection of food that does not meet the required specification
- uncertainties in demand
- improper handling
- breaks in the cold chain

The cold chain is the uninterrupted temperature controlled transport and storage system of perishable goods between producers and consumers. Only about 10% of perishable foods are refrigerated worldwide[23], yet refrigeration is the best technology, with no associated risks, to ensure food safety and prolong the shelf life of perishable food. For example, milk can last for up to two weeks at 0^{o}C but just a few hours at 30^{o}C[24]. More than 50% of global food loss and waste is comprised of commodities that can benefit from refrigeration[25].

India loses as much as 20-50% of all its perishable food due in part to an inadequate or non-existent cold chain, equating to a cost of US$ 4.5 billion while Africa loses up to US$ 4 billion worth of perishable food[26]. In Tanzania 97% of meat has never come into contact with refrigeration as a cold chain does not exist except for imported meat that goes to hotels and supermarkets and the shelf life of fresh meat is just one day or less with an estimated 40% of red meat lost post slaughter[27]. Where cold storage facilities do exist, they are often only

suitable for one type of commodity. For example 75% of India's cold storage warehouses are only suitable for potatoes, a commodity that produces only 20% of agricultural revenue.

Much of the total food loss and waste in developed countries is due to consumer wastage, accounting for 61% and 52% of the total food loss and waste in North America and Europe respectively[2] which equates to 95-115 kg/year of food per capita wasted [12]. This compares to just 5-13% or 6-11 kg/year in Sub-Saharan Africa and South/Southeast Asia.

In 2010, about 31% of the available food supply in the United States at the retail (10%) or consumer (21%) levels was lost or wasted[28]. The estimated value of the 133 billion pounds of food that was lost or wasted was US$ 161.6 billion. The three food groups with the highest value of loss or waste were meat, poultry and fish (30%, $48 billion), vegetables (19%, $30 billion) and dairy products (17%, $27 billion). Approximately 25% of all the food and drinks that consumers buy is thrown away, either due to spoilage or cooking or serving too much and subsequently discarding the remainder[29]. Per household, the cost of food waste is as much as US$ 936 a year[30].

Supermarket losses in the US in 2005 and 2006 were found to be approximately 12% for fruit and vegetables and 7% for meat, poultry and seafood[28,31]. A further study found a similar level of loss with 11.4% for fresh fruit, 9.7% for fresh vegetables and 4.5% for fresh meat, poultry and seafood[30,31].

In Switzerland almost half of the avoidable loss and waste, in terms of calorific content, occurs at the household level[32]. In Germany, there are approximately 11 million tonnes of loss and waste with 61% at household level, 17% during industrial production, 17% from large scale consumers and 5% at retail [33]. Around 12-22% of meat and meat products are lost or wasted[34]. There is approximately 12% of loss or waste in fresh poultry meat chains with 0.5% at processing, 1% due to logistics, 1% at wholesale, 2.5% at retail and 6% consumer waste. The total amount of preventable food loss and waste over the whole supply chain of Austria is estimated to lie at about 350,000 tonnes annually or at 42 kg/inhabitant annually[35].

The total UK food and drink loss and waste is estimated to be around 15 million tonnes per year with households generating 7.2 million tonnes per year (4.4 million tonnes of which is avoidable). In 2007, the Waste and Resources Action Programme (WRAP) published an influential report which revealed that 22% of food and drink purchases were being thrown away by consumers[36]. However, due to campaigns such as Love Food Hate Waste, agreements with the food industry and government, and changes in policy and regulation, for example, the removal of 'display until' dates and changes to freezing guidance, the total avoidable household food waste had been reduced by 21% by 2012, saving consumers almost £13 billion[37].

Dr Marcos David Ferreira from the Brazilian Corporation of Agricultural Research (Embrapa):
"Postharvest food loss reduction is one of the main issues of this century. When food is thrown away, as food loss or waste, it is not only the produce that is wasted, but also labour, energy and water. I believe the whole food chain will have to be more conscious about this, from grower to consumer. Considerable changes can be done, with low investment, by training people in the supply chain, as well as increasing consumer involvement."

2.1 Summary

- While figures vary, around a third of food production is lost or wasted.
- The scale of global hunger and hidden hunger is significant.
- Reducing perishable food loss in developing countries could improve this situation, especially for hidden hunger.
- The causes of food loss and solutions to reduce it are complex and varied suggesting there is no one solution that is appropriate in all cases and countries.

The rest of the report highlights the myriad causes of food loss, the drivers for change and the potential solutions. Clearly the scale of food loss is significant but it varies across sectors. Reducing food loss in the grain and cereals sector, for example, would increase availability of calories but would do little for the micronutrient levels of those consuming the grains. Equally, there is little need of cold chain support for grains and cereals.

To reflect the fact that reducing loss is not simply about increasing calorie intake, we focus on the fresh fruit and vegetable sector. The level of potential improvement in micronutrient levels arising from reduction in loss in this sector is significantly higher than in grains and cereals and also would benefit more squarely from cold chain technologies in helping this goal to be achieved. As such, perishable foods will form the central focus of the rest of the current report. Further, through the use of case studies we highlight how solutions vary across the globe and along supply chains.

3. Food loss and waste–terminology and the study

3.1 Terminology

The terminologies of food loss and waste vary considerably in the literature, as explained in detail in a report by HLPE (2014)[14]. Many authors make a distinction between loss and waste where:

- **Food loss** is food that has decreased in quality and is no longer fit for human consumption due to inadequate supply chain systems.
- **Food waste** generally relates to behavioural issues and is often defined as edible food that has been unutilised as a result of human action or inaction[30].

However, food waste or wastage are also frequently used as a generic terms for both waste and loss which can add to the confusion.

The definitions of loss and waste can be simplified to what stage the food is lost or wasted so that food waste refers only to consumers and food loss relates to all stages prior to the consumer level. The HLPE report uses the following definitions[14]:

- **Food loss and waste (FLW)** refers to a decrease, at all stages of the food chain from harvest to consumption in mass, of food that was originally intended for human consumption, regardless of the cause.
- **Food losses (FL)** refer to a decrease, at all stages of the food chain prior to the consumer level, in mass, of food that was originally intended for human consumption, regardless of the cause.
- **Food waste (FW)** refers to food appropriate for human consumption being discarded or left to spoil at consumer level – regardless of the cause.
- **Food quality loss or waste (FQLW)** refers to the decrease of a quality attribute of food (nutrition, aspect, etc.), linked to the degradation of the product, at all stages of the food chain from harvest to consumption.

A further problem with these definitions is whether the non-edible parts of food are included within the figures relating to food loss or waste. To remove the uncertainty, some authors refer to avoidable or unavoidable food loss or waste[32].

Food loss can also be categorised into quantitative food loss which is caused by a reduction in weight caused by spillage or unintended losses and qualitative food losses which are those that relate to unwanted changes in taste, colour, texture or nutrient value caused by pests, inadequate climate control, handling or contamination[18].

A further distinction that can be made is between physical and economic losses as defined by Naziri (2014)[38]:

- **Physical loss (PL)** is something that disappears from the chain, thrown away (regardless of whether this in unavoidable or not)
- **Economic loss (EL)** is something that incurs some level of damage (e.g. partially spoiled or broken cassava root) that determines a price discount or processing into lower value product.

Additionally, these different terminologies often do not take into account what happens to the food loss or waste. For example, food that may be labelled as lost as it is not ultimately consumed by humans may in fact be consumed by animals, particularly in less developed countries. This means that some of the food loss or waste actually remains within the food chain.

The reminder of this report will use loss and waste in terms of the definitions provided by HLPE (2014).

3.2 The study

The findings draw on a literature review but more centrally from a survey of 30 experts from different geographical regions and areas of expertise to enable us to produce a more accurate picture of where food is lost in the supply chain and what measures can be implemented to reduce this loss.

In this study we have focused particularly on the loss of perishable foods, such as meat, fish, fruit, vegetables and dairy products. We have explored the entire (potential cold chain) process from harvesting or slaughtering all the way through to the point of supply to the consumer.

The first survey round asked a number of general questions as to the extent and causes of perishable food loss. The experts were then asked how food loss in the perishable supply chain could be reduced in their region and the financial costs associated with these approaches. Finally, the experts were asked to identify the possible approaches to unavoidable food loss utilisation.

One of the main findings from the first round was the significant lack of data in many areas. The experts were, therefore, asked to identify the areas most in need of new or additional data. Due to the many differences between developing and developed countries, the second round questionnaires were divided into separate surveys for either developing or developed countries.

Appendix 1 has the full list of the survey questions.

3.3 Summary

- There is some blurring of the terms for food waste and food loss in the literature.
- We make a clear distinction between food loss and food waste for this report.
- It is an important distinction to make in that the implications of focusing on reducing food loss are more apparent in developing countries whereas food waste reduction is more relevant for developed countries.
- The survey of experts helps frame this discussion of causes and possible outcomes and helps to shape the findings outlined in the rest of the report.
- The next section outlines the main causes of perishable food loss in developing and developed countries based on the survey work and literature search.

4. The causes of perishable food loss

In identifying the causes of perishable food loss it is extremely important to make a distinction between a focus on developed countries and developing countries. This is not only as factors vary but the solutions vary too so there needs to be appropriate care taken in exploring the causes. We begin with developing countries.

4.1 Developing countries

Perishable food loss in developing countries is often reported as being between 20 and 50%[12,39,40], with some studies reporting losses as high as 80%[17]. There are a number of interconnected causes of perishable food loss such as, poor harvesting practices, little or no cold chain, poor infrastructure such as bad roads or unreliable electricity and unhelpful governmental policies.

4.1.1 Harvesting practices

Many of the causes of food loss in developing countries start with poor harvesting practices. Some of the most common harvesting practices that can cause food loss include:

- **Poor harvest timing -** wrong harvesting period e.g. when it's too hot leading to dehydration, or harvesting when the crop is too ripe. It is important to harvest food at the correct time as the quality can only ever be maintained and not improved after harvest [41].
- **Poor harvesting methods** - where food is left in the field.
- **Harvesting equipment** - use of substandard or dirty equipment, for example packing fruit or vegetables into plastic bags or broken crates which lead to the produce being bruised. Dirty equipment will contaminate the food.
- **Poor hygiene** - for example the use of dirty hands when milking effects milk quality
- **Unhygienic harvesting area** - for example milking dairy animals in an open, dirty area especially when it is raining, where mud can get into the milk.
- **Poor sorting and grading methods** - perishable foods are particularly sensitive to temperatures so if exposed for long periods when sorting and grading the quality will deteriorate. Mixing high and low quality produce together will result in an overall deterioration of quality. If pests or diseases are not detected during harvesting and grading they will progressively affect quality.
- **Poor stock rotation** - failure to maintain a 'first in, first out' policy can lead to old produce going bad if it is not marketed promptly.
- **Contamination** - mixing of produce with other products or equipment/products. Various goods are sometimes mixed in the same truck without considering the effects on the produce, for example, transporting farm inputs such as fertilizer together with food to be sent to the market. The trucks are also often dirty.
- **Mechanical damage of produce -** when produce is packed into large containers resulting in the produce at the bottom of the container is crushed.

4.1.2 The cold chain

Perishable food quickly deteriorates and spoils after it has been harvested or slaughtered. The most effective way to slow down the rate of spoilage is lowering the produce temperature, for example, the same amount of deterioration can occur in one hour at 25°C as in one week at 1°C for many horticultural commodities[42]. However, in many areas of the less developed world, the cold chain is limited or does not exist[43].

Table 1 shows the impact of temperature on the storage potential of different fresh foods. These figures were derived from the general rule that most degradation processes (which lead to a loss in colour, flavour, nutrients and textural quality) double their rate for each increase of 10°C, known as the Q10 quotient[44]. Microbial growth and water loss can also be reduced by lowering the temperature at which foods are stored and transported.

Table 1. Predicted loss of storage potential increases as handling temperatures increase for fresh food commonly handled at ambient temperatures in developing countries. Adapted from Kitinoja (2013)[24].

Food product	Storage potential			
	At optimum cold temperature	Optimum temperature + 10°C	Optimum temperature + 20°C	Optimum temperature + 30°C
Fresh fish	10 days at 0°C	4-5 days at 10°C	1-2 days at 20°C	A few hours at 30°C
Milk	2 weeks at 0°C	7 days at 10°C	2-3 days at 20°C	A few hours at 30°C
Fresh green vegetables	1 month at 0°C	2 weeks at 10°C	1 week at 20°C	Less than 2 days at 30°C
Potatoes	5-10 months at 4-12°C	Less than 2 months at 22°C	Less than 1 month at 32°C	Less than 2 weeks at 42°C
Mangoes	2-3 weeks at 13°C	1 week at 23°C	4 days at 33°C	2 days at 43°C
Apples	3-6 months at -1°C	2 months at 10°C	1 month at 20°C	A few weeks at 30°C

4.1.3 Market conditions

The majority of farmers in developing countries rely on rain for production. This can lead to excess production after the rains. This applies to both horticultural produce and dairy, where there is high milk production after the rains due to increased fodder. Many horticultural products also have very short harvest seasons, for example almost all mangoes from the Ivory Coast are harvested within a 4 to 6 week period in April and May, resulting in an overabundance of the fruit, with few storage facilities available to growers. The production driven market, as opposed to market driven production, leads to considerably lower prices for farmers and high levels of loss due to the lack of cold storage.

The marketing systems are often complex and fragmented with many different stages in the supply chain. Almost 90% of horticultural transactions in India are brokered by commission agents who take a commission in the range of 2.5-6%[45]. The multiple layers of middlemen can lead to a cost inflation of over 250%[46]. The inefficiencies along the entire chain then result in high consumer prices.

Most agricultural products are traded in open-air markets, with very little cold storage, potentially exposing the products to high temperatures, causing the food to deteriorate rapidly, resulting in further losses.

4.1.4 Infrastructure

Poor infrastructure greatly hampers the movement and storage of food[47]. Poor quality roads mean that it will take far longer for fresh produce to reach markets (Figure 1), while in the rainy season roads may become impassable so the food cannot make it to market. Food is often transported in uncovered trucks so dust and smoke from the roads will affect produce quality. The food is also exposed to the sun which will lead to dehydration. Moreover, there is a greater chance of the produce being damaged on rough roads, particularly if incorrect packaging is used (for example, bags instead of plastic crates).

David Williams, Chartered Engineer, UK:
"I have visited numerous crop stores in countries including the former Soviet Union (Russian Federation, Ukraine, Kazakhstan, Kyrghyzstan, Georgia), Africa (Tanzania and Zambia), Iraq, Afghanistan and DPR Korea where a lack of reliable electrical supplies was a major limiting factor. In Southern Afghanistan, a programme in which I worked installed small scale cold storage facilities for grapes, pomegranates and vegetables. These were not successful because there was no reliable main power supply and the cost of importing diesel through a war zone to run generators increased the cost of power to unsustainable levels [for storage of primary products].

A much larger programme erected a large cold store in Kandahar with a great deal of publicity. To my knowledge it has never been used for the same reason of a lack of reliable and affordable electrical power. The military has attempted to refurbish the local hydro-electric station, but 8 years on, it still is not in action. I was hired to commission several fruit processing units in Northern Afghanistan, these also failed as none of the sites had access to either potable water or to electricity.

I visited a number of small scale food processing plants in three regions of Tanzania as part of a USAID funded study. The lack of reliable electrical power was a major problem, but so was the lack of potable water. We found that the majority of water being used for food processing was badly contaminated with all kinds of dirt and potential pathogens, meaning that even if the crop was harvested in good condition by the farms, it was badly contaminated by the processors. Unfortunately they didn't have any alternative supply."

Approximately 2.6 billion people lack access to affordable and reliable energy services[48,49]. 18% of developing Asia does not have access to electricity[50]. In many areas, processing facilities (and even state of the art equipment provided by international donors) can be idle for days due to a lack of power. In some countries, such as Kazakhstan or the DPR Korea, power is controlled by politicians and is only available in rural areas for limited periods. The cost of importing diesel or setting up hydroelectric or solar power stations in rural areas or war torn regions is often unsustainably high which results in storage facilities that have been built standing idle (See box below). Electric power is frequently even more costly in outlying provinces than in the larger cities[51].

4.1.5 Government policy

It is often the case that weakly defined or implemented regulations can impede innovation and trade. Country specific legislation can have an impact on food losses, for example, in India truck drivers have to stop at each state border to obtain approval to continue driving while there are numerous roadblocks in Uganda, lengthening journey times considerably[45]. A government imposed limit on farm size in India[52] creates difficulties in investment while restrictions on farmers selling directly to retailers cause many additional layers in the supply chain. In Kenya levies are applied per package rather than by weight which encourages the use of large bags and consequent overfilling[53].

Figure 1. A road in Liberia, Source: USAID's Food and Enterprise Development.

Figure 2. Milk being transported in Uganda. Source: Nick Morgan (Global78)

Figure 3. Wholesale fish market in Beijing. Source: Charlie Winkworth-Smith

4.2 Developed countries

Perishable food losses in the developed world are generally low due to extensive cold chains, advanced logistics and more efficient farming methods. However, out-grading, improper handling, overproduction, uncertainties in demand and breaks in the cold chain can all contribute to food losses.

4.2.1 Field losses

To ensure they do not fall foul of retailer penalties or changes in demand, growers often overproduce. It may therefore be uneconomical to harvest the extra produce resulting in it being left in the field or diverted to a secondary market such as processing or animal feed. Low market prices can similarly result in growers leaving food in the field if the costs of harvest (labour, transport etc.) cannot be recovered[29]. Fields that are left unharvested are known as "walk-bys"[54]. Disease or the increasingly variable climate may also cause field losses. In the US, approximately 7% of all planted fields go unharvested every year[55]. Exclusive contracts can also mean that growers are unable to sell excess produce to other buyers while the cost of donating the surplus food to charity food banks can be prohibitively expensive.

A study commissioned by the National Resources Defence Council (NRDC) of 16 large commercial vegetable and fruit growers and packers in the US found that in some cases, up to 30% of fields were not harvested, 1-4% of products were left in field after harvesting[54]. The authors emphasize that due to the small size of the study, the results are preliminary and anecdotal, but nevertheless it indicates that significant losses may be occurring within the industry.

4.2.2 Out-grading

The rejection of food that does not meet the required specification (out-grading), due to visual and sizing requirements demanded by consumers and retailers, is one of the major causes of food loss in developed countries[28,56,57]. In the US, out-grading can lead to losses of as much as 20-50%[29] while an NRDC report found that 2-30% of fruit and vegetables were removed during packing[54]. The retailer specifications are often inflexible and do not take into account natural variability. While the food is perfectly edible, retailers claim that consumers would be unwilling to purchase the produce.

Out-grading represents a significant aspect of food loss but is difficult to quantify as some produce that has not met certain quality criteria may enter the food processing sector while other produce may simply be left in the field[57].

Table 2 shows how much food loss occurs at each stage of the supply chain for different fruits and vegetables in the UK. On average, the levels of loss and waste are less than 10% but can be as high as 25%[58]. Grading losses are particularly high for apples, onions, potatoes and avocados. If the produce is out-graded it will often be sent to an alternative market,

sent for animal feed or be ploughed back into the field. Only a small proportion in the UK will be sent to landfill. The levels of loss and waste at retail level are much lower but the food is often sent to landfill as it is in packaging. Segregation of the food from its packaging is often needed before it can be sent for anaerobic digestion.

Table 2. Summary of resource maps detailing percentage loss and waste for eleven different fruits and vegetables through the supply chain. Source: WRAP (2011)[58].

Product	Field loss (Central range)	Grading loss	Storage loss	Packing loss	Retail waste
Strawberry	2-3%	1%	0.5%	2-3%	2-4%
Raspberry	2%	No data	No data	2-3%	2-3%
Lettuce	5-10%	No data	0.5-2%	1%	2%
Tomato	5%	7%	No data	3-5%	2.5-3%
Apple	5-25%	5-25%	3-4%	3-8%	2-3%
Onion	3-5%	9-20%	3-10%	2-3%	0.5-1%
Potato	1-2%	3-13%	3-5%	20-25%	1.5-3%
Broccoli	10%	3%	0%	0%	1.5-3%
Avocado	No data	30%	5%	3%	2.5-5%
Citrus	No data	3%	No data	0.1-0.5%	2-2.5%
Banana	No data	3%	No data	0-3%	2%

4.2.3 Uncertainties in forecasting demand

Overproduction and oversupply, caused by uncertainties in forecasting demand, is another major cause of food loss and waste in developed countries. Sudden changes, for example in the weather, can shift consumer demand. Growers, suppliers or manufacturers often overproduce due to penalty clauses that can be imposed by retailers.

Uncertainties in demand are particularly problematic for collective catering where staff are unable to know how many guests there will be each day. There is also little ability in changing portion sizes to adapt to demand.

4.2.4 Improper handling/loading/temperature

If perishable food is mishandled, for example, by using the wrong type of packaging or using the wrong temperature setting, food losses will occur downstream. A common issue seen in the reefer industry is where many different products are loaded into the same container. This can then affect the hibernation of the products during transportation if they have different respiration rates or if they are sensitive to different temperatures. Incorrect storage during transportation will limit the lifespan of the product at retail. It is therefore often difficult to quantify losses that occur during transit and they are instead attributed to retail.

Even when a cold chain is in place there may be serious temperature fluctuations if there are breaks in the cold chain[59]. Figure 4 shows the temperature of an air shipment from

Europe to the USA where, although the instructions were to keep the temperature between 2°C and 8°C it actually varied from -1°C to 26°C. With such large changes in temperature perishable food is likely to be damaged. Purfresh have estimated that 20-30% of quality losses during shipping are due improper temperature or atmosphere in the perishable cold chain[60].

Trucks that deliver to smaller retailers and foodservice operators can still be unrefrigerated. This may be due to cost factors or the belief that this 'short delivery system' doesn't have as big of an impact on loss. However, refrigeration during the 'last mile' is absolutely essential.

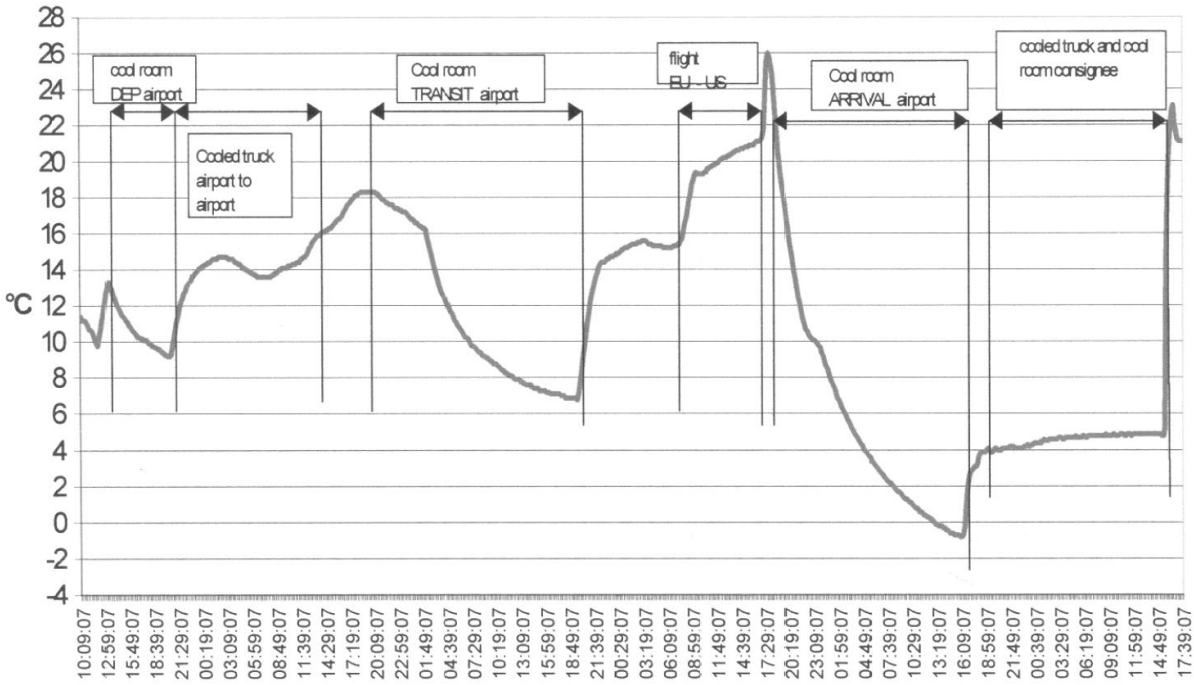

Figure 4. Temperature fluctuations in an air freight shipment with the instruction to maintain temperatures between 2°C and 8°C. From Heap (2006)[61].

