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HOW ACCESS TO ENERGY CAN INFLUENCE FOOD LOSSES

A brief overview



ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

ENVIRONMENT CLIMATE CHANGE [ENERGY] MONITORING AND ASSESSMENT

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A brief overview

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EXECUTIVE SUMMARY

The global population surpassed seven billion people during 2011 and is predicted to reach 9.3 billion by 2050, with a projected increased food demand of around 60 percent. At the same time, 795 million people are chronically under-nourished globally. Against this backdrop of rising population and undernutrition, it is scandalous that an estimated one third of all food produced globally for human consumption is lost or goes to waste. The causes of this magnitude of food loss are multidimensional, spanning from lack of physical infrastructure and technology in developing countries such as roads and food processing equipment to behavioural aspects such as over-buying and food consumption habits in developed countries.

IMPORTANT FACTS

1. Approximately one out of every four calories grown to feed people is not ultimately consumed by humans (Searchinger et. al, 2013).
2. FLW of 1.3 billion tonnes of food results in:
   a. Loss of almost 1.4 billion hectares of land that were used to produce food not consumed. This represents a surface area larger than Canada and India combined.
   b. A global blue water footprint for the agricultural production of food wastage was about 250 km³ in 2007; 3.6 times the blue water footprint of total USA consumption. In terms of volume, it represents almost 3 times the volume of Lake Geneva, or the annual water discharge of the Volga River.
   c. GHG emissions of an estimated at 4.4 Gtonnes of CO_2 equivalent translating to approximately 8 percent of anthropogenic GHG emissions. If food loss was a country, it would be the third largest emitter after China and the USA.
   d. An estimated 38 percent of the total energy consumed by food systems is utilized to produce food that is ultimately never consumed by humans (FAO, 2011a).
3. The cold chain is the key to tackling the loss of perishable produce. In this regard, it is estimated that around a quarter of total food wastage in developing countries could be eliminated if these countries adopted the same level of refrigeration equipment as that in developed economies. (Source: IoME, 2014)
4. The challenge is that in nearly all cases, cooling and refrigeration rely on access to a reliable and affordable source of either electricity or diesel fuel, which are often lacking or virtually non-existent in developing countries, particularly in rural areas where energy security is a significant issue. (Source: IoME, 2014)

5. If 50 percent of the food waste generated each year in the U.S. was anaerobically digested, enough electricity would be generated to power over 2.5 million homes for a year (Source: United States environment protection agency: www3.epa.gov/region9/waste/features/foodtoenergy/index.html)

This report focusses on understanding how access to energy is a key factor affecting the magnitude of food loss in developing countries. It identifies the main stages of the food value chain where increasing access to energy can play a dominant role in reducing food losses directly, by making food processing possible, as well as indirectly by acting as the main enabling factor affecting the rate at which cooling technologies are adopted. Access to low-cost but dependable energy acts as a pre-requisite to developing any form of cold chain, which is essential to reduce post-harvest food losses in developing countries.

Cold chain is the key to tackling the loss of perishable produce. In this regard, it is estimated that around a quarter of total food wastage in developing countries could be eliminated if these countries adopted the same level of refrigeration equipment as that in developed economies (IoME, 2014). However, the primary challenge in developing a cold chain resides in the fact that in nearly all cases, cooling and refrigeration relies on access to a reliable and affordable source of either electricity or diesel fuel, which are often lacking or virtually non-existent in the rural parts of developing countries. However, expanding grid connection to rural and far off parts of a region requires significant amount of time and investment and therefore there is an immediate need to develop low-cost off grid solutions that can enable rural farmers to preserve and process food which consequently can have an immediate impact on food losses in developing countries.

The report begins by reviewing the evidence to date focussing on the magnitude and geographical distribution of food losses. In the subsequent parts the role of energy in post-harvest losses is discussed. Thereafter, the main entry points within the food value chain where lack of access to energy is the dominant factor influencing food losses is discussed. This report outlines low cost and off-grid post-harvest cooling and processing technologies that can be made available in developing countries. These household to community scale evaporative cooling systems, solar assisted cooling systems and as well as solar drying systems that can help increase shelf life.[1]

Additionally, through case studies, focus is laid on assessing the technical and economic feasibility of cooling and processing technologies. This is because, the capital spending required for the deployment of these technologies can be a significant barrier in the developing world. From an economic and commercial perspective, a positive decision to introduce a given post-harvest technology such as refrigeration, chilling or food drying for a given perishable product will depend largely on whether the value of the produce saved exceeds the cost of investment and operation. In many cases, food losses or waste may be unavoidable to some extent due to behavioural, technological or economic reasons. In such cases, discarded food can be used to feed animals or to recover resources through other

1 It should be noted that increasing shelf life does not directly decrease food losses.

physical and chemical processes such as biogas production or composting, which can then be used as a soil amendment thereby replacing chemical fertilisers.

Finally, recommendations are made that could be incorporated to further develop food loss strategies that can classify food value chains based on their energy demand. This will enable policy makers to quickly understand the main technologies for food preservation and processing that can be introduced based on the available energy sources in a given region.

CHAPTER 1 INTRODUCTION

According to the latest estimates by the Food and Agriculture Organization of the United Nations (FAO), around 795 million people were undernourished globally (FAO, 2015). The pressure on food production is expected to increase as the rising global population will require an estimated 60 percent increase in food production to meet the demand of food by 2050 (FAO, 2012). At the same time, one third of all food amounting to 1.3 billion tonnes is lost or wasted globally. As a result, overall global food availability is lower than it would be otherwise, negatively affecting food security and requiring the global agriculture system to produce additional food to compensate for the food that is not ultimately consumed by people. On the production side, crop production contributes significant proportions of typical incomes in rural areas (up to 70 percent in Sub-Saharan Africa) and reducing food loss can directly leads to an increase in real income of the producers (World Bank, 2011). In the past decades, significant resources have been allocated to increase food production. However, most of these investments have been in the form of R&D targeted at increasing productivity and only a minor share has been directed to reducing losses. While increasing agricultural productivity is essential to ensure food security for humanity, it may not be sufficient as food production is a resource intensive process and many of the resources that are required to produce food are already under stress. With the limited capacity to expand agricultural land, the increase in food production would not only rely on increasing yields but would also depend in increasing efficiencies along the food value chain by reducing food loss and waste.

Approximately one out of every four calories grown to feed people is not ultimately consumed by humans (Searchinger et. al, 2013). Food is lost and wasted to a varying extent in all countries, across all stages of the food value chain, and in all types of food chains. In addition to undermining efforts to increase global food security, food loss and waste (FLW) inevitably translates into a loss of resources like energy and water and causes other negative externalities to the society such as monetary and environmental costs associated with waste management and greenhouse gas production (GHG)

Currently, agriculture already uses around 11 percent of the world's land surface for crop production, and accounts for 70 percent of all water withdrawn from aquifers, streams and lakes (FAO, 2011c). Additionally, the food system currently accounts for about 30 percent of the world's total energy consumption (FAO,2011a) and is responsible for about 20 percent of the global GHG emissions (FAO, 2011a).

A loss or waste of edible food translates into a loss of resources like water and energy that went into the production food. FLW of 1.3 billion tonnes of food results in a loss of almost 1.4 billion hectares of land that were used to produce food not consumed. This represents a surface area larger than Canada and India combined. Additionally the global blue water footprint for the agricultural production of food wastage was about 250 km^3 in 2007; 3.6 times the blue water footprint of total USA consumption. In terms of volume, it represents almost 3 times the volume of Lake Geneva, or the annual water discharge of the Volga River. In terms of GHG emissions the global carbon footprint, excluding land use change, of food waste has been estimated at 4.4 Gtonnes of CO_2 eq. around 8 percent of anthropogenic GHG emissions (FAO, 2015). A loss or wastage of one third of the food produced for human consumption accounts for around 8 percent of anthropogenic GHG emissions (Vermeulen, et. al, 2012) and it is estimated that 38 percent of the total energy consumed by food systems is utilized to produce food that is ultimately never consumed by humans(FAO, 2011a).

It is therefore imperative to take a holistic look at the current food production system by simultaneously dedicating efforts to increasing yield as well as to increase efficiencies in the food value chain.`

The main drivers of FLW can broadly be divided into two main categories; behavioural or infrastructural. Human behaviour and preferences towards foods having specific aesthetic requirement may lead to food, which is fit for human consumption being wasted. A large proportion of food is wasted in industrialized countries due to the prevalence of strict grading and aesthetic standards and waste due to consumer behaviour. Infrastructural limitation on the other hand lead to food being lost due to the non-existent or inefficient infrastructure such as food harvesting, storing and processing technologies but also roads for transportation of food along the value chain. Such infrastructure limitations are widespread in developing countries and have become severely acute in least developed countries where food is lost due to lack of adequate infrastructure. A key component of infrastructural limitation is the post-harvest technologies which include modern or traditional harvesting, processing and storing technologies which facilitate the maintenance of quality (appearance, texture, flavor and nutritive value), the protection of food safety, and the reduction of losses (both physical and in market value) between harvest and consumption.

Post-harvest technologies require energy to run and operate. Most industrialised countries depend on grid-supplied power to run large-scale operations using specialized handling machinery and high-tech postharvest treatment and storing technologies. In developing countries the primary sources of energy in rural areas are traditional fuels like firewood and dung cakes. Consequently only rudimentary forms of storing and processing technologies are possible in such countries. Having access to modern and reliable sources of energy can provide a better means of processing, storing and transporting goods, which in turn can reduce the amount of product losses and waste. Additionally, simple, low cost technologies for drying/processing, and refrigeration of food can be more appropriate for small volume, limited resource commercial operations associated with subsistence farmers and for farmers that are involved in direct marketing. Reducing food loss and waste is a challenge that encompasses many spheres.

In light of these, this study aims to identify the links between access to energy and the role it can play in reducing post-harvest losses in rural value chains in developing countries. Energy-food loss links have been previously studied; however, these studies often focus only on the reuse of lost food to produce energy and hence fall short of identifying the role of energy in reducing or preventing food losses in the first place. This study focuses on rural food value chains given their importance for reducing food loss at the rural level to identify potential costs and benefits of using low cost, decentralized solutions and technologies at the post-harvest (handling, processing and storing) stage. Food waste at the wholesale, retail and consumption level as such is not considered.

WHAT IS FOOD LOSS, FOOD WASTE, AND THE FOOD SUPPLY CHAIN (FSC)?

FAO defines food loss and waste as the decrease in edible food mass throughout the supply chain that specifically leads to a decrease in the quantity of edible food available for human consumption. Food is lost or wasted throughout the value chain from initial agricultural production to the final household consumption level. These include losses at the production, postharvest and processing stages in the food supply chain. While all crops are naturally subjected to biological deterioration, the extent of such degradation depends on a range of factors like individual farming practices and other interdependent activities between harvest and delivery of food to consumers.

DEFINING FOOD LOSS AND WASTE

Food loss is defined as a decrease in quantity and quality of agricultural, forestry and fisheries products intended for human consumption that are ultimately not eaten by people. Food losses occur along the supply chain from harvest, post-harvest handling, to storage and processing. Food losses are largely unintentional and are caused by inefficiencies in the food supply chain such as insufficient access to energy and technologies, poor infrastructure and logistics, inadequate market access as well as managerial limitations of supply chain actors. Climatic changes and natural disasters can also lead to food losses.

Food waste refers to food appropriate for human consumption being discarded, either by choice or after the food has been left to spoil or expire as a result of negligence or oversupply. Food waste occurs predominantly, but not exclusively at consumption level and is related to consumer behaviour as well as being policy and regulatory driven.

Food loss and waste (FLW) is defined as 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.

Source: (FAO, 2014; HLPE, 2014)

Food losses can be quantitative or qualitative. Quantitative food losses can be measure by decreased weight or volume at a certain stage in the FSC and can be caused by spillage, consumption by pests and due to chemical and physical changes due to changes in temperature and moisture content. Weight loss due to processing such as drying in the in the case of grains is not considered a food loss since although it results in a considerable weight loss, there is no actual loss in food value. In this study therefore, quantitative weight loss refers to loss in weight due to unintentional loss of food in post-harvest stages of the supply chain.

Qualitative losses result from reduced nutrient value or other unwanted change in shape, colour, texture, or other cosmetic features and can occur due to insects, mites, rodents and other pests or by physical and chemical changes in nutrients, fats, carbohydrates or proteins. Qualitative loss in food can lead to weight reduction and hence to quantitative loss when the deterioration reaches a level rendering food unfit for human consumption. Proper refrigeration and storing technologies can slow natural degradation and prevent food from pest, rodent and other contaminations. Both quantitative and qualitative food loss takes place at each step of the value chain and occur due to varying reasons.

FIGURE 1.

Food value chin and associated losses at each stage

Source: adapted from Lipinski et.al, 2013

CURRENT GLOBAL AND REGIONAL ESTIMATES

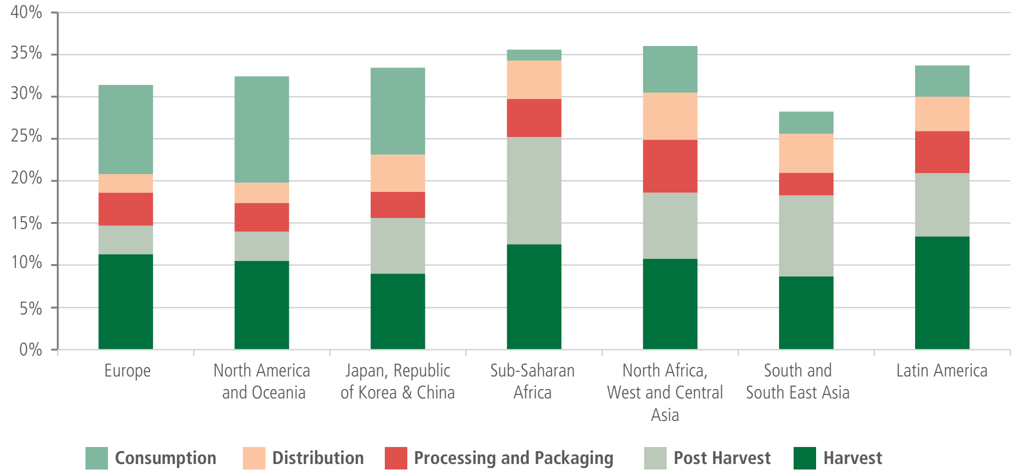
The magnitude and pattern of post-harvest losses vary across countries depending on their economic and infrastructural development status. Nevertheless, irrespective of the country development status, in terms of volume, most food is lost at the agricultural production stage[2] of the food supply chain, although for very different reasons. In industrialised countries, field losses at the production stage reflect economic decisions of the farmer to forgo harvesting due to market conditions or due to non-conformity of the produced food to the grading and aesthetic standards set by the consumers. In developing countries however, field losses at production stage result from poor state of the value chains and infrastructure. Specifically, due to the combination of poor education, farming methods (including improper handling, inefficient harvesting methods and premature harvesting) and infrastructure. Pests, disease, overplanting (often motivated by the uncertainty of weather) and labour shortages contribute to losses at this stage. Additionally, premature harvesting, poor storage facilities, inability to deal with pests and other external shocks

2 On average for all crops. For individual crops, the stage at which most of the crop is lost may vary.

result in high losses in the early part of the food supply chain (Fig. 2). On a per capita basis, more food is wasted in industrialized countries than in developing countries, peaking at 280–300 kg/cap/year in Europe and North America and around 120–170 kg/cap/year in sub-Saharan Africa and South/Southeast Asia. While fruits and vegetable being highly perishable constitute the largest share of the total food lost by weight, FWL in cereals comprise the largest share by calorific content (Fig.3). In sub-Saharan Africa specifically, around 36 percent of food harvested is lost, equating to an average 167 kg/cap per year where only 7 kg is at the consumer level. (Gustavsson.*et.al*, 2013).

