Greening Food and Beverage Value Chains: the Case of the Asian Fruit and Vegetable Industry

A report for the UNIDO Green Industry Initiative

UNIDO
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Green Industry

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Executive Summary

The World Health Organisation (WHO) and the Food and Agriculture Organization of the United Nations (FAO) strongly support the increased consumption of fruit and vegetables across the globe. The vitamins, minerals and carbohydrates found in fruit and vegetables are essential for a healthy diet and the prevention of chronic diseases such as heart disease, cancer, diabetes and obesity. In addition, they play an important role in the alleviation of several micronutrient deficiencies prevalent in developing countries. There are, however, serious environmental challenges in continuing to provide the world's growing population with sufficient amounts of quality fruit and vegetables.

This report seeks to identify where environmental challenges and greening opportunities can occur across the entire supply chain. It showcases innovation and best practice in environmental management with a focus on Asia where a large percentage of the world's fruit and vegetables are produced and consumed. The report aims to serve as a point of orientation in the adoption of green industry policies and practices and the improvement of the environmental performance across the value chain. Greening opportunities are discussed in keeping with a 'closed-loop' approach. Wherever possible, consideration is given to by-products or wastes from one stream and the potential for them to be used as a resource or input stream in another part of the value chain. Information and data presented in this report has been compiled from publicly available literature.

Given Asia's growing population, dominance in the fruit and vegetable sector globally, and the myriad of environmental challenges the region faces, the imperative to implement greening opportunities across the supply chain is great. Asia, and in particular leading producers China and India, contribute to over half of the world's total tonnage of fruit and around three quarters of its vegetables. Many of these products are grown by millions of small-scale farmers on parcels of land less than a hectare in size.

Per capita fruit and vegetable production in Asia has doubled over the 20 years to 2010 and will continue to rise. China is the world's largest exporter of fresh, prepared and frozen fruit and vegetables, exporting mainly to Europe and the USA. Of the total volume of fruit and vegetables produced in Asia, it is estimated that only around 5% is processed into value added products such as juices and concentrates. In addition to this is the volume of products produced by informal channels such as cottage industries, for which data is not accurately captured.

Asia is facing a multitude of environmental and societal challenges that impact profoundly on the fruit and vegetable sector. These include depleting water supplies; climate change; water pollution; urban sprawl into limited arable land; and competition for resources with the energy sector. Other issues include a prolonged history of land degradation, biodiversity loss, and excessive nutrient and pesticide use.

Adding to the imperative to green the supply chain is Asia's high levels of waste due to poor harvesting equipment and techniques as well as its limited and often aging processing, storage, and transport facilities. In the developing regions of South and South East Asia, over half of fruit and vegetable products are wasted, with 20% occurring during the production and post-harvest stage, and a further 20% during processing and distribution. For industrialised Asia, the wastage figures are a little better but still around 25%, 18% and 7% respectively.

The demand for value added products is expected to increase as Asian consumers enjoy increased disposable incomes and a tendency to adopt western diets with the attraction of convenient, pre-prepared products.

Whilst the challenges facing the sector are immense, this report presents opportunities for a way forward. It details a host of examples of greening opportunities for producers, processors, transporters, retailers, and consumers. Many of these initiatives can be adopted by individuals while others will require support from other actors along the supply chain including government agencies; aid and development organisations; financial agencies; researchers; extension officers; educators; and the private sector.

Emphasis has been given to those opportunities that prevent waste and utilise constrained resources more efficiently. Greening opportunities for the fruit and vegetable industry in Asia are often regionally specific in relation to the impact of climate, water availability, and access to markets and land. These 'high level' differences aside, there are also significant opportunities to improve resource use efficiency, particularly with regards to best practice irrigation and nutrient and pesticide management. For example, training in precision farming in India using technologies such as Global Positioning Systems (GPS) and Geographical Information Systems (GIS) has proven to significantly reduce water and chemical use and soil residuals. Continued research into the breeding of high yielding fruit and vegetable species that are disease and pest resistant and suited to local growing conditions (water logging or drought, salinity levels, temperatures, etc.) is vital given the unpredictability of future climate trends. There is also significant opportunity to invest in carbon offsetting activities and low carbon technologies such as energy efficient greenhouses and solar pumps.