4.2.5 Other causes of food loss

Food loss or waste may occur in the food production stage where there are processing errors or excessive waste from manual or automated trimming[62]. Low staffing levels or a lack of skilled employees (i.e. butchers) can lead to further loss and waste.

Retailer practices can also affect food loss, for example, when product displays are kept full resulting in produce having to be thrown out at night. There are further problems with the use of sell by dates (product quality) rather than use by dates (product safety). Products are thrown away if they are near their sell by date even if they are still perfectly edible.

Finally, there are many difficulties in donating surplus food to charity food banks due to regulations, high costs, uncertainties in terms of liability and a legislative environment in many countries that provides subsidy and support to anaerobic digestion rather than food donation.

4.3 Summary

- Table 3 summarises the major causes of food loss described above in both developing and developed countries.

Table 3. The major causes perishable of food loss.

Developing countries	Developed countries
Harvesting practices • Poor harvest timing • Poor harvesting methods where food is left in the field • Substandard harvesting equipment • Poor hygiene (e.g. dirty hands or containers) • Poor sorting • Lack of preservation techniques and technologies • Rain-fed agricultural production • A lack of knowledge about low cost post-harvest techniques that can reduce loss • Inappropriate packaging • Delays in handling • Rough handling /mechanical damage **Infrastructure** • Poor roads and transportation links • Lack of reliable energy supply **Supply chain management** • Lack of quality control in managing post-harvest collection and storage • Lack of sufficient systems controls in processing/packaging of food • Failures in operation and maintenance of storage facilities • Poor record keeping **Government and policy** • Poor regulations that impedes innovation and trade • Lack of unified and coherent national policies • Lack of market mechanisms to reward infrastructure/cold chain investments • Poor financing and Government intervention during bumper harvest and peak seasons	**Field losses** • Overproduction • Crop damage (weather/pests) **Out-grading** • Rejection of food due to aesthetic or size defects **Inconsistent cold chain** • Poor temperature management • Breaks in the cold chain **Manufacturing and processing** • Processing errors • Excessive waste from manual or automated trimming **Handling** • Improper handling • Mechanical damage **Long transportation times** **Retailer practices** • Penalty clauses levied on growers. • Exclusive contracts • Variation of purchase contract terms in last hours before supply • Poor stock rotation • Overstocked product displays • Low staffing levels **Lack of skilled employees** **Food dates** • Use of sell by dates rather than use by dates **Difficulties in donating surplus food**

- Section 7 will explore some of the ways of dealing with these various factors to help reduce perishable food loss. In the following section we explore the potential value of reducing fruit and vegetable loss in terms of both calorific and micronutrient content.

5. The potential value of reducing fruit and vegetable loss

A number of studies have looked at the effect of reducing food loss in terms of calorific content[2,13,63]. Many fruit and vegetables are relatively low in energy compared to cereals so their impact in reducing hunger is also comparatively low, indeed Munesue, *et al.* (2014) do not include them in their calculations due to their small contribution to the dietary energy supply. It is useful, however, to also consider their micronutrient content.

Micronutrient deficiencies, commonly referred to as hidden hunger, affect around 2 billion people worldwide[4,5]. Around 1.2 billion people have a weakened immune system due to zinc deficiency, 1.6 billion people suffer from anaemia caused by a lack of iron, 1.8 billion people are affected by iodine deficiency which can cause brain damage in new-borns and reduce mental capacity while 190 million pre-school age children and 19 million pregnant women are at risk of severe visual impairment or blindness due to vitamin A deficiency[64]. The predominantly cereal based diets of many in the developing world are deficient in micronutrients due to the low intake of the more expensive fruits, vegetables and foods of animal origin. A varied diet is essential to provide micronutrients[65].

Micronutrient deficiency – a definition
"A form of undernourishment that occurs when intake or absorption of vitamins and minerals is too low to sustain good health and development in children and normal physical and mental function in adults. Causes include poor diet, disease, or increased micronutrient needs not met during pregnancy and lactation." from the 2014 Global Hunger Index[64]

The Micronutrient Initiative has identified hidden hunger as "*a global problem of enormous importance that is as yet little recognised*"[66]. It also has an economic aspect, with some reports estimating that on average, a country's GDP can decrease by about 1% due to the health consequences of micronutrient deficiencies[66].

Table 4 shows a number of micronutrient indicators for China, India, Pakistan and Kenya. A government report looking at the nutrition status of Pakistan in 2011 found that the vitamin A status had deteriorated in the last decade and there had been little or no improvement in other areas linked to micronutrient deficiencies[67]. The report found that stunting, wasting and micronutrient malnutrition are endemic in Pakistan. Similarly, micronutrient deficiency in Kenya is a serious concern, with nearly three quarters of children under five suffering from anaemia while for infants less than six months old, this percentage may be as high as 99.5%[68,69]. Iron deficiency anaemia is one of the most serious public health problems in India, with an estimated 50-70% of women and children affected[70-73]. More than 70% of pre-school children consume less than half the recommended daily intake of iron or vitamin A. Despite the recent socioeconomic reforms in China, poor iron and zinc levels are still prevalent in Chinese pre-school children, with 38% having low levels of zinc[74]. Another study found that 64.6% of children under the age of 11 had insufficient zinc intake[75].

Table 4. Selected micronutrient indicators by country. Adapted from Micronutrient Initiative's global report (2009)[66].

	Proportion of pre-school age children with anaemia	Proportion of pregnant women with anaemia	Proportion of non-pregnant women with anaemia	Proportion of pre-school age children with vitamin A deficiency	Proportion of population at risk of inadequate intake of zinc
China	20.0	28.9	19.9	9.3	15.7
India	74.3	49.7	52.0	62.0	31.3
Pakistan	50.9	39.1	27.9	12.5	11.1
Kenya	69.0	55.1	46.4	84.4	32.9

There are a number of ways to combat hidden hunger, such as food fortification, where essential vitamins and minerals are added to foods such as flour or salt, and supplementation, where vulnerable groups are provided with vitamin and mineral tablets, capsules or syrups[66]. Increasing the consumption of fruits and vegetables is perhaps one of the most important ways of addressing hidden hunger.

Affognon, *et al.* (2015) have recently conducted a meta-analysis of the amount of food loss in Sub Saharan Africa[76]. They found that fruit and vegetable loss was 55.9 ± 25.4% and 43.5% ± 16.6% respectively, without any intervention. With the adoption of various interventions such as improved handling, new storage structures, processing or chemical treatments, the postharvest losses were found to reduce to 24.8 ± 15.6% and 10.7 ± 13.8% for fruits and vegetables respectively. The use of interventions was, therefore, able to lead to loss reductions of 56% and 75%. Whilst it must be noted that these figures are for Sub Saharan Africa where the levels of food loss are particularly high, they nonetheless show that large reductions in postharvest losses of fruits and vegetables are possible.

By weight, fruit and vegetables have the highest levels of loss and waste globally at 44% of the total, yet account for just 13% of total loss and waste in terms of energy content[2]. It is useful to explore the micronutrient content of fruit and vegetables to better understand the implications of reducing food loss.

5.1 Method

We have investigated the micronutrient content of 46 types of fruits and vegetables, using the 2012 production figures from FAOSTAT, to assess the value of reducing fruit and vegetable loss in China, India, Pakistan and Kenya.

There are a number of different estimates as to the scale of fruit and vegetable loss, for example, estimates vary from: 10-30%[77-79] in China; 10-50%[22,80-82] in India; 15-40%[22,83,84] in Pakistan; 20-50%[85,86] in Kenya.

Our aim with these calculations is to estimate the potential amount of energy or micronutrients that could be saved if fruit and vegetable loss is reduced. Owing to the difficulties in estimating the total levels of loss that could potentially be reduced, because of the number of varied ways this could be achieved, we have based our calculations on the assumption that fruit and vegetable loss could be reduced by at least a quarter (25%) in the countries we have investigated, with the use of appropriate interventions.

Due to the broad range of estimates of loss in the literature, for this study, an upper limit of 30% loss and a lower limit of 10% loss per annum have been used, so in other words we have calculated the calorific or micronutrient value of 7.5% or 2.5% of the total fruit and vegetable production of China, India, Pakistan and Kenya.

Unavoidable waste, such as peel, stalks or outer leaves has been accounted for by assuming that 30% of the produce weight has zero nutritional value. For example, while production figures will include the whole weight of a banana (i.e. peel and flesh), we have estimated that the peel (unavoidable waste) is 30% of the weight. This is a very broad assumption as the unavoidable waste fraction for each fruit or vegetable will be different.

In order to present the data in relatable terms, the total calorific and micronutrient content that could be saved has been has been converted into the total number of people that could have sufficient intake of calories or nutrients from the fruits and vegetables that are saved by reducing loss by 25%. The average nutrient requirement is based on that of an adult male aged 19-30 years old for a year. This clearly then does not take into account the different dietary requirement for different age groups or genders and particularly pregnant women. Further, people's diets obviously include other food types such as cereals.

A number of other broad assumptions have also had to be made:

- The calorific and micronutrient content of raw fruits or vegetables are used (from the USDA Nutrient database)
- Calories are directly related to the number of people that can be fed
- The average calories needed per person are 2100 kcal
- Protein deficiency is not taken into account[87]
- Changes in food prices are not taken into account

The figures presented here are therefore somewhat abstract and should be read with caution, but we hope they demonstrate the importance of reducing fruit and vegetable food loss.

Please see Appendix 2 for a full list of the fruits and vegetables analysed as well as an example calculation.

5.2 Results and discussion

The values presented in Table 5 show the potential amount of food that could be saved if fruit and vegetable loss was reduced by 25%. Due to the uncertainties in the actual amount of food loss in each country analysed, we have estimated a relatively broad range of loss, from 10% to 30%. The figures calculated show that even at the lowest level of loss, the total amount of fruits of vegetables that could be saved in China, India, Pakistan and Kenya, if loss was reduced by 25%, may be 17 million tonnes a year, while at the upper limit of loss this value could be as high as 53 million tonnes. To put this in perspective, the total European consumption of fresh fruit in 2011 was just over 50 million tonnes while the total fresh vegetables consumption was about 60 million tonnes[88].

Table 5. The potential amount of food, by weight, or calorie and nutrient intake that could be saved if fruit and vegetable loss was reduced by a quarter, for a lower limit of loss of 10% and an upper limit of loss of 30%.

	Weight of food (million tonnes)	Sufficient intake for an adult male (aged 19-30) for a year, based on recommended daily allowances (millions of people)			
		Calories	Iron	Zinc	Vitamin A
China	13-40	4.7-14	17-50	5.5-16	20-60
India	3.8-11	2.3-6.8	5.1-15	2.3-7.0	2.8-8.3
Pakistan	0.25-0.77	0.16-0.48	0.26-0.77	0.11-0.33	0.33-0.99
Kenya	0.17-0.52	0.10-0.29	0.14-0.41	0.06-0.17	0.16-0.49

Figure 5 shows the potential amount of calories or selected micronutrients that could be saved by reducing fruit and vegetable loss by up to 25%. The data for Pakistan and Kenya are not shown due to their much smaller values. In order to present the data in more relatable terms, Figure 6 converts the number of calories or micronutrients that could be saved into the number of people that would be able to fulfil their average daily recommended intake for a year. As these figures are calculated using the recommended daily intake for an adult male (aged 19-30), the values would be likely to change somewhat if corrected for each country's demographics. The results are also calculated using the calorific or micronutrient content of raw fruits and vegetables. Cooking and processing the produce would, therefore, considerably alter the levels of micronutrients, but due to the many ways fruit and vegetables are processed (if at all) before consumption, estimating these differences would present considerable difficulties.

It is interesting to compare the calorific and micronutrient contents of fruit and vegetables. The total calorific content that could potentially be saved if loss was reduced by a quarter in the four countries we have investigated would be the equivalent of enough energy for between 7-22 million people for a year. This figure is considerably lower when compared to

the benefits of the micronutrient content of the fruit and vegetables, having the equivalent iron content for 22-66 million people and vitamin A content for 23-70 million people.

As will be described in Section 7, there are a number of approaches that will help reduce perishable food loss such as better packaging, processing and farming practices, implementing or improving the cold chain, upgrading infrastructure, utilising new information technologies, increased access to credit, better regulations and education, as well as country specific measures described in Sections 11, 12, 13 and 14.

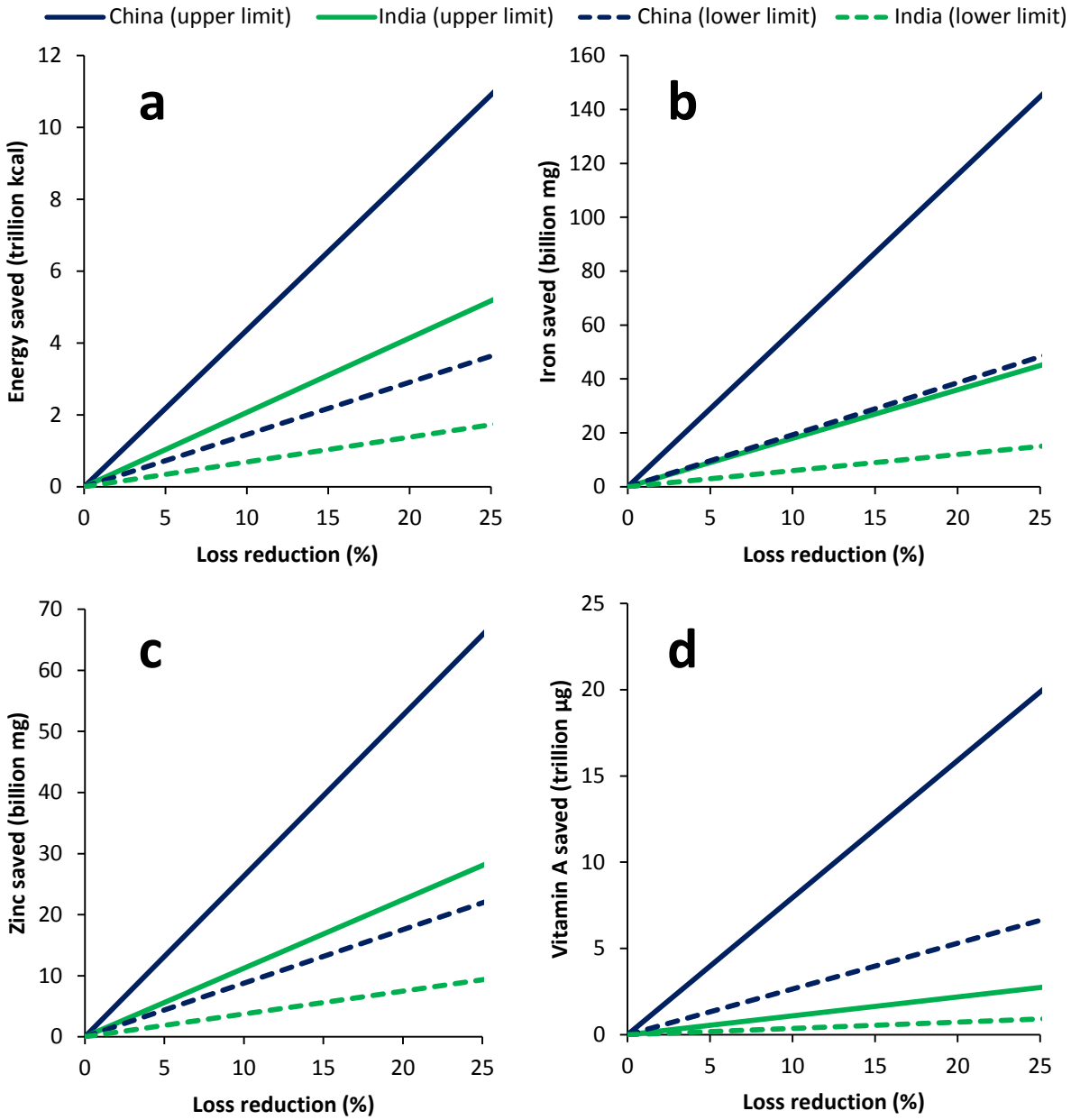

Figure 5. The potential value of reducing fruit and vegetable loss in China (blue) and India (green) in terms of (a) energy (b) iron) (c) zinc and (d) vitamin A. Solid lines represent the upper limits of loss of 30% and the dotted lines represent the lower limits of loss of 10%. The data for Pakistan and Kenya are not shown due to their much smaller values.

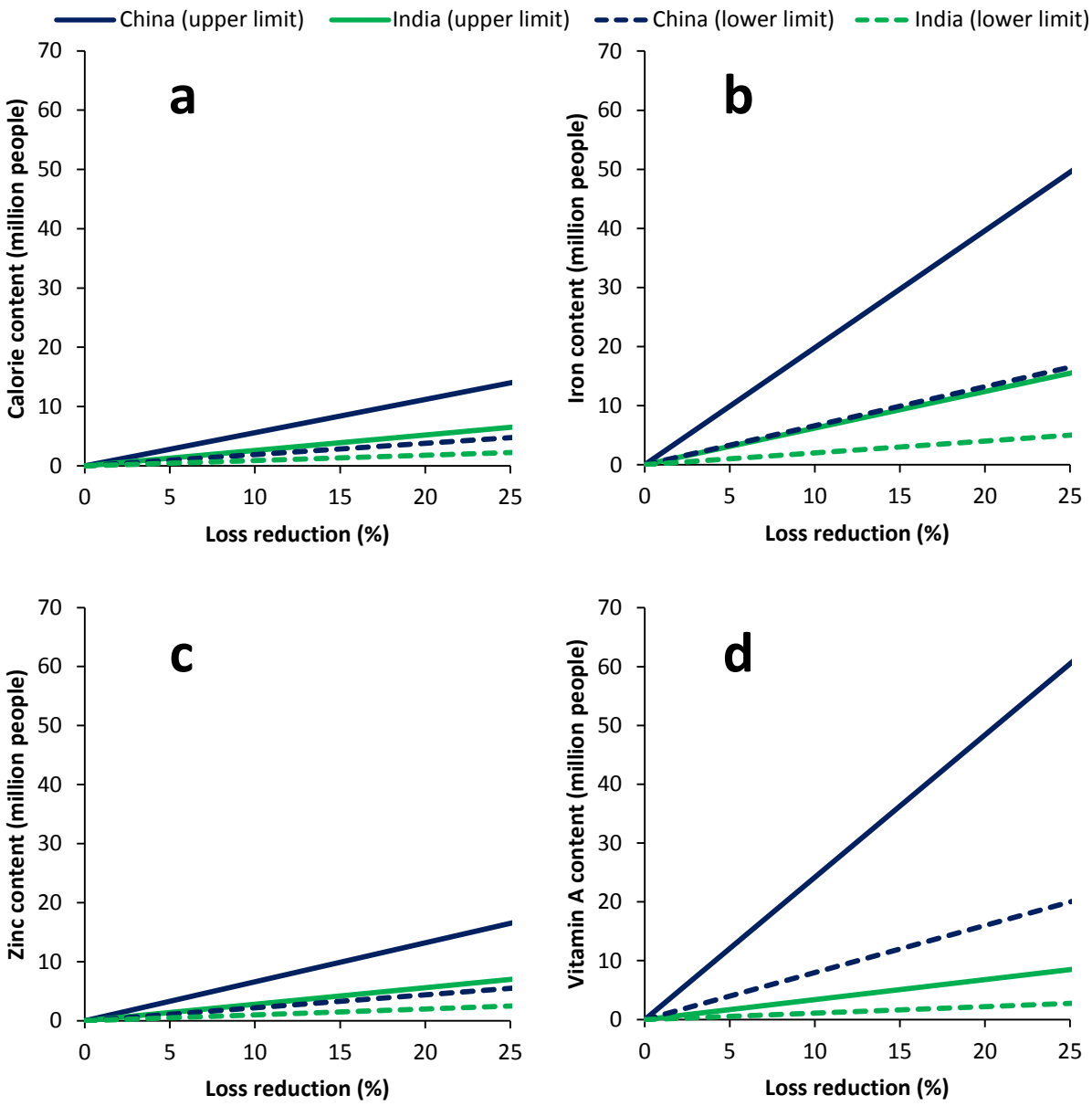

Figure 6. The potential value of reducing fruit and vegetable loss in China (blue) and India (green) in terms of sufficient (a) energy (b) iron) (c) zinc or (d) vitamin A to meet the average daily requirements for adult males (aged 19-30). Solid lines represent the upper limits of loss of 30% and the dotted lines represent the lower limit of 10%. The data for Pakistan and Kenya are not shown due to their much smaller values.

From these simple calculations we hope to have shown that it is useful to think about the micronutrient content of food, and in particular fruit and vegetables. This highlights the pressing need to reduce global perishable food loss. As section 7 will show, one aspect associated with this is the role of better cold chain function and management, but this is only one part of a wider group of factors that need considering.

Further work needs to be done to assess the potential micronutrient value of other types of perishable foods such as meat, fish or dairy loss.

5.3 Summary

- Focussing simply on energy gain from reducing food loss can mask the issue of low micronutrient levels in the food consumed by poorer people.
- Reducing food loss in key food groups, notably fruit and vegetables can help provide significant improvement in micronutrient availability for consumers.
- If food loss was reduced by 25% in the four countries studied, the benefits of the micronutrient content of the fruit and vegetables would provide the equivalent iron content for up to 66 million people and vitamin A content for up to 70 million people. This highlights the pressing need to reduce global perishable food loss.
- What though are the consequences for reducing such loss? The next section briefly examines some implications.

6. Implications of reducing food loss and waste

By 2050, the global population will reach 9 billion. If current levels of food loss and waste are maintained, food production will need to increase by as much as 70% in developing countries, requiring investment of $83 billion a year[1]. Reducing the levels of loss and waste will have a large impact on food security, rural income and the environment.

6.1 Increased food availability

Reducing the levels of food loss and waste should lower the levels of global food insecurity, particularly in the less developed world where the majority of undernourished people live. Kummu, *et al.* (2012) have estimated that if the current minimum loss and waste percentages in each food supply chain step were applied globally there would be enough food to feed one billion people[13]. Lipinski, *et al.* (2013) have estimated that by reducing loss and waste from 24% currently to 12%, by 2050 the world would need 1,314 trillion kcal less food per year[2].

Munesue, *et al.* (2014) have calculated that by reducing the levels of food loss and waste by up to 50% in developed regions, the number of undernourished people would decrease by up to 63.3 million in developing regions (7.4% of undernourished people in 2007), with 25.8 million in Southeast Asia, 20.5 million in Eastern Asia and 10.6 million in Sub-Saharan Africa[63]. There would also be a decrease in the harvested area, water utilisation and greenhouse gas emissions associated with food production. Reducing loss and waste in the developed would also help combat hunger in developed countries. The Natural Resources Defence Council (NRDC) has estimated that if food losses could be decreased by 15% there would be enough food to feed up to 25 million Americans each year[29].

Reducing perishable food loss and waste will increase the availability of fruits, vegetables, meat, dairy and seafood. More dietary variables will help to combat micronutrient deficiencies (hidden hunger).

6.2 Food safety

Reducing food loss and waste will be achieved in some part better hygiene, handling and refrigeration. Biosensors and trackers will also enable awareness of food safety issues. This should help improve food safety and limit the number of food-borne diseases.

6.3 Food prices

The economic retail value of food loss and waste is estimated to be about US$ 1 trillion, equivalent to twice the GDP of Norway[89]. Food loss is estimated to reduce income for 470 million smallholder farmers and 290 million other downstream agricultural workers by at least 15%[1,12].

If food losses are substantially reduced there will be a knock on effect to food commodity prices. Munesue, *et al.* (2014) analysed 30 different commodities and found that if there was a 50% reduction in food losses in developed regions, all international prices would decrease[63]. This would result in an increase in the purchasing power of the poor in developing countries and therefore food consumption in the less developed world would increase. There would however be problems for agricultural producers in developing countries.

Lower food prices caused by loss reduction may negatively affect farmers in developing countries; however, improving food quality through correct handling and storage should help increase the prices farmers are able to get for their produce, especially if the food is of export quality.

Investment in cold storage could bring a long term benefit to smallholder farmers. The ability to store food rather than having to sell their produce immediately will mean that the farmers could avoid selling their food at lower prices when there is a glut in the market. Apps that are currently being developed will give farmers more information on food prices which will allow them to make far more informed decisions as to when they sell their produce. This could help counter the high levels of price fluctuations that are so deleterious to smallholder farmers[90].