FIGURE 2.

Food loss and waste along the value chain by region

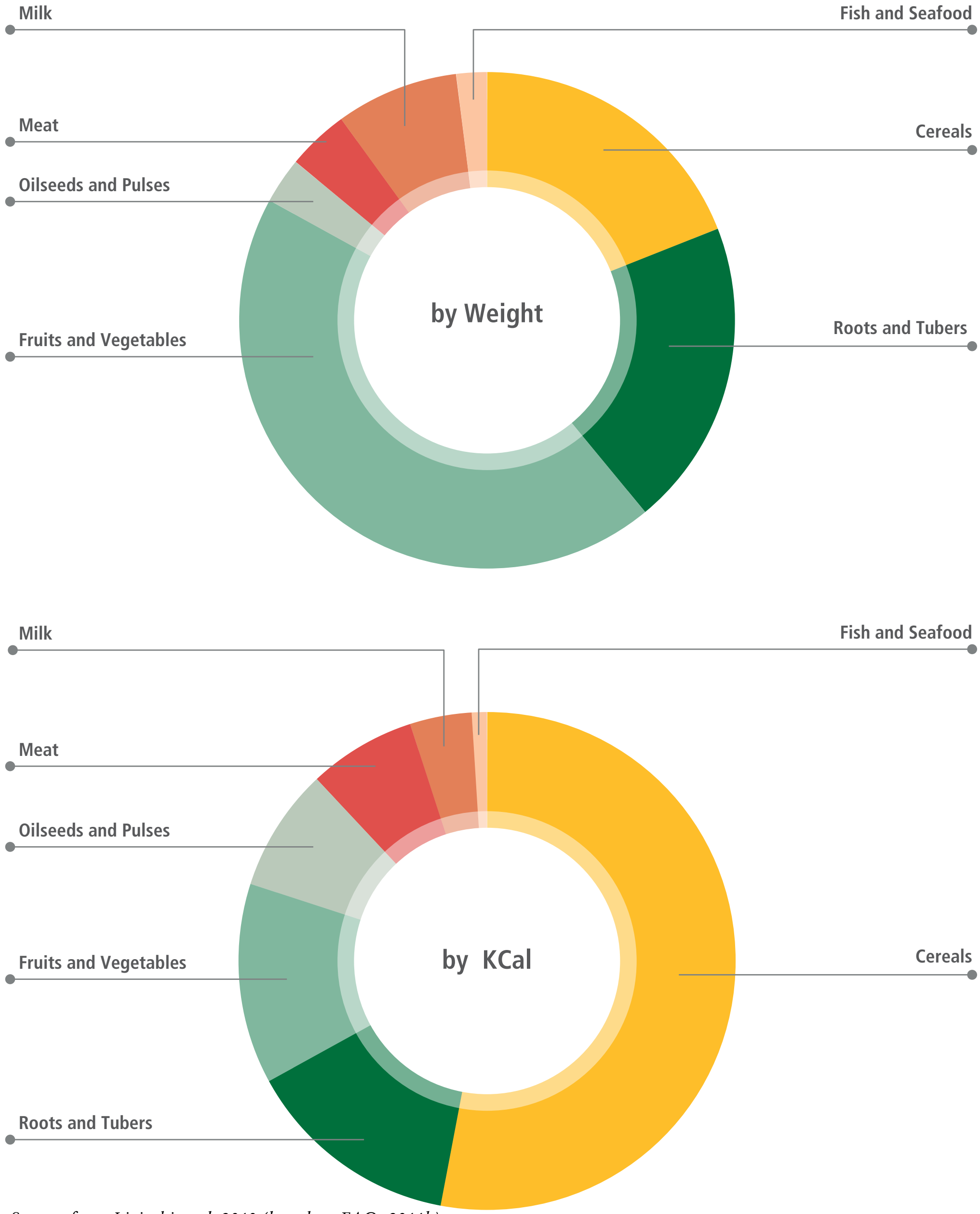


Source: FAO, 2011b

In absolute terms, food losses by weight in developing and developed countries do not vary substantially although they occur at different stages of the FSC. Around 40 percent of food losses in developing countries occur at post harvest and processing levels, while in developed countries around 40 percent of the losses occur at retail and consumer level.

FIGURE 3.

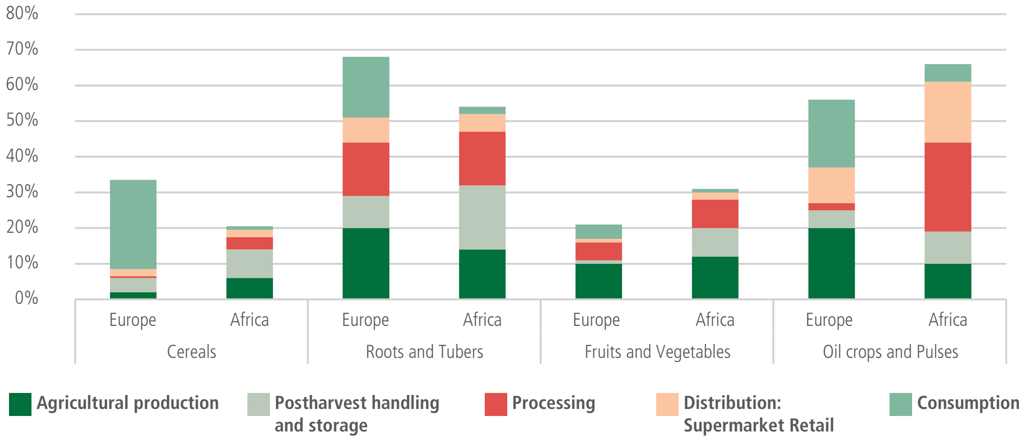
Loss and waste by weight and by kcal per commodity



Source: from Lipinski et.al, 2013 (based on FAO, 2011b)

FIGURE 4.

Comparison of food loss between Europe and Sub-Saharan Africa



Source: FAO, 2011b

Perishable food losses in both developed and developing countries could be reduced by improving infrastructure, increased investment in the cold chain, improved regulations, and better forecasting and technological innovations. A large proportion of food in developing countries is lost due to infrastructure constraints manifested as limited post-harvest processing and storage technologies. Substantial opportunities exists to reduce these losses by developing and improving processing and storing infrastructure through low cost decentralized solutions powered by modern energy. In Africa, the total value of lost food is USD 4 billion per year, (IMechE, 2014). In India this is estimated to be around USD 4.5 billion annually (IMechE, 2014). Therefore, in addition to undermining both food security and food safety, food loss also translates into substantial economic losses.

The adoption of modern technologies in the early stages of supply chains (harvest, storage, transport) in developing countries is still relatively low. There are thus potentially large benefits to prioritizing interventions in this area. Of particular importance are measures aimed at the early stages of supply chains such as resource-efficient production and processing practices; modern processing, preservation and packaging technologies (which will enhance food availability, safety and shelf life). For many small holder and subsistence level farmers, food loss can have dire consequences. It directly impacts poor producers through foregone income and impacts poor consumers through reduced food availability, increased prices, and decreased nutritional content. Given that many smallholder farmers in developing countries live on the margins of food insecurity, a reduction in food losses could have an immediate and significant impact on their livelihood and wellbeing.

Reducing FLW is a multidimensional challenge and hence no one single sectoral strategy can be employed to tackle it. It requires efforts on both technological and behavioural fronts to substantially reduce the extent of FLW. Improved primary production practices together with the use of advanced and more efficient harvesting, handling and storage technologies at the initial stages of the value chain are required to reduce food losses. Furthermore, improving skills, knowledge and management capacity in supply chain actors in developing countries should also be prioritized. A simultaneous re-examination of the ideas of aesthetic standards that currently define what is edible and what is not is also required.

CHAPTER 2

CAUSES AND DRIVERS OF FOOD LOSS AND ACCESS TO ENERGY

MAIN DRIVERS OF FOOD LOSSES

The main drivers of food loss vary across commodities and regions. In developing countries, food is lost due to infrastructural constraints including lack of access to modern energy to drive improved food processing technologies, and to optimize storing facilities. Different food commodities are lost due to different reason at the post-harvest stage of the supply chain. In developing countries, one of the main causes of food losses is biological spoilage due to lack of appropriate storing infrastructure. Livestock products, fish, fruits and vegetables lose value very quickly without refrigeration. A large proportion of fresh products such as fruits, vegetables, meat and fish, straight from the catch or the farm are spoiled due to the lack of cooling, drying and technologies that would enable safe storage. They lose quantitative and qualitative value if stored in an unregulated environment with high temperature. They also lose value due to mechanical damage during harvesting and handling and improper postharvest sanitation. Roots and tubers are less susceptible than fruits and vegetable to biological decay but post-harvest storage and processing are required to limit losses. Especially with potatoes for example which require a high humidity environment to prevent sprouting. They are normally stored at a temperature of 4 to 7 degrees centigrade and relative humidity of 90 percent in a dark location, as potatoes turn green when exposed to light. If storage temperatures are above 45 degrees Fahrenheit, the potatoes will start to sprout after two or three months. Cereals are the least susceptible to post harvest losses but may be scattered, dispersed and crushed during handling.

In developing countries, cereals are often dried directly under the sun on open ground due to lack of appropriate drying technology resulting in losses due to pest and rodent attacks. Losses are even higher under unfavourable weather conditions when open sun drying is not possible. Suboptimal drying practices and poor storage of grain can lead to the growth of micro toxin producing moulds which produces aflatoxin, a potent carcinogen (Wareing, 2002). A typical food value chain along with the reasons of food loss and waste at each stage is shown in figure 5.

FIGURE 5.

Food Value chain and reasons for FWL

	Production	Handling and storage	Processing and packaging	Distribution and market	Consumption
Definition	Food loss while harvesting	Food lost on farm or off farm and storage	Food lost during processing, at village level or industrial	Food lost during transporation, wholesale or retail market	Food lost at home or businesses, including in restaurants
What does it include?	Damage while harvesting	Biological degradation due to poor storage	Edible food sorted out as not fit for processing	Food sorted out due to quality	Purchased food not eaten
	Sorting out of crops due to not meeting quality and aesthetic standards	Pest and rodent attacks	Losses during processing like canning and packaging	Food reaching expiry date before being purchased	Food wasted due to large portions
	Crops not collected due to poor harvesting or lack in demand	Often caused by inadequate access to modern energy	Often caused by inadequate access to modern energy	Food does not look aesthetically fit although is edible	Food reaching expiry date before being cooked

Source: adapted from Lipinski et.al, 2013

STAGE SPECIFIC FOOD LOSSES ALONG THE VALUE CHAIN

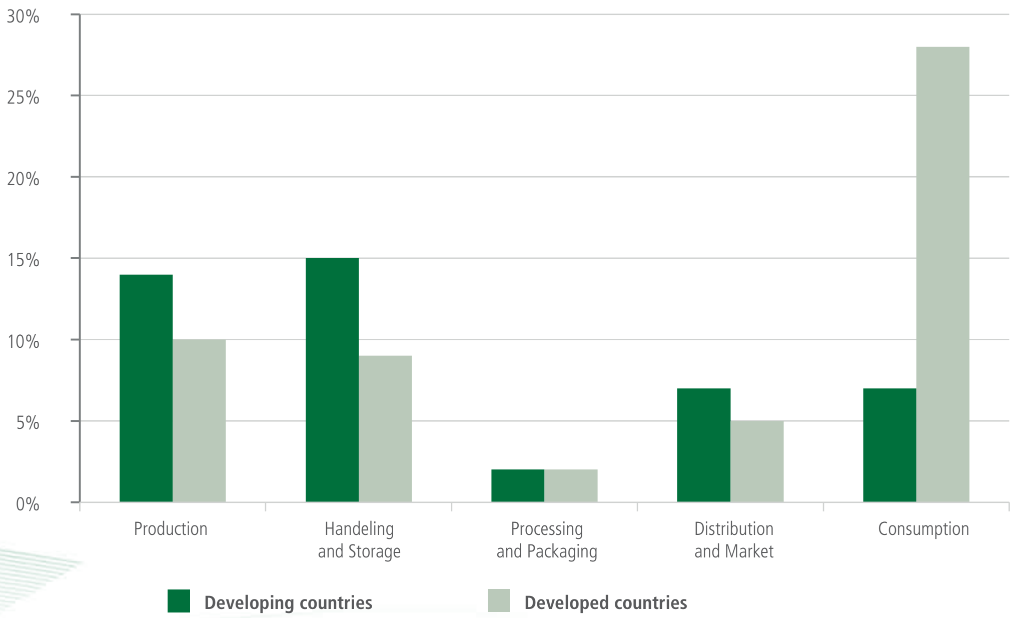
Once food is harvested it is then stored until it is ready to be processed. This is the post-harvest handling and storage stage of the FSC. For vegetables and milk products, losses are generally caused by degradation—the breakdown of enzymes in products owing to temperature, moisture and oxygen content, which causes deterioration, spoilage and spillage. For animal products, including meat, losses at this stage include premature death, particularly during transport to slaughter and, in the case of fish, spillage and degradation during icing, packaging, and storage. Losses at this stage are related to the improper handling of food, underdeveloped and insufficient infrastructure and inefficient agricultural procedures. For example, in some developing countries, farmers habitually leave cereals such as maize in the field upon maturity to dry because they lack facilities for drying. However, when the harvest season coincides with the second rains, as is the case in some countries, there is increased rotting and aflatoxin contamination, a major cause of food losses in cereals (Alakonya *et.al,* 2008). Because they are highly perishable and require extremely efficient production and post-harvest systems to minimize loss, fruits, vegetables, roots and tubers have the highest proportion of loss globally during the first two stages of the FSC, especially in warm and humid climates. A study in Cameroon (FAO 2014) identified as a major cause of loss tubers being harvested too late, after having been "stored" in the field, getting lignified or eaten by rodents.