Greening opportunities in fruit and vegetable processing include optimising refrigeration systems, water recycling and re-use, and the use of environmentally friendly packaging designs and materials.

Given the resources embodied in fruit and vegetable produce, reducing post-harvest losses is an important greening opportunity. Increased access to refrigeration and improving cold supply chains will go a long way to not only reducing the high levels of waste, but also assisting in the development of domestic and broader markets. Reduced waste will help to offset the corresponding increase in carbon emissions associated with expanding cold supply chain infrastructure.

Improving cold supply chain infrastructure and management during transport, distribution, retail, and consumption is also key to minimising waste, particularly in those areas of industrialised Asia that have moved away from daily purchasing in open air markets. Furthermore, education campaigns for consumers are an important greening initiative if unnecessary waste due to over consumption and poor storage (greater than 10% in industrialised Asia) is to be reduced.

Identifying exactly where to focus greening efforts for maximum benefit is currently hampered by a lack of research quantifying impacts across the entire life cycle in Asia. Life Cycle Assessment (LCA) studies have been undertaken for the United States and Europe which generally focus on water and energy impacts across the supply chain. However, these results are often conflicting and difficult to transpose into the Asian context. Furthermore, there is also a lack of recent sector benchmark data on resource use, which would also help to determine where to focus efforts.

The Asian continent is vast with large variability in climate, infrastructure, and the types of fruit and vegetable products grown. Greening opportunities are regionally specific and particular issues need to be evaluated and appropriate policy directives developed at a regional level in the areas of government regulation; economic arrangements and incentives; research; capacity building; education; and extension. There are numerous intervention points across the supply chain, which can benefit from the implementation of well-directed policy. This report includes a compilation of policy interventions that will benefit the sector.

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1 INTRODUCTION

As part of the UNIDO Green Industry Initiative, the UNIDO-UNEP Green Industry Platform set out to analyse environmental practices in industrial value chains focusing on three selected sub-sectors: the meat industry; the fruit and vegetable processing industry; and the soft drinks industry. The result is a set of best practice compendiums, identifying greening opportunities which can be undertaken along the value chain, making the case for less resource-intensive ways of production and recycling. With this, the Platform aims to contribute to its global mandate to accelerate the uptake of green industry policies and practices in high-impact sectors. Whilst best practise examples from around the world are included in this document, there is a particular focus on issues and opportunities arising in Asia.

This report identifies and showcases best practices in environmental management and resource efficient production in the fruit and vegetable industry. It serves as a point of orientation in the adoption of green industry policies and practices and the improvement of the environmental performance along the value chain and within individual enterprises engaged in it. Greening potentials are identified particularly in the areas of: improved farming and processing practices; efficient energy use and generation of energy; reduced water consumption; and treatment of contaminated water; air contamination and CO_2 emissions; and waste management. These areas have a strong link to the four priority areas of the UNIDO-UNEP Green Industry Platform, which are: resource efficiency; industrial energy efficiency; water optimisation; and chemicals management. The report is aimed at decision-makers in private sector entities as well as policy-makers interested in exploring the greening potential of the fruit and vegetable industry. The Green Industry Platform will serve as the forum to share the lessons learned among industry associations and governments and to ensure its wide dissemination.

The report starts from the premise that the greening potentials of an industry are best identified in the context of a value chain, defined by the flow of products from primary production to consumption, passing through various stages of processing and value addition. For this reason, a value-chain map is introduced at the beginning of the report, followed by a detailed description of environmental issues for the fruit and vegetable sector in Asia. Subsequent chapters discuss greening opportunities along the chain, starting at production and followed by post-harvest and handling, processing, transport, and finally retail and consumption.

2 SECTOR OVERVIEW

Over the next four decades, the world's population is forecast to increase by 2 billion to exceed 9 billion people by 2050. Recent FAO estimates indicate that to meet the projected demand, global agricultural production will have to increase by 60% from 2005–2007 levels (FAO 2013).