Clearly there is no way to completely stop price fluctuations due to seasonality, disease or bad weather but reducing food loss would to some degree help stabilise prices. Reducing price shocks with better harvesting practices, handling and storage would help farmers obtain credit as they have more predictable incomes. This should then increase their investment in further storage options, thus producing a virtuous cycle.

6.4 Environment

Food loss and waste contribute to greenhouse gas emissions by both the decomposition of wasted food in landfill and even more importantly the embedded emissions associated with its production, processing, transport and retailing[91,92]. The 3.3 billion tonnes of CO_2e attributed to food loss and waste places it as the third largest emitter of greenhouse gases after China and the US[93]. Agriculture represents the largest human use of water[94] and the global footprint of wasted water is about 250 km^3. The land required to produce all the uneaten food is estimated to be as much as 1.4 billion hectares (3.45 billion acres), or 30% of the world's agricultural land area. Reducing food loss and waste would have an enormously positive effect on the environment.

Monier (2011) has estimated that the EU generates around 90 million tonnes of food waste each year, which can be broken down into manufacturing (39%), food service/catering (14%), retail/wholesale (5%) and households (42%)[95]. Using a life cycle analysis the average total emissions of each tonne was estimated to be at least 1.9 tonnes CO_2e (with the household sector presenting the most significant impact at 2.07 tonnes CO_2e per tonne of

food waste). The overall environmental impact was calculated to be at least 170 million tonnes of CO_2e and approximately 3% of total EU27 emissions in 2008. By 2020, due to population growth, food waste has been forecast to rise to as much as 126 million tonnes which would increase the related emissions to about 240 million tonnes by 2020[95].

The US Environmental Protection Agency has created a Waste Reduction Model (WARM) that helps organisations track greenhouse gas[96]. This enables companies to compare their emissions using different waste management practices such as source reduction, recycling, combustion, composting and landfilling.

Dr Raymond Anthony, University of Alaska Anchorage
"For a large segment of the population in the United States, the urgency of the problem goes unappreciated, especially the long term environmental impact of food loss and waste on future generations – awareness needs to be raised."

6.5 Summary

- Reducing food loss can have significant effects on other aspects of the global economy.
- Interventions to store and handle food more effectively to reduce loss can also raise standards of hygiene and thus food safety.
- Unintended consequences may be seen in the price of food in local markets as more supply could drive down prices received by producers. Equally, better storage could help spread income flows over a longer period thus ameliorating the very spiky nature of income presently when entire crops must be sold immediately.
- Current loss and waste creates greenhouse gases and thus reducing loss would appear to be helpful in reducing such emissions. However, the development of new cold chain solutions might add to emissions where no cold chain currently exists.

7. Approaches to reducing food loss

Affognon, *et al.* (2015) conducted a meta-analysis of all the data available on post-harvest losses of food in Sub-Saharan Africa from both the grey literature and journal articles[76]. As Table 6 shows, food loss can be significantly reduced if interventions are introduced. Perishable food loss can be drastically reduced, often with simple interventions and better education. In this section we have identified a number of approaches to reducing food loss, such as better harvesting practices, better packaging, processing, the adoption of a cold chain and perhaps the most important part of any intervention, appropriate education and training. Whilst many of these changes can happen at farm or retail level, a number of other changes such as improved infrastructure, better regulations and access to credit will require changes to government policy or large scale private sector investment.

Table 6. Food losses in Sub-Saharan Africa. Source: Affognon, *et al.* (2015)[76].

	Without any intervention	With intervention
Cereals	**25.6 ± 27.4%**	**5.6 ± 5.4%**
Pulses	**23.5 ± 22.0%**	**2.1 ± 3.0%**
Roots and tubers	**43.7 ± 27.4%**	**7.0 ± 2.8%**
Fruits	**55.9 ± 25.4%**	**24.8 ± 15.6%**
Vegetables	**43.5 ± 16.6%**	**10.7 ± 13.8%**
Fish	**27.3 ± 14.3%**	**14.7 ± 11.9%**

7.1 Smallholder commercialisation

A number of the harvesting practices mentioned in Section 4.1.1 will be improved with better education, for example, better hygiene or harvesting crops at the optimum time. However, the lack of access to credit means that many farmers are unable to buy the equipment, irrigation or storage facilities needed to significantly reduce postharvest loss.

72% of the 570 million farms worldwide are less than one hectare and only 6% are larger than 5 hectares. In South Asia 80% of the 125 million farm holdings have an average size of 0.6 hectares[97]. By comparison, in high income countries, 97% of the farms are over 5 hectares in size[98]. Agriculture in many parts of the developing world is based on semi-subsistence smallholder farming. Farmers have little disposable income from which they can invest in better equipment, fertilizer or crop varieties and due to a lack of connectivity they are unable to reach more lucrative markets, such as export markets.

There are some advantages in smaller farms with manual harvesting, for example, little is left in the fields due to poor villagers scavenging the leftovers or the food is diverted to sub-value chains. In larger mechanised farms more food is likely to be left in the fields. However, it is often not economically viable to purchase farm machinery or storage facilities for small

holder farmers. Substandard harvesting equipment can lead to crops being damaged by rough handling.

By commercialising smallholder farming, farmers will be able to generate larger revenues by specialising in particular crops or livestock which will earn them a larger income[99]. They will then be able to reinvest and improve the productivity of their farms (See Box).

Smallholder commercialisation, as defined by Jayne, *et al.* (2011)[100] refers to:
"a virtuous cycle in which farmers intensify their use of productivity-enhancing technologies on their farms, achieve greater output per unit of land and labour expended, produce greater farm surpluses (or transition from deficit to surplus producers), expand their participation in markets, and ultimately raise their incomes and living standards."

However, it is important that commercialisation is achieved in a sustainable way where there is 'inclusive agricultural development'. For example, in some cases poor households are forced to sell produce when they are desperate for cash, only to buy back food later in the season when prices are higher[100]. By specialising, smallholder farmers will also become more dependent on the market than subsistence oriented households, exposing them to fluctuations in market prices[101] so it is vital that they have access to market information, particularly via new mobile platforms (See Section 7.6.2).

Contract farming, where retailers or wholesalers sign contracts with farmers to grow specific crops and guarantee to buy the produce at a pre-agreed price allows much greater predictability so that farmers are better able to get access to credit. Contract farming will also ensure there is market driven production which will help avoid losses.

7.2 Better packaging

7.2.1 Returnable plastic crates

Food loss can be reduced significantly by making changes to the type of packaging that food is stored and transported in. Currently, many fruits and vegetables are over packed, (for example large wooden crates with as much as 50-60 kg of tomatoes have been used in Ghana[102]) which can result in the food being crushed. Returnable plastic crates (RPCs) are an attractive alternative to wooden crates or plastic bags.

The solid RPCs better protect food when it is transported on rough roads, with studies showing a reduction in loss of mangoes and avocados from 30% to 6%[103], while a further report showed that losses of tomatoes in Afghanistan were reduced from 50% during transport to just 5% with the use of RCPs[104]. The costs of RPCs are often much less than the savings that can be made by reducing food loss and many countries (for example India, Sri Lanka and Afghanistan) now offer subsidies to enable the purchase of RPCs. The benefits of

RPCs are explained in detail by Kitinoja (2013)[102] as well as a report by the World Packaging Association (WPO) and the International Packaging Press Organisation (IPPO) in 2009[105]. The Postharvest Education Foundation also offers a cost and benefit calculator[102].

7.2.2 Modified atmosphere/active packaging

Advanced packaging such as modified atmosphere packaging (MAP) will help increase the shelf life of many perishable foods by limiting their exposure to oxygen and water vapour and so limit oxidation and water activity[106]. Active packaging can also allow the controlled release of molecules[107]. Mathematical prediction modelling can now be used to correlate respiration rates of produce with the permeability properties of the packaging films in order to avoid anaerobic conditions which can lead to fermentation[108].

MAP has been shown to delay fruit ripening and markedly reduce weight loss[109]. Currently there is little use of modified or controlled atmosphere packaging in less developed countries due to cost and the need for a reliable cold chain[110].

7.2.3 Smart packaging

An alternative to use by dates may be smart packaging which will inform the consumer when the food is no longer safe to eat[111,112]. For example, miniature gel sensors have recently been developed to change colour at the same rate that milk goes off and costs just a fraction of a cent[113]. The gels are designed to change colour from red to green which corresponds to the rate of *E coli* growth or can be modified to monitor the growth rate of other pathogens. Other smart packaging materials include 'intelligent plastics' which change colour when oxygen has entered a pack, which will help indicate if a modified atmosphere package (MAP) has been damaged. This technology has been further adapted to make oxygen sensitive, solvent based inks[114]. New nanomaterials and nano-based antimicrobials are also likely to have a big impact on food sustainability[115].

7.2.4 Edible coatings

Edible coatings such as gum Arabic, alginate or chitosan slow down ripening by inhibiting the migration of moisture, oxygen, carbon dioxide or aroma compounds, even at ambient temperature[116]. For example, using 10% gum Arabic as an edible coating, the ripening process of tomatoes can be delayed and the antioxidants can be preserved for up to 20 days during storage at 20^{o}C without any negative effects on postharvest quality[117]. It is important to also include an antimicrobial agent to reduce the level of spoilage.

Edible coatings therefore provide an attractive alternative to the far more expensive controlled atmosphere or hypobaric storage techniques.

7.3 Improving the cold chain

Investment in the cold chain and its expansion will help significantly reduce perishable food loss in developing countries[24]. At present this presents numerous difficulties due to the highly fragmented nature of the cold chain in many countries. Relaxing investment restrictions or the creation of national champions or organisations that bring together the different players in the supply chain would help enormously. Better collaborations among firms involved in the cold chain is needed to enhance efficiency and responsiveness[118].

7.3.1 Pre-cooling

Pre-cooling is one of the most cost effective and efficient ways of preserving produce quality. The respiration rate of fruit and vegetables increases approximately 2 to 3 fold for every 10^{o}C rise[119]. After harvesting, the rate of transpiration (the process by which heat is dissipated) is dramatically reduced so heat from respiration accumulates rapidly[120]. Highly perishable produce will deteriorate within hours of harvest if not cooled, for example, every hour of delay in cooling strawberries harvested at 30^{o}C will result in a 10% loss in shelf life[42]. It is vital therefore that produce is cooled as quickly as possible after harvest. Even by just putting crops under shade immediately after harvest will help prevent moisture loss, lower the temperature and maintain quality for far longer than if the produce is left out in the sun.

Pre-cooling is required for all perishable foods before transport or storage as most refrigerated trucks or storage rooms have neither the refrigeration capacity nor air movement capability needed to rapidly cool produce straight from harvest[41]. Pre-cooling is particularly important for crops with high respiration rates such as peas, asparagus or broccoli. There are a number of different pre-cooling options, depending on the type of product and their sensitivity to chilling or moisture, such as hydro-cooling, forced air pre-cooling, vacuum cooling or simply packing in ice[121,122].

7.3.2 Cold storage and transportation

In areas with little access to electricity, evaporative coolers are an affordable way of prolonging the shelf life of tropical fruits and vegetables[123]. They are constructed by placing a vessel containing the food inside a larger vessel. Water is poured into the gap between the vessels and as the water evaporates, the inner vessel is cooled to a temperature significantly lower than ambient temperature. In Nigeria, simple evaporative coolers, using wet sand between two clay containers, can be constructed for less than US$ 2 and are able to preserve tomatoes and guavas for up to 20 days which would have otherwise had a storage life of just two days at ambient temperature[2]. In Cambodia and Lao, simple brick walled evaporative coolers with moistened sawdust or sand have been found to decrease the storage temperature by 1-10^{o}C lower than ambient while increasing the relative humidity by 10-35%, reducing weight loss considerably[124,125]. Forced ventilation evaporative cooling systems are more advanced and require extra investment than simple pots but are considerably cheaper than mechanical compression refrigeration systems as they require a

low initial investment and low installation and maintenance costs so are attractive for small scale farmers or retailers[126].

A cost effective alternative to buying commercial cold storage units is through the use of CoolBots which adapt window style air conditioning units into cooling units. The full CoolBot system (CoolBot controller, air conditioner, insulated room and electricity) costs about US$2,000-3,000 which is less than half that of commercial cold storage units. USDA Porta-Coolers, portable forced air cool rooms, cost approximately US$ 1,200 or less if using a used air conditioning unit[127]. If temperatures of below 15^{o}C are required then CoolBots can be installed on the units.

For larger farms, reefer technology is a relatively inexpensive solution as a 40 foot reefer container can be placed on the field during harvest.

Currently much of the food in developing countries is transported in open back trucks. Ideally, reefer trucks should be used to transport produce from farm to market and so small reefer vans could potentially benefit small farmers.

Joan Rosen from JC Rosen Resources, USA:
"Trucks that deliver to smaller retailers and foodservice operators can still be unrefrigerated. This may be due to cost factors or the belief that this 'short delivery system' doesn't have as big of an impact on loss. Better understanding of this latter part of the supply chain and its needs, as well as education, could benefit temperature management and help cut food losses."

7.3.3 Cold chain technology

As much as 15% of the total electricity produced worldwide is used for refrigeration and air conditioning[128]. With the increased need for refrigeration, there is a real risk of hugely increased carbon emissions if traditional fossil fuel powered cooling systems are used. Liquid air or liquid nitrogen cooling units have huge potential as a more sustainable solution. Surplus liquid nitrogen, a by-product of liquid oxygen production, is available in most developing countries. An in depth insight into this technology is given in "A tank of cold" by IMechE [129]. Carbon dioxide (CO_2), a by-product from many industrial processes is one of the most promising refrigerants due to its excellent thermodynamic and transport properties[130]. With the lowest Global Warming Potential (one) of any natural refrigerant, CO_2 refrigeration systems are both energy efficient and environmentally sustainable.

Areas with the greatest need for refrigeration have the greatest potential for solar energy. Solar refrigeration therefore may be a solution for rural areas with little access to mains electricity as well as an alternative to fossil fuel powered refrigeration systems[131]. Cooling can be achieved either with the use of photovoltaic (PV) panels which produce electricity to power conventional refrigeration systems, or using the more efficient solar thermal refrigeration where the refrigerant is directly heated by a solar collector[132]. Solar PV is the

fastest growing energy technology, with production doubling every 2 years and costs continually lowering[133,134]. Combined solar/biomass generators for refrigeration units may be a cheaper alternative.

Advances in refrigeration technologies will lower the energy consumption and greenhouse gas emissions associated with the cold chain. Perhaps one of the technologies with the greatest potential for this will be the recovery of thermal energy from engine exhausts which will be used to drive sorption systems, thermoacoustic refrigerators and for power generation using thermoelectrics or turbogenerators[135].

Superchilling food, whereby a minor part of the water in the product is frozen, enables a much faster chilling process[136]. The small amount of ice also acts as a heat sink to absorb heat from the surrounding environment without greatly altering the product temperature. The shelf life of superchilled food can be prolonged by at least 1.4-4 times compared to traditional chilling[137]. There are, however, some issues in microstructural changes to food tissue due to ice crystal formation so superchilling may only be appropriate for certain types of food.

7.3.4 Cold chain management

Management of the cold chain must also be improved, which can be achieved to some degree by modelling food degradation[138]. Raab, *et al.* (2008) have produced a generic model to predict the remaining shelf life of meat in different steps of the supply chain[139] while Rong, *et al.* (2011) have provided a mixed-integer linear programming model focused on product quality with is strongly related to temperature throughout the supply chains which will help support decision making[140].

Other models have been produced which also include the discarding costs associated with the disposal of spoiled food products[141] or models based on the advancement of a Multi-Temperature Joint Distribution System (MTJD)[142]. Montanari (2008) compared two different cold chain management system approaches to choose the most cost effective logistics configuration[143].

Joshi, *et al.* (2011) have developed a benchmarking framework which will help companies evaluate their cold chain performance using a Delphi-AHP-TOPSIS based methodology[144]. This will enable companies to identify their strengths and weaknesses and ways to potentially improvement performance. Another recent cold chain benchmarking model has also been developed by Shabani, *et al.* (2012)[145]

7.4 Improved infrastructure

Large scale investment is needed in many developing countries to improve road and rail networks as well as energy supplies[47], for example, in 2010, the Asia Pacific region's share of

world energy consumption was a third but is estimated to rise to between 51-56% by 2035[50,134]. A report by the Asian Development Bank in 2009 estimated that between 2010 and 2020, approximated US$ 8 trillion is needed in overall national infrastructure investment in member countries, with US$ 4.1 trillion in energy and US$ 2.5 trillion in transport infrastructure. McKinsey have estimated that US$ 1 trillion of this investment could be open to private investors under public private partnerships (PPPs), particularly in India, Indonesia, Thailand, Vietnam and the Philippines[146]. In October 2014, the Asian Infrastructure Investment Bank was launched which currently includes 21 countries, and is backed by paid up capital of US$ 50 billion [147].

Transnational infrastructure projects are underway in some regions, for example, the ASEAN (Association of Southeast Asian Nations) Highway Network will improve road links between seven ASEAN countries (Singapore, Malaysia, Thailand, Cambodia, Vietnam, Myanmar and Lao) to China. The ASEAN economic area requires US$ 60 billion in annual investments for critical infrastructure. The ASEAN Infrastructure Fund, established by the Asian Development Bank, has been set up to boost investment in the region's infrastructure[148]. It will provide loans about US$ 300 million a year to finance infrastructure projects.

The Economic Commission for Latin America and the Caribbean (ECLAC) has recently drawn attention to the infrastructure gap in the region[149]. Only a third of roads in most Latin American countries are in good condition, except Argentina (80%) and Guatemala (75%)[150]. Rural roads are in particularly bad condition, especially in Peru and Ecuador. Most of the countries in the region have low rankings in the World Economic Forum's 2013 Global Competitiveness Report, largely due to the region's infrastructure deficit. ECLAC has estimated that, between 2006 and 2020, the region needs to invest at least 7.9% of annual GDP to close the gap with industrialised East Asian countries[149]. The cold chain sector has grown rapidly in South America over the last two decades. It accounts for 30% of global reefer exports, which equated to 30 million tons of perishable goods in 2011[151]. Reefer capacity has increased by 200% between 2000 and 2012[151].

7.4.1 Small scale infrastructure

Small scale infrastructure projects (i.e. projects that require less than US$ 30 million in capital expenditure) such as rural roads, small scale processing facilities or small scale power generators are vital yet there are often many difficulties in the provision of funding. The responsibility of implementing these projects is regularly down to local governments which have scarce resources and little access to international development money (which instead goes directly to central government), or the private sector which may be unwilling to fund the projects due to the high commercial risks[152].

Pension funds in developing countries, which have grown from an estimated US$ 422 billion in 2001 to US$ 1.4 trillion in 2010[153], are growing rapidly in part due to the young populations of most of these countries. The long term nature of pension funds make them

ideally placed to invest in local infrastructure. Other institutional investors such as insurance companies or mutual funds may also benefit from the long term returns of small scale infrastructure investment which would help develop their local economy.

Bond, *et al.* (2012) have proposed a pooled financing approach for small rural infrastructure[152]. This was first developed by the United Nations Capital Development Fund's 'Local Finance Initiative' in partnership with the Global Clearinghouse for Development Finance in 2009. With risk mitigation tools and technical assistance, pooled finance will incentivise the private sector over the long term. Local government expertise would then identify the most important and economically viable infrastructure projects but would not be burdened with municipal debt.

7.5 Processing

Fruits and vegetables that are unmarketable as they do not meet product specifications or are physically damaged but still edible can be processed into value added products such as juices, jams, jellies or dehydrated products[154]. This will increase their shelf-life by denaturing enzymes and killing microorganisms. Processing will also provide an alternative route when market prices for the raw commodities are low due to seasonal gluts. The United Nations Industrial Development Organisation (UNIDO) has published a technology manual which gives detailed methods, equipment needs and quality assurance practices for small-scale fruit and vegetable processing[155].

The demand for fruit and vegetable juice beverages has been increasing in recent years. Between 2003 and 2009 the global volume of fruit based beverages consumed increased by 30.2%, with much of the growth from increased consumption in lower social classes in emerging countries[156]. This presents an opportunity for the use of fruits and vegetables that would have otherwise been lost due to a lack of storage for the raw produce, especially for the more lucrative export market. Most fruit juices have a high acidity as well as natural antioxidant and antimicrobial properties so can be stored for long periods of time (months) at room temperature, especially if blended which highly acidic fruits such as lemons or limes[157]. Small scale juicing can be done on farm or in larger processing plants.

Sammy Kariuki from Tymax Agribusiness Solutions Limited, Kenya:
"*A lot of excess produce goes to waste in times of excesses. There is a need to enhance value addition, for example, processing excess fruits, freezing vegetables such as garden peas and making powdered milk during peak and glut periods.*

However, there is also a need to improve varieties to ensure they can be easily processed. In addition, since most of the growers are small scale, there will be a requirement to organise the farmers into farmer groups/production organisations to ensure consistent production that will motivate investors to build processing factories."

Modern processing techniques, with an emphasis on safety, stability, quality and energy efficiency include microwave heating, radio frequency heating, infrared heating, Ohmic heating, refractance window drying, high pressure processing, pulse electric field treatment, high intensity pulse light treatment, irradiation, ultrasonication, quality monitoring by near-infrared spectroscopy and hurdle technology[158].

7.6 Information technology

7.6.1 Sensors and trackers

Many temperature tracking systems make the receiver aware that there was an issue in the past, but they do not necessarily provide real-time communication about issues or the ability to fix the situation. In-transit temperature monitoring is essential for aggregating data and analysing to spot trends before they become problems; coupled with a real-time monitoring system delivers just-in-time corrective actions. This could be aided with improved and active alarm/communications systems to notify operators when there is a break in the cold chain. Temperature tracking will also help give operators a better understanding of temperature abuse during the "in between" steps of the supply chain (e.g. pallets waiting to be loaded into a container, waiting to go into a warehouse, store, etc.).

Sensors have been used to measure the heat distribution in a container of bananas (which produce large amounts of heat through respiration) transported from Central America to Europe. Through data aggregation, the results showed that less than 10% of the available cooling capacity of the unit actually arrived at the bananas in the centre of a pallet load. The cooling efficiency could be improved by 50% with better packing and loading schemes[165].

Radio Frequency IDentification (RFID) tags use a wireless microchip and an antenna so there is no need for physical contact or sight positioning with the reader. This has obvious benefits when compared to barcodes as the reading phase will be automated and thus much faster. RFID smart tags are being developed which have temperature and relative humidity sensing capabilities. Abad, *et al.* (2009) validated a RFID smart tag along an intercontinental fresh fish logistic cold chain[159]. The data could be read at any time without opening the fish boxes and provided real-time traceability. This will allow much better safety and quality control along the entire cold chain. Other RFID tags can sense concentrations of gasses such as acetaldehyde or ethylene[160], shock or vibration[161] pH[162] or light[163]. Much of the research, however, has been over the time period of days or weeks so longer testing times are required to fully validate these applications[164].

A supply chain management solution, first introduced at the end of the 1980s, that is becoming more widely used, is First-Expired-First-Out (FEFO). By utilising the advances in sensor technology described above, food that is likely to expire quickly due to poor temperature control can be used before other produce that may be older but has a longer

expected life. FEFO consequently is able to cut food loss when used instead of the traditional 'use-by' dates[165] (Figure 1). Using FEFO shelf life based stock rotations, strawberry losses were reduced from about 35% to just over 20%, while losses of cooked ham could be halved[165].

A 2012 study showed that by monitoring berries from field to pack house, pallets that had had a poorer temperature profile and hence had a lower 'remaining shelf life index' could be intelligently routed to a closer distribution centre than those with a high index, which would help reduce loss[166]. They found that 30% of the pallets required prioritised routing. The report also detailed the temperature of the pallets from Mexico to a distribution centre in California. There was as much as a 30% difference between the temperatures of the pallets compared to the ambient temperature of the refrigerated container. Further, the shelf life loss of the pallets within one container varied by up to 40%. By using sensors (printed tags in this case) to utilise the loss reduction by applying FEFO, the report suggested that the cost of implementation could be recovered in one growing season.

Rossaint and Kreyenschmidt (2014) found that through the implementation of time-temperature indicators, levels of poultry waste along the supply chain could be reduced by 35% (from an initial level of 12% waste) [34].