Food processing includes both domestic and industrial processing, and covers operations such as pasteurisation, canning, preparation and packaging. Losses during processing are mainly caused by spillage and degradation. Food processing is an important stage of the value chain because it can allow the food to retain nutrient value while increasing the longevity of the food. Losses during food processing include trimmings of both the edible (e.g., fat, skins, peels, end pieces, crusts) and inedible (e.g., pits and bones) portions of the fresh produce. For instance, during juice production, once the juice of a fruit or vegetable is squeezed, the pulp is typically discarded. Trimming and processing spillages for processes such as smoking or canning account for the majority of animal product food losses during this stage. In most countries where national or regional food chains exists, food enters the retail and wholesale markets after processing. The food losses at these stages are caused during transportation of the food and at the retail stores. The reasons of FLW during distribution, transport, handling and storage are multidimensional. In industrialized countries loss at the retail distribution centre are primarily due to expiry dates as well as the fresh produce not meeting specifications for shape, size and freshness. As supply chains increase in length there is an increasing possibility that food could be spoilt or damaged particularly if inadequate packaging is used. During transportation and handling, packaging may be damaged resulting in food loss.

The lack of a well-developed cold chain, appropriate processing and storing technologies are the main cause for such high rates of food loss. It is easy to derive from the above discussion that the production; handling and storage; as well as primary farm based processing are the main stages where food loses can be significantly reduced in developing countries. Effective and efficient food drying, processing and storage technologies are fundamental to reduce food losses in developing countries but require access to modern energy as well as substantial investments, training and capacity building. Small-scale farmers in developing countries are particularly vulnerable to food loss due to constraints in processing and storing equipment that can enable them to have access to food over longer periods of time.

FIGURE 6.

Share of total food loss and waste by stage in the value chain by percentage Kcal lost



Source: from Lipinski et.al, 2013 (based on FAO, 2011.)

Given the importance of handling, storing and processing of food to reduce food losses in developing countries, this study will primarily focus on the role of energy in these processes of the value chain (Fig. 7)

FIGURE 7.

Stages of the value chain considered in the study

	Production	Handling and storage	Processing and packaging	Distribution and market	Consumption
Definition	Food loss while harvesting	Food lost on farm or off farm and storage	Food lost during processing, at village level or industrial	Food lost during transporation, wholesale or retail market	Food lost at home or businesses, including in restaurants
What does it include?	Damage while harvesting	Biological degradation due to poor storage	Edible food sorted out as not fit for processing	Food sorted out due to quality	Purchased food not eaten
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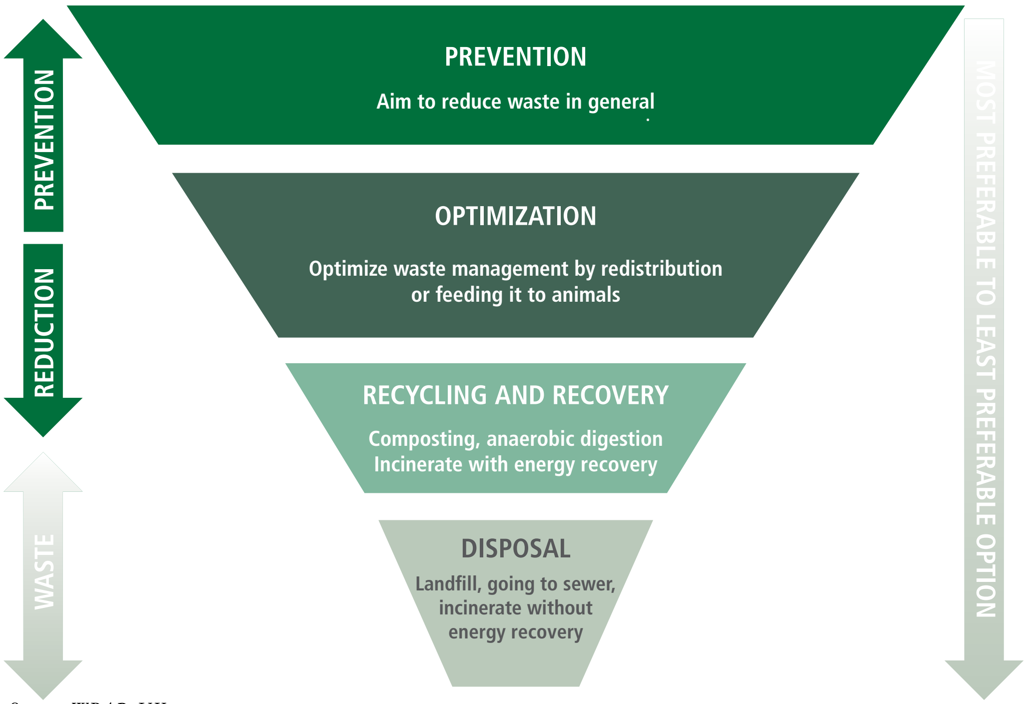
Source: adapted from Lipinski et.al, 2013

ROLE OF ENERGY IN POST-HARVEST VALUE CHAIN

Considering the magnitude of food losses and the current knowledge on their causes, it is pertinent to address ways to limit these causes of food losses. The following figure proposes a hierarchy of measures in that respect. Within these measures, energy directly concerns the prevention, recycling, and recovery options.

FIGURE 8.

Food waste pyramid



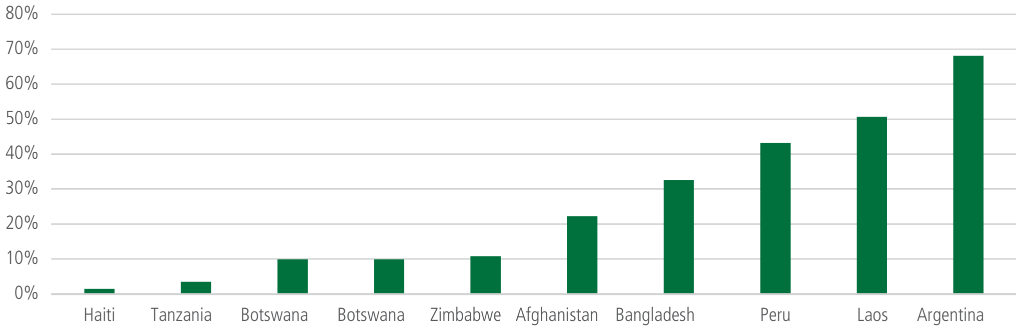
Source: WRAP, UK

Access to energy can speed up the adoption of better storage and processing technologies thereby preventing excess food loss in the post-harvest stage of the food value chain. Food that is lost or wasted can also be recycled into energy through anaerobic digestion or incinerated to recover energy.

Energy access can be characterized by different levels of need and by the various resources and technologies that can meet these needs (UNDP, 2012). Energy access can refer to the point of use and the services that are used directly (e.g. lighting) or it can refer to the energy consumed through energy carriers (e.g. electricity) that act as inputs for various energy services. Energy needs can be classified as fundamental (i.e. necessary for human survival, including cooking food and space heating), basic (health, education, communication, and transportation), and for productive uses and income generation (UNDP, 2012). At any rate, rural electrification rates remain low in most developing countries in Africa and Asia (Fig. 9 and 10).

FIGURE 9.

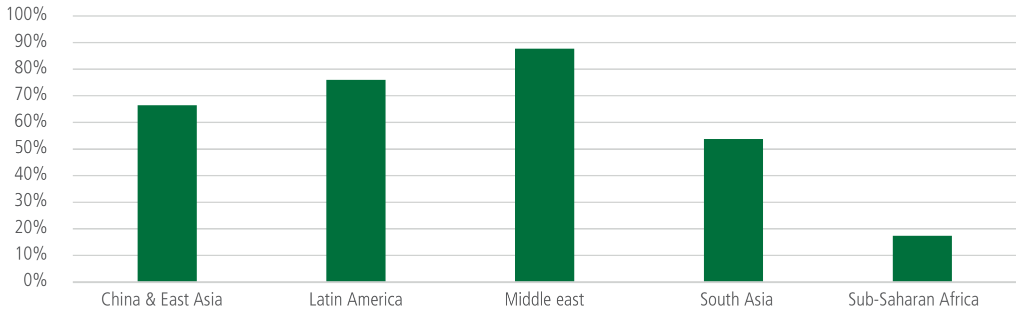
Average rural electrification rate in select countries



Source: IEA, 2010

FIGURE 10.

Average rural electrification rate by regions



Source IEA, 2010

Rosegrant *et.al* (2015) in their analysis identify key infrastructural variables (Table 1) including access to energy and through a regression assess the extent to which each variable can positively or negatively influence food losses.

TABLE 1.

Selected infrastructural variables and its effect on food losses

VARIABLE	RATIONALE	EXPECTED EFFECT ON FOOD LOSSES
Electric power consumption(Kwh/capita)	Access to technology	Reduce PHL directly
Port infrastructure (million ton/km)	Access to markets by sea	Reduce PHL indirectly
Air transport (million ton/km)	Access to markets by air	Reduce PHL indirectly
Road density(km of road per 100 sq. km of land area)	Ability to transport goods	Reduce PHL directly
Paved roads (% of total roads)	Quality of transport capability	Reduce PHL directly
Railways, goods transported (million tons/km)	Access to markets by train	Reduce PHL indirectly

VARIABLE	RATIONALE	EXPECTED EFFECT ON FOOD LOSSES
Roads, goods transported (million ton-km)	Intensity of transport capability	Reduce PHL directly

Source: World Bank, WDI 2013

The coefficients of the results presented in Table 2 are expressed in odds ratios. The coefficients measure the impact of changes identified variables on the ratio of PHL over the rate of no PHL.

TABLE 2.

Econometric results (Standard errors in parenthesis* p<0.01, ** p<0.05, * p<0.1)**

VARIABLE	ECONOMETRIC RESULTS
Electric power consumption(Kwh/capita)	0.688** (0.110)
Port infrastructure (million ton/km)	1.327** (0.151)
Air transport (million ton/km)	1.073 (0.0516)
Road density (km of road per 100 sq. km of land area)	1.121 (0.148)
Paved roads (% of total roads)	0.573** (0.145)
Railways, goods transported (million tons/km)	0.921*** (0.0262)
Roads, goods transported (million ton-km)	0.876** (0.0485)

Source: Rosegrant et.al (2015)

Therefore, coefficients greater than one increase the odds of PHL, while coefficients less than one decrease it. The results provide support to the importance of roads, particularly paved roads, which reduce the odds of PHL by half. Higher usage of railroads expressed by the amount of goods transported, which also measures to some degree the intensity of market transactions, also helps decrease PHL. Considering that all these means of transportation require modern energy, one can reasonably argue that energy is a major factor in reducing FLW. Additionally, higher consumption of electricity also helps decrease the odds of PHL, signalling that more consumption leads to increased use of technologies that require power which can help reduce food losses. Lack of access to reliable and affordable electricity services in rural areas significantly reduces the opportunities for the development of many economically productive activities, including agro-enterprises and fishing (Weingart & Giovannucci, 2004). Nevertheless, rudimentary storage and processing activities do take place depending on the economic capabilities of the farmer/household. Such storage and processing activities are dependent on locally available resources, often-traditional bio fuels for processing, cooking and mud and straw for storing food. Such technologies and practices can often be inefficient and may lead to higher than normal losses. In Africa, for example, the natural drying of crops by sunshine and natural air flow is the most widely used drying method. The use of wood to smoke fish is also a common practice in many countries.

Under these conditions, drying time ranges from weeks to months depending on factors such as weather, final desired moisture content, and batch and crop variation. This leaves the products susceptible to damage and loss from adverse weather conditions and pests. Slight improvements or advancements in drying methods and storage technologies could serve to reduce damage and losses at the drying stage. Additionally, most low and medium income farmers lack cooling or refrigeration equipment (Table 3) leading to high losses in perishable food.

TABLE 3.

End uses by energy sources in agriculture in developing countries

TYPICAL END USES BY ENERGY SOURCE IN AGRICULTURE SECTOR IN DEVELOPING COUNTRIES			
	INCOME LEVEL		
	LOW	MEDIUM	HIGH
Tilling	Human Labour	Draft Animals	Animal, gasoline, diesel
Irrigation	Human Labour	Draft Animals	Diesel, grid electricity
Processing	Human Labour	Draft Animals	Diesel, grid electricity
Milling/Mechanical	Human Labour	Human Labour, draft animals	Grid electricity, diesel, gasoline
Process heat	Wood, residues	Coal, Charcoal, wood and residue	Coal, charcoal, wood, kerosene, residues
Cooling/ Refrigeration	None	None	Grid electricity, LPG, kerosene
Transport	Human Labour	Draft Animals	Diesel, gasoline

Source: UNIDO, 2007

Access to modern energy provides the base on which more efficient, handling, storage and processing infrastructure can be built. Data on energy and post-harvest operations in developing countries and its effect on reducing food losses is scant. However, looking at energy use in the food processing sector in developed countries where food losses at the post-harvest stage (before consumption) are comparatively less, can provide evidence on energy access and how it assists in the reduction of food losses through efficient storage and handling. This however does not imply that the post-harvest systems in industrialized countries are perfect although they definitely perform better than their developing country counterparts due to superior access to resources like energy and finance.

Access to energy in most industrialised countries is close to 100 percent; which enables further development of storage and other efficient post-harvest technologies. This has resulted in low food losses at the handling, storing and processing stages of the value chain specifically due to high prevalence of handling and storage infrastructure. Food processing utilises significant amounts of machinery and energy to convert edible raw material into higher value food products. In the European Union for instance, the food and tobacco sector account for around 9 percent of the total industrial energy demand and 23 percent of the industrial value added (Ramirez et. al., 2006). Additionally, the total cost of purchasing fuel and electricity in the US food industry in 2006 was around USD 9.92 billion which was 9.57 percent of total energy cost of all manufacturing industries. Purchased electricity and natural gas were the largest consumed energy source in the US food manufacturing industry in 2002 contributing to 21 and 52 percent of the total energy use in the food industry, respectively. Processing of food facilitates the transformation of perishable items like milk into relatively long shelf life food items such as cheese and whey. Food processing involves different unit operations such as drying and cooling and energy consumption and energy use may differ significantly based on the process followed, the initial physical properties of the food as well as the desired properties of the final product. For instance, around 9 385 and 9 870 MJ of energy is required to produce a ton of milk and whey powder while around 2 MJ is required to produce around 1 ton of pasta (Wang, 2014).

TABLE 4.