Fruit and vegetable production continues to play a vital role in providing vitamins and nutrients to the world's growing population. Approximately 1% of the world's total agricultural area is allocated to permanent fruit crops and orchards, with an additional 1.1% of the world's total agricultural area used to grow vegetables (FAO 2012 a). Of the total world acreage, Asia contributes 72% for vegetables and 50% for fruits (Table 1 and Table 2) (FAO 2013). In 2010, the world produced 1 billion tonnes of vegetables and 609 million tonnes of fruit crops, of which Asian produce was 76% and 51% respectively (FAO 2013). In the Asian region, the top producers of vegetables are China and India with 81% of total vegetable production and 64% of fruit production (Table 1 and Table 2). Per capita fruit and vegetable production in Asia has doubled over the 20 years leading up to 2010 with fruit production increasing from 36 to 75 kg/capita/yr and vegetable production increasing from 85 to 190 kg/capita/yr (FAO 2013).

The rise of a more affluent middle class is contributing to this increase in demand as well as more developed supply chains and increasing numbers of supermarkets. In contrast, the World Health Organisation (WHO) has identified that 1.7 million deaths worldwide are attributable to low consumption of fruit and vegetables, with low consumption being one of the top ten risk factors attributable to global mortality (WHO 2014). The WHO is targeting figures such as this through its Global Strategy on Diet, Physical Activity and Health, which is promoting the increased consumption of fruit and vegetables.

China is the world's leading exporter of fruit and vegetables (fresh and preserved) and the world's largest importer of fresh fruit and vegetables (Appendix A)(FAO 2014). Of the 540 million tonnes of vegetables and 122 million tonnes of fruit produced by China in 2010 (Table 1 and Table 2), only around 3.9 million tonnes were exported, or less than 1%, mostly to Europe and the USA (see Appendix A) (FAO 2014).

Table 1: Asian vegetable production, 2010, includes melons

	Total '000 ha	Total '000 tonnes	% of world ha	% of world tonnes
World	55,598	1,044,380	-	-
Asia	40,241	794,278	72%	76%
			% of Asian ha	**% of Asian tonnes**
China	23,458	539,993	58%	68%
India	7,256	100,405	18%	13%
Japan	407	10,746	1%	1%
Indonesia	1,082	9,780	3%	1%
Republic of Korea	268	9,757	1%	1%
Vietnam	818	8,976	2%	1%
Uzbekistan	220	7,529	1%	1%
Philippines	718	6,299	2%	1%
Myanmar	378	5,195	1%	1%
Pakistan	401	5,064	1%	1%

Table 2: Asian fruit production, 2010

	Total '000 ha	Total '000 tonnes	% of world ha	% of world tonnes
World	55,856	608,926	-	-
Asia	28,168	310,267	50%	51%
			% of Asian ha	**% of Asian tonnes**
China	11,316	122,350	40%	39%
India	6,403	75,121	23%	24%
Philippines	1,228	16,182	4%	5%
Indonesia	607	14,598	2%	5%
Thailand	1,172	10,274	4%	3%
Vietnam	526	6,428	2%	2%
Pakistan	781	6,370	3%	2%
Bangladesh	455	4,004	2%	1%
Japan	197	2,883	1%	1%

Fruit and vegetable products can generally be categorised as:

- Fresh fruit and vegetables, including whole washed or unwashed product and cut or prepared portions.
- Preserved products: canned and bottled fruits and vegetables, dried fruits, candied fruits, frozen vegetables.
- Pulped products: juice, syrups, jellies and marmalades, jam, nectars, purees, sauces.
- Extracted products: pectin and papain, oil and fat, sugar, starch.

The fruit and vegetable value chain in Asia is heavily focused on the production and consumption of fresh and minimally processed products. Given that the volume of processed fruit and vegetable exports is in the order of ‹ 1% of total fruit and vegetables grown (Table 3), it is estimated that the percentage of fruit and vegetables processed in all of Asia is in the order of 5% of the total grown. This estimate is supported by figures cited by Singh et al, 2012 who state that fruit and vegetable processing in India is currently around 2% of total production and is expected to increase to 25 % by 2025 (Food Processing, 2006, cited by (Singh, Tegegne et al. 2012)). As illustrated in Table 3, volumes of processed fruit and vegetables have increased substantially since 2000, particularly in China and India. Note that these figures are estimates based on processing which is reported via formal channels and do not include the amounts processed via informal channels, which are more difficult to quantify.