7.6.1.1 Market size

The global food traceability and tracking technologies market is expected to have revenues of US$ 14.1 billion by 2020, with a growth rate of 8.7%[167]. Worldwide revenues of RFID technologies for food and biopharmaceutical cold chains was US$ 361.6 million in 2012 and expected to grow to US$ 1.22 billion by 2017[168] at a rate of 19.4%[167]. The growth has been helped by some retailers such as Walmart, since 2003, requiring suppliers to place RFID tags on perishable pallets and cases[169].

7.6.2 Mobile technology

By the end of 2014 there will be over 635 million mobile subscriptions in Sub-Saharan Africa[170]. The numbers are expected to rise to around 930 million by the end of 2019, helped by the rapid increase in low-cost smartphones and tablets. 75% of mobile subscriptions will be 3G/4G by 2019. The increasing availability of ICT services in Africa and other developing regions will have a big impact on agriculture. For example, in Nigeria farmers can now receive electronic vouchers, using an electronic wallet system, to purchase subsidised seeds and fertilizer or buy farming equipment directly from their mobile phones[170].

There are now a number of mobile apps available in Africa that are empowering farmers to use the best farming practices and inform them about market prices:

- **iCow[171] –** is a mobile app subscription service which sends advice to help small scale farmers enhance productivity throughout their cow's lifecycle, using text messages

and voice prompts. The app raises awareness of the cow oestrus cycle, advises on optimal nutrition and provides information and access to vets and AI agents. It will also help with milk record keeping and explain the best ways of preventing and curing milk related diseases as well as let farmers know about the most cost effective milk production practices.

- **M-Farm**[172] **–** is a transparency tool for farmers to get information on retail prices of their products using text messages. Farmers can buy their farm inputs directly from manufactures at favourable prices and find buyers for their produce.
- **Mkulima Young**[173] **–** connects young farmers in a virtual space and enables them to sell their farm produce online and give advice about successful farming techniques.
- **Cheetah**[174] is an app which helps transporters find the quickest routes and also informs them on the quality of roads or delays as well as any expected costs (bribes) they may have to pay using a particular route. Simple to use on smartphones, the app makes use of the very good 3G network that is already in place in much of Africa. The app has recently won the European Space Agency's App Challenge and the company behind Cheetah are now looking to deploy the app in India.

7.7 Better data and forecasting

Better data will drive organisational changes, for example, LeanPath, Oregon, has shown that by implementing a system where food is weighed before it is thrown out, enabling companies to monitor in real-time how much and what types of food are being wasted. They state that their customers have seen their waste levels drops by as much as 80%.

By using an analysis of freshness, shrink and customer satisfaction, Stop and Shop in the US was able to save US$ 100 million in its perishable department[29]. The Food Waste Alliance has produced a "Best Practices and Emerging Solutions Tool Kit" to help guide companies to reduce food waste.

There are substantial problems in how food wastage statistics are presented as described by Dr Hubert Reisinger, Umweltbundesamt, Austria:
"A core problem with food wastage prevention is the definition of system boundaries for food loss and waste statistics. Open questions include:

- *To which degree losses on fields and farms should be taken into account?*
- *To which degree losses of water evaporation during processing, storage and use should be taken into account?*
- *To which degree water which is added during processing or use should be taken into account?*
- *To which degree drinks should be taken into account (starting from pure mineral and tap water to highly processed drinks like brandy)?*
- *To which degree food which is used as feed shall be regarded as wastage or as just feed?*
- *To which degree food disposed of via the drainage system (such as left-over soups)*

should be taken into account?

- *To which degree garden waste and home-composting should be considered?*
- *How to deal with waste fractions which are not identifiable?*
- *Should the food, where too much is eaten be considered as part of the food waste?*

All these questions have enormous implications not only on food and food wastage statistics but also on food wastage prevention potentials and food wastage prevention strategies."

With improved data, an economic analysis of the value of lost food and accurate modelling, better forecasting will help reduce food losses. Many retailers have started to implement automated order practices based on previous sales at the store level. Decentralised buying (i.e. for individual stores) will help overcome forecasting errors.

Supply chain management software could help to visualise per day demand and decide optimal quantity and optimum cost for multiple periods when demand is problematic in nature.

7.8 Large retailer practices

There are a number of retailer practices which if improved could help to reduce food loss and waste but there needs to be a clear corporate commitment. This can be achieved with the setting of targets and the implementation of food loss and waste prevention campaigns in their operations. Table 7 shows the total waste breakdown for Tesco supermarkets.

Better handling and temperature management in the 'back room' when product is received is necessary. When retailers receive deliveries, pallets may often sit out for hours before they are unloaded[175]. If retailers are able to change these procedures, it could lead to improvements. The temperature of refrigerated display cabinets can vary considerably. Adding doors to the cabinets could help, as well as reduce the energy required to power the units. More effective stock rotation is also required.

Table 7. Tesco (UK) waste breakdown. Source: Tesco 2013.

Food type	Waste
Bakery	**41%**
Fruit and vegetables	**21%**
Convenience foods	**8%**
Dairy	**8%**
"Impulse", such as confectionery and soft drinks	**6%**
Meat, fish and poultry	**5%**
"Counters", such as cheese and deli meats	**2%**
Frozen foods	**2%**
Cereals	**2%**
Beers and spirits	**2%**
Pasta, rice and grains	**2%**
World foods	**1%**

7.8.1 Use ugly food

Huge quantities of food are lost as they do not meet strict product requirements (out-grading). Quality standards should ideally be based on eating quality and nutrition, not on visual appearance or size. To support such a change, there would need to be a move to revisit public attitudes towards quality and food aesthetic standards, for example, dispel the myth that oddly or irregular shaped produce means that something is wrong with it and help producers envision how to market these foods. A number of retailers have begun to promote the use of ugly food:

- **Rewe Group (Germany)** – has a line of nonconformist produce
- **Edeka (Germany)** – sell flawed items as part of their "nobody is perfect" campaign
- **Tesco (UK)** – are encouraging consumers to buy ugly food with their Wonky food initiative.
- **Intermarche (France)** – 'Les fruits et légumes moches' (ugly fruit and vegetables). Products are sold at a 30% discount.

7.9 Financing

Access to credit is essential for farmers or market retailers so they can invest in better machinery, storage or transportation. Agricultural finance in developing countries was historically delivered through government subsidised directed credit but many of these attempts to intervene in the financial markets ended in failure as they did not create sustainable credit supplies[176,177]. However, agricultural financing began to improve in the 1980s with the introduction of market-based (i.e. able to set their own interest rates) micro-financing institutions (MFI), which make small, affordable loans to the poor. The creation of farming associations also helps farmers gain access to microfinance by lowering costs and spreading the risk. The increasing use of mobile phone banking should help make rural areas more attractive to financial institutions[177].

In many regions, women make up the bulk of the agricultural labour force, but discrimination often limits their access to credit. A large shift in cultural norms is needed and in many cases legal barriers must be removed. Many MFIs actively support women, for example, 96% of the borrowers of the Nobel Peace Prize winning Grameen Bank in Bangladesh are women.

USAID are currently running a US$ 2 million Asset-Based Financing for Smallholder Farmers Project which will help 110,000 small holder farmers in 13 counties of Kenya double their farm income by providing loans for quality seeds and fertilizer[178]. The project is primarily focussed on staple crops such as maize, millet, sorghum and kale. Extension training, such as better storage practices, is also provided to minimise post-harvest losses.

Further projects like this, focussed on cold storage of perishable food would enable farmers to have the appropriate facilities to significantly reduce food losses.

7.10 Better regulations

Whilst writing about regulations poses some difficulties due to significant differences between countries, there are a number of changes to regulations and tax laws which could greatly help reduce food loss. It is also important to note that it is vital that any changes to policy or regulations are properly implemented, adhered to and monitored to ensure compliance. Better communication is also needed between stakeholders along the entire food supply chain. Some regions have started to implement waste prevention programmes to reduce waste, such as the European Waste Directive (EU Commission 2008)

Casper Jacobsen from Maersk Container Industry, Denmark:
"Different countries face different obstacles within their regulatory regime. In China, for example, a very fragmented cold supply chain across the Chinese provinces makes it inefficient; the solution here is greater consolidation of the cold supply chain industry either by creating national champions or by relaxing investment restrictions. In Africa, the challenges are of a very different nature, where underinvestment in infrastructure makes reefer transport difficult/ impossible."

7.10.1 On farm

The use of standardised Good Agricultural Practices (GAP) will help improve food safety. There are initiatives such as KenyaG.A.P. (part of GlobalG.A.P.) which are aiming to improve farm standards but it must be ensured that the standards are implemented. Many retailers already require that their farm suppliers adhere to basic hygiene standards.

7.10.2 Taxation

Some types of tax incentives may be beneficial, for example, providing tax reductions for growers or logistics providers that implement loss reduction strategies, or tax rebates when purchasing cold storage or transportation.

7.10.3 Levies on capital goods

Ending tax on imports of capital goods would help to boost investment in cold chain infrastructure.

7.10.4 Packaging levies

In a number of countries, levies are applied which relate to the number of containers rather than weight. This results in overfilling which inevitably leads to damage. Freight charges by weight rather than by the number of containers might help reduce container size.

Incentives are also needed to encourage farmers to use stackable, returnable plastic crates (RPCs) rather than bags or large baskets and crates.

7.10.5 Food Safety

Improving food safety standards will help enforce better hygiene practices. Many countries and companies now use Hazard Analysis and Critical Control Point (HACCP) approaches during production and processing. This is where stringent controls, at each step in the process, are put in place to prevent hazards occurring. HACCP is one of the best methods of controlling food borne disease or chemical contamination and has been adopted by the joint FAO/WHO Food Safety Standards Programme.

HACCP– a definition
"HACCP is a science based systematic system which identifies specific hazards and measures for their control to ensure the safety of food. HACCP is a tool to assess hazards and establish control systems that focus on prevention rather than relying mainly on end-product testing. Any HACCP system must be capable of accommodating change, such as advances in scientific knowledge about food safety hazards, equipment design, processing procedures or technological developments." standards.org (2014)[179]

By first identifying possible hazards and then determining critical control points (CCPs) and critical limits, potential risks in a process can be considerably reduced, ensuring food is safe and losses are reduced. However, due to the costs associated with HACCP, especially for small companies, governments need to work at an international level to co-ordinate activities[180].

Whilst it is imperative to have food safety labelling, sometimes these can be too strict and based on quality rather than safety, for example, 'display until' dates. Date labels, and more importantly consumers misunderstanding them, are one of the major causes of food being thrown out while it is still perfectly edible. Research by WRAP showed that 45-49% of consumers misunderstood the meanings of "best before" and "use by"[181]. Date label confusion is linked to about 20% of the avoidable waste in the UK. Recent changes to legislation in the UK which has banned 'display until' and 'sell by' dates has helped reduce food waste significantly[37].

Improving oversight in the food import sector would help minimise poor handling as well as ensure quality and safety[182].

7.11 Education

To implement all the approaches mentioned above requires a great deal of education and training along the entire supply chain, from farmers adopting better harvest practices to retailers understanding the economic burden of food loss and waste. In many areas there

are weak links between research institutions and the agricultural sector so research on proper handling methods is not reaching the end user. Basic training in the importance of cleanliness, hygiene, sorting, handling and the cold chain (and especially pre-cooling) is required. In many areas, food loss is accepted as a part of business[183]. Education and extension programmes are needed, to show that with small changes in harvesting practices, investment in low cost storage facilities, or through the use of better packaging, food losses can be dramatically reduced. Training given on production planning including harvest forecasting will ensure that harvesting is done at the right time. There would also need to be greater training on the added value of processing and preservation techniques.

Examples of organisations that are running education and training programmes include:

- **USAID rural extension and advisory services -** USAID runs agricultural extension programmes in many countries, and currently has over 150 projects running worldwide. The organisation aims to involve diverse public and private sector providers such as suppliers, buyers, farmer organisations, NGOs and government organisations. USAID works to transfer new technologies and provide advice to farmers and rural people and facilitate the development of local skills.
- **The Postharvest Education Foundation -** Formed in 2011, the Postharvest Education Foundation is a non-profit organisation which provides educational programmes aimed at reducing food losses, maintaining quality, market value, nutritional value and food safety. It also provides access to references, resources, training activities and mentoring services for young professionals in the field of postharvest technology. The Postharvest Education Foundation runs global e-learning programmes as well as short courses in developing countries[184].
- **World Food Preservation Centre -** The World Food Preservation Centre has recently been opened which will train students from developing countries to Masters or PhD level who will then establish independent research, education and extension programmes in their home countries. This will aid the implementation of advanced preservation technologies and methodologies specific to their respective countries. There are currently 10 universities from around the world that form the World Food Preservation Centre.

7.12 Summary

- The factors that influence the occurrence and level of food loss range widely across a number of areas and vary over time and space.
- Of particular note is the distinction between developed and developing country experience.

- Given our focus on the fruit and vegetable sector, some of these factors are less relevant in reducing loss than they could be in other sectors such as cereals.
- However it is clear that a good infrastructure is central to supporting a more effective supply chain particularly one that could be enhanced with a more efficient– or indeed new – cold chain linking producers to consumers.
- The context in which these solutions might be offered means that not all will be appropriate in all circumstances. The case studies later in this report highlight the fact that there is no one solution that works in all cases and in all countries.
- The factors that could help drive these changes are explored in the next section.

8. Drivers of change

8.1 The growing middle class

Demographic changes in the developing world will have a big impact on food consumption. Nearly 90% of the world's rural population currently live in Africa and Asia. Globally, 54% of the world's population live in urban areas; by 2050, this number is expected to grow to 66% of the world's population[185]. The global rural population will decrease from 3.4 billion to 3.2 billion. The largest shift will be seen in Africa and Asia where the number of people living urban areas will grow from 40% to 56% and from 48% to 64% respectively, by 2050.

The global middle class is forecast to grow from 1.8 billion in 2009 to 4.9 billion by 2030[186]. The majority of this growth will be in the Asia Pacific region, and in particular China and India (Figure 7). By 2050, as much as two-thirds of global consumption could be from emerging markets, compared with one-third today[187]. This will be driven by the large increase in the middle class.

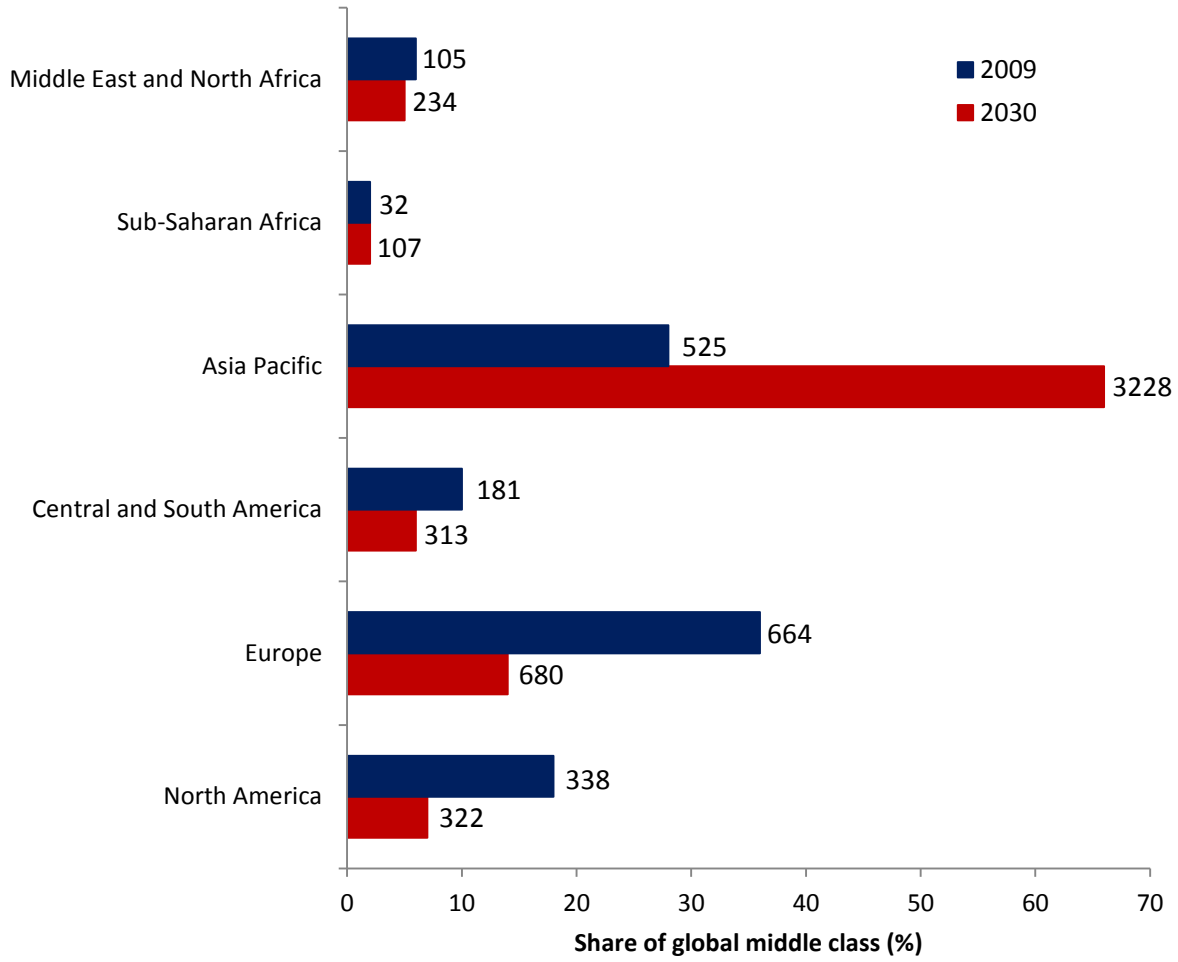

Figure 7. The global middle class in 2009 and 2030. Numbers next to the bars indicate the total middle class population (millions). Source: Kharas (2010)[186].

Urbanisation and the burgeoning middle class in emerging markets are likely to have a large impact on food supply chains. There will be an increased demand for perishable food[110], especially meat, with a much greater emphasis on quality[188]. There will also be a shift in shopping habits with the growth of supermarkets and home refrigeration (there are now over about 1.4 billion domestic refrigerators and freezers worldwide[189]). Rather than shopping daily at local markets or convenience stores, the middle class are likely to shop less frequently, requiring food to have a longer shelf life. There will also be huge growth in e-commerce where consumers have food delivered directly to their homes. Unbroken cold chains must therefore be developed to meet this demand.

The growth of supermarkets will have a big impact on smallholder farmers in developing countries. As commercial demand increases, farmers can earn greater income by specialising in crops that they have a competitive advantage in. With greater income they are able to improve productivity by investing in better machinery, better crop varieties or new postharvest storage and processing facilities.

In Latin America supermarkets have grown from having just 10-20% of the food retail sector in 1990 to being one of the dominant players with 50-60% of the market share in 2000[190]. This has led to a massive increase in the need for a reliable and effective cold chain.

Rao, *et al.* (2012) found that in Kenya, participation in supermarket channels had a positive impact on farm productivity[191]. With higher prices and better market assurances farmers had an increased ability and willingness to upgrade their technology. Farmers increased their scale efficiency by 30%, which was attributed mainly to reduced marketing risks and the ability to specialise.

8.2 Summary

- The rising middle class in many rapidly growing countries will see an increase in demand for perishable foods and lead to greater incentives to ensure food loss is minimised.
- Changing diets associated with greater wealth will have implications for the supply chains in those countries, not least of which will be in the retail sector as shopping habits evolve.
- As countries reach maturity it is possible to imagine the focus of attention shifting from food loss to food waste if current patterns remain the same. At present developed economies tend to see food waste as the more pressing issue and the next section explores how this might be reduced.

9. What are the possible approaches to food waste utilisation?

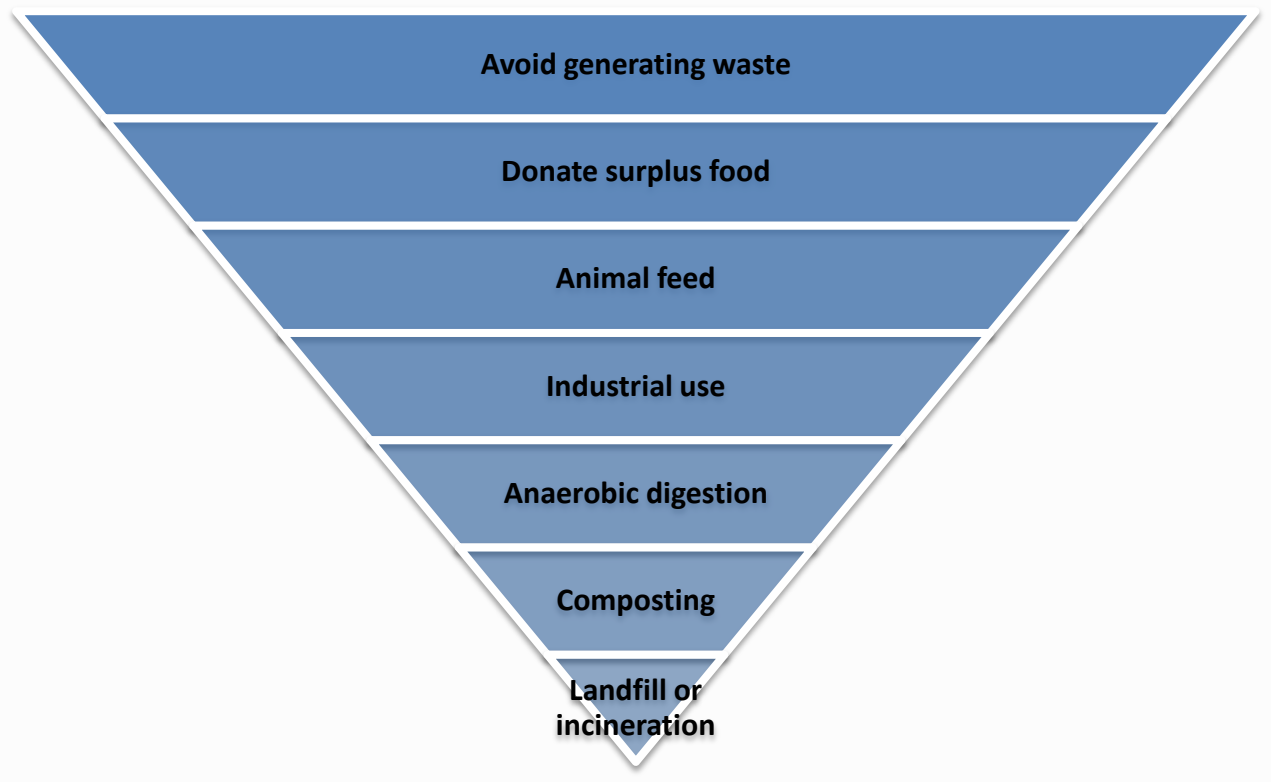

Figure 8. Food waste hierarchy

The food waste hierarchy (Figure 8) ranks the most important uses of food waste. If at all possible, generating waste should be prevented, for example by having better supply chains and order management, as described in the previous sections. The following sections will describe the best approaches to food waste utilisation.

9.1 Food donation

Food that has passed its sell by date so cannot be sold by retailers is often still fit for human consumption. Charity food banks, such as Feeding America (US) or Fare Share (UK), usually collect food from growers that have a surplus, manufacturers that have over produced or retailers that have over ordered. Similarly, second chance food stores in disadvantaged neighbourhoods are being set up which sell food that is past its shelf date, but still within the window of being edible. However, better integration with the for profit supply chain is needed to minimize the cost of hunger relief food recovery.

Feeding America currently receives about 600 million pounds of produce 'loss' from growers, packers and shippers which is primarily due to overproduction or food produce not meeting specifications[192]. They receive a further 1,200 million pounds of perishable food waste, mainly due to unpredictability of demand or handling damage, from consumer facing

retail outlets. The cost of perishable food recovery for the Feeding America network varies from $0/lb to $0.25/lb. The network spends more than US$ 800 million to move the estimated 4 billion pounds of food annually. They estimate that to close the entire domestic meal gap by scaling the existing hunger relief model, about US$ 1.5 billion would be needed annually. To achieve this, better collaboration with the for-profit sector is also needed.