Cost of Energy and Electricity use in food processing in USA in 2006

SECTOR	PERCENTAGE OF TOTAL ENERGY COST IN THE WHOLE FOOD INDUSTRY (%)	PERCENTAGE OF ELECTRICITY COST IN TOTAL ENERGY COST (%)
Animal food manufacturing	5.3	47
Grain and oilseed milling	22.	37
Sugar and confectionery product manufacturing	5.8	36
Food and vegetable preserving and speciality food manufacturing	13.1	44
Dairy product manufacturing	11.9	52.4
Animal slaughter and processing	20.7	53.4
Sea food manufacturing and packaging	2.5	45.5
Bakeries	9.2	54.7

Source: Wang, 2014

In most industrialised regions of the world, the end users of energy in the food processing industry are process heating, process cooling and refrigeration and machines drive. About half of all energy is used to process raw materials into products (Wang, 2014). Fuels are mainly used for process heat and space heating while electricity is mainly used for refrigeration, motor drives and automations. In the US, process heat for thermal processing and dehydration consumes around 59 percent of total energy in the whole food industry. Boiler fuel constitutes around a third of the total energy consumption. Motor drives and refrigerators consume the largest share of electricity in the food industry with 48 and 25 percent of the total electricity use respectively. In the perishable food subsector, the use of refrigeration is even more prevalent. In the meat sector for instance, refrigeration constitutes between 40 and 90 percent of the total electricity during production time and almost 100 percent during non-production times (Ramiez et. al., 2006). It is evident that access to energy, especially electricity for refrigeration and fuels for process heat and cooling are important in the storage and processing of food. A major reason for comparatively lower food loss of fruits and vegetables in industrialized countries is the availability and access to electricity powered refrigeration equipment which are absent in many developed countries. For many developing communities in Sub-Saharan Africa and Asia, renewable energy resources are available in abundance and can support sustainable cold chains through technologies that can either utilize these directly, such as cooling through solar-driven absorption, or to power existing or new technologies through electricity generation. In many cases, the costs of installing small-scale renewable infrastructure are already about the same or lower than those involved for establishing connections to a large-scale centralized electricity grid. This economic reality, combined with the substantial engineering resource needed to create a grid, means that local off-grid or micro-grid-based solutions are an attractive option (IMechE, 2014).

ENTRY POINTS WHERE ACCESS TO ENERGY CAN REDUCE FOOD LOSSES

In developing countries where post-harvest losses take place at the early stages of the FSC (post-harvest, handling and storage), losses can be reduced -

1. By ensuring adequate storage facilities are available to avoid bio-degradation of perishable food like fruits and vegetables, roots and tubers, meat and fish. This encompasses providing cooling and refrigeration storage room as well as to control humidity and microenvironment.
2. When long-term storage is not possible or if the qualitative loss of food has already begun, processing food into other forms can increase shelf file of the product. For instance, drying of tomato, canning and pickling of vegetables and fruits, smoking of fish and other meat products can reduce losses and increase food availability.

Both the above ways depend on energy and other low cost technologies at medium to large scale. Storing facilities need energy to optimize the temperature and humidity where food is stored. Energy is also required to process food into other high value products and to subsequently pack them.

Post-harvest cooling and refrigeration

Food losses from field to local market in the developing world are particularly high in the case of perishables such as fruit, vegetables, fish, meat and dairy, and this is often exacerbated by temperature in the warm countries of the tropical and sub-tropical regions. In sub-Saharan Africa and India for example, losses can reach 50 percent annually for perishable fruit and vegetables alone (IMechE, 2014 Timmermans *et.al*, 2014). A recent study (Liu, 2014) considers that (cold) storage is the most important cause of post-harvest losses for all types of food in China. Cold storage facilities and other refrigeration equipment are non-existent or inaccessible to the majority of smallholder farmers in sub-Saharan Africa due to lack of access to electricity. Even for those who have access to electricity, the cost of acquiring and operating cooling and refrigeration appliances can be prohibitive. In Tanzania, for instance, up to 25 percent of milk produced deteriorates and some 97 percent of meat sold in the country is warm, having never been exposed to refrigeration (3adi, 2012). The majority of developing countries are located in the hottest regions of the planet; nearly four billion people live in areas with annual average ambient temperatures above 22.5°C. For more than one billion people living in South Asia and sub-Saharan Africa, the average temperature for the

> “The challenge is that in nearly all cases cooling and refrigeration rely on access to a reliable and affordable source of either electricity or diesel fuel, which are often lacking or virtually non-existent in developing countries, particularly in rural areas where energy security is a significant issue.”
>
> *Source: Institution of mechanical engineers, 2014*

hottest month of the year exceeds 30°C. A lack of appropriate cooling within the field and storage is a significant challenge (IMechE, 2014). Pre-cooling, chilling or freezing produce at source retains original nutrients and can add several days to the life of a product, thereby substantially reducing subsequent food losses, boosting food safety, improving product quality and increasing incomes for producers. Therefore, storage in cold rooms or under shade immediately after harvest makes a significant difference in shelf life of the produce. Most farmers in developing countries lack on-farm cold storage facilities or shade and the perishable produce is left in the open or kept under ambient room conditions (Timmermans *et.al*, 2014).

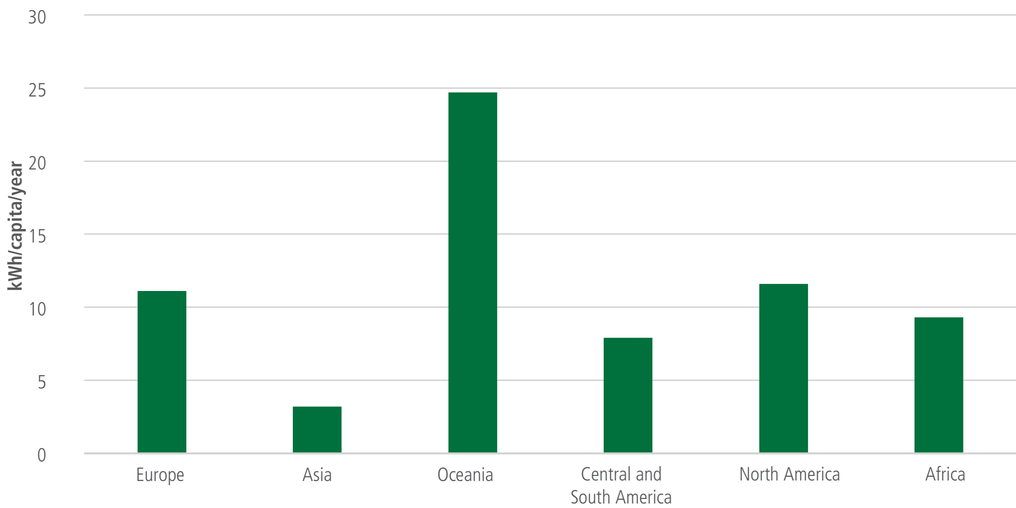
"Cold chain is the key to tackling the loss of perishable produce. In this regard, it is estimated that around a quarter of total food wastage in developing countries could be eliminated if these countries adopted the same level of refrigeration equipment as that in developed economies."

Source: Institution of mechanical engineers, 2014

Generally, food is stored from a few hours to several months after harvesting. It provides a means to deal with time, enabling delayed marketing and consumption of the produce. However, long-term storage of food is only possible if the storage conditions are optimized, otherwise significant losses will be incurred. It should be noted, however, that even with the best storage conditions, the shelf life is dependent on the initial quality and storage stability resulting from decisions made at the earlier stages of the supply chain (Timmermans *et.al*, 2014).

FIGURE 11.

Energy consumption by cold storages per urban resident by regions in 2010



Source: Global cold storage alliance, 2014

Highly perishable produce requires adequate storage facilities with controlled temperature, relative humidity and gas composition. If infrastructure for initial storage is lacking, perishable produce can spoil within hours (Rolle, 2006; Stuart, 2009). Without storage facilities, growers and producers need to sell their production regardless of market price (not being able to wait for better price conditions), or leave the produce unharnessed, or face the risk of a total loss, in the case of delayed collection by transporters, wholesale or retail stores. Grains can be stored for much longer periods as compared to fruits and vegetables if the storage conditions are optimized. Most farmers in Sub-Saharan Africa still use traditional grain stores made of grass, wood and mud. These structures do not guarantee protection against major storage pests such as rodents, insects, birds and fungal infections (Yusuf and He, 2011; Kankolongo,*et.al,* 2009). Lack of storage, again, may lead to food loss and economic losses, as farmers needing to sell their grains soon after harvest due to lack of storage facilities create conditions of oversupply in the market, which attracts low prices further reducing farmer's income.

Processing and drying

In Addition to cooling and refrigeration, a number of preservation methods are possible, including drying and curing. Due to factors such as poor weather and lack of knowledge by the farmers, grains for instance are often improperly dried. Such grains are predisposed to pest damage and fungal growth (IFPRI, 2010). For example, in maize, losses attributed to post-harvest pests are estimated to be 30 percent. The major pests in this case are common weevil (*Sitophiluszeamis*) and the larger grain borer (*Prostephanustruncatus*), reported to cause 0–20 percent and 30–90 percent losses, respectively (Bett and Nguyo, 2007). The damage caused by these pests results in low nutritional value, high percentage germination (for seed grains), reduced weight and low market value (Yusuf and He, 2011).
Mechanical drying can help to reduce post-harvest losses because it protects the product, promotes even drying and reduces the drying time, which leaves the product less susceptible to deterioration from pests and adverse weather conditions. For example, a mechanical dryer for rice requires energy to move air through the bulk of the rice grain and to heat the drying air in order for it to absorb more water from the wet grains. For moving the air, energy options include electricity, diesel or gasoline, and free convection. For heating the drying air, the energy options include kerosene, rice hull, and solar energy. Since the cost of energy is the largest cost factor in mechanical drying, it is important to choose the most appropriate energy source to minimize the drying cost.
For many poor rural households who rely on their own farm produce for the basic staple of their diet, processing crops by hand at home is the only option. This role is typically performed by women and is extremely labour intensive. Households may also need to carry or transport heavy produce long distances to be processed by powered machinery, often at great expense. Agro-processing extends markets in which goods can be sold and facilitates sales at higher prices and in larger quantities. Furthermore it transforms agricultural produce into both food and non-food commodities through processes ranging from simple preservation (e.g. sun drying) or transformation (e.g. milling) to the

production of goods by more capital and energy-intensive methods (e.g. food industry, textiles, paper).

Agro-processing often depends on the resources and expertise of small enterprises, co-operative millers, or other specialists who provide important energy services to farmers. It allows agricultural products to be conveniently:

- **heated**: withering tea leaves, roasting coffee
- **preserved**: smoking, forced air drying, sun drying
- **transformed to higher-quality/added-value forms**: flour, de-husked rice, expelled nut oil, fibre extraction.

Modern energy services can significantly reduce the time and heavy work involved in traditional agro-processing while improving incomes for smallholder farmers with higher prices from finished products. For example a project in Mali uses a multifunctional platform which is a simple low cost diesel generator that performs a range of functions such as providing electricity for refrigeration, lighting, and other appliances, pumping water, and grinding cereal. It is widely used for agro-processing and has saved women customers on average 2–6 hours per day (UNDP, 2004). Economies of scale and specialization can often be achieved by semi-centralizing processing, for example, through community watermills.

When considering strategies to reduce losses and improve food security through improved drying methods, the quantity and type of energy must be taken into consideration. Energy plays an important role in the drying process since it is required for the removal of water from food. The ambient air is one medium that can provide the energy needed to evaporate water from food. A warmer and drier climate is optimal for drying food products, while in cooler and humid climates alternative methods are necessary for optimal drying. In addition to the climate, other important factors to consider when selecting optimal drying methods, particularly in developing countries, are the amount, form, and cost of energy locally available and required for drying. It is important to also keep in mind that when food loss occurs at the post-harvest stage, for example, the energy inputs are also lost as energy embedded in the previous production phases.

HOW MUCH FOOD IS LOST PRIMARILY DUE TO LACK OF ACCESS TO ENERGY?

The lack of consistent and solid data on post-harvest losses in developing countries makes it difficult to quantify exactly how much food loss can be prevented by expanding access to energy. This is partly due to the fact that losses can vary among crops, countries and climatic regions, and also because a universal method does not exist for measuring and quantifying losses. Moreover, without a proper understanding of the situation, countries are less likely to provide international support toward food loss prevention. For example, less than five percent of funding for horticultural research and extension has been allocated to post-harvest losses over the past 20 years (Kitinoja et al., 2011).

Nevertheless, based on case studies and by comparing food losses corresponding to specific chains and post-harvest technologies and practices, an estimate can be obtained. The importance of refrigeration in preventing food losses is evident from the above discussion. Estimates based on figures from the International Institute of Refrigeration (IIR, 2009) suggest that around one quarter of food loss and waste in developing countries could be eliminated if these countries had the same level of refrigeration equipment as found in developed economies (IMechE, 2014). Biological decay of food increases with the increase in temperature, affecting the duration for which food can remain fresh and usable. Fresh fish for instance can be stored for as long as 10 days with refrigeration while in its absence, it rots in a few hours resulting in loss of food. Similarly, access to refrigeration can allow storage of potatoes for up to 10 months against merely 2 weeks without refrigeration (Table 5).

TABLE 5.

Food loss increases as handling temperature increases

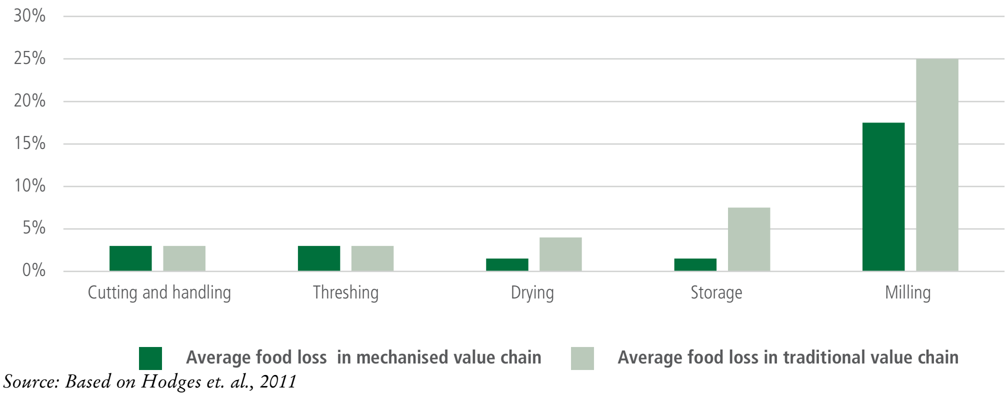
FOOD PRODUCT	STORAGE POTENTIAL			
	AT OPTIMAL COLD TEMPERATURE	OPTIMAL TEMPERATURE +10 °C	OPTIMAL TEMPERATURE +20 °C	OPTIMAL TEMPERATURE +30 °C
Fresh Fish	10 days at 0°C	4 – 5 days	1 - 2 days	A few hours
Milk	2 weeks at 0°C	7 days	2 -3 days	A few hours
Fresh Green Vegetables	1 month at 0°C	2 weeks	1 week	Less than 2 days
Potatoes	5 to 10 months at 4 to 12°C	Less than 2 months at 22 °C	Less than 1 month at 32 °C	Less than 2 weeks at 42 °C

Source: Kitinoja, 2013

Similarly, comparing food losses in traditional value chains where most activities like drying and threshing are done manually or without a modern source of energy or technology with the food losses in mechanized value chains could help estimate the excess food losses due to lack of mechanization. For instance, based on a study by Hodges, et al.(2011) on losses across the rice value chain in south east Asia (Fig. 12) it can be estimated that if traditional value rice value chains adopt mechanized operations, around 16 percent losses can be reduced between the harvesting and milling stages of the rice value chain.