Table 3: Processed fruit and vegetable exports and tonnes produced#

	China		India		Philippines		Indonesia	
	2000	2011	2000	2011	2000	2011	2000	2011
Fruit, prepared	349,874	1,207,289	69,963	96,595	61,187	95,806	8,491	14,435
Juice, citrus, concentrate	0	1,271	0	168	512	591	22	17
Juice, fruit, drinks	18,174	74,901	3,858	18,596	18,729	15,303	6,445	3,182
Tomato paste	154,606	1,126,397	25	453	54	73	88	23
Vegetables, frozen	309,924	834,333	17,247	24,330	0	0	1,030	12,910
Vegetables, preserved	439,793	951,092	258	15,213	661	509	804	1,771
Mushrooms, canned	215,595	332,687	6,807	14,940	0	87	26,284	8,950
Pineapples, canned	22,367	50,553	10	145	251,423	138,742	131,690	136,934
Total export	1,510,333	4,578,523	98,168	170,440	332,566	251,111	174,854	178,222
Fruit produced (2010)*	122,350,000		75,121,000		16,182,000		14,598,000	
Veg produced (2010)*	539,993,000		100,405,000		6,299,000		9,780,000	
Export as % produced	0.69%		0.10%		1.12%		0.73%	

Compiled from data downloaded from (FAO 2014) and (FAO 2013). Note that it is unclear from the data if canned mushrooms are included in the preserved vegetable figure. There is also no data provided on canned vegetables generally.

Across Asia, fruits and vegetables are mainly produced on thousands of small domestic farms of generally less than a hectare (Chand, Lakshmi Prasanna et al. 2011). Most produce is transported to local markets by farmers on foot, or with the use of small-scale transport. Increasingly, farmers are establishing cooperative groups to pool resources and develop greater bargaining power (Srimanee and Routray 2012). There is generally a low uptake of storage and processing technology ((APO 2006) (Singh, Tegegne et al. 2012)) and an absence of traders, who buy raw material, cold store it and then resell it to exporters, local markets or processors at a later time for a higher price. For example, the first controlled atmosphere / ultra-low oxygen storage (CA/ULO) cell in Central Asia was built in Margilan, Uzbekistan, as recently as 2007 (FAO 2009). According to Singh et al. (Singh, Tegegne et al. 2012), in India, the cold chain capacity caters to less than 10 % of the produce, and within that facilities are so rudimentary that over 80% are only capable of handling potatoes.

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Market stalls, shops, supermarkets and retailers distribute produce to domestic consumers, restaurants and hotels. According to Reardon and Gulati (Reardon and Gulati 2008), supermarkets enjoy a retail share of 50-60% in East Asia excluding China, and a 30-50% share in much of South East Asia. In China, India and Vietnam, the retail market share is still low (2-20%), however growing fast with an annual growth of between 30% and 50%. This leaves a significant share of retail distribution which does not enjoy the benefits of cold supply chains which correspondingly results in significant volumes of waste product.

There is increasing demand from retail suppliers and consumers for value added products. In emerging markets, the import of high quality, packaged fresh food items is raising the expectations of the rising Asian middle class who are becoming more discerning with product choices and can afford to pay extra for well-presented produce. In addition, the increasing purchasing influence of large supermarket chains will encourage the adoption of food safety and certification processes (HACCP, ISO9000, EuropGap etc.) (FAO 2009) which is likely to have a positive impact on the supply chain via improved production and market certainty.

Figure 1 depicts the typical supply chain for the production, processing, distribution and consumption of fruit and vegetables. The opportunities for reducing environmental impacts along the supply chain are discussed throughout this report.