Daniel Krohm from Feeding America:
"To address hunger in the U.S. based on current levels of food insecurity there is an annual need of about 8.5 billion meals (1 meal = 1.2lbs) to feed 49 million people. (Note: food insecure individuals do not typically source all of their meals through hunger relief channels.) The Feeding America network provides about 3.5 billion meals annually. With more than 70 billion pounds of potentially recoverable food waste generated in the U.S. for profit supply chain, the total need of the food insecure in the U.S. could be addressed via food waste recovery."

While food waste is often thought to primarily be a problem in the developed world, there are huge amounts of food wasted during festivals and wedding ceremonies in developing countries, for example, in Kashmir, only a fraction of the 'Wazwan' dishes which are served at weddings are eaten, although people can spend up to 25% of their life savings on the food. Food donation schemes are now being set up in many areas which aim to give the surplus food to people from the surrounding areas. An event in Annakshetra, Jaipur, India, was able to provide food to 10,000 people with surplus food from weddings the previous day (Figure 9).

Regulations such as the EU Hygiene Package (Regulation (EC) No 852/2004) can make donation far more difficult, where retailers or manufacturers do not want to risk donating unsafe food. Countries such as the US and Italy have tackled the legal indemnity problem with the Federal Good Samaritan Food Donation Act which relieves liability concerns over donation. Food donation is also often seen as being too expensive, especially when subsidies are provided to support anaerobic digestion rather than donation. A number of European countries have now implemented tax incentives which should help to redress this imbalance. California and several other states in the US have recently passed legislation to provide tax credits to farmers who donate their surplus food[54].

Mark Varney from FareShare:
"A legislative environment that provides subsidy and support to anaerobic digestion and other energy technologies creates a 'race to the bottom' of the food use pyramid."

Figure 9. Muhana Mandi, Jaipur on the 4th November 2014. Source: Ravi Dhingra, CDC India.

9.2 Animal Feed

Historically, food waste was commonly used as animal feed. In the developing world much of the food waste is still used as animal feed, however, following the BSE (bovine spongiform encephalopathy) outbreak in the 1980s, in the UK and much of Europe, the feeding of processed animal protein (PAP) to most farm animals has been prohibited. Subsequently, the foot-and-mouth outbreak led to the UK prohibiting the feeding of animals of catering waste that had been in contact with animal products. Some of these restrictions are in the process of being relaxed, but stringent safety and processing regulations must be put in place. One third of all cereals produced worldwide are used for animal feed rather than directly for human consumption (FAO, 2013) so any food waste that could be used to reduce this number will be a huge benefit. Food waste is now also being used to grow fly larvae for aquaculture feed.

9.3 Industrial uses

With the increasing costs and environmental concerns of fossil fuels, new sources for the production of chemicals and materials are needed. Food waste provides an alternative feedstock, although there are many difficulties associated with it due to the large differences in composition (lipids, carbohydrates, proteins) as well as problems with collection, fluctuations in volumes and contamination (bacterial or chemical)[193]. A further barrier includes strict regulations which may add to costs.

Bio-refineries process the raw materials which are then converted into valuable chemicals. Economically, refining food waste is an attractive option, for example, bulk chemicals and transportation fuels have been estimated to generate $1000 and $200-400 per tonne of biomass respectively while cattle feed is in the range of $70-200 and electricity (from AD) just $60-150 per tonne of biomass[194].

There are some forms of food waste which contain valuable compounds such as antioxidants which could potentially be recovered and re-used in the food chain as functional foods[193]. Some types of food waste, for example, wine grape skins can be dried and used to produce edible flour or vitamin rich food powders.

9.4 Anaerobic digestion/renewable energy

Anaerobic digesters (AD) convert food waste into biogas (60% methane, 40% carbon dioxide and traces of other gases such as hydrogen sulphide) using naturally occurring micro-organisms. The biogas can be used to produce electricity and heat, while the digestate (the indigestible material) can be used as fertiliser. The biogas can also be purified into pure methane which can be used as road fuel or added to the mains gas grid. AD plants can come in a variety of sizes from those used by local authorities or industry to much smaller farm scale units.

However, there are regulations that must be adhered to in many countries when using AD. Meat and other products of animal origin must go through a process of hygienisation to ensure that there is sufficient pathogen removal so that the treated digestate can be used as fertiliser.

9.5 Composting

Composting food rather than disposing of it in landfill has multiple benefits such as reducing the amount of methane produced in landfills and producing cost effective natural fertiliser.

9.6 Landfill and incineration

Landfill or incineration should only be used if all the other options in the food waste hierarchy cannot be achieved. Many governments have started to impose fines on companies that send food waste to landfill, for example the Landfill Directive in Europe. Approximately 33 million tonnes of food waste is currently sent to landfill or incinerated in the US [195], at a cost of nearly US$ 750 million a year[196,197].

9.7 Summary

- Food waste is generally a more pressing matter for developed economies than developing economies.
- Much of the waste arises from consumer behaviour that reflects the relative value of food to other goods and services.
- However, there are many practices in the food chain that might contribute to waste including promotional activity centring on volume discounts.
- There are many potential uses of food that otherwise would be wasted with a hierarchy of value being a good indicator of where best to make intervention.
- Activities such as food donation though, are affected by regulations and government policies and thus while on the face of it appear simple solutions to reducing waste they are in fact more nuanced than that.

10. Future challenges in understanding food loss

There are a number of areas which have been identified while undertaking this research that show where more information is needed to get a better understanding of the problems and indeed where lessons can be learned from other sectors.

10.1 Limitations of data

Significant limitations to research arise from a lack of data in a number for key areas. These include:

10.1.1 The amount of food loss throughout the entire supply chain

The US Department of State (Office of Agriculture, Biotechnology, and Textile Trade Affairs Bureau of Economic and Business Affairs) has recently published a discussion paper looking at the postharvest challenges in developing countries[198]. The paper highlights the severe lack of postharvest data in many regions[16,21]. National surveys and studies are needed so that there can be a better understanding of where food losses are occurring along the entire supply chain so that suitable interventions can be identified. Change will happen when governments or the private sector understand the huge levels of loss and waste that are occurring at each stage of the food supply chain, but much more data is needed to achieve this.

Case studies on different commodities, such as those already done on bananas in India[199] or mangoes from the Ivory coast[200], have the potential to create strong business cases and highlight where investment could have the greatest impact. 'Champion' stories of successful companies that have made significant gains in reducing food loss, how they achieved their results and the beneficial outcomes – financial and otherwise, will help demonstrate the potential gains that can be made and inspire others.

10.1.2 Nutrient content of food loss

Whilst it is useful to know the monetary or energy (kcal) value that is lost, it is also important to consider food loss in terms of micronutrients. Many types of perishable foods have a relatively low energy content or monetary value, but they are important nonetheless due to their micronutrient content. While there is some progress being made with genetically modified cereals, for example, golden rice which contains vitamin A, it is vital that people eat a varied diet. It is important therefore, that we understand how much food loss impacts hidden hunger.

10.1.3 Geographic Information System (GIS)/remote sensing

GIS enables many different types of data sets to be combined to get a better understanding of a particular geographical area. There are a number of GIS solutions which are already helping estimate food loss levels or provide a mapping system to reduce loss:

- **The African Postharvest Losses Information System (APLIS)** helps estimate levels of postharvest cereal loss. A network of experts supply data into a shared database and using an algorithm, the postharvest loss calculator generates estimates of weight losses of cereals in Sub-Saharan Africa by country and province which can be viewed as maps or tables.

GIS could also be used as a tool for private investors to know which regions have the necessary infrastructure (e.g. tarmac roads, water, electricity) for implementing a cold chain. By knowing where there is loss and why that loss is happening (e.g. lack of cold storage facilities or poor roads), as well as what infrastructure is already in place, specific solutions could be targeted which should help reduce food loss.

10.1.4 Impact on rural income

Reducing food loss will result in greater food availability. It is important to know what impact this will have on rural incomes. It may result in cheaper food so there is less malnutrition, but how will lower prices affect farmers? Lower prices received for food could lead to less desire to invest in better cold chain and other technologies as returns fall.

10.1.5 Education

It would be useful to have a better understanding of the effectiveness of education and agricultural extension, especially using new technologies such as mobile and web based services, provided by governments, NGOs or the private sector so that the most effective training systems can be promoted.

10.1.6 Harvest

Harvesting crops within a defined window of maturity is essential; harvesting before or after that window will likely result in higher levels of food loss. Whilst information on the best time to harvest certain crops is available, the information is by no means complete. It is important that we know the levels of loss associated with incorrect harvest timing so that farmers can be aware of its importance.

10.1.7 Cold chain

More data is needed on the number of cold chain facilities (pre-cooling, storage and transportation), as well as if they are being used correctly and are in good working order. The costs associated with cooling facilities must also be known.

There need to be more studies which will help demonstrate to farmers and market retailers the potential benefit of utilising a cold chain and that loss does not have to be a standard part of their business.

A better understanding of temperature abuse during the “in between” steps of the supply chain would also help reduce breaks in the cold chain.

10.1.8 Transportation

There needs to be more data on the time taken to transport perishable foods and the loss of product value from farm to market (and prices at the different stages).

There would be value in having data on when transit times are 'pushed' for economic reasons. Often longer trips are pursued to capture beneficial markets; however, it may be beyond the food's ability to last with resulting loss[175].

10.1.9 Out-grading

Whilst out-grading is a serious problem, there is little data on the amount of food that is left in the field, sent to AD or diverted to other food supply chains (e.g. jams or jellies). More data is needed to understand the real impact of out-grading.

10.1.10 Retail

Many retailers lack reliable data on food wastage, much of which is based on assumptions or estimates rather than real data. Only by understanding their wastage levels will they be able to make a big impact in reducing loss and waste. This may be helped with the development of standard methodologies.

10.1.11 What happens to food waste?

There is very little data on what happens to food waste. How much food that is still fit for human consumption is sent instead to be used for animal feed or anaerobic digestion? Are these levels due to costs associated with food donation or difficulties presented by unhelpful regulations?

10.2 Other sectors similar to the food cold chain

Biopharmaceutical products such as vaccines and blood as well as most fresh cut flowers should also be transported via cold chains. They often face high levels of loss due to similar problems associated with the food cold chain. However, there are often cold chains already in place for biopharmaceuticals or fresh cut flowers in developing countries due to their higher economic value while there are few cold chain facilities available for perishable food. Expertise and infrastructure that is already in place could therefore give a boost to the nascent food cold chain in these countries if capabilities were shared among sectors.

The cold chain biopharma industry is valued at more than US$ 200 billion and is likely to grow to US$ 300 billion by 2018, with the largest growth in Asia. Biopharma cold chain logistics spending is about US$ 8.4 billion worldwide, consisting of US$ 5.6 billion for cold chain transport and US$ 2.8 billion for cold chain packaging, in a US$ 64 billion overall biopharma logistics market[201]. By 2018, seven out of the top ten pharma products are predicted to be biopharmaceuticals that require refrigeration at 2-8^{o}C. Sales of insulin,

which also needs refrigeration, are expected to grow by as much as 20% in emerging markets.

Fresh cut flowers are sensitive to many of the same factors as perishable foods, such as temperature, humidity and ethylene. Europe is the largest producer of fresh cut flowers, with the Netherlands traditionally the centre of the global flower industry. Aalsmeer in the Netherlands is still the largest flower market in the world but the industry is becoming more fragmented as retailers have started buying directly from growers. Less developed countries, such as Kenya, Columbia and Ecuador, which have better suited climates and lower labour costs are now major producers. Exports of fresh cut flowers in Africa grew at an annual rate of 20% between 2000 and 2007, doubling its share of world exports from 4% to 8%[202].

10.3 Summary

- Food loss is a highly complex problem with a range of inter-related solutions available.
- Finding an appropriate solution has to start by gathering sound and comprehensive evidence.
- It is clear that data at present are limited in a number of key areas and more research is needed to generate better and more extensive research.
- Some solutions could be drawn from other sectors, not least of which is the biopharmaceutical and fresh flower sector which currently utilises cold chain technology to ensure effective operation of a global business.
- Local contexts will be important in shaping the appropriate response to reducing food loss as the next section highlights.

Case studies

11. China – an introduction

China has the largest population in the world at 1.4 billion people and 46% of China's population still lives in rural areas. China is the largest producer of rice, vegetables and hen eggs, second largest producer of chicken (after the US) and third largest producer of beef (after the US and Brazil). However, 10.6% or 150.8 million people are undernourished, placing it second in the world after India[3,11,203]. Largely due to a poorly developed cold chain, there are high levels of food loss[77] (Table 8).

Table 8. Post-harvest losses of different foods in China, adapted from Wang *et al.* (2013)[77] and Jiang (2013)[79]

	Loss (%)	Transported via cold chains (%)
Fruit and vegetables	**20-30**	**5**
Meat	**12**	**15**
Aquatic products	**15**	**23**

The cost of the 12 million tonnes of fruits and 130 million tonnes of vegetables that are damaged every year due to an underdeveloped cold chain, approximates to a cost of over RMB 100 billion a year[204]. A further report on food losses in China states that 10-15% of perishable food is lost[78]. The author notes that the data available along the whole food value chain is deficient and rarely complete. The author also emphasises the decentralised agricultural system as a major cause of post-harvest loss.

Along with problems in infrastructure, there are also problems with education and culture. For instance there are reports of truck drivers turning off the refrigeration units during transportation to save costs and only turn them on when they arrive at their destinations[205].

11.1 Food safety

Food safety is a particular concern in China after a number of damaging incidents. Examples include the tainted baby milk scandal where dangerous levels of melamine (a chemical which makes milk appear to have a higher protein level) were found[206]; the reports of illegally recycled cooking oil[207]; or the recent 'out-of-date' meat scandal[208].

All these incidents have severely affected consumer confidence. Further to this, a study published in the *Chinese Journal of Food Hygiene* suggested that as many as 94 million people became ill due to bacterial food borne disease in 2011[209].

Figure 10. Wholesale market in Beijing. Source: Author's photo.

Developing a cold chain should to some degree help reduce the number of foodborne diseases as well as improve consumer confidence. However in 2008, Zhang [210] estimated that US$ 100 billion in supply chain investment was needed to fix China's food safety problems with the number of refrigerated trucks rising from 30,000 to over 365,000 over the next decade. In 2013 there were approximately 10,000 cold storage units in China while the total cold storage capacity in 2011 was 71 million cubic metres, with a storage capacity of 17.4 million tonnes[77]. The number of storage units constructed between 2008 and 2012 has doubled each year[77].

11.2 Opportunity

Despite the fact that China is the world's largest investor in infrastructure (investing 8.5% of the country's GDP in roads, power, rail etc. between 1992-2011) it will continue to invest aggressively as its level of infrastructure is still below that of developed countries[211]. This should help the cold chain sector develop at a very fast rate. A recent report suggests that the cold chain logistics sector in China will grow at a rate of 25% per year until 2017 and will be worth more than RMB 470 billion[212,213].

The Chinese middle class in 2010 had 157 million people, second only to the United States, although this is still a small percentage of the total population (12%)[186]. As many as 1 billion people or 70% of the population could be middle class by 2030[214]. Chinese consumers spend up to 9.8 hours per week shopping compared to just 3.6 hours for Americans[215] and the middle class are forecast to spend more than US$ 650 billion on food by 2017 from US$ 150 billion in 2007[216].

This will include a shift towards perishable foods such as meat, fruits and vegetables, processed and ready-to-eat foods. For example, the per capita spending on fresh fruits and vegetables increased by 83.7% and 82.5% respectively over the last 5 years[79]. Concurrent with this, the drive for home refrigeration has also increased substantially. Between 1995 and 2007, the number of urban households that had a refrigerator jumped from just 7% to over 95%.

Whilst business to business (B2B) transport has the largest share of the cold chain logistics market, the business to consumer (B2C) market segment, which was worth RMB 400 million in 2012, is estimated to grow at a rate of 80-120% per year, fuelled by the rise of e-commerce where consumers want fresh produce delivered to their door[212]. Sales of fresh produce from Taobao, an e-commerce platform, grew by 195% in 2013. International firms are also entering the market with Amazon investing US$ 20 million in the Shanghai-based fresh food e-store Yummy77 and Walmart increasing its funding in Yihadodian, in which it has had a majority stake since 2012 and had sales of US$ 1.9 billion last year.

12. India – an introduction

By population, India is the world's second largest country with 1.25 billion people, but it is expected to overtake China by 2028 according to the UN. It is one of the largest food producers in the world yet struggles to feed its population with 190.7 million people or 15.2% of the population undernourished while one in every three of the malnourished children in the world lives in India[3,5,203,217].

The country is the world largest milk producer with 16% of global production yet losses are responsible for 50% of the cost of milk[218]. It is also ranked third for hen egg production, third for fish production and sixth for chicken meat production[219]. It is the second largest producer of fruits and vegetables in the world after China. But due to losses of up to 20-50% of total production[82] it accounts for just 1.5% of the world's exports[144].

While many factors contribute to these post-harvest losses, a major cause is an almost non-existent cold chain[144]. Maheshwar and Chanakwa [82] have suggested that 30-35% of fruit and vegetable losses could be reduced by transporting fresh produce in refrigerated containers.

12.1 Limited cold chain

India has around 6000 cold storage units which are only able to store about 11% of the country's total perishable produce. While 75% of the storage (most of which were developed in the 1960s) is used for potatoes and only 23% is available for multi-purpose storage, potatoes contribute just 20% of the total cold chain storage revenue, compared to 54% from multi-purpose storage[220].

The lack of a cold chain is particularly acute in the south of the country where there are almost no cold storage units and the climate is hotter and far more humid. A knock on effect of limited storage is price spikes, where fruit and vegetable prices fall to as little as a few rupees at harvest time but increase hugely during the off-season[221].

In addition, there are approximately 104 million tonnes of perishable food transported between cities throughout India every year, but only 4 million tonnes are transported in refrigerated vehicles, the majority of which are used for milk products[220]. While there are more than 3,500 companies that operate within the nascent cold supply chain, the industry is highly fragmented and organised players make up only 10% of the industry.

12.2 Barriers to implementation

A major barrier to cold chain implementation in India is cost. The operating costs for Indian cold chain storage units are double those of the West (US$ 60 per cubic metre compared to less than US$ 30 in the West[82]). Similarly, energy expenses account for 28% of the total expenses in India but just 10% in the West. Further, most Indian farms are very small (a few acres) and nearly 70% of all rural villages lack access to a reliable electricity supply[129]. Cold

storage hubs will need to be built around the country but there must first be adequate infrastructure such as roads and power stations.

India is aiming to hugely increase its power generating capacity, as it currently has a peak power deficit of at least 16%[222], but much of this will be from coal. Outside air pollution in India is estimated to cause 620,000 premature deaths per year[129] and the carbon dioxide emissions from transport in 2010 were 185MtCO_2 but are projected to grow 10-fold by 2050[223]. Consequently, it is vital that sustainable and efficient cold chain systems are implemented.

12.3 Opportunities

A report by McKinsey has suggested that India's middle class will grow from 50 million in 2007 to 583 million by 2025[224]. Other authors have suggested that with a population of 1.6 billion forecast for 2039, India could have as many as 1 billion people within the middle class[186]. The increase of the middle class will therefore drive consumption of perishable foods requiring refrigeration.

In 2012, India formed the National Centre for Cold-chain Development (NCCD). The government has recently relaxed regulations so that it is now possible for 100% foreign direct investment (FDI) in cold chain infrastructure, as well as boosting the opportunities for new ventures with private and government partnerships. The government is also forecast to invest up to US$ 15 billion in the cold chain over the next 5 years[129]. A recent report has estimated that the cold chain will grow from a value of US$ 4.7 billion in 2013 to approximately US$ 11.6 billion by 2017 with a compound annual growth rate (CAGR) of 28.3%[225].

The grocery retail market was worth US$ 500 billion in 2012 and is expected to grow to US$ 847.9 billion by 2020[226]. India is forecast to have the second largest grocery market by 2028. Currently, traditional outlets account for 80% of sales while organised retail is valued at US$ 35 billion in 2012 and expected to grow at CAGR of more than 20%. There are now over 300 hypermarkets trading across the country. Grocery e-commerce is negligible and still in the early stages (only 19% of the population uses the internet), although sales are likely to double by 2016[227]. The top five grocery retailers are domestic but with the recent government reforms allowing 51% FDI in multi-brand retailing, Tesco has announced it will invest US$ 140 million to take a 50% share in Tata-owned Trent Hypermarket Ltd.

12.4 Bananas – a case study

A recent report into the banana industry in India highlights the potential gains for export if a cold chain and export model are initiated[199]. India currently produces 28% of the world's bananas yet represents just 0.3% of all internationally traded bananas. The report suggests that the number of containers of bananas that could be exported has the potential to grow from 3,000 currently to as many as 190,000 if the cold chain infrastructure was sufficiently

upgraded. This would provide an additional 95,000 jobs and benefit as many as 34,600 smallholder farmers.

Dr Vivek Agrawal from CDC, India:
"India has practically everything to boost its perishable food production; it has cultivable land; it has all the seasons needed for the production of many different varieties of food and vegetables; and an agriculture business system.

The problem with this system is that a huge gap exists between what is produced and what finally reaches the customer. It has to go through several middlemen, travel along several poor roads, which worsens the quality, and leads to loss. The biggest challenge is to connect the remote villages of India to robust supply chains so that all stakeholders are benefitted and wastages can be mitigated to the maximum extent possible.

There are a few challenges that occur such as the lack of integrated approaches and efforts for effective policy formulation. The viability of cold chain continues to remain a question mark for many reasons; existing facilities are outdated and poorly maintained; awareness and hence demand for cold chain services continues to be low; lack of availability of technically qualified people to support efficient operations."

13. Pakistan – an introduction

Pakistan, with a population of 182.1 million, has a GDP of US$ 236.6 billion. Since 2005 the GDP has been growing at a rate of about 5%. Energy shortages and rising food prices (food price inflation has averaged 18% for the last five years) are likely to have a destabilising effect on the country with the Sandi National Laboratories ranking Pakistan at number 12 in countries most at risk of state failure[228].

Despite political uncertainties, especially on the border of Afghanistan and the rise of Islamist extremism, structural reforms in the fiscal and energy sectors will help growth. The country is ideally located to serve as a major trade route and energy corridor. Pakistan has the potential to become the 18th largest economy (it is currently 44th) by 2050, according to economist Jim O'Neill, but many hurdles have to be overcome first, such as corruption and political instability. International companies are increasingly looking to invest in the country. Proctor and Gamble has recently identified Pakistan as one of its top 10 emerging markets and is also part of Goldman Sach's "Next Eleven" countries.

13.1 Agriculture

Agriculture, the largest sector of the economy, contributes 21.4% to GDP, employs 40% of the labour force and provides 60% of the country's exports[229]. Farming is dominated by smallholders, with 86% of farms between 0.5-5 hectares and only 1% over 20 hectares[230]. Pakistan is the world's third largest chickpea producer and fifth and sixth largest producer of milk and apricots respectively[231], while its most important crops are wheat, maize, rice and sugarcane. However, 39.6 million people or 22% of the population[203] are undernourished, the major causes being high levels of post-harvest loss (20-40% of horticultural crops are lost[84]) and natural disasters such as flooding.

Pakistan is prone to flooding but in recent years they have become much more frequent. For the fifth year in a row Pakistan has been hit by severe floods at harvest time, especially in the Punjab, which accounts for 80% of the country's agricultural production. This can severely damage production, for instance, in 2010 the rice production was 28% lower than the year before due to flooding[232]. The damage to the agricultural economy due to flooding in 2014 is estimated to be US$ 2.3 billion[233].

13.2 Food cold chain

A report published in 2007 found that of the 13.67 million tonnes of fruit and vegetable produced annually, 25% was lost and that only 4% was exported and at far lower prices (41%) compared to world averages due to poor produce quality[83]. Horticultural exports are worth about US$ 400 million. Bananas, mangoes, dates and citrus are the most important fruits for export. One of the most important factors contributing to the high levels of post-harvest loss are the long distances that fruit and vegetables are transported in open non-refrigerated trucks.

A recent report by USAID found that one of the major hurdles in reducing food loss (30-40% of fruit and vegetables) is the general acceptance of losses and that nothing needs to be done to reduce them[183]. Combined with this, the importance of temperature, handling, hygiene and humidity are not appreciated and the basic principles of the cold chain not fully understood (i.e. the necessity of an unbroken chain rather than isolated operations).