FIGURE 12.

Losses in Traditional vs. Mechanized Post harvest rice chain in South Asia[3]

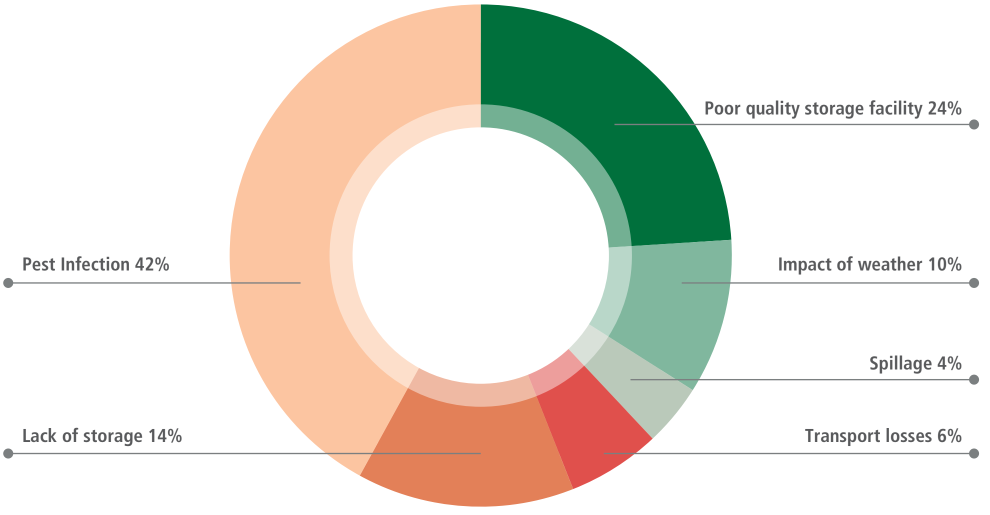


Source: Based on Hodges et. al., 2011

In the case of Tanzania where only around 2 percent of the rural population has access to electricity, a lack of appropriate temperature controlled storage infrastructure has resulted in postharvest losses of approximately 63 percent. Maize losses alone can be around 40 percent yearly of which lack of or inadequate storage accounts for 35 to 40 percent of losses. Fruit farming which is also dominant in Tanzania experiences high losses as high temperatures in afternoon and evaporation cause fruits to shrink and rot, making them unfit to sell.

FIGURE 13.

Main causes of food losses in Tanzania



Source: ACTS, 2014

3 Note: In mechanized value chains, threshing and drying is mechanical, storage is sealed and milling in commercially done. In traditional value chains threshing is done manually and open air sun drying and storage is used. Milling is done at village level and not commercially.

The lack of an agro-processing industry in Tanzania results in a large-scale export of unprocessed products, which increases losses at the post-harvest stages of the FSC. Limited capacity of agro-processing results in a loss of between 30 to 70 percent of cereals and fruits respectively at the post-harvest stage. In the fisheries sector, around 15 to 20 percent of output is lost due to lack of appropriate processing technologies. The main reason for inadequate agro-processing sector in Tanzania is the lack of energy and other physical infrastructure.

Similarly in India where food grain stocks procured by the national government are released through the Public Distribution System (PDS), and sold to low-income families at a subsidized rate. However, due to a lack of storage capacity, an estimated 6–10 per cent of food grain and 12 to 20 percent of fruits and vegetables stocks are damaged annually by moisture, insects, rodents and fungi due to either lack of proper storage facilities or where such facilities exist, due to lack of reliable power to operate them. India's warehousing capacity is currently about 108.75 million metric tonnes. It has been estimated that an additional 35 million metric tonnes will be required in next five to ten years (NTS and NSCS, 2012).

CHAPTER 3

ENERGY ACCESS AS AN ENABLER FOR FOOD STORAGE AND PROCESSING TECHNOLOGY

Simple, low-cost storage and processing methods can drastically cut food loss, especially for small-scale farmers in the developing world, who frequently lose food to factors like pests, spoilage, and transportation damage. A significant share of total energy inputs is embedded in food losses that occur at the harvest and storage stages. As a result, significant attention is given to renewable energy in developing decentralised processing and storage infrastructure. For instance, solar energy and biomass have been used successfully for both dry and cold storage. Compared to other food preservation techniques, food drying can be performed using low-temperature thermal sources and is applicable to many different types of food (including fish, fruits and vegetables). The dried food produced is lightweight, is easily stored and transported and has an extended shelf life. Low cost decentralised energy systems can help speed up adoption of food cooling and processing technologies.

COOLING

Various technologies exist at the postharvest level of the FSC that can help to significantly reduce losses in developing countries where post-harvest stages account for the majority of food losses. Such losses occur mainly in traditional supply chains characterized by production of small-scale farmers. In developing countries, the most important interventions have to be targeted at the early stage of the value chains. These include on farm and community level cooling, refrigeration technologies and processing technologies that can extend shelf life. A key step before introducing an intervention is to analyse its technical and economic suitability in a given country or region and the scale at which it would operate. This is imperative as the cost associated with a storage, value addition and processing technology/ infrastructure vary significantly depending on the local skill levels as well as the level of development of the country. This is especially true for refrigeration infrastructure as the cost of constructing or providing cold storage facilities or technologies vary with scale. In kenya for example a charcoal cooler for instance costs from about USD 125 to as high as USD 2 000, a refrigerated container can cost up to USD 7 500 while a cold room costs begin at approximately USD 20 000 . The cost of providing equipment or introducing a technology to process or add value can also vary significantly.

A simple value addition unit can cost from USD 250 (e.g. homemade juice) and a modern value addition unit that would accommodate huge volumes costs from USD 200 000 and above (Winkworth-Smith *et.al*, 2012). For smallholder farmers with limited capital, the risk of investing in better inputs or processes to reduce PHL is very high, thus limiting the resources they have available to make needed changes. However, innovative financing mechanisms such as new models for low-interest lending can increase investment and opportunities for greater returns later (Rockefeller foundation, 2014).

Therefore, introducing decentralized and standalone practical and cost-effective solutions that can be implemented relatively quickly, and could achieve near-term gains once put into place is required. At the post-harvest handling, storage and processing level, such solutions range from small scale evaporative cooling chambers to solar powered small to medium cooling infrastructure to efficient post-harvest handling equipment such as plastic crates and bags. At the processing level, solar dryers can be installed to extend shelf life of various perishable foods while conserving the nutritional value of the food.

In hot climates, farm, fish and animal produce do not stay fresh for long. Cooling is often preferred since the process does not significantly change the produce. There are various technologies available for cooling but their success depends on the locally available resource and skilled labour to construct and operate as well as access to some form of energy carrier. Broadly they can be classified into three categories;

1. Evaporative cooling,
2. Heat driven cooling and
3. Mechanical cooling.

Mechanical cooling is dependent on a reliable supply of electricity through grid or diesel generators and are hence more suited to industrialized or recently industrialized economics. Evaporative cooling and heat driven coolers can be more suited for rural areas of developing countries. Table 6 provides a comparison of these technologies.

TABLE 6.

Technologies available for cooling

	ENERGY SOURCE	LABOUR	PARTS AND MAINTANCE	10 YEAR TOTAL COST
MECHANICAL COMPRESSION				
Grid	Grid electricity. Cost of connecting/ transforming can be high.	Maintenance: skilled personnel.	Source of parts may be distant. Supply may be uncertain.	Purchase cost, electricity, personnel, and replacement parts.
Diesel	Diesel generator	Maintenance: skilled personnel permanently on-site.	Source of parts may be distant. Supply may be uncertain.	Purchase cost, diesel, replacement parts.
Solar photovoltaic	Irradiation of 10-20 MJ/ day/m². Long cloudy periods problematic.	Skilled personnel permanently available.	Battery life 2 to 4 years. Control electronics can fail.	£3500-6500 for 60-80 W cooling includes replacement costs.
HEAT DRIVEN COOLERS				
Conventional	Gas/kerosene quality must be adequate.	Burner parts, wick adjustment, etc.	Replacement of burner parts routine.	£1 000-2 000 for 60-100 W cooling and small maintenance cost.
Biomass driven	Any locally available heat source suitable, e.g. charcoal, coal, agro wastes, cow dung fossil fuels.	Maintenance of open burner, brine tank, cooling water. Local skills sufficient.	Locally available spare parts.	Purchase cost projected at £2 000 for 100 kg ice/day. Fuel cost £50-100 per year.
Solar	Solar irradiation 10-120 MJ/ day/m². Long periods of cloud problematic.	Local skills sufficient, few moving parts.	Solar panels may require import of spare parts.	Current purchase cost £1 500-2 500 for 10 kg ice/day. Projected cost £4 000 for 100 kg ice/day (including solar panel).
EVAPORATIVE COOLERS				
Clay or Porcelain made coolers	Access to water to and dry air to produce slow evaporation	Local skills, no moving parts	NA	Can range from USD 2 to 20 depending on the size and scale.

Source: Practical action, 2003

Passive cooling methods can be very effective in prolonging the life of food and dairy products and fruits and vegetables. Technologies include the zeer pot and cooling chamber. Passive technologies are very economical since they require no fuel or electric input and can be built using widely available materials (Practical Action, 2014) and can provide important co-benefits. A comparison of various types of storage technologies is presented in table 7.

TABLE 7.

Comparison of cooling technologies

COLD STORAGE TECHNOLOGY	PURCHASE PRICE OR CONSTRUCTION COST	TYPICAL CAPACITY (MT)	ENERGY USE PER MT	ESTIMATED MAX. ENERGY USE/ DAY
Bricks and sand evaporative cool box	USD 200 to USD 300	0.2	0	0
Evaporatively cooled storage room 20 m² floor area	varies	5 to 6	0.09 kWh	0.45 kWh to 0.54 kWh
Evaporatively cooled storage room 40 m² floor area	varies	10 to 12	0.09 kWh	0.9 kWh to 1.2 kWh
Ventilation fan for night air cooling	USD 200 to USD 300	varies	100 watts/ hr (8 hour night)	0.8 kWh
New prefabricated cold roomn 20 m² floor area	USD 20 000	6	50 kWh for 4°C or 30 kWh for 12°C	300 kWh or 180 kWh
New prefabricated cold room 40 m² floor area	USD 32 000	12	50 kWh for 4°C or 30 kWh for 12°C	600 kWh or 360 kWh
Used prefabricated 20 m²	USD 4000 to USD 12 000	6	50 kWh for 4°C or 30 kWh for 12°C	300 kWh or 180 kWh
Used prefabricated 40 m²	USD 7 200 to USD 21 000	12	50 kWh for 4°C or 30 kWh for 12°C	600 kWh or 360 kWh
Cold room (small scale, owner built) 20 m²	USD 4000 to USD 8000	6	50 kWh for 4°C or 30 kWh for 12°C	300 kWh or 180 kWh
Cold room (small scale, owner built) 40 m²	USD 7 200 to USD15 000	12	50 kWh for 4°C or 30 kWh for 12°C	600 kWh or 360 kWh
Cold room (small scale, owner built) 60 m²	USD 10 800 to USD 22 500	18	50 kWh for 4°C or 30 kWh for 12°C	900 kWh or 540 kWh
Refrigerated cold room 80 m²	USD 14 400 to USD 30 000	24	50 kWh for 4°C or 30 kWh for 12°C	1200 kWh or 720 kWh
40 foot reefer retrofit – 25 m² (used highway van or refrigerated marine container as 4 C cold room)	USD 24 000 to USD 32 000	7	40-48kWh or 3.5 to 5.0 L/ hour	280 kWh to336 kWh or 84 L to 120 L diesel fuel
20 foot reefer retrofit – 12 m² (used highway van or refrigerated marine container as 4 C cold room)	USD 12 000 to USD 16000	3	40-48kWh or 2.2 to 4.0 L/ hour	120 kWh to144 kWh or 53 L to 96 L diesel fuel

COLD STORAGE TECHNOLOGY	PURCHASE PRICE OR CONSTRUCTION COST	TYPICAL CAPACITY (MT)	ENERGY USE PER MT	ESTIMATED MAX. ENERGY USE/ DAY
Back-up generator 100 kW	USD 15 000 to 20 000		21 L/hour diesel fuel	
Back-up generator 400 kW	USD 60 000 to 80 000		84 L/hour	
Back-up generator 800 kW	USD 1 20 000 to 1 60 000		168 L/hour	

Source: Empowering Agriculture report, 2014. USAID

Evaporative cooling

Evaporative cooling is a naturally occurring phenomenon. The physics underlying evaporative cooling is based on the fact that water must have heat applied to it to change from a liquid to a vapour. When evaporation occurs, this heat is taken the surroundings, resulting in a cooler liquid or the air around it. Evaporative coolers harness this effect in a number of different ways, but the general design of each is similar. One vessel, holding the food being stored, is placed inside another vessel filled with water. As the water evaporates, the inner vessel stays cool. Water is then refilled as needed. Evaporative cooling devices are generally easy to make and depend on locally available material. They are a relatively low-cost way of preserving fruits, vegetables, roots, and tubers, especially in regions where electric refrigeration is either prohibitively expensive or unavailable due to lack of a reliable electricity supply. The only cost associated with evaporative coolers is up-front, which reduces the operational costs and increases certainty around the expenses associated with using these coolers.

There are various designs and materials like clay and ceramic that can be used to make evaporative coolers. In addition, sand or charcoal can be used to produce evaporation. They can range from pots intended for household use to medium scale coolers to be utilised at community level.

ZEER POT IN NIGERIA, SUDAN AND GAMBIA:

The ZEER pot is one example of a successful low cost refrigeration device that was tested in Sudan, Nigeria and Gambia. A earthenware pot with a lid on the top is fitted inside a larger pot with an insulating layer of sand in between. This layer can be kept cool by adding water at regular intervals (generally twice a day), thus providing a refrigerated storage space at minimal cost. As water in the sand evaporates through the surface of the outer pot, it carries heat, drawing it away from the inner core, thus cooling the inside of the inner pot. The zeer itself costs less than USD 2 to produce, can hold up to 12 kg, and can be reused for several years before becoming saturated with salts and needing replacement. The zeer dramatically extends the shelf life of the items kept in it. For example, tomatoes and guavas, which might normally expire within two days without any storage, last up to 20 days in a zeer pot.