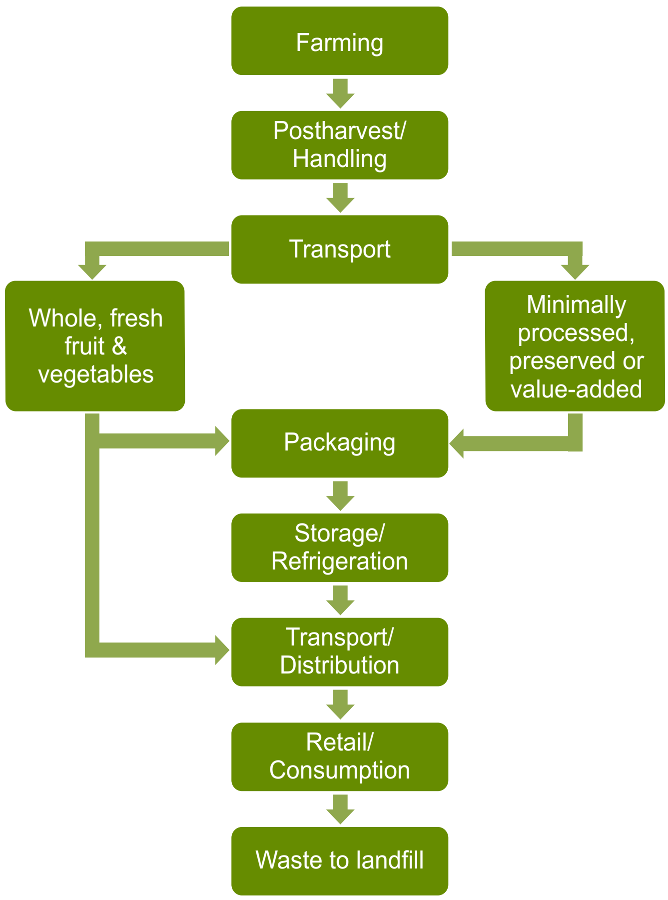

Figure 1: Fruit and Vegetable Supply Chain

3 ENVIRONMENTAL IMPACTS AND ISSUES FACING THE SECTOR

A range of resources are used across the fruit and vegetable value chain resulting in various environmental impacts. The types of resources used and related impacts are shown in Table 4 and discussed in the upcoming section.

Life cycle assessment (LCA) is a useful tool for determining the extent of environmental impacts across supply chains. However, there is generally a lack of research regarding the impacts over the full life cycle of fruits and vegetables grown in Asia. A number of LCA studies have been undertaken in the US and Europe (Hofer 2009) (Stoessel, Juraske et al. 2012) which are mainly focussed on carbon and water footprints. These reports indicate that, for carbon emissions, the largest contribution is related to energy consumption in greenhouses along with emissions from freight, particularly air transportation, for the distribution of produce. Emissions from the operation of greenhouses are important for Asia given that China, Japan and South Korea are amongst the top five production countries in the world that use greenhouses (Arizona University 2012).

In developed countries, there is strong demand for produce to be available at all times throughout the year, regardless of season. To meet this demand, produce is often freighted around the world and over long distances within countries. Such demand also leads to the production of excess produce during the growing season, which may then be stored at controlled temperatures for months at a time, further contributing to the carbon footprint. As Asia develops, it is likely that there will be similar trends in demand for 'out of season' fruits and vegetables which will serve to increase greenhouse emissions if fossil fuels continue to be used as a source of energy for long-term storage.

With respect to water, water footprints are regionally specific based on the water intensity of the crop, water availability and climate of the growing regions, and therefore generalised conclusions are difficult to make and even then are subject to many exceptions. Research to develop water footprints for each crop or region would increase water awareness and provide a starting point for water conservation within the fruit and vegetable sector.

Table 4: Resource use and environmental impacts across the fruit and vegetable value chain

Resource Use	Source of Environmental Impacts
• **Feed stock:** Seed, seedlings or root stock • **Nutrients:** Inorganic fertiliser, organic fertilisers (manure, compost, cover crops, seaweed, blood meal, fish meal, other soil amendments, nitrogen from legumes • **Energy:** Diesel and petrol for machinery, pumps and transport, electricity, gas or other for processing equipment, refrigeration, lighting, animal (ox, buffalo), treadle pumps • **Ecosystem services:** **Water:** Rain fed, surface or groundwater irrigation, wastewater, town water for processing Genetic resources: CO2 **Soils:** Substrate, moisture, carbon, filtering and minerals Living organisms: Pollination, regulation of pests, recycling, sequestering and conversion of nutrients etc **Sunlight** • **Capital:** Ploughs, harrows, rakes, levellers, irrigation delivery system, harvesting equipment • **Chemicals:** Pesticides - insecticides, herbicides, rodenticides, fungicides & miticides for farming, cleaning and sanitising chemicals for processing • **Labour:** Often intensive labour (typically family members) • **Minerals:** Lime, dolomite, gypsum, phosphorous	• **Emissions to the atmosphere:** Carbon emissions from fossil fuels, direct and indirect denitrification of N and volatilisation of NH4 from nutrient inputs • **Depletion of non-renewable resources:** Consumption of diesel, petrol, oil, coal, phosphorous and other • **Pollution and eutrophication of water sources:** Toxic pesticide and nutrient runoff • **Land degradation and loss of biodiversity:** Habitat loss or fragmentation, erosion, salinity etc from poor irrigation practices and excessive tillage and land clearing • **Water depletion:** Especially of groundwater aquifers • **Wastewater generation:** Run-off from production and wastewater from processing • **Solid waste generation** - e.g. packaging and organic wastes generated across the supply chain