While there is some cold chain capacity in Pakistan, much of it is inefficient and expensive due to outdated equipment and infrastructure and is mainly used for apples or potatoes. The lack of cold storage is estimated to cause milk losses of 15-20% of total milk production[234]. There is very limited access to cold storage facilities throughout the country, with the total capacity meeting only about 6% of the requirement. There are also almost no cold storage units at any of the airports or seaports. Upgrading and enlarging the present facilities is essential and will reduce storage expenses and extend the shelf life of the produce. Many more cold stores must be built in combination with modern grading and packaging facilities. Further, much of the data on cold storage capacity is out of date. The last major study looking at cold storage was carried out in 2006 by the Pakistan Horticulture Development and Export Company[235]. Primary data must be collected to update national and regional figures.

The USAID report highlighted four interventions which should help reduce food loss:

1) The need to provide clearly demonstrable benefits on the small scale
2) The reduction in the energy input into the cold chain
3) Improving the local infrastructure for exports and supply to the supermarket sector
4) Training in all sectors of the value chain

In 2009, the Government of Pakistan embarked on a programme to establish a Cool Chain System along the National Trade Corridor (NTC). This is where most horticultural production areas are located. The improvement initiative is aimed at improving infrastructure such as roads, railways, ports and airports. However, there have been very few updates on the progress of this project.

13.3 Opportunities

The size of the middle class is estimated to be about 33% of the population, second only to Sri Lanka in the region and larger than India in percentage terms[236], although other reports suggest a much lower figure, for instance only 17% of the population have incomes of US$4 a day or more. Consumer spending is expected to grow from US$ 182 billion in 2013 to US$ 334 billion in 2018[237].

As the Pakistani population becomes increasingly urbanised, modern grocery retailers (hypermarkets, supermarkets, discount stores, etc.) are becoming ever more important, with a CAGR of 6%, while traditional grocery retailing (small stores, street vendors, etc.) which at present comprises about 95% of food retail[238], is declining at a CAGR of -1%[239]. The

largest supermarket retailer is the Utility Corporation of Pakistan which has a value share of 4% and operates over 6,000 grocery retailers.

13.4 Pharmaceutical cold chain

Recent aid projects backed by UNICEF have provided funding for new cold storage facilities in Khanewal district which enables the storage of vaccines[240]. Funding from the Global Alliance for Vaccines and Immunization (GAVI) enabled the enhancement of cold chain capacity, bridging gaps in the cold chain and the provision of education and training for staff. Hundreds of thousands of children will benefit from the greater reach of the vaccines. Additionally, a Vaccine Logistic Management Information System (vLMIS) has been introduced to keep an up to date database of status of cold chain equipment.

A study by The World Bank found that investing in the cold chain would represent value for money[241]. The report showed that for pentavalent vaccine alone, with an initial investment of about US $300,000 followed by annual expenditure of US$ 50-100,000, the level of vaccine wastage could be reduced from 10% to 5%, potentially saving US$ 2 million a year. For more expensive vaccines the cost savings would be even greater. They found that full investment in cold chain equipment for all vaccines would be less than US$ 1million per year, and in most years, under US$ 500,000.

Table 9. Estimated Cold Chain Capacity in Pakistan in 2009. Adapted from Brenzel, *et al.* (2011)[241]

Item	Number (according to the national EPI)	Number (according to the cMYP)
Cold room	**41**	**63**
Deep freezer	**1,001**	**1,153**
ILR	**3,512**	**5,693**
Refrigerator	**3,382**	**422**
Solar refrigerator	**47**	**5**
Cold box	**1,951**	**4,113**
Vaccine carrier	**59,352**	**6,894**

Source: Ministry of Health, National EPI Programme.

This suggests that a similar exercise could and should be undertaken for the food cold chain.

14. Kenya – an introduction

Despite Kenya's recent political turmoil, the 2013 elections were largely peaceful and the political environment is relatively stable with the adoption of a new constitution, although corruption is still a major problem (ranking 136 out of 177 countries in Transparency International's Corruption Perception Index). Kenya is the region's financial centre and has a strong private sector. Nairobi is the largest city between Cairo and Johannesburg and acts as the main transportation hub for Eastern and Central Africa, while the Port of Mombasa is the most important deep-water port in the region.

As part of Kenya's Vision 2030, Lamu Port, located on the north-east coast, is being developed (at a cost of US$ 16-26 billion) which will help open up a new transport corridor between Kenya, South Sudan and Ethiopia. The government also plans to invest US$ 1.4 billion on new geothermal plants which will support energy production, the majority of which currently comes from hydroelectric generation (45% of total installed capacity). Only 18% of households in Kenya are connected to the grid[53], with the majority of the population obtaining their energy from biomass[242], so energy infrastructure must continue to expand.

Kenya has a population of 44.4 million people and a GDP of just over US$ 44 billion, the largest in East Africa, with the agricultural sector contributing 24% of GDP. 70% of the country's labour force is involved in agriculture[231], many of whom depend on subsistence farming. Kenya is the largest exporter of black tea worldwide. Other important crops include coffee, cut flowers, fruit and vegetables. Over 90% of fruit and vegetables are consumed domestically and the majority of the exports are targeted at the European market. However, 10.8 million people or a quarter of the total population are undernourished due to frequent droughts, high cost of food production and high levels of food loss (20-50%)[85,86]. In 2014, Kenya received 74,780 million tonnes (US$ 92.3 million) in food aid from Food For Peace, partners of the World Food Programme[243].

14.1 Fresh cut flowers - supply chains already in place

Kenya already has highly developed supply chains for the export of fresh cut flowers to Europe. Valued at about US$ 0.5 billion[244] and with 7% of the world market, Kenya is the largest exporter of flowers in Africa and is the leading supplier of roses for the European market[245]. Flowers bring in the bulk of the horticultural export income (Table 10) and contribute 1.29% to the national GDP[244]. Much of the success of the Kenyan flower industry is attributed to international private sector investment.

Almost all flowers are exported by air freight and exporters continue to invest in modern cold storage facilities around airports, especially Jomo Kenyatta International Airport. Recently, there has been a growing interest in shipping flowers by sea to reduce costs, but there are substantial hurdles to overcome, for instance, inadequate pre-cooling and bottlenecks caused by poor service of shipping lines as well as threats of piracy. The Dutch association of flower wholesalers (VGB) have set a goal to transport 40% of flowers from

Kenya by sea freight by 2020, which would amount to 4,800 containers a year[246]. Shipping by sea containers would reduce cost by 40-50% compared to air freight, as well as reduce CO_2 emissions (182,000 tonnes a year of CO_2 would be saved if the 40% goal is achieved[199]).

Table 10. Kenyan Horticultural exports, January-April 2013 and 2014. Quantity '000' Tons; Value Million US$. Source: USAID-KHCP[247]

	2013		2014		% Change	
	Quantity	Value	Quantity	Value	Quantity	Value
Flowers	46.5	205.9	47.4	239.2	2.0	16.0
Vegetables	24.0	71.6	28.9	69.1	20.2	(3.5)
Dry vegetables	33.4	23.0	20.7	16.4	(38.0)	(29.0)
Processed vegetables	12.3	38.5	11.1	25.	(9.0)	(35.0)
Nuts	3.9	5.6	4.5	8.8	15.0	55.0
Fruits	17.3	17.3	17.7	18.2	2.3	5.3
Processed Fruits	25.3	30.9	29.7	33.2	17.3	7.6
Total	162.7	392.9	160.0	410.0	(2.0)	4.0

There are many inefficiencies with the current supply chains, for instance, where flowers are "re-cooled" at Kenyan airports, which is inefficient and costly compared to if the flowers were delivered to the airport at the correct temperature to start with. There are large temperature variations down the entire supply chain due to the absence of adequate standards and protocols. Poor packaging and handling practices due to a lack of education and training also cause damage to the flowers. There are further problems caused by transporting different flowers together, (e.g. roses which have an ideal storage temperature of 0-1^{o}C, with Anturium which has a minimum storage temperature of 15^{o}C). About 20% of the value of flowers is wasted due to poor cold chain management, equating to a loss of US$ 100 million for retailers[248].

Whilst most flowers used to be sold at auction, for instance at Aalsmeer Flower Auction in the Netherlands, the largest in the world, retailers are beginning to buy directly from growers. This is driven by the increased demand for cut flowers, for instance, Tesco has seen a 10-fold growth in sales in the last seven years[248]. This shift is likely to cause an increase in efficiency and reduction in losses as retailers look to reduce their costs.

14.2 The seafood value chain

About 90% of fishing in Kenya is artisanal (subsistence) where fish are caught for direct consumption and the surplus sold to supplement the fishermen's income. Just 10% is semi-industrial, with exports valued at about US$ 10 million[249]. In recent years the Kenyan seafood sector has seen little growth. High levels of post-catch losses (about 35%[249]) are caused by a lack of refrigeration as well as unhygienic processes, so the introduction of coolers and improved ice distribution systems could stimulate growth.

The Kenya government along with financial support from the European Union has provided funding for modern fish landing facilities which should be fitted with cold storage room, ice plants and wash rooms which comply with EU regulations, however, few of these facilities are functioning as they are incomplete or in a state of disrepair[250]. More sustainable approaches are now being pursued, such as solar powered cold storage and ice units which will be able to operate in remote fishing communities[251].

14.3 The dairy sector

Approximately 3.7 billion litres of milk are produced from 3.4 million heads annually[219,252]. Dairy production is dominated by smallholders. In the rainy season when there is a glut in production, poor roads and the large distance to markets means that surplus milk cannot be marketed and is therefore lost as there are very few cold storage or processing facilities[252]. This is largely due to the unavailability of electricity in rural areas and the high costs. Each year about 95 million litres of milk are lost, at a value of US$ 22.4 million per year[253].

14.4 Fruit and vegetable supply chains

Kenya produces 2.4-2.6 million tonnes of fruit a year, with bananas, mangoes and pineapples the major crops[254] as well as 5.5 million tonnes of vegetables such as Asian vegetables, fresh beans and peas[255]. The majority of Kenyan farms are less than two hectares and have limited access to electricity or irrigation and the surrounding infrastructure such as road and rail networks is inadequate (Kenya is ranked 99 out of 155 countries in logistics quality by the World Bank's Connecting to Compete 2010[254])[86]. Combined with these limitations, poor post-harvest practices, such as damage cause by improper handling, contamination (e.g. high levels of pesticides or pests like the mango weevil) and insufficient cold storage result in large losses. Due to a lack of on-farm storage facilities, farmers are forced to sell their produce immediately resulting in lower prices. In addition, counterproductive policies also impact food loss, for instance levies applied per package rather than by weight which encourages the use of large bags and overfilling[53].

Low cost storage options are now becoming available for farmers, through support from NGO's like Feed the Future. For instance, the CoolBot system (CoolBot controller, air conditioner, insulated room and electricity) which cost about $2,000-3,000, less than half that of commercial cold storage units, and has already been successfully been introduced in Bangladesh and India. The CoolBot itself can cost as little as $150 when purchased in partnership, for example, with the Horticulture Collaborative Research Support Programme (Hort CRSP) at UC Davis (USA)[53]. Power generation can come from PV solar panels (which are becoming increasingly affordable). This is particularly attractive for rural areas with little connectivity to the power grid.

Currently, perishable food is transported at night and left in the shade in order to keep them out of direct sunlight where ambient temperatures can be over 30^{o}C[53]. The lack of storage, and most importantly cold storage, is also one of the major constraints for traders. A report

by USAID found that only 16% of traders they interviewed had storage onsite or near the market[256]. Most traders would expect to sell out in a single day or would have to store their produce overnight on the ground at the market or in trucks, resulting in prices dropping over the course of the day. The traders that did have access to storage were able sell their produce at higher prices when supplies from other traders had dwindled.

Food often travels through many intermediaries before reaching consumers which increases the likelihood of the food going bad. Much of the total cost of fruit and vegetables is due to brokers who act as middlemen between farmers, traders and retailers and collusion is common, causing prices to further increase.

According to the USAID report, the most significant restraints faced by retailers were lack of storage/cold storage in marketplaces, poor market infrastructure, and seasonality of supply as well as price fluctuations and volatility[256]. Most fresh fruit and vegetables at retail (except in supermarkets, which account for just 5% of sales) are displayed under ambient conditions which expose them to high temperatures causing softening and shrivelling making the produce unmarketable[250].

14.5 The growth of supermarkets

Total supermarket sales are expected to grow, with their market share increasing to 10-20% within the next 10 years. Seeing the potential opportunities presented by the burgeoning middle class[257], Walmart and Carrefour have recently invested in Africa, with construction set to begin at a number of sites in Kenya. Supermarket sales have been growing at 7% per year for the last five years and are forecast to grow at 10-11% over the next five years in East Africa[258].

The growth of supermarkets is important as they require superior quality produce which must therefore be transported and stored using hygienic and temperature controlled systems. This will reduce the costs associated with the processing and wholesale sectors and help reduce food safety problems as well as food loss[257].

14.6 Mangoes – an opportunity

Kenya is one of the largest producer of mangoes worldwide (over 0.5 million tonnes tons produced annually), yet only 2% are exported (at a value of US$ 10 million in 2010[219]) and 5% processed[254,259], partially due to the limited production of internationally preferred varieties and to large post-harvest losses of 45%[260] (with some estimates being as high as 64% for small scale farmers[261]). A recent report has estimated that as much as 30% of mangoes are not harvested due to market price which makes it uneconomic to harvest[254] and that a further 30% of the remaining crop is lost postharvest.

Mangoes have a short growing season, which results in all the fruit ripening at once, creating a surplus which cannot be marketed due to a lack of infrastructure. Juicing or drying the surplus mangoes would open up new markets and help reduce loss. A small

mango processing plant is estimated to cost approximately €90,000 and would be able to handle 1,000 tons of mangoes per year. Coca Cola has recently invested US$ 62 million to increase capacity at a juice manufacturing plant in Kenya[254]. In Tana River County, a new mango fruit processing plant has also been established. At a cost of US$ 1.34 million, the plant will be able to process 30 tonnes of mangoes a day, most of which would have previously gone to waste[262]. Juicing the mangoes can increase the shelf life to up to a year. The mangoes for the Tana River County plant are supplied by a farmer's collective of more than 10,000 farmers.

Commitments by members of the FAO's *Save Food* initiative should help reduce the levels of loss by 2015, with an aim to reduce loss by 30,000 tons. Foreign investment is encouraged by Export Processing Zones (EPZ). This provides companies with a 10 year corporate tax holiday and a flat tax of 25% for 10 years (corporate tax is usually 30% and the overall tax rate is 49.6%), certain tax exceptions and 100% investment deduction on capital expenditure for 20 years[263]. The Kenyan Horticulture Competitiveness Project (KHCP) which is funded by USAID is backing a new project aimed at increasing the exports of mangoes grown by smallholders by 20% through a combination of grafting (to adopt new mango varieties) and increased irrigation.

Additionally, a recent report has highlighted that by using special reefer containers that are both temperature and atmosphere controlled, mangoes from the Ivory Coast, were able to be stored for an extra 9 weeks[200].

The value of exporting fresh produce using an uninterrupted cold chain has also been shown for avocados, with price premiums for avocados that had been packed and cooled as close to the farm as possible. A longer shelf life due to the use of a cold chain means that avocados can now be exported to Europe where they can fetch up to three times the price compared to the traditional Middle Eastern markets[264].

14.7 The financial cost of upgrading the value chain

The financial cost will largely depend on the approach selected. Below are the costs, estimated by an agricultural consultancy, of different approaches in Kenya[265].

- **Capacity Building:** A consultant would charge between US$ 300 to US$ 450 to train a maximum of 30 people per day
- **Cold storage facilities**: A charcoal cooler unit would cost from about US$ 125 to as high as US$ 2,000, a refrigerated container would cost US$ 7,500 while a cold room would cost from about US$ 20,000 onward
- **Value addition:** A simple value addition unit would cost from US$ 250 (e.g. homemade juice) and a modern value addition unit that would accommodate huge volumes costs from US$ 200,000 and above
- **Roads:** The cost would vary depending on the type selected for example tarmac would cost US$ 375,000 to 750,000 per km

15. The UK – an introduction

The food and drinks industry is the largest manufacturing sector in the UK, with a turnover of over £92 billion[266,267] and total consumer expenditure on food and drink exceeding £196 billion. The agri-food sector employs about 3.6 million people (13% of UK employment) across the whole food supply chain. The value of food and drink exports in 2013 was £18.9 billion while imports were £40.2 billion (according to a recent Defra report, the agricultural industry produces 59% of the UK's food needs, the remainder of which is imported[268]).

15.1 Food loss and waste

In the UK, approximately 14.8 million tonnes of food is lost or wasted every year; the production of this food produced 20 million tonnes of GHG emissions and consumed 6.2 billion litres of water[37]. Food loss and waste occurs throughout the food supply chain, although the majority occurs either during initial production or final consumption[62]. The Waste and Resources Action Programme (WRAP) has made the following estimates:

- **Agriculture** – up to 30% of vegetable crops are not harvested (out-graded) due to their physical appearance[40] (although some of this may be further processed for soups, pies etc.)
- **Food and drink manufacturing** – produce approximately 3.2 million tonnes of food loss[269], caused by technical errors, process inconsistencies, last-minute order cancellations or food offcuts (e.g. trimmings such as crusts or tomato ends)[270].
- **Food distribution** – there are few figures for food loss for logistics as it is usually assigned to either manufacturing or retail, however, WRAP has estimated that 4,000 tonnes of waste occur during distribution[269-271]. Losses are generally caused by human error or lack of planning.
- **Grocery retail** – about 300,000 tonnes of food are lost or wasted every year with at least 200,000 of this avoidable. Reducing this loss could potentially save retailers more that £360 million and 800,000 tonnes of GHG emissions[269,270]. Losses can be due to over-ordering, damaged stock or refrigeration breakdowns.
- **Catering and hospitality** – WRAP estimates that in the private sector, 600,000 tonnes of food are wasted every year and that if food had been better planned, stored and prepared about 400,000 tonnes of this could have been eaten[272]. In the public sector as much as 3.4 million tonnes of food is wasted, 2 million tonnes of which is avoidable.
- **Households** – contribute 7.2 million tonnes of food waste, 4.4 million tonnes or 61% of which is thought to be avoidable[273].

There has been significant progress in the UK at reducing food waste and loss. These are being achieved through initiatives such as:

- **The Courtauld Commitment** – delivered by WRAP and launched in 2005, a voluntary agreement to improve resource efficiently and reduce waste in the UK grocery sector[274].
    - Phase 1 – Prevented 1.2 million tonnes of packaging and food loss or waste and saved 3.3 million tonnes of CO_2e and £1.8 billion.
    - Phase 2 – A further 1.7 million tonnes of loss or waste was reduced, which cut CO_2e by 4.8 million tonnes and saved £3.1 billion. This was achieved by reducing loss in the supply chain by 7.4%, household food and drink waste by 3.7% and using 10% less packaging.
    - Phase 3 - The initiative is now in its third phase. 80% of waste is now recovered or recycled[274]. Phase three could help realise savings of £1.6 billion by reducing 1.1 million tonnes of waste as well as reduce GHG emissions by 2.9 million tonnes[275].
- **The Federation House Commitment** – established by the Food and Drink Federation (FDF), which aims to reduce overall water usage in the food and drink sector by 20% by 2020, compared to the 2007 baseline.
- **A Better Retailing Climate** – launched by the British Retail Consortium in 2008, the first phase which ended in 2013 exceeded all its targets to reduce the environmental impact of the retail sector. A new set of targets were launched at the start of 2014 to make the sector even more environmentally sustainable by 2020.
- **Vision 2020** - 40% of the waste ends up in landfill[266], launched in 2011, the initiative aims to reduce this to zero, which could produce over 1.1TWh of energy, reduce emissions by 27 million tonnes, return 1.3 million tonnes of nutrient to the soil and save £3.7 billion for the public sector, £12 billion for households and £2 billion for retailers, manufacturers and caterers[270].
- **Love Food Hate Waste** – launched by WRAP in 2007, the initiative is helping reduce household waste.

These initiatives are making a big impact. A recent WRAP report has shown that household waste has reduced in the UK by 21% between 2007 and 2012 due in part to changes in policy and regulation, for example the removal of 'display until' dates and changes to freezing guidance.

15.2 The grocery market – new trends

The UK grocery market is worth £174.5 billion (2013-2014) and is forecast to grow to £203 billion by 2019[276]. It accounts for 54.5p in every £1 of UK retail spending. The grocery market is dominated by the 'Big Four' supermarkets which account for nearly three quarters of all food and drink retail sales. One of the most significant shifts in recent years has been the rise of budget supermarkets such as Lidl and Aldi, and most recently Netto, as a consequence of the economic crisis, both of whom plan to double their number of stores over the next decade.

Online shopping is becoming far more popular with sales in 2013 of £6.5 billion (compared to £74 billion at superstores) and forecast to grow to £14.6 billion by 2018[276], which will result in the need for far more flexibility. A further change that has happened in the industry is a drop in warehouse stock levels with 72% of manufacturers and 65% of retailers making reductions in the last five years as supply chains have become more responsive. Reducing supply chain costs has enabled retailers to fund price cuts. According to IGD Research 6.3 billion cases of product are distributed through 3.2 million square metres of warehouse space. Most stock (93.4%) is supplied via centralised distribution which is a cost effective and more streamlined system compared to direct supplies to stores.

15.3 The cold chain

The UK has one of the leading food supply chain networks in the world. The temperature controlled logistics market is estimated to be worth about £23 billion (or 24% of the UK's £96 billion road transport market)[277]. There were 134,100 temperature controlled vehicles operating in the UK in 2010, with this number expected to grow by 28% and reach 172,000 vehicles by 2013[278]. This will be driven, in part, by the frozen food market which grew by 2.5% (for the year ending June 2014) with the sector worth just under £5.8 billion. The fastest growth was in sales of ice cream which have grown by 7.1% this year.

15.4 Environmental focus

The UK domestic food sector emitted around 176 million tonnes of CO_2e in 2011. There is a continued focus on environmental issues driven by consumer concerns. An example is Marks and Spencer's Plan A, a set of environmental commitments which aim to make the whole company more sustainable. They have managed to reduce emission levels from refrigeration and air conditioning by 68%, or 41,000 CO_2e tonnes compared to 2006 levels when the initiative was introduced[279]. This was achieved mainly by reducing leaks and increased efficiency. The company's stores and transportation fleet now use 20% less energy[278]. New nitrogen powered refrigeration systems pilot schemes are also in development. M&S now aims to reduce their store refrigeration emissions by 80% by 2020 and replace all store refrigeration which use hydrofluorocarbons (HFCs) with CO_2 by 2030.

16. Conclusions

- A third of all food produced globally is lost or wasted. Reducing this must be a global priority, to feed the millions of undernourished people worldwide and limit the huge environmental and economic burden imposed by food loss and waste.
- The major causes of perishable food loss in developing countries include: poor harvesting practices; lack of access to cold chains and reliable energy sources required to power them; market conditions; inadequate infrastructure; design of government policies
- Due to advanced cold chains and supply chain practices the levels of perishable food loss are generally much lower in developed countries. The major causes of food loss in developed countries include: field losses; out-grading; uncertainties in demand; improper handling; breaks in the cold chain
- Reducing food loss could be achieved by: implementing or improving the cold chain; better packaging; food processing; improved farming practices; upgrading infrastructure; utilising new information technologies; increased access to credit; better regulations; more and better education
- Some solutions to reduce loss can be implemented at specific sectors in the supply chain (farm or retail level) such as the use of better types of packaging, while others are more generic including large infrastructure projects. A broad range of stakeholders, from smallholder farmers to national governments, need to mount a concerted effort to reduce these huge levels of loss.
- We have highlighted a number of the approaches that can be employed to reduce food loss including the use of better packaging, processing and farming practices, implementing or improving the cold chain, upgrading infrastructure, utilising new information technologies, increased access to credit, better regulations and education.
- Case studies help to highlight the fact that one solution does not fit all contexts and that while the overall aim of reducing loss will be common, the solutions will vary.
- Whilst there are many challenges presented by food loss, education and investment will help reduce perishable food loss
- By weight, fruit and vegetables have the highest levels of loss and waste globally at 44% of the total, yet account for just 13% of total loss and waste in terms of energy content[2].
- Reducing fruit and vegetable loss would have a significant impact on the amount of micronutrients that would be available in developing countries, which would help to some degree, alleviate hidden hunger.
- The total calorific content that could potentially be saved if fruit and vegetable loss was reduced by 25% in the four countries we investigate (China, India, Pakistan and Kenya) would be the equivalent of enough energy to satisfy the requirements of up to 22 million people for a year.