Source: Practical Action, 2014a

ZERO ENERGY COOL CHAMBER (ZECC) IN INDIA

The zero energy cool chamber (ZECC) is a low cost refrigeration technology based on evaporative cooling. It has considerably larger capacity than zeer coolers and can be used at small community level. It consists of two brick walls, one nested inside of the other, with the cavity between the two filled with wet sand. The external wall is submerged in water before construction in order to soak the bricks and then is removed for construction. The chamber has a cover constructed out of bamboo and an awning to avoid direct sunlight or rain. The outer wall and the sand inside are re-wet twice daily while the chamber is in use. The total cost of construction is about USD74, and the finished chamber can hold 100 kg. Like the zeer, the ZECC can be reused for many years.

CROP	SHELF LIFE AT ROOM TEMPERATURE (IN DAYS)	STORAGE LIFE IN ZECC (IN DAYS)	INCREASE IN SHELF LIFE (%)
Banana	14	20	43 %
Carrot	5	12	140 %
Cauliflower	7	12	71 %
Guava	10	15	50 %
Lime	11	25	127 %
Mango	6	9	50 %
Mint	1	3	200 %
Peas	5	10	100 %
Potato	46	97	111 %

Studies in India found that a ZECC was up to 11°C cooler than the outside air temperature in the hottest months of the year. The chamber significantly increases shelf life and reduces weight loss for fruits and vegetables stored within it. Thus far, ZECCs seem to be most common in India, and are now being actively promoted in Tanzania by the World Vegetable Center (AVRDC). Commercial size ZEEC with a capacity of 6-8 ton have also been built in India though they require a fan to draw air into the chamber and were found effective in storing citrus, banana, potato and tomato during the rainy season.

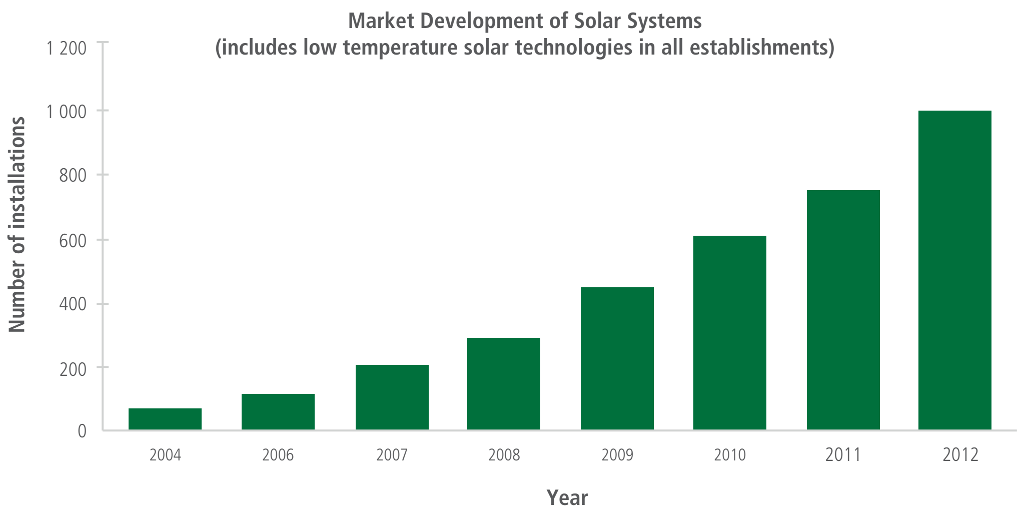
Source : Lipinski et.al, 2013 & http://ucce.ucdavis.edu/files/datastore/234-2143.pdf

Solar assisted cooling, absorption chillers

Developing cooling solutions from solar energy offers a clean way to cool and preserve agricultural products for a longer period. Two types of cooling machines are generally available in the market; one that works on electricity, i.e., the Vapor Compression Machine (VCM) and the other that works on thermal heating; the Vapor Absorption Machine (VAM). The VCM generally works on electricity while the VAM are used at places where waste heat is available or conventional electricity is either not available all the time or is expensive. Both solar photovoltaic (PV) and solar thermal energy can be used for refrigeration. Solar photovoltaic panels produce dc electrical power that can be used to operate a dc motor, which is coupled to the compressor of a vapour compression refrigeration system. The major considerations in designing a PV-refrigeration cycle involve appropriately matching the electrical characteristics of the motor driving the compressor with the available current and voltage being produced by the PV array. Solar thermal energy can also be used to produce ice which in turn can be used to preserve perishable agricultural commodities like milk, fruits and vegetables. A solar-powered heat-driven refrigerator boils the refrigerant out of an absorbent material and condenses the gaseous refrigerant to a liquid thereby cooling the surrounding. Many such solar cooling stations and cold storage infrastructures have been developed and the trend seems to increasing (Figure 14).

FIGURE 14.

Global solar cooling installations



Source: Based on Global Status Report, REN21 (2013) and Mungier and Jakob, Keeping Cool with the Sun (2011)

SOLAR ASSISTED MILK CHILLING IN INDIA

India is the world's largest producer of milk. However, due to an unreliable electricity supply as well as inadequate cooling infrastructure, large quantities of milk are lost every year.

Promethean power systems has developed a new thermal battery, which led to the creation of a "rapid milk chiller" (RMC). The RMC is currently being deployed in the agricultural areas of Maharashtra, West Bengal and Tamil Nadu. It employs the use of a thermal energy battery pack that charges on solar power and, when available, on grid electricity when solar power is unavailable. The loaded battery powers the cold storage continuously regardless of unreliable access to electricity. The Rapid Milk Chiller can thus close the cold-chain from the small producers to the dairy.

India's dairy industry is dominated by farmers with a only a few cows who depend on rickshaws, bikes, or their own feet to transport the warm milk on the first leg of its long journey from farm to local village collection center to the dairy plant.

The rapid milk chiller is a dome-shaped machine that couples to a thermal energy battery to cool milk from 35°Celsius down to 4°Celsius. The rapid milk chiller cools the milk by means of a heat exchange with cold fluid inside the dome. Even when electrical power is unavailable, the rapid milk chiller can cool up to 500 liters of milk using only the thermal energy stored in the battery. The chiller-battery pair is installed in village collection centers enabling villagers to keep their milk fresh for up to two days. Dairy trucks do not have to make daily rounds and no longer need to transport milk from a village collection center to a separate chilling center. The dairy plants can also extend their reach to more isolated villages with rapid milk chillers.

Promethean Power has sold 60 chiller-battery pairs to dairy processing facilities. The company plans to produce more chiller-battery pairs as demand rises, and it intends to apply its technology to cool vegetables and other perishable food items.

Source: www.rural21.com/francais/initiatives-du-secteur-prive/detail/article/solar-powered-milk-chillers-for-rural-india-00001192/

SUNDANZER REFRIGERATION KENYA

Due to limited electrification in rural areas, 85 percent of Kenya's 800 000+ dairy farms do not have access to refrigerated storage and transportation. This lack of access to electricity and hence cooling solutions results in less than half of the milk produced reaching dairy processors while the majority of it is lost or consumed soon after the production. Furthermore, of the milk that is processed, up to 30 percent of it may spoil without appropriate cold-storage options. As a result, many dairy farmers as well as processors lose significant earning potential from their operations.

SunDanzer is a small-scale portable cooling system tailored for use in the Kenyan dairy market. The system comprises a photovoltaic refrigerator (PVR) that uses solar energy to cool a chest refrigerator. This technology may use a battery for energy storage or phase-change materials—substances which are capable of storing and releasing large amounts of energy—or a combination of both. SunDanzer will evaluate freezing phase-change material into milk packs. The portable milk packs retain their cold temperature overnight, and in the morning, farmers use them to keep collected milk cold in sterilized aluminium milk containers as they transport it to dairy processing facilities.

This clean energy solution aims to increase dairy farm productivity and income by significantly decreasing milk spoilage. Effective cold-chain storage lowers bacteria count and improves milk quality for consumers. These improvements can play a major role in the livelihoods of approximately one million-smallholder dairy farming families in Kenya. Furthermore, it contributes to Kenya's sustainable development by improving the distribution and access to renewable energy technologies.

Source: Powering Agriculture Winner, 2013 (https://poweringag.org/innovators/solar-powered-refrigeration-dairy-farms

SUN CHILL

Post-harvest, spoilage due to various reasons make getting high quality horticultural products to market a significant challenge. A key reason for such spoilage is the lack of cooling and removing field heat from these products which can double shelf life and reduce spoilage rates that often exceed 40 percent in developing countries. Lack of access to energy is fundamental to enable cooling technologies but current off-grid cooling technologies are expensive, energy intensive, and difficult to maintain.

SunChill is an off-grid refrigeration solution that reduces post-harvest losses by: (i) Removing field heat from crops immediately following harvest, and (ii) Providing continued product cooling at local markets and/or central processing facilities. Sun Chill can transforms 50°C solar thermal energy into 10°C refrigeration using water-based refrigerants, zero electricity and local, non-precision components. These characteristics enable production of a low cost, low-maintenance technology that reduces spoilage and benefits smallholder farmer livelihoods.

The low-cost system enables increased horticultural production both for domestic and export consumption, generating additional income for smallholder farmers and increased access to nutritional fruits and vegetables while generating both manufacturing and service based employment.

Source: Powering Agriculture Winner, 2013 (https://poweringag.org/innovators/sunchill-solar-cooling-horticultural-preservation)

BIOGAS MILK CHILLER IN PAKISTAN

Pakistan is among the top 5 milk producers in the world. It is estimated that only 3% to 5% of Pakistan's total milk production is processed and sold through normal channels. Lack of access to electricity resulting in lack of milk chilling facilities at farm is the main cause of low processing rate. Lack of storage facilities means that the evening milk, which represents a significant portion of the total volume, cannot be properly marketed, which results in lower returns for dairy farmers.

As there is a shortage of grid electricity, many milk chillers are powered, at least partially, by diesel generators. Winrock International suggested that biogas could be used as an alternative power source for milk chilling. A demonstration project was implemented to demonstrate to dairy farmers and milk collection companies that biogas-generated electricity is a viable and sustainable alternative to diesel. 4 biogas plants were installed of which 2 plants were $50m^3$ and 2 plants were $100m^3$.

Three plants were installed on farms that each had around 100 cows and one was installed in a community where each villager owns a small number of cows. The smaller biogas plants can produce about 32kWh of electricity and the bigger plants about 64kWh, which is sufficient to run milk chillers with capacities of 500l (12kWh) and 1 000l (20,8 kWh) for 8 hours. The additional electricity generated is used to run other farm equipment such as fodder cutters or fans, or is used for lighting purposes.

Feasibility assessments of 12 dairy farms were conducted to select the farms where the biogas plant was established. Based on the assessment, 4 farmers decided to install biogas plants. The others 8 farms opted out because they did not have available finance to make the high upfront investment required for the biogas units. The 4 farms that installed the biogas units received subsidies of about USD 1 000 for the larger plants and USD 800 for the smaller plants. Milk chillers and electric generators were provided by Nestlé Pakistan Ltd, on the condition that farmers would continue to supply milk to them. The equipment remained the property of Nestlé. Nestlé paid the farmers the standard chilling cost of US$0.01/l and an additional biogas incentive of USD 0.0125/l. The payback period for the farmers to recover their investment costs is anticipated to be around 3 years.

Source: www.wisions.net/projects/powering-milk-chilling-units-with-iogas#project69

MINI COOLER BASED ON THERMOELECTRIC CHIP IN INDIA

The idea to address the basic refrigeration needs of rural families in India began in 2006 at a disruptive innovation workshop led by Professor Clayton Christensen of Harvard Business School through Innosight.

The Innosight team began its work by imagining living in a home without a refrigerator. Electricity is unavailable or unreliable in many rural parts of India, where families earning under USD 5 per day can't afford major appliances.

Based on a direct interviews and discussion it was found that people needed an affordable way to keep milk, vegetables and leftovers cool for a day or two—both at home or away. Godrej developed prototypes for feedback at "co-creation" events. In a straw poll of 600 women in the village of Osmanabad, the community voted to make the product red, the color of harmony and bliss.

From this effort came the ChotuKool, or "little cool" in Hindi. A disruptive innovation for the base of the economic pyramid, instead of traditional compressors, ChotuKool is based on a thermoelectric chip that maintains a cool temperature on a 12-volt DC current or an external battery. The unconventional opening ensures cold air settles down in the cabinet to minimize heat loss and power consumption. The unit is highly portable, with 45 liters of volume inside a fully plastic body weighing less than 10 pounds.

Priced at USD 69, about half of an entry level refrigerator, Chotukool creates a new product category, with a targeted value proposition that serves a new segment of customers.

Source : www.innosight.com/impact-stories/chotokool-case-study.cfm

SOLAR DRYING OF FOOD

Drying of food is a way to increase the shelf life of many kinds of fruits and vegetables. Drying prevents or inhibits the growth of micro-organisms as well as reduces the weight and bulk of food for cheaper transport. If done correctly, the nutritional quality as well as the colour and texture of rehydrated dried fruits is only slightly less than that of fresh food (Practical Action, 2007). The temperature at which food is dried varies with food type. Many food items must be dried at relatively low temperatures, i.e. less than 100 oC to ensure the desired product quality. Solar dryers can often be used instead of sun drying or conventional dehydration systems. Drying mainly entails removing water from the food item to make it less susceptible to microbial growth. Energy required for removing moisture from agricultural products is higher than the theoretical values for evaporating water because water must be removed from inside the cells of the product, and extra energy is required. Pimentel and Pimentel (1996) report that the theoretical value for evaporating one kilogram of water is 2.60 MJ, but the real energy use is 2 to 6 times higher at 5.2 to 15.6 MJ. Post-harvest grain drying, in particular, is an energy intensive process. For example, Pimentel et al. (1973) report that 6.4 MJ are required to reduce the moisture level in 7.4 kg of corn from 26.5 percent to 13 percent. Sources such as electricity, natural gas or liquid petroleum gas (LPG) can be used increase the rate of drying, providing heat at around 500 to 750 MJ for drying one ton of wet grain down to an acceptable moisture content for storage. Mechanical drying can help to reduce post-harvest losses because it protects the product, promotes even drying and reduces the drying time, which leaves the product less susceptible to deterioration from pests and adverse weather conditions. For example, a mechanical dryer for rice requires energy to move air through the bulk of the rice grain and to heat the drying air in order for it to absorb more water from the wet grains. For moving the air, energy options include electricity, diesel or gasoline, and free convection.

For heating the drying air, the energy options include kerosene, rice hull, and solar energy. Since the cost of energy is the largest cost factor in mechanical drying, it is important to choose the most appropriate energy source to minimize the drying cost. Furthermore, scaling up renewable energy and energy efficiency measures in drying technologies should also be promoted in support of countries' transition towards low carbon development.

Solar dryers are a viable technology, which can be used at the farm or village level to process food. There are three main types of solar dryer (direct, indirect and mixed modes) but these classifications can be further sub-divided depending on the type of heat transfer fluid, the direction and the source of the flow, and the inclusion of thermal storage and a supplementary energy system. In practice, however, some types of solar dryer have proven to be more feasible than others. The simplest system of food drying is the direct drying in open air system where food is exposed to the sun and wind by placing in trays, on racks, or on the ground. This is the most prevalent way of drying in developing countries as it is cheap and does not involve any mechanised or moving parts. However, because the food is exposed to the surrounding environment, it is rarely protected from pests, predators and weather. Direct insulation drying is time consuming and labour-intensive. Additionally, it is impossible to regulate the dryer temperature which inhibits optimal or desired level of drying.

In an indirect mode solar dryer, the crop is not directly exposed to solar radiation. The incident solar radiation is absorbed by some other surface – usually a solar collector – where it is converted into heat. The air for drying flows over this absorber and is heated. The warmed air is then used to transfer the heat to the crop located within an opaque structure. Such a system uses heat collectors and conductors powered by solar or other sources of energy. The scale at which the dryer operates depends on the usage, availability of capital labour and material. However, in general, direct insulation drying is only suitable for on-farm or household level. The size depends on the amount of material and capital available. Indirect solar powered dryers can range from small farm level to greenhouse level drying (Weiss and Buchinger , 2012). As an example,[4] loading capacity of a PV powered solar dryer can range from 8 Kg to 200 Kg with a drying area ranging from 0.56 m^2 to 14.4 m^2

TABLE 8.

Various solar drying methods

TYPE	DESCRIPTION
Open-Air	Food is exposed to the sun and wind by placing in trays, on racks, or on the ground. Food is rarely protected from predators and the weather.
Direct Sun	Food is enclosed in a container with a clear lid allowing sun to shine directly on the food. Vent holes allow for air circulation.
Indirect Sun	Fresh air is heated in a solar heat collector and then passed through food in the drier chamber. In this way the food is not exposed to direct sunlight.

4 http://mnre.gov.in/file-manager/akshay-urja/july-august-2014/EN/34-37.pdf

TYPE	DESCRIPTION
Mixed Mode	Combines the direct and indirect types; a separate collector preheats air and direct sunlight adds heat to the food and air.
Hybrid	Combines solar heat with another source such as fossil fuel or biomass.
Fueled	Uses only electricity or fossil fuel as a source of heat and ventilation.

Source: Green and Schwarz, 2001

Most direct insulation drying systems do not require specialized manufactured equipment and hence are easy to set up with locally available resources. Solar powered air as heating medium systems can be manufactured locally in most countries. In cases of specialized solar technology (e.g. PV) systems being used, they may need to be imported. 3

Dryers can further be classified as active, passive or greenhouse type depending on the scale and the way air is circulated in the dryer.

Passive solar dryers are also called natural circulation or natural convection systems. They are generally of a size appropriate for on-farm use. They can be either direct (e.g. tent and box dryer) or indirect (e.g. cabinet dryer). Natural circulation solar dryers depend exclusively on solar-energy. In such systems, solar-heated air is circulated through the crop by buoyancy forces or as a result of wind pressure, acting either singly or in combination.

Active solar dryers are also called forced convection or hybrid solar dryers. Optimum air flow can be provided in the dryer throughout the drying process to control temperature and moisture in wide ranges independent of the weather conditions. Furthermore, the bulk depth is less restricted and the air flow rate can be controlled. Hence, the capacity and the reliability of the dryers are increased considerably compared to natural convection dryers. It is generally agreed that well designed forced-convection distributed solar dryers are more effective and more controllable than the natural-circulation types. The use of forced convection can reduce drying time by up to three times and decrease the required collector area by 50 percent.

A greenhouse dryer is a large scale drying system where the idea is to replace the function of the solar collector by a greenhouse system. The roof and wall of this solar dryer can be made of transparent materials such as glass, fiber glass, plastic or polycarbonate sheets. The transparent materials are fixed on a steel frame support or pillars with bolts and nuts and rubber packing to prevent humid air or rain water leaking into the chamber other than those introduced from the inlet opening. To enhance solar radiation absorption, black surfaces should be provided within the structure. Inlet and exhaust fans are placed at proper positions within the structure to ensure even distribution of the drying air. These can be natural convection based where hollow spaces are provided on the top of the system to allow air circulation or forced convection where fans are used to have a controlled flow of air. These fans can be run by PV or other sources of energy.

Solar tunnel dryers have also been constructed and tested which are well suited to medium sized farms or small cooperatives. The Hohenheim-type dryer results in faster and higher quality drying than traditional open-air methods. In Turkey, for example, apricots can be dried in 2 days – half the time required by traditional methods. An important feature contributing to consistent quality is the use of photovoltaic powered fans for forced convection. The acceptable load for the dryer ranges from 1.5 kg/m² for medicinal herbs to 25 kg/m² for rice or coffee. For a standard dryer with a 20 m² drying area, this corresponds to 30 to 500 kg per batch (Weiss and Buchinger , 2012).

PV ASSISTED SOLAR CABINET GRAIN DRYING IN MALAWI

A PV powered solar dryer integrating DC fan was developed and field-tested for small-scale use in Malawi to dry maize. With a capacity of 90 kg, the dryer has been designed to utilize forced air circulation without the use of external power supplies like grid electricity, fossil fuels and batteries. A main design constraint was to limit the air temperature to a maximum of 60°C, which is the international drying standard for maize grain used for human consumption. Temperatures in excess of 60°C lead to grain overheating, cracking and subsequent microbial attack. Results indicated that the PV-driven fan provided a passive control over the airflow and hence the drying air temperature. The dryer was coupled to a solar air heater having a sun-tracking facility and optimized blackened sisal rope grids for improved energy collection efficiency of the order of 80 percent. Grain drying with the solar dryer reduced the drying time by over 70 percent as compared with sun drying,. Grain quality, texture, and flour quality and flavour improved significantly with the dryer, as grain was permanently protected from sudden rains, vermin and dust contamination. Although the capital cost of the solar dryer was about USD 900, the dryer was found to be cost-effective with a payback period of less than one year if it is used to dry grain for purchasing by the Cereal Boards

Source: Weiss and Buchinger, 2012

DRYING FRUITS AND VEGETABLES IN WESTERN CAMEROON

Agriculture in Cameroon's northwest and western provinces is highly intensive and produces a variety of foodstuff. However, there is limited capacity to process and prolong the shelf life of agricultural goods. This forces many producers to sell their harvest during peak periods at a loss, since they are unable to preserve the fresh food. This also results in rotting of large quantities of food which is lost due to the overabundance of production. A dryer capable of producing high-quality dried fruit and vegetables allows producers greater control over produce prices, as well as access to more distant and lucrative markets. Winrock International developed a low-cost, medium-sized ventilated gas dryer to assist producers in the high quality drying of numerous agricultural products (e.g., peppers, spices, greens, medicinal plants, fruits, mushrooms, meat, and fish). The dryer has a drying space of 5m² and uses an innovative ventilation system allowing users to control air circulation throughout the drying process. Such control over air circulation allows for efficient energy consumption and produces high-quality finished dried products. The dryer is constructed using locally available materials, thus permitting to train local manufactures in the construction

and maintenance of the dryers. Assuming the processing of one ton of fresh peppers a year, an approximate of USD 2 000 in net income is expected to be generated, which is more than three times the capital investment made in the dryer. Winrock has trained three local metal manufacturers in the construction of the dryer technology. Trained in dryer operation, three small enterprises are currently drying a variety of local crops, including fruits, peppers, ginger, greens, and other specialty products.
Source: Powering Agriculture report, 2014

GREENHOUSE SOLAR DRYER FOR SMALL-SCALED DRIED FOOD INDUSTRIES IN THAILAND

Thailand produces large amounts of dried fruits and vegetables. Most farmers use the traditional natural sun drying method to produce dried agricultural products. Despite a low drying cost, products dried with this method are subjected to contaminations by dirt and dust, insect infestation, and loss by birds and animals. To mitigate these losses a polycarbonate sheet-covered greenhouse solar dryer was constructed. It consists of a parabolic roof made from polycarbonate sheet on a concrete floor. The parabolic cross-sectional shape helps to reduce wind load in case of a tropical storm. The structure of the dryer is made of galvanized iron bars. The products to be dried are placed in a thin layer on arrays of trays. These arrays of trays are placed on single-level raised platforms with passages between the platforms for loading and unloading the products inside the dryers. Polycarbonate sheet is used as a cover of the dryer, because it has high transmittance (about 0.5), thus creating a good greenhouse effect in the dryer. In addition, the polycarbonate sheet has a light weight and easy to bend and cut, thus reducing the construction cost. DC fans operated by PV-modules are installed in the wall opposite to air inlet to ventilate the dryer. Three sizes of this type of dryer are available: small size with the base area of 6x8 m^2 and the loading capacity for fruits or vegetables of 200 kg, medium size with the base area of 9x12 m^2 and the loading capacity of 500 kg and large size with the base area of 9x20 m^2 and the loading capacity of 1000 kg. A version of this type of dryer with LPG burner as a supplementary heater for continuous drying in case of rain or cloudy skies has also been developed. The estimated payback periods of the greenhouse type solar dryer with LPG for tomato are about 0.65 years

ITEM	COSTS AND ECONOMIC PARAMETERS
Materials of constructions of the greenhouse dryer	10860
Polycarbonate plates	4000
Solar modules and fans	1140
Labor costs for constructions	2285
Auxiliary heater system	2000

ITEM	COSTS AND ECONOMIC PARAMETERS
Repair and maintenance cost	1% of capital costs per year
Gas consumption	
- Amount of LPG for operating	666 kg per year
- Price of LPG for LPG burner	0.43 USD per Kg
Electricity consumption:	
- Amount of electricity	252 kWh per year
- Price of electricity	0.114 USD per kWh
Labor cost for operating the dryer:	
- Labor cost	5.7 USD per person per batch
- Number of labor per batch	2
Price of dried osmotically dehydrated tomato	4.57
Expected life of the dryer	15 years
Interest rate	7%
Inflation rate	3.50%

Source: Janjai, 2012

TECHNO-ECONOMIC EVALUATION OF THESE TECHNOLOGIES

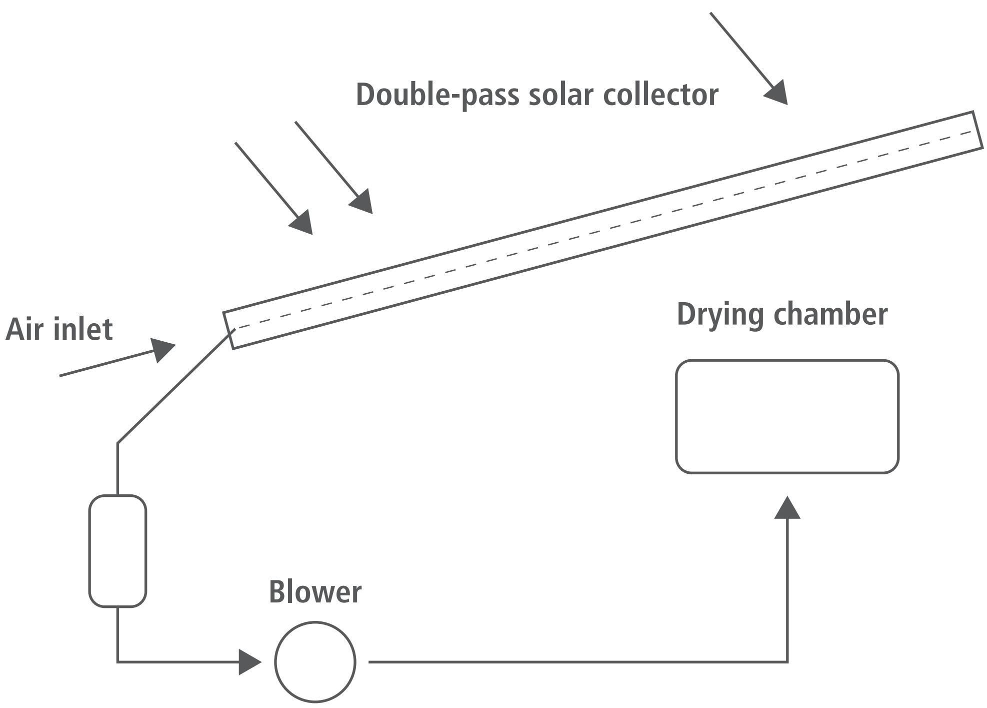
Investing in cold chain and drying technologies is generally a cost effective way to reduce postharvest losses of perishable produce as well as to connect farmers with higher value market options in industrialized countries, thereby improving incomes for producers. However, the capital required for the deployment of these technologies can be a significant barrier in the developing world. From an economic and commercial perspective, a positive decision to introduce a given post-harvest technology such as refrigeration, chilling or food drying for a given perishable product will depend largely on whether the value of the produce saved exceeds the cost of investment and operation. Such investment is more likely to be made on higher value produce, such as fresh berries, snow peas, seafood and flowers, but may be difficult to justify for lower value staples without accounting for the broad societal benefits of increased well-being and health that agricultural development brings along with the environmental benefits from improving access to clean technologies. In such cases, there is a role for government intervention and subsidy to reduce the risks for early adopters and encourage deployment to a point of critical mass. (IMechE, 2014; pg 25). It is important therefore to undertake a cost benefit analysis of a given technology before investing in it. It should be noted that the costs involved and benefits obtained from a specific technology are based on various factors including the ones outlined above and hence, the success of one technology in one country or region does not necessarily mean that the technology would also be successful in other regions of the world. Nevertheless, it is useful to look at certain cases where introduction of these technologies was economically viable and where it was not.

Solar drying of sea weed in Malaysia

Malaysia exports many agricultural and marine products to other countries. Demand for agriculture and marine products is high. Most agricultural commodities and marine products such as dried seaweed require drying process in an effort to prolong its shelf life as well as to increase the quality of the product. The average solar radiation in Malaysia is around 4-5kWh/m^2 and the average number of hours of irradiation is between 4 and 8 hours making it suitable for using solar dyers. Seaweed is widely used in production of food and medical products and industry manufacturing at present. Problems faced by seaweed farmers are variations of weather, the requirement of large space and the associated long drying time.

FIGURE 15.

Forced convection solar dryer (fudholi.*et.al,* 2011).



Open sun drying takes 10-14 days for 10 percent of the original weight. Electrical energy was supplied for the blower. A solar forced convection dryer (Fig. 15) with a capacity of 300 kg of seaweed was installed by the University of Kebangsaan in Malaysia and its techno economic analysis was conducted based on current market prices of dried sea weed. The cost structure is given in table 9. The operational costs include the cost of fresh material, labour costs, electricity cost, maintenance costs and cost of insurance.