- The impact of the micronutrient content of the fruit and vegetables is even greater, having the equivalent iron content for up to 66 million people and vitamin A content for up to 70 million people. This highlights the pressing need to reduce global perishable food loss.
- Food waste should be avoided if possible, but if waste does occur, it is important that all efforts are made to re-use the food by donating to charity food banks or using as animal feed. Other uses further down the food waste hierarchy include industrial uses, anaerobic digestions or composting. Landfill or incineration should be a last resort.
- Reducing food loss has consequences beyond simply increasing calories available for consumption. Market effects of increased supply can have an impact on price and income for producers which might affect future production decisions. Equally, smoothing of supply over longer periods through storage could reduce the spike-like nature associated with short harvest and marketing periods.
- More data is needed to assess the amount of food loss and the micronutrient impact of this food loss. Additional data is also needed on the impact on rural income, the most effective types of education, especially using new technologies such as mobile services, the amount of out-grading and what happens to food waste.
- Many governments are beginning to invest seriously in cold chain infrastructure. For example, in India, the National Centre for Cold Chain Development has recently been established which aims to promote and develop an integrated cold chain for perishable produce. There is also investment from developed countries such as the US (through USAID or the USDA Emerging Markets Programme) or Japan (through the Cool Japan Fund). Other drivers of change such as the growing middle class in emerging markets will increase the consumption of perishable foods, which will increase the potential returns for private investors and help improve supply chains.

17. References

1. Rockefeller_Foundation. Waste and Spoilage in the Food Chain. in *Decision Intelligence Document* (Rockefeller Foundation, 2013).
2. Lipinski, B. *et al.* Reducing food loss and waste. *World Resources Institute Working Paper, June* (2013).
3. FAO, I.a.W. The State of Food Insecurity in the World 2014: Strengthening the enabling environment for food security and nutrition. (FAO, Rome, Italy, 2014).
4. Kennedy, G., Nantel, G. & Shetty, P. The scourge of" hidden hunger": global dimensions of micronutrient deficiencies. *Food Nutrition and Agriculture*, 8-16 (2003).
5. Wu, S.-H., Ho, C.-T., Nah, S.-L. & Chau, C.-F. Global Hunger: A Challenge to Agricultural, Food, and Nutritional Sciences. *Critical Reviews in Food Science and Nutrition* **54**, 151-162 (2014).
6. FAO, W.a.I. The State of Food Insecurity in the World 2012: Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. (FAO, Rome, 2012).
7. Roberts, L. 9 Billion? *Science* **333**, 540-543 (2011).
8. Chakraborty, S. & Newton, A.C. Climate change, plant diseases and food security: an overview. *Plant Pathology* **60**, 2-14 (2011).
9. Vermeulen, S.J., Campbell, B.M. & Ingram, J.S. Climate change and food systems. *Annual Review of Environment and Resources* **37**, 195 (2012).
10. Qadir, M., Sharma, B., Bruggeman, A., Choukr-Allah, R. & Karajeh, F. Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. *Agricultural water management* **87**, 2-22 (2007).
11. FAO. The state of food insecurity in the world 2000. (FAO, Rome, Italy, 2000).
12. Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R. & Meybeck, A. *Global food losses and food waste: extent, causes and prevention*, (FAO Rome, 2011).
13. Kummu, M. *et al.* Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment* **438**, 477-489 (2012).
14. HLPE. Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. (Rome, 2014).
15. Tilman, D., Balzer, C., Hill, J. & Befort, B.L. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences* **108**, 20260-20264 (2011).
16. Kader, A.A. Increasing food availability by reducing postharvest losses of fresh produce. in *V International Postharvest Symposium 682* 2169-2176 (2004).
17. Kitinoja, L., Saran, S., Roy, S.K. & Kader, A.A. Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy. *Journal of the Science of Food and Agriculture* **91**, 597-603 (2011).
18. Parfitt, J., Barthel, M. & Macnaughton, S. Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences* **365**, 3065-3081 (2010).

19. APHLIS. Estimated Postharvest Losses (%) 2003-2013. (African Postharvest Losses Information System, 2014).
20. Weinberger, K., Genova Ii, C. & Acedo, A. Quantifying postharvest loss in vegetables along the supply chain in Vietnam, Cambodia and Laos. *International Journal of Postharvest Technology and Innovation* **1**, 288-297 (2008).
21. Genova, C., Weinberger, K. & Acedo, A. Understanding postharvest losses in vegetables using an upstream supply chain approach in South East Asia. *Proceedings of Tropentag, Utilisation of diversity in land use systems: sustainable and organic approaches to meet human needs, Witzenhausen, Germany*, 9-11 (2007).
22. Acedo, A. & Easdown, W. AVRDC-The World Vegetable Center's Postharvest Initiatives in South Asia. in *National Conference on Pre-/Post Harvest Losses and Value Addition in Vegetables.* (Varanasi, India, 2014).
23. Coulomb, D. Refrigeration and cold chain serving the global food industry and creating a better future: two key IIR challenges for improved health and environment. *Trends in Food Science & Technology* **19**, 413-417 (2008).
24. Kitinoja, L. Use of cold chains for reducing food losses in developing countries. (The Postharvest Education Foundation 2013).
25. FAO. Food Wastage Footprint - Impacts on natural resources - Technical Report. (2013).
26. IMechE. A tank of cold; Cleantech leapfrog to a more food secure world. (Institute of Mechanical Engineers, 2014).
27. Igbinnosa, M.A. Opportunity for Value Chain Development by Improving Beef Processing Practices in Rural Tanzania. (2011).
28. Buzby, J.C., Wells, H.F. & Hyman, J. The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States. *Economic Information Bulletin, United States Department of Agriculture, ii-33* (2014).
29. Gunders, D. Wasted: How America is losing up to 40 percent of its food from farm to fork to landfill. *Natural Resources Defense Council Issue Paper. August. This report was made possible through the generous support of The California Endowment* (2012).
30. Buzby, J.C. & Hyman, J. Total and per capita value of food loss in the United States. *Food Policy* **37**, 561-570 (2012).
31. Buzby, J.C., Wells, H.F., Axtman, B. & Mickey, J. Supermarket loss estimates for fresh fruit, vegetables, meat, poultry, and seafood and their use in the ERS loss-adjusted food availability data. (United States Department of Agriculture, Economic Research Service, 2009).
32. Beretta, C., Stoessel, F., Baier, U. & Hellweg, S. Quantifying food losses and the potential for reduction in Switzerland. *Waste management* **33**, 764-773 (2013).
33. Kranert, M. Determination of discarded food and proposals for a minimization of food wastage in Germany. (University of Stuttgart, 2012).
34. Rossaint, S. & Kreyenschmidt, J. Intelligent label - a new way to support food waste reduction. . *Waste and Resource Management* (2014).
35. Schneider, F., Part, F., Lebersorger, S. & Bohm, K. Sekundärstudie Lebensmittelabfälle in Österreich. ABF-BKOU. . in *unpublished* (Umweltbundesamt, Vienna, 2012).
36. Quested, T. & Johnson, H. *Household food and drink waste in the UK: final report*, (Wastes & Resources Action Programme (WRAP), 2009).

37. Quested, T., Ingle, R. & Parry, A. Household Food and Drink Waste in the United Kingdom (WRAP, UK, 2012).
38. Naziri, D. (University of Greenwich, 2014).
39. Kader, A. Increasing food availability by reducing post harvest losses of fresh produce. 5th Int. in *Postharvest Symposium. Retrieved* Vol. 28 (2012).
40. IMechE. Global Food: Waste Not Want Not. (IMechE, 2013).
41. Srivastava, P. & Ahmad, S. Advancements in Post-harvest Management of Fruits and Vegetables. in *Food Processing: Strategies for Quality Assessment* 427-452 (Springer, 2014).
42. Brosnan, T. & Sun, D.-W. Precooling techniques and applications for horticultural products—a review. *International Journal of Refrigeration* **24**, 154-170 (2001).
43. Yahia, E. Cold chain development and challenges in the developing world. in *VI International Postharvest Symposium 877* 127-132 (2009).
44. Kitinoja, L. Use of cold chains for reducing food losses in developing countries. *Population* **6**, 5.60 (2013).
45. Artiuch, P. & Kornstein, S. Sustainable approaches to reducing food waste in india. in *MIT Independant Activities Period Research Project* (MIT, 2012).
46. Agrawal, V. Personal communication. (CDC India, Jaipur, India, 2014).
47. Birthal, P.S. & Joshi, P.K. Smallholder farmers' access to markets for high-value agricultural commodities in India. in *Case study #6-4* (eds Pinstrup-Andersen, P. & Cheng, F.) (Cornell University, Ithaca, New York. , 2007).
48. IEA. World Energy Outlook 2012: Measuring progress towards Energy for All. (International Energy Agency (IEA)/Organization for Economic Co-operation and Development (OECD), Paris, 2012).
49. Terrapon-Pfaff, J., Dienst, C., König, J. & Ortiz, W. A cross-sectional review: Impacts and sustainability of small-scale renewable energy projects in developing countries. *Renewable and Sustainable Energy Reviews* **40**, 1-10 (2014).
50. ADB. Asian Development Outlook 2013 - Asia's Energy Challenge. (Asian Development Bank, 2013).
51. Salin, V. & Nayga Jr, R.M. A cold chain network for food exports to developing countries. *International Journal of Physical Distribution & Logistics Management* **33**, 918-933 (2003).
52. FAO. Land reform - Land settlement and cooperatives. (ed. Groppo, P.) (FAO, 2003).
53. Alexiades, A., Sánchez, J.I., Lekashman, K. & Muse, W. Cost and Commercialization Analysis for Cold Storage Technology in Kenya. (UC Davies, 2014).
54. NRDC. Left-Out: An Investigation of Fruit and Vegetable Losses on the Farm (NRDC, 2012).
55. Kantor, L.S., Lipton, K., Manchester, A. & Oliveira, V. Estimating and addressing America's food losses. *Food Review* **20**, 2-12 (1997).
56. WRAP. Sector guidance note: Preventing waste in the fruit and vegetable supply chain. (WRAP, 2012).
57. Stuart, T. *Waste: uncovering the global food scandal*, (WW Norton & Company, 2009).
58. WRAP. Fruit and vegetable resource maps. (WRAP, 2011).
59. Raab, V., Petersen, B. & Kreyenschmidt, J. Temperature monitoring in meat supply chains. *British Food Journal* **113**, 1267-1289 (2011).

60. Purfresh. Purfresh Total Active Environment Solution for Intermodal Shipping of Perishable and Temperature Sensitive Commodities. (UC Davis Emerging Postharvest Technologies, 2013).
61. Heap, R. Cold chain performance issues now and in the future. *Bulletin of the IIR*, 1-11 (2006).
62. Bond, M., Meacham, T., Bhunnoo, R. & Benton, T. Food waste within global food systems. (Global Food Security Programme (GFS), 2013).
63. Munesue, Y., Masui, T. & Fushima, T. The effects of reducing food losses and food waste on global food insecurity, natural resources, and greenhouse gas emissions. *Environmental Economics and Policy Studies*, 1-35 (2014).
64. von Grebmer, K. *et al.* 2014 Global Hunger Index: The challenge of hidden hunger. *IFPRI books* (2014).
65. Miller, B.D.D. & Welch, R.M. Food system strategies for preventing micronutrient malnutrition. *Food Policy* **42**, 115-128 (2013).
66. Micronutrient_Initiative. *Investing in the Future: A United Call to Action on Vitamin and Mineral Deficiencies: Global Report, 2009*, (Micronutrient Initiative, 2009).
67. Government_of_Pakistan. National Nutrition Surevy 2011. (Ministry of Planning and Development, Ministry of National Health Services, Regulations & Coordination, 2011).
68. MoPHS. Report on Nutrition Situation in Kenya. (Ministry of Public Health Services [Kenya] & Save the Children UK, 2011).
69. Transform_Nutrition. Kenya: Situation analysis for Transform Nutrition. (Transform Nutrition, 2011).
70. NNMB. Prevalence of micronutrient deficiencies; Technical report No.22. (National Nutrition Monitoring Bureau, National Institute of Nutrition, ICMR, 2003).
71. NNMB. Diet and nutrition status of populations and prevalence of hypertension among adults in rural areas;. Technical Report No 24. (National Nutrition Monitoring Bureau, National Institute of Nutrition, ICMR, 2006).
72. NFHS-3. National Family Health Survey. (International Institute of population Sciences, Mumbai, India, 2006).
73. INSA. Micro-nutrient security for India - Priorities for research and action. (Indian National Science Academy, New Delhi, 2011).
74. Liu, J. *et al.* Micronutrients deficiency and associated sociodemographic factors in Chinese children. *World Journal of Pediatrics* **7**, 217-223 (2011).
75. Qin, Y. *et al.* Association of dietary pattern and body weight with blood pressure in Jiangsu Province, China. *BMC public health* **14**, 948 (2014).
76. Affognon, H., Mutungi, C., Sanginga, P. & Borgemeister, C. Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-Analysis. *World Development* **66**, 49-68 (2015).
77. Wang, W., Jaeger, F., Li, X., Wang, X. & Zhang, J. China's food production and Cold Chain Logistics. in *Paper presented at 5th Int. Workshop on Cold Chain Management at University of Bonn, Germany during June 10–11* (2013).
78. Liu, G. Food losses and food waste in China: a first estimate. (OECD Publishing, 2014).
79. Jiang, X.-m. Development Status of China's Logistics Market. in *Contemporary Logistics in China* 17-31 (Springer, 2013).
80. Sudheer, K. & Indira, V. *Post harvest technology of horticultural crops*, (New India Publishing, 2007).

81. Rolle, R.S. 2. IMPROVING POSTHARVEST MANAGEMENT AND MARKETING IN THE ASIA-PACIFIC REGION: ISSUES AND CHALLENGES. *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* (2006).
82. Maheshwar, C. & Chanakwa, T. Postharvest losses due to gaps in cold chain in India-a solution. in *IV International Conference on Managing Quality in Chains-The Integrated View on Fruits and Vegetables Quality 712* 777-784 (2006).
83. PHDEB. Establishment of cold chain system under NTC improvement project. (Pakistan Horticulture Deveopment and Export Board, 2007).
84. Ibrahim, M. & Anwar, R. Horticultural Education, Extension and Training System in Pakistan. in *IV International Symposium on Horticultural Education, Extension and Training 672* 145-151 (2004).
85. FAO. FAO Statistical Yearbook 2012 Africa. (FAO, Accra, 2012).
86. van der Lans, C., Snoek, H., de Boer, F. & Elings, A. Vegetable chains in Kenya. (2012).
87. Katona, P. & Katona-Apte, J. The interaction between nutrition and infection. *Clinical Infectious Diseases* **46**, 1582-1588 (2008).
88. CBI. CBI Tradewatch Fresh Fruit and Vegetables. (CBI Minsitry of Foreign Affairs, 2014).
89. FAO. Food wastage footprint Full-cost accounting. (2014).
90. FAO. How does international price volatility affect domestic economies and food security? in *The state of food insecurity in the world* (FAO, 2011).
91. Garnett, T. *Cooking up a storm: Food, greenhouse gas emissions and our changing climate*, (Food Climate Research Network, Centre for Environmental Strategy, University of Surrey, 2008).
92. Venkat, K. The climate change and economic impacts of food waste in the United States. *International Journal on Food System Dynamics* **2**, 431-446 (2012).
93. FAO, O.J., Tostivint, C., Turbé, A., O'Connor, C. & Lavelle, P. Food Wastage Footprint, Summary Report2013. 63 p.
94. Lundqvist, J., de Fraiture, C. & Molden, D. Saving water: from field to fork: curbing losses and wastage in the food chain. (2008).
95. Monier, V. *Preparatory study on food waste across EU 27*, (European Commission, 2011).
96. EPA. Waste Reduction Model (WARM). (EPA, 2014).
97. Torero, M. A framework for linking Small Farmers to Markets. in *Paper presented at the IFAD Conference on New Directions for Smallholder Agriculture* Vol. 24 25 (2011).
98. Lowder, S.K., Skoet, J. & Singh, S. What do we really know about the number and distribution of farms and family farms in the world? *Background paper for The State of Food and Agriculture*, 8 (2014).
99. Jaleta, M., Gebremedhin, B. & Hoekstra, D. Smallholder commercialization: Processes, determinants and impact. (2009).
100. Jayne, T.S., Haggblade, S., Minot, N. & Rashid, S. Agricultural Commercialization, Rural Transformation and Poverty Reduction: What have We Learned about How to Achieve This? in *Synthesis report prepared for the African Agricultural Markets Programme Policy Symposium, Alliance for Commodity Trade in Eastern and Southern Africa* (Kigali, Rwanda, 2011).
101. Zeller, M. *et al.* Policies for sustainable development: the commercialization of smallholder agriculture. in *Sustainable Land Use and Rural Development in Southeast Asia: Innovations and Policies for Mountainous Areas* 463-490 (Springer, 2013).

102. Kitinoja, L. Returnable Plastic Crate (RPC) systems can reduce postharvest losses and improve earnings for fresh produce operations. Vol. PEF White Paper No. 13-01 (Post harvest Education Foundation, 2013).
103. Fernando, M.D. Country paper – Sri Lanka (2). in *Proceedings of seminar on post-harvest management of fruit and vegetables in the Asia-Pacific region* pp. 264–275 (Asian Productivity Organization (Tokyo) and UN FAO (Rome), 2006).
104. CNFA. Afghanistan: Longer shelf life for tomatoes drastically improves incomes. in *E-Newsletter Issue No. 2* (CNFA, 2006).
105. WPO. Packaging is the answer to world hunger. (World Packaging Organization, 2009).
106. Manzini, R. & Accorsi, R. The new conceptual framework for food supply chain assessment. *Journal of Food Engineering* **115**, 251-263 (2013).
107. Caleb, O.J., Mahajan, P.V., Al-Said, F.A.-J. & Opara, U.L. Modified Atmosphere Packaging Technology of Fresh and Fresh-cut Produce and the Microbial Consequences—A Review. *Food and Bioprocess Technology* **6**, 303-329 (2013).
108. Caleb, O.J., Opara, U.L. & Witthuhn, C.R. Modified atmosphere packaging of pomegranate fruit and arils: a review. *Food and Bioprocess Technology* **5**, 15-30 (2012).
109. Vanndy, M., Buntong, B., Acedo Jr, A. & Weinberger, K. Modified atmosphere packaging to improve shelf life of tomato fruit in Cambodia. in *Europe-Asia Symposium on Quality Management in Postharvest Systems-Eurasia 2007 804* 453-458 (2007).
110. Yahia, E.M. Needs for active packaging in developing countries. *Intelligent and Active Packaging for Fruits and Vegetables*, 263 (2010).
111. Vanderroost, M., Ragaert, P., Devlieghere, F. & De Meulenaer, B. Intelligent food packaging: The next generation. *Trends in Food Science & Technology* **39**, 47-62 (2014).
112. Heising, J.K., Dekker, M., Bartels, P.V. & Van Boekel, M. Monitoring the quality of perishable foods: opportunities for intelligent packaging. *Critical Reviews in Food Science and Nutrition* **54**, 645-654 (2014).
113. Zhang, C. Knowing whether food has spoiled without even opening the container. in *47th National Meeting & Exposition of the American Chemical Society (ACS)* (Dallas, 2014).
114. Mills, A. Oxygen indicators and intelligent inks for packaging food. *Chemical Society Reviews* **34**, 1003-1011 (2005).
115. Jiang, X. *et al.* Future Perspectives Towards the Use of Nanomaterials for Smart Food Packaging and Quality Control. *Particle & Particle Systems Characterization* (2014).
116. Nandane, A.S. & Jain, R. Value Addition of Fruits and Vegetables by Edible Packaging: Scope and Constraints. (2011).
117. Ali, A., Maqbool, M., Alderson, P.G. & Zahid, N. Effect of gum arabic as an edible coating on antioxidant capacity of tomato (< i> Solanum lycopersicum</i> L.) fruit during storage. *Postharvest Biology and Technology* **76**, 119-124 (2013).
118. Nair, S. & Lau, K. Postharvest Food Wastage Reduction in Fruit and Vegetables through Cold Chain Collaboration: a Theoretical Framework. in *VII International Postharvest Symposium 1012* 1311-1315 (2012).
119. Atkin, O.K. & Tjoelker, M.G. Thermal acclimation and the dynamic response of plant respiration to temperature. *Trends in plant science* **8**, 343-351 (2003).

120. Hsiao, T.C. Plant responses to water stress. *Annual review of plant physiology* **24**, 519-570 (1973).
121. Kitinoja, L. & Thompson, J.F. Pre-cooling systems for small-scale producers. *Stewart Postharvest Review* **6**, 1-14 (2010).
122. McDonald, K. & Sun, D.-W. Vacuum cooling technology for the food processing industry: a review. *Journal of Food Engineering* **45**, 55-65 (2000).
123. Mogaji, T.S. & Fapetu, O. Development of an evaporative cooling system for the preservation of fresh vegetables. *African Journal of Food Science* **5**, 255-266 (2011).
124. Vanndy, M. *et al.* Evaporative cooling storage of tomato in Cambodia and Laos. in *Europe-Asia Symposium on Quality Management in Postharvest Systems-Eurasia 2007 804* 565-570 (2007).
125. Vanndy, M., Buntong, B., Acedo Jr, A. & Weinberger, K. Improving postharvest reddening and shelf life of fresh chili (Capsicum annuum) using simple evaporative cooler. in *Europe-Asia Symposium on Quality Management in Postharvest Systems-Eurasia 2007 804* 561-565 (2007).
126. Tilahun, S. Feasibility and economic evaluation of low-cost evaporative cooling system in fruit and vegetables storage. *African Journal of Food, Agriculture, Nutrition and Development* **10**(2010).
127. Mitcham, B. Postharvest Handling Systems for Small-Scale Farmers Throughout the World. (Horticulture Collaborative Research Support Program (Hort CRSP), UC Davis, 2011).
128. Choudhury, B., Saha, B.B., Chatterjee, P.K. & Sarkar, J.P. An overview of developments in adsorption refrigeration systems towards a sustainable way of cooling. *Applied Energy* **104**, 554-567 (2013).
129. IMechE. A tank of cold: cleantech leapfrog to a more foodsecure world. (IMechE, 2014).
130. Bansal, P. A review–Status of CO 2 as a low temperature refrigerant: Fundamentals and R&D opportunities. *Applied Thermal Engineering* **41**, 18-29 (2012).
131. Otanicar, T., Taylor, R.A. & Phelan, P.E. Prospects for solar cooling–An economic and environmental assessment. *Solar Energy* **86**, 1287-1299 (2012).
132. Ullah, K., Saidur, R., Ping, H., Akikur, R. & Shuvo, N. A review of solar thermal refrigeration and cooling methods. *Renewable and Sustainable Energy Reviews* **24**, 499-513 (2013).
133. Devabhaktuni, V. *et al.* Solar energy: Trends and enabling technologies. *Renewable and Sustainable Energy Reviews* **19**, 555-564 (2013).
134. FS-UNEP. Global trends in renewable energy investment 2014. (The Frankfurt School-UNEP Collaborating Centre, the United Nations Environment Programme (UNEP) and Bloomberg New Energy Finance (BNEF), 2014).
135. Tassou, S., Lewis, J., Ge, Y., Hadawey, A. & Chaer, I. A review of emerging technologies for food refrigeration applications. *Applied Thermal Engineering* **30**, 263-276 (2010).
136. Magnussen, O.M., Haugland, A., Torstveit Hemmingsen, A.K., Johansen, S. & Nordtvedt, T.S. Advances in superchilling of food–Process characteristics and product quality. *Trends in Food Science & Technology* **19**, 418-424 (2008).
137. Einarsson, H. Deep chilling (Superchilling, partial freezing)-a literature survey. *SIKs Service series (30). Gothenburg, Sweden, SIK-The Swedish Food Institute, Chalmers University of Technology* (1988).