TABLE 9.

Cost of components of the solar dryer in Malaysia

COMPONENT	COST (USD)
Double pass solar collector	4050.00
Ducting system	67.50
Blower	432.00
Auxiliary heater	324.00
Distribution systems and installation	2700.00
Flooring and drying chamber	1080.00
Total capital cost	8653.50

Source: Fudholi et.al, 2011

It was found that at the prevailing price (USD 1.35/kg of dried seaweed) of dried seaweed, the economic benefit from investing in the solar drier was less than the costs, resulting in a negative net present value (NPV) of the investment, thereby making the investment in solar dryer an economic burden. However, calculating the NPV on an assumed price of 5.4 USD, the benefits out scaled the costs resulting in a positive NPV and a payback period of 2.33 years.

TABLE 10.

NPV of solar dryer build in Malaysia to dry seaweed

COSTS AND NPV	
Capital costs	8650.80 USD
Operating costs	4163.67 USD
Prevailing market price of dried sea weed = USD 1.35/kg	
Net Present Value (NPV)	Negative (over 10 years)
Assuming potential market price of dried sea weed = USD 5.4 /kg	
Net Present Value (NPV)	Positive (over a period of 10 years), simple payback period of 2.33 years

Source: Fudholi et.al, 2011

Solar drying of Chili in India

India consumes large quantities of chili every year. In most places, chili is dried and then ground to make chili powder. Sun drying is the most commonly used method to dry the agricultural material like grains, fruits and vegetables where the crop is spread in a thin layer on the ground and exposed directly to solar radiation and other ambient conditions. The rate of drying depends on various parameters such as solar radiation, ambient temperature, wind velocity, relative humidity, initial moisture content, type of crops, crop absorption and mass of product per unit exposed area. The solar cabinet dryer coupled with gravel bed heat storage system was evaluated for drying of green chilli.

The loading capacity of the dryer was about 15 kg of fresh produce per batch. An exhaust fan was provided in the drying chamber to suck the hot air from gravel bed heat storage during off sun shine hours for better heat retrieval. The temperature was recorded in the solar dryer at three positions; at the lower, middle and upper drying trays using thermocouples and average temperature was observed in the range of 25 to 55°C. Drying time for drying green chilli from initial moisture content of 88.5 percent (wet basis) to 7.3 percent (wet basis) was estimated to be 56 hours in the solar dryer whereas 104 hours was observed in open sun drying. Drying time due to introduction of heat storage system was extended by 4 hours after sunset. Drying efficiency of the solar cabinet dryer was found to be 34 percent. The benefit cost ratio and payback period for drying chili in the solar dryer coupled with the gravel bed heat storage system was found to be 1.11 and 7 months and 11 days respectively. (Kamble et. al, 2013)

TABLE 11.

Investment and NPV for solar dryer for chilli drying in India

Initial investment (USD)	393.85
Annual use no. of batches	0.76
Cost of raw green chilli (USD/year)	181.49
Cost of labour for drying (USD/year)	37.81
Operation and maintenance cost (USD/year)	19.69
Total electrical charge for operating exhaust fan (USD/year)	5.21
Net Present worth (USD)	206.25
Cost to benefit ratio	1.11
Payback period	7 months and 11 days

Source: Kamble et. al., 2013

CHAPTER 4

FOOD WASTE AS A RESOURCE.

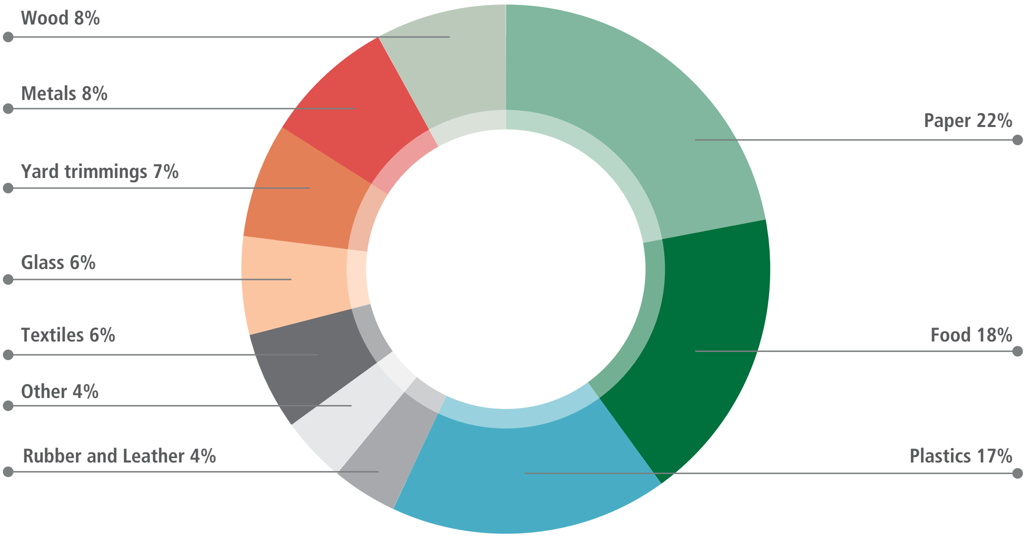
In many cases, food waste or loss may be unavoidable due to behavioural, technological or economic reasons. In such cases, food waste can be used to feed animals or to recover resources through other physical and chemical processes. Currently, a majority of collected food waste ends up in landfill, which has significant negative environmental impacts including land degradation as well as GHG emission. In landfills, organic materials, like food scraps and yard trimmings, are broken down to produce methane. Which has a warming potential of 21 times that of carbon dioxide. Putting food waste into a landfill is also a wastage of valuable resources. Adequately processed food scraps can generate renewable energy, enhance the soil as a fertilizer, and feed animals. Composting food waste produces a natural fertilizer, which can be used as a soil amendment substitute for synthetic fertilizers. Through anaerobic digestion, food waste can be used to produce methane, a valuable energy source when captured.

> "If 50% of the food waste generated each year in the U.S. was anaerobically digested, enough electricity would be generated to power over 2.5 million homes for a year."
>
> *Source: United States environment protection agency www3.epa.gov/region9/waste/features/foodtoenergy/index.html*

In the United States for instance, food waste is the second largest category of municipal solid waste (MSW) sent to landfills, accounting for approximately 18% of the waste stream. This translates to around 30 million tons of food, which can be used to produce feed for animals, energy for power and heating as well as fertilizers through composting. It has been estimated that if 50% of the food waste generated each year in the U.S. was anaerobically digested, enough electricity would be generated to power over 2.5 million homes for a year.

FIGURE 16.

U.S. Waste Characterization in 2007



Source: U.S. EPA, 2007

CHAPTER 5 WAY FORWARD FOR FOOD LOSS STRATEGIES

Food loss along the value chain is a growing concern in all countries. It is evident that there is a need to increase investment in post-harvest technologies in developing countries that would allow small holders to better produce, process and store agricultural commodities. Energy plays a pivotal role in bringing about this change. However, expanding grid connection to rural and isolated parts of a region can take a significant amount of time and investment. As discussed in the previous sections, many approaches and technologies can be employed at considerably lower cost compared to electric grid expansion and with important co-benefits to sustainable development. These can have immediate impacts on food losses in developing countries. Additionally, developing common methodologies to assess food losses and energy use at each step of the value chain can allow uniform data reporting allowing the development of specific interventions.

In this respect, it is useful to look at agricultural value chains based on their energy use patterns. USAID (2014) divide the value chain into 4 categories and estimate energy use and costs involved at each step of the value chain (Table 12, 13, 14 and 15).

TABLE 12.

Classification of value chain by technology

CATEGORIES	COMMODITIES/ TECHNOLOGIES	ENERGY SOURCES
Low tech (<5 kWh/day)	Field packing of leafy, stem, or fruit vegetables, root, tuber and bulb crops, fruits and berries	Electric grid; Solar power with battery back-up
Basic tech (5 to 25 kWh/day)	Packinghouse operations and pre¬ cooling for tropical and subtropical fruits and vegetables; Evaporative cool storage. (Temperature range 15°C to 20°C)	Solar water heater, Electric grid; Generator (diesel or gas); Hybrid PV/ Generator systems with battery back-up
Intermediate tech (25 to 100 kWh/day)	Cooling and cold storage for temperate fruits and vegetables. (Temperature range 0°C to 7°C)	Electric grid; Generator (diesel or gas)
Modern tech (> 100 kWh/day)	Automated packinghouse operations, pre-cooling and cold storage for any kind of fruits and vegetables. (Temperature range down to 0°C)	Electric grid; diesel back-up generators

Source: USAID, 2014

TABLE 13.

Low Technology value chain (< 3 kWh/day) < 1 MT/day

ACTION	METHOD	NO. OF POWER-USING TOOLS/ EQUIPMENT	CAPITAL COST	ENERGY USE	HOURS OF USE/ DAY	KWH/ DAY	COST PER KWH	COST OF ENERGY PER DAY
Harvest	Manual	0		0			0	0
Cleaning/ trimming	Manual, outdoors	0		0			0	0
Sorting/ grading	Manual	0		0			0	0
Packing	Manual, field packing	0		0			0	0
Pre-cooling	Via shade	0	USD 200	0			0	0
Cool storage	Night air ventilation (electric fan)	1	USD 300	0.1 kW	12	1.2 kWh	USD 0.35	USD 0.42
Transport	Animal- powered wagon	0		0			0	0
Total								USD 0.42

Source: USAID, 2014

TABLE 14.

Basic Technology value chain (5 to 25 kWh/day) 1 to 2 MT/day

ACTION	METHOD	NO. OF POWER-USING TOOLS/ EQUIPMENT	CAPITAL COST	ENERGY USE KW OR L OF FUEL/ HOUR	HOURS OF USE/ DAY	KW HOURS /DAY OR L/ DAY	COST PER KWH OR L	COST OF ENERGY PER DAY
Harvest	Manual	0		0			0	0
Cleaning/ trimming	Manual	0		0			0	0
Pest mgmt	Hot water dip	1	USD 500	18 to 30 kW	8	144 to 240 kWh	USD0.35	USD 50 to USD 84
Cooling after hot water treatment	Ice bath	1	USD 6 000 to USD 10 000	varies	varies	27 to 67 kWh/MT	USD 0.35	USD 12 to USD 24
Sorting/ grading	Manual natural lighting	0					0	0
Packing	Manual	0					0	0
Pre-cooling	Via evaporative forced air	2	USD 800	0.7 kWh/ MT/hr	12	8.4 kWh	USD 0.35	USD 2.94
Cool storage	Night air ventilation (electric fan)	1	USD 300	0.1	12	1.2	USD 0.35	USD 0.42
Transport	0.5 MT Portacooler	1	USD 1 600	2 kW	8	16 kWh	USD 0.35	USD 5.60
Total								USD 70 to USD 117

Source: USAID, 2014

TABLE 15.

Intermediate Technology value chain (250 to 1 000 kWh/day) 3 to 5 MT/day

ACTION	METHOD	NO. OF POWER-USING TOOLS/ EQUIPMENT	CAPITAL COST	ENERGY USE KW OR L OF FUEL/HR	HOURS OF USE/ DAY	KW HOURS / DAY OR L/ DAY	COST PER KWH OR L	COST OF ENERGY PER DAY/ MT
Harvest	Manual	0		0		0		
Water storage tower	Pump	1	varies	varies 1.1 to 1.8 kW/ Hr	8 hours/day	8.8 to 14.4 kWh/day	USD 0.35	USD 3.08 to USD 5.04
Cleaning/	Spray washer	1	USD 1 000	300 watts to	8 hours/day	2.4 to 12	USD 0.35	USD 0.84 to
drying	air dryer			1.5 kW		kWh/day		USD 4.2
Pest management	Hot water dip	1	USD 500	36 to 60 kW	4	144 to 240 kWh	USD 0.35	USD 50 to USD 84
Cooling	Ice bath				varies	27 to 67 kWh/MT	USD 0.35	USD 28.35 to USD 117
Sorting/ grading	Manual, high quality lighting	3	USD 50	1 kW	8	8 kWh	USD 0.35	USD 2.80
Packing	Manual	0		0				
Pre-cooling	Via portable forced air	2	USD 2 400	55 kWh / MT	8	165 to 275 kWh	USD0.35	USD 58 to USD 96
Cold storage (10 MT)	Cold room (refrigerated)	1	USD 30k	1.25 to 2.1 kWh / MT	24	300 to 500 kWh	USD0.35	USD1 05 to USD 175
Transport	20 ft reefer truck	1	lease					varies
Back-up generator	400 kW	1	USD 60 to USD 80K	84 L/hour	varies			varies
Total								USD197 to USD 395

Source: USAID, 2014

Such categorization can allow a systematic stepwise upgrade of technologies and practices from low technology value chains to intermediate and high technology value chains. Economically viable decentralized energy systems like solar powered cooling and solar drying can be relatively quickly constructed and made operational. However, replicating and scaling up of these technologies through predefined packages is not advisable and thorough context analysis is required.

In addition to this, FAO is currently working on a project "An enabling environment to foster investments in sustainable energy interventions in the agrifood sector", that would assess the specific financial and economic implications of specific energy technologies in the milk, rice and vegetable value chain, the technology potential in specific countries, the actual return on investment expected. It will also endeavour to examine specific enabling conditions and policies needed to trigger the much sought pro-poor investments in the agrifood sector with regard to clean energy solutions.

Once developed this study would be able to provide standard approach to undertake the cost-benefit analysis of selected agrifood technologies which can be a useful resource for energy interventions aimed at reducing food losses and waste.

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NOTES

NOTES

ENVIRONMENT – CLIMATE CHANGE – BIOENERGY – MONITORING AND ASSESSMENT

FAO - ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

An estimated 795 million people are chronically under-nourished globally. In addition to this, the global population is expected to reach 9.3 billion by 2050 requiring 60 percent increase in food production to keep up with food demand. Against this backdrop of rising population and undernutrition, it is scandalous that an estimated one third of all food produced globally for human consumption is lost or goes to waste. Reducing food loss and waste is a way to reduce pressure on agricultural production system as well as avoiding the wastage of limited natural (and other) resources like water and energy embedded in food that is lost or wasted. The causes of food loss and waste are multidimensional, spanning from lack of physical infrastructure and technology in developing countries, such as roads and food processing equipment to behavioral aspects such as over-buying and food consumption habits in developed countries.

This report focusses on understanding how access to energy is a key factor affecting the magnitude of food lost in developing countries. It identifies the main stages of the food value chain where increasing access to energy can play a dominant role in reducing food losses directly, by making food processing possible, as well as indirectly by acting as the main enabling factor influencing the rate at which cooling technologies are adopted. Access to low-cost but dependable energy acts as a pre-requisite in developing any form of food storage infrastructure, which is essential to reduce post-harvest food losses in developing countries.

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