138. James, S., James, C. & Evans, J. Modelling of food transportation systems–a review. *International Journal of Refrigeration* **29**, 947-957 (2006).
139. Raab, V. *et al.* Generic model for the prediction of remaining shelf life in support of cold chain management in pork and poultry supply chains. *Journal on Chain and Network Science* **8**, 59-73 (2008).
140. Rong, A., Akkerman, R. & Grunow, M. An optimization approach for managing fresh food quality throughout the supply chain. *International Journal of Production Economics* **131**, 421-429 (2011).
141. Yu, M. & Nagurney, A. Competitive food supply chain networks with application to fresh produce. *European Journal of Operational Research* **224**, 273-282 (2013).
142. Kuo, J.-C. & Chen, M.-C. Developing an advanced multi-temperature joint distribution system for the food cold chain. *Food control* **21**, 559-566 (2010).
143. Montanari, R. Cold chain tracking: a managerial perspective. *Trends in Food Science & Technology* **19**, 425-431 (2008).
144. Joshi, R., Banwet, D. & Shankar, R. A Delphi-AHP-TOPSIS based benchmarking framework for performance improvement of a cold chain. *Expert Systems with Applications* **38**, 10170-10182 (2011).
145. Shabani, A., Saen, R.F. & Torabipour, S.M.R. A new benchmarking approach in Cold Chain. *Applied Mathematical Modelling* **36**, 212-224 (2012).
146. McKinsey. Asia's $1 trillion infrastructure opportunity. (2011).
147. Ong-Junio, D.R. Asian Infrastructure Investment Bank: An Idea Whose Time Has Come? in *The Diplomat* (2014).
148. ADB. ASEAN Infrastructure Fund. (Asian Development Bank, 2014).
149. CEPAL. The economic infrastructure gap in Latin America and the Caribbean. (The Economic Commision for Latin America and the Caribbean (CEPAL), 2011).
150. World_Bank. Key Data from Infrastructure in Latin America and the Caribbean: Recent Developments and Key Challenge. (World Bank, 2014).
151. CEPAL. Maritime reefer trade in South America: a comparison of the west and east coasts (The Economic Commision for Latin America and the Caribbean (CEPAL), 2013).
152. Bond, D.L., Platz, D. & Magnusson, M. Financing small-scale infrastructure investments in developing countries. *United Nations Department of Economic and Social Affairs*, 1 (2012).
153. J.P.Morgan. EM Moves into the Mainstream as an Asset Class, Emerging Markets Research. (J.P. Morgan Securities LLC, New York, 2010).
154. Parveen, S., Ishfaq, B., Kausar, H., Saeed, S. & Ali, M.A. Value Addition: A Tool to Minimize the Post-harvest Losses in Horticultural Crops.
155. UNIDO. Small-scale Fruit and Vegetable Processing and Products. in *UNIDO Technology Manual* (United Nations Industrial Development Organisation Vienna, 2004).
156. Neves, M.F., Trombin, V.G., Lopes, F.F., Kalaki, R. & Milan, P. World consumption of fruit juices, nectars, and still drinks. in *The orange juice business* 119-119 (Springer, 2012).
157. Bhardwaj, R.L. & Pandey, S. Juice blends—a way of utilization of under-utilized fruits, vegetables, and spices: a review. *Critical Reviews in Food Science and Nutrition* **51**, 563-570 (2011).

158. Mohapatra, D., Mishra, S., Singh, C.B. & Jayas, D.S. Post-harvest processing of banana: Opportunities and challenges. *Food and Bioprocess Technology* **4**, 327-339 (2011).
159. Abad, E. *et al.* RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain. *Journal of Food Engineering* **93**, 394-399 (2009).
160. Vergara, A. *et al.* An RFID reader with onboard sensing capability for monitoring fruit quality. *Sensors and Actuators B: Chemical* **127**, 143-149 (2007).
161. Todd, B., Phillips, M., Schultz, S.M., Hawkins, A.R. & Jensen, B.D. Low-cost RFID threshold shock sensors. *Sensors Journal, IEEE* **9**, 464-469 (2009).
162. Steinberg, I.M. & Steinberg, M.D. Radio-frequency tag with optoelectronic interface for distributed wireless chemical and biological sensor applications. *Sensors and Actuators B: Chemical* **138**, 120-125 (2009).
163. Cho, N., Song, S.-J., Kim, S., Kim, S. & Yoo, H.-J. A 5.1-μW UHF RFID tag chip integrated with sensors for wireless environmental monitoring. in *Solid-State Circuits Conference, 2005. ESSCIRC 2005. Proceedings of the 31st European* 279-282 (IEEE, 2005).
164. Ruiz-Garcia, L., Lunadei, L., Barreiro, P. & Robla, I. A review of wireless sensor technologies and applications in agriculture and food industry: state of the art and current trends. *Sensors* **9**, 4728-4750 (2009).
165. Jedermann, R., Nicometo, M., Uysal, I. & Lang, W. Reducing food losses by intelligent food logistics. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* **372**, 20130302 (2014).
166. Intelleflex. The cost of cold chain skrink and the value of delivered freshness for produce. (Intelleflex, 2012).
167. Allied_Market_Research. Food Traceability Market (Tracking Technologies) Global Industry Analysis, Size, Share, Trends, Opportunities and Forecast, 2012 - 2020. (Allied Market Research 2014).
168. Bhattacharya, N. Strategic Analysis of Global RFID in Cold Chain Market. (Frost & Sullivan, 2013).
169. Hardgrave, B.C., Waller, M. & Miller, R. Does RFID reduce out of stocks? A preliminary analysis. *Information technology research institute* (2005).
170. Ericsson. Sub-Saharan Africa - Ericsson Mobility Report. (2014).
171. http://icow.co.ke/. Vol. 2014 (2014).
172. http://www.mfarm.co.ke/. Vol. 2014 (2014).
173. http://www.mkulimayoung.co.ke/. Vol. 2014 (2014).
174. http://cheetah.ujuizi.com/. Vol. 2014 (2014).
175. Rosen, J. Personal communication. (JC Rosen Resources 2014).
176. Yaron, J., Benjamin, M.P. & Piprek, G.L. *Rural finance: Issues, design, and best practices*, (World Bank Washington, DC, 1997).
177. Meyer, R.L. Microcredit and Agriculture: Challenges, Successes, and Prospects. *Microfinance in Developing Countries: Issues, Policies and Performance evaluation, Gueyie, JP., Manos, R et Yaron, J. éd.(New York: Palgrave Macmillan)*, 199-222 (2013).
178. USAID. Asset-Based Financing for Smallholder Farmers Project. (USAID, 2014).
179. standards.org. Hazard Analysis Critical Control Point. (standards.org, 2014).

180. Taylor, E. HACCP in small companies: benefit or burden? *Food Control* **12**, 217-222 (2001).
181. WRAP. Improving the application and understanding of date labels and storage guidance: Activity brief United Kingdom (WRAP, 2010).
182. FAO. Reducing Food Losses and Waste in the Near East & North Africa Region. in *FAO Regional conference for the Near East* (Rome, Italy, 2014).
183. Bishop, C. Cold Chain and Postharvest Sector in Pakistan. in *The Agribusiness Project* (USAID, 2013).
184. PEF. Small scale Postharvest Handling Technologies Short Course/Study Tour 23-27 February 2015 in Arusha, Tanzania. (Postharvest Education Foundation, 2014).
185. UN. World Urbanization Prospects: The 2014 Revision. (United Nations, New York, 2014).
186. Kharas, H. *The emerging middle class in developing countries*, (OECD Development Centre Paris, 2010).
187. HSBC. The World in 2050. (HSBC, 2012).
188. Wilkinson, J. & R., R. Agri-processing and developing countries. in *Background paper for the world develpment report 2008* (World Bank, 2006).
189. Barthel, C. & Götz, T. The overall worldwide saving potential from domestic refrigerators and freezers. (Wuppertal Institute for Climate, Environment and Energy., 2012).
190. Reardon, T. & Berdegue, J.A. The rapid rise of supermarkets in Latin America: challenges and opportunities for development. *Development policy review* **20**, 371-388 (2002).
191. Rao, E.J., Brümmer, B. & Qaim, M. Farmer participation in supermarket channels, production technology, and efficiency: the case of vegetables in Kenya. *American Journal of Agricultural Economics*, aas024 (2012).
192. Krohm, D. Feeding America, Personal communication. (2014).
193. Lin, C.S.K. *et al.* Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective. *Energy & Environmental Science* **6**, 426-464 (2013).
194. Tuck, C.O., Pérez, E., Horváth, I.T., Sheldon, R.A. & Poliakoff, M. Valorization of biomass: deriving more value from waste. *Science* **337**, 695-699 (2012).
195. BSR. Food Waste Study—Tier 1 Assessment (GMA/FMI) (2012).
196. EPA. Feeding the Hungry and Reducing Solid Waste Through Food Recovery. in *Waste not, want not* (EPA, 2010).
197. Hall, K.D., Guo, J., Dore, M. & Chow, C.C. The progressive increase of food waste in America and its environmental impact. *PLoS One* **4**, e7940 (2009).
198. U.S.DoS. Postharvest Loss Challenges Discussion Paper. (Office of Agriculture, Biotechnology, and Textile Trade Affairs. Bureau of Economics and Business Affairs. U.S. Department of State, 2013).
199. Maersk. Unlocking the potential of the Indian banana trade. (Maersk Line, 2011).
200. Maersk. MCI eyes “revolution” of mango trade. (Maersk Container Industry, 2014).
201. Lipowicz, M. & Basta, N. Biopharma cold-chain forecast. in *The 2014 Pharmaceutical Commerce Biopharma Cold Chain Sourcebook* (Pharmaceutical Commerce, 2014).
202. WTO. Merchandise trade by product. (World Trade Organisation (WTO), 2008).
203. FAO. Food security indicators. in *FAOSTAT* (2014).

204. Emerson. Integrated Cold Chain Solutions from Emerson Climate Technologies Facilitate Cold Chain Logistics and Food Freshness Preservation. (2013).
205. Bamboo_Innovator. More Chinese firms eye potential of cold chain logistics. (Bamboo Innovator, 2014).
206. BBC. Timeline: China milk scandal. (BBC, 2010).
207. BBC. Mass arrests in China illegal 'gutter oil' police sting. (BBC, 2011).
208. BBC. Bad taste lingers over China's latest food scandal. (ed. Sudworth, J.) (2014).
209. Mao, X., Hu, J. & Liu, X. Epidemiological burden of bacterial foodborne diseases in China—preliminary study. *Chin J Food Hyg* **23**, 132-136 (2011).
210. Zhang, T.B. (A. T. Kearney, Global Cold Chain China Summit, 2008).
211. Wilkins, K. & Zurawski, A. Infrastructure Investment in China. *RBA Bulletin*, 27-36 (2014).
212. RBS_Consultants. Cold chain logistics to grow 25% a year, players must seize opportunities. (Roland Berger Strategy Consultants, 2014).
213. Tang, O.T.K. & Liu, T. China Logistics. (KimEng, 2014).
214. EY. China and India: tomorrow's middle classes. (EY, 2013).
215. Chan, W. & Tse, A. The consumer trap: retailers need to adapt to entice fickle Chinese shoppers into their stores. *McKinsey & Company* (2007).
216. AT_Kearney. The China Cold Chain Is Heating Up. (AT Kearney, 2009).
217. unicef. Picture in India - Nutrition. (2014).
218. Emerson. The food wastage and cold storage infrastructure relationship in India: Developing realistic solutions. (Emerson, 2013).
219. FAOSTAT. Food and Agricultural commodities production. (2014).
220. Assocham. Cold Chain industry in India. (Assocham and Reed Anlalysis, 2014).
221. Celestine, A. How Agra became India's cold storage hub and what impact it has on price of potatoes. in *The Economic Time (India)* (2012).
222. Ghosh, S. Loss Reduction and Efficiency Improvement: A Critical Appraisal of Power Distribution Sector in India. *International Journal of Modern Engineering Research (IJMER)* **2**(2012).
223. Gambhir, A. Imperial College London (2012).
224. Farrell, D. & Beinhocker, E. Next big spenders: India's middle class. *Business Week* **19**(2007).
225. TechSci_Research. India Cold Chain Market Forecast & Opportunities, 2017. (TechSci Research, 2012).
226. IGD. Tackling India's modern grocery sector. (IGD, 2014).
227. BCG. Turning Online Grocery Sales to Gold. (Boston Consulting Group, 2014).
228. Council, N.I. *Global Trends 2030: Alternative Worlds*, (Central Intelligence Agency, 2013).
229. Aslam, M. & Amin, S. Fruit, Vegetables and Condiments statistics of Pakistan. (Ministry of National Food Security and Research, Islamabad, 2013).
230. PBS. Number and area of farms by size of farm. (Pakistan Bureau of Statistics, 2010).
231. FAOSTAT. Country Profiles. (FAO, 2014).
232. Williams, D. Floods in Pakistan. in *Global Agricultural Information Network* (USDA, 2014).
233. Azad, A.R. Floods inflict Rs 240 billion loss on frail agriculture economy: Country likely to miss Kharif targets. in *Business Recorder* (2014).
234. Zia, U., Mahmood, T. & Ali, M. Dairy development in Pakistan. *FAO, Rome* (2011).

235. Mahmud, R. Cold storage in Pakistan. (Pakistan Horticulture Development & Export Company, 2014).
236. Nayab, D. Estimating the middle class in Pakistan. (Pakistan Institute of Development Economics, 2011).
237. Statista. Total consumer spending in Pakistan from 2013 to 2018 (Statista, 2014).
238. Raja, R.Y. The Retail Food Sector - 2011. in *Global Agricultural Information Network* (USDA, Islamabad, 2011).
239. Euromonitor. Grocery Retailers in Pakistan. (Euromonitor International, 2014).
240. unicef. Cold storage facility transforms vaccination. (unicef, 2012).
241. Brenzel, L., Sanderson, C., Galayda, V. & Masud, T. Cost-effectiveness and financial consequences of new vaccine introduction in Pakistan. (2011).
242. Kiplagat, J., Wang, R. & Li, T. Renewable energy in Kenya: Resource potential and status of exploitation. *Renewable and Sustainable Energy Reviews* **15**, 2960-2973 (2011).
243. USAID. Food assistance fact sheet - Kenya. (2014).
244. Council, K.F. The flower industry in Kenya. (Kenya Flower Council, 2014).
245. Hortiwise. A Study on the Kenyan – Dutch Horticultural Supply Chain. (The Dutch Ministry of Economic Affairs, Agriculture & Innovation, The Hague, The Netherlands 2012).
246. Post, M. From Kenya with Avocados. (Maersk Post, 2013).
247. USAID-KHCP. Horticulture Market News: June 2014. (USAID-KHCP, 2014).
248. Lennane, A. Retailers take the lead in the flower supply chain in a bid to cut wastage. in *The Loadstar* (2013).
249. Theuri, F. & Mwirigi, F. The challenge of value addition in the seafood value chain along the Kenyan north coast. (2012).
250. FAO. Food Loss Assessments: Causes and solutions. (FAO, Rome, 2014).
251. Ltd, A.G. A solar-powered cold storage for Kenya's fishing industry program. (Atlas Group Ltd, 2014).
252. Muia, J. *et al.* Smallholder dairy production in high altitude Nyandarua milk-shed in Kenya: Status, challenges and opportunities. *Livestock Res. Rural Dev* **23**(2011).
253. Muriuki, H. *et al.* The policy environment in the Kenya dairy sub-sector: A review. *Smallholder Dairy (Research and Development) Project, Nairobi, Kenya* (2003).
254. ACET. The fruit value capture opportunity in Africa. in *Pathways to Transformation* (African Centre for Economic Transformation, 2012).
255. HCDA. Horticultural crops production report. (Horticulture Crops Development Authority (HCDA) - Ministry of Agriculture, Kenya, 2010).
256. USAID. The fresh fruit and vegetable markets of East Africa. (USAID, 2013).
257. Tschirley, D., Reardon, T., Dolislager, M. & Snyder, J. The rise of a middle class in East and Southern Africa. (2014).
258. Tschirley, D.L., Ayieko, M.W., Hichaambwa, M., Goeb, J. & Loescher, W. Modernizing Africa's fresh produce supply chains without rapid supermarket takeover: towards a definition of research and investment priorities. (Michigan State University, Department of Agricultural, Food, and Resource Economics, 2010).
259. Zander, M. The mango project in Kenya. (XCOM Africa GmbH, 2014).
260. Gathambiri, C. *et al.* Assessment of potential and limitations of post-harvest value addition of mango fruits in Eastern Province: A case study in Mbeere and Embu Districts. in *Transforming agriculture for improved livelihoods through agricultural*

product value chains. Proceedings of the 12th KARI biennial scientific conference, Kenya Agricultural Research Institute, Nairobi, Kenya 564-566 (2010).
261. Kenya_Investment_Authority. (2012).
262. Market_Insider. Sh120m mango juice processing plant opened in Kenya in *Intracen* (2014).
263. BusinessUSA. Doing business in Kenya. (Embassy of The United States - Nairobi, Kenya, 2014).
264. WEForum. Enabling Trade From Valuation to Action. (World Economic Form, 2014).
265. Kariuki, S. Financial cost of implementing a cold chain. (Tymax Agribusiness Solutions Limited, Agribusiness Specialist, 2014).
266. Defra. Agriculture in the United Kingdom. (Defra, 2013).
267. ONS. Annual Business Survey. (Office for National Statistics, 2013).
268. Defra. Trends in UK food self sufficiency 1960-2012. (Defra, 2013).
269. WRAP. Waste arising in the supply of food and drink to households in the UK. (WRAP, 2010).
270. Vision_2020. UK Roadmap to zero food waste to landfill. (Vision 2020, ReFood, 2014).
271. WRAP. Supply chain – Manage and Measure Waste. (WRAP, 2012).
272. WRAP. The composition of Waste Disposed of by the UK Hospitality Industry. (WRAP, 2011).
273. WRAP. New estimates for household food and drink waste in the UK. (WRAP, 2011).
274. WRAP. Courtauld Commitment. (WRAP, 2013).
275. WRAP. Launch of Courtauld Commitment 3. (WRAP, 2013).
276. IGD. Market and channel forecasts 2014-2019. (IGD UK Grocery, 2014).
277. Massey, T., Nash, S. & Stiles, D. *Top 25 UK Temperature-Controlled Logistics Providers 2014: State of the market 2014*, (CreateSpace Independent Publishing Platform, 2014).
278. Stiles, D. & Nash, S. UK temperature controlled-transport market booms. (Global Cold Chain news, 2011).
279. M&S. Plan A Report 2014. (Marks and Spenser's, 2014).

Appendix 1. Survey questions

Round 1

1. Which of the following best describes your area of expertise

Logistics	
Food Science/Microbiology	
Economics	
Policy/Government	
Other - Please specify	

2. To which region or country does your expertise relate?

Global	
Africa	
Asia	
Europe	
Middle East	
Latin America	
North America	
Countries - Please specify	

3. How much food is lost in the perishables supply chain in your region/country of expertise? Please cite references where appropriate.
4. How much perishable food is also wasted in your region/country?
5. What are the major causes of food loss in the perishables supply chain in your region/country?
6. How could food loss in the perishables supply chain be reduced in your region/country?
7. What would be the financial cost (e.g. for infrastructure improvements) of reducing food loss in the perishables supply chain in your region/country?
8. What would be the impact of reducing food loss in the perishables supply chain in your region/country?
9. How many more people would you estimate could be fed in your region/country if food loss in the perishables supply chain was reduced?
10. What are the possible approaches to unavoidable food loss utilisation (e.g. anaerobic digestion)?
11. Any other comments?

Round 2 – Developing world

1. There is significant food loss along the whole perishable supply chain, however, there is a real lack of data. In your opinion, where is data most urgently needed?
2. It is evident that poor education and poor training can lead to food loss. Which areas require more education and/or training?
3. Implementing or improving cold chain systems would help reduce food loss. Which foods would benefit the most from implementing or improving a cold chain in your country/region?
4. What infrastructure or sustainable energy sources are needed for a cold chain to be implemented or improved in your country/region?
5. What would be required to promote changes in organisational culture and ethos within the perishable supply chain to help reduce food loss?
6. Better regulations could help reduce food loss. Which regulations or policies need introducing or changing?
7. How could on-farm practices be improved to help reduce food loss?
8. Wholesale distribution networks in developing countries can be complex. How could those networks be improved to reduce food loss?
9. Most developed countries have advanced food supply chain systems. What aspects of these supply chains could best help improve supply chain systems in your country/region, for example HACCP?
10. Any other comments?

Round 2 – Developed world

1. There is significant food loss along the whole perishable supply chain, however, there is a real lack of data. In your opinion, where is data most urgently needed?
2. It is evident that poor education and poor training can lead to food loss. Which areas require more education and/or training?
3. Operational aspects such as breaks in the cold chain and poor temperature management cause food loss. How can this be avoided?
4. Where is investment needed in the cold chain?
5. What would be required to promote changes in organisational culture and ethos within the perishable supply chain to help reduce food loss?
6. Better regulations could help reduce food loss. Which regulations or policies need introducing or changing?
7. How could retail practices be improved so as to reduce food loss?
8. Charity food banks offer a way of utilising food loss. How can the supply of surplus food to charity food banks be improved?
9. What lessons can be learnt from cold chains in the developed world that could be applied to help cold chain implementation in the less developed world?
10. Any other comments?

Appendix 2. Micronutrient calculations

Fruit and vegetables production quantities from 2012 are taken from FAOSTAT for China, India, Pakistan and Kenya. The following fruit and vegetables were used for the calculations:

Apples, Apricots, Artichokes, Asparagus, Avocados, Bananas, Cabbages and other brassicas, Carrots and turnips, Cauliflowers and broccoli, Cherries, Chick peas, Chillies and peppers, Cucumbers and gherkins, Dates, Eggplants (aubergines), Figs, Garlic, Ginger, Grapefruit (inc. pomelos), Grapes, Green beans, Green peas, Leeks other alliaceous vegetables, Lemons and limes, Lettuce and chicory, Mangoes, mangosteens, guavas, Melons, other (inc. cantaloupes), Okra, Onions and shallots, Oranges, Papayas, Peaches and nectarines, Pears, Pepper (piper spp.), Pigeon peas, Pineapples, Plantains, Plums and sloes, Pumpkins, squash and gourds, Quinces, Spinach, Strawberries, Tangerines, mandarins, clementines and satsumas, Tomatoes, Watermelons.

For each country we calculated the gain in calories or micronutrients arising from 50% reduction in loss over the extreme values of total loss currently experienced (10% minimum and 30% maximum). Thus the reduction means loss is reduced to either 5% or 15%. The resulting increase in micronutrient is calculated for each commodity for each country.

Example Calculations:

Tomatoes in India, at an upper limit of 30% loss:

Table 11. Tomato (red, ripe, raw, year round average) calorific and nutrient values from the USDA Nutrient database, per 100g and per tonne as well as the daily recommended intake for an adult male aged 19-30.

	Per 100g	Per tonne	Daily recommended intake
Energy	**18 kcal**	**180,000 kcal**	**2,100 kcal**
Iron, Fe	**0.27 mg**	**2,700 mg**	**8 mg**
Zinc, Zn	**0.17 mg**	**1,700 mg**	**11 mg**
Vitamin A, RAE	**42 µg**	**420,000 µg**	**900 µg**

Total production = 17,500,000 tonnes

Reduce loss by a quarter, therefore loss is reduced from 30% to 22.5%, therefore the total amount that may be saved is 7.5% of total production:

$$17{,}500{,}000 \times 7.5\% = 1{,}312{,}500 \text{ tonnes saved}$$

Convert to calories, giving potential calories saved, and taking into account unavoidable waste of 30% (i.e. only 70% of food has calorific content):

$$(1{,}312{,}500 \times 0.7) \times 180{,}000 = 1.65 \times 10^{11} \text{ kcal}$$

Energy equivalent for X people:

$$\frac{1.65 \times 10^{11}}{(2100 \times 365)} = 215{,}753 \text{ people}$$

Iron content, taking into account unavoidable waste of 30%:

$$(1{,}312{,}500 \times 0.7) \times 2{,}700 = 2.48 \times 10^{9} \text{ mg}$$

Iron content equivalent for X people:

$$\frac{2.48 \times 10^{9}}{(8 \times 365)} = 849{,}529 \text{ people}$$

Zinc content, taking into account unavoidable waste of 30%:

$$(1{,}312{,}500 \times 0.7) \times 1{,}700 = 1.56 \times 10^{9} \text{ mg}$$

Zinc content equivalent for X people:

$$\frac{1.56 \times 10^{9}}{(11 \times 365)} = 389{,}010 \text{ people}$$

Vitamin A content, taking into account unavoidable waste of 30%:

$$(1{,}312{,}500 \times 0.7) \times 420{,}000 = 3.86 \times 10^{11} \text{ µg}$$

Vitamin A content equivalent for X people:

$$\frac{3.86 \times 10^{11}}{(900 \times 365)} = 1{,}174{,}658 \text{ people}$$