3.1 Production

3.1.1 Water scarity and pollution

Asia is water constrained, possessing only 27% of the globe's freshwater supplies to feed over 60% of the world's population (FAO 2010, World Population Statistics 2014). Table 5 highlights the high level of freshwater that is withdrawn by the agricultural sector in Asia to meet the demand for food. It also highlights Asia's reliance on irrigation with nearly two thirds (174 Mha) of the globe's total irrigated area (301 Mha) falling within southern and eastern Asia. Also of concern is Asia's dependence on dwindling groundwater supplies with over 50% (68.6Mha) of global area irrigated with groundwater located in Asia (FAO 2010).

China and India alone have just 11% of the freshwater resources, yet they collectively produce 62% of the world's vegetables and 32% of the world's fruit (FAO 2010, FAO 2013). Reconciling increasing demands for fruit and vegetables with decreasing water security demands urgent and efficient water management. This is particularly crucial in the face of climate change which will force the agricultural sector to compete with other sectors and the environment for water.

Table 5: Freshwater withdrawals by Asia and area irrigated

(FAO 2010)

Region	% of world freshwater resources	Total withdrawal by sector			Area equipped for irrigation (Mha)	By groundwater		Total irrigation as % of cultivate land
		Municipal %	Industrial %	Agricultural %		Area (Mha)	%	
Asia	27.7	9	10	81	174	69	40	40
South Asia	4.1	7	2	91	85	48	57	42
East Asia	7.9	14	22	64	68	19	29	51
Mainland SE Asia	4.1	5	12	83	13	0.6	5	28
Maritime SE Asia	10.9	8	6	85	8	0.3	4	15

South Asia Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
East Asia China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea
Mainland Southeast Asia Cambodia, Lao People's Democratic Republic, Myanmar, Thailand, Viet Nam,
Maritime Southeast Asia Brunei Darussalam, Indonesia, Malaysia, PNG, Philippines, Singapore, Timor-Leste

Along with overall increased demand from population growth, there is also increasing demand for high-value products which also tend to have higher water footprints per caloric value. Between 1972 and 2002, the average supply of fruit per person in Asia increased from 18 kg to 43 kg and vegetables from 41 kg to 137 kg (Weinberger and Lumpkin 2005). There is a growing expectation that these products should be readily available in markets. While the water footprint of fruit and vegetables appear low per kg because of their low caloric content, they have a relatively large water footprint per kcal (see Table 6).

Table 6: Global average water footprint of 14 primary crop categories (1996-2005) based on 2008 FAO data

(Mekonnen and Hoekstra 2010)

Primary crop category	Caloric value (Kcal/kg)	Water footprint (L/Kcal)
Vegetables	240	1.34
Fruits	460	2.10
Sugar crops	290	0.68
Cereals	3200	0.51
Roots and tubers	830	0.47
Pulses	3400	1.19
Oil crops	2900	0.81

Depleting groundwater supplies are an issue. Both China and India have a strong reliance on groundwater supplies (40% and 80% of all irrigation water respectively) (Brooks 2007 a, Brooks 2007 b). Inexpensive individual pumps and electricity subsidies in countries such as India allow farmers to pump groundwater cheaply and encourage excess water withdrawal and inefficient usage patterns (Kondepati 2011). In the North China Plain, where 65% of the country's agricultural land is found, the water table has dropped between 20-40 metres (Pengra 2012). Similarly, in the north west of India, the Upper Ganges and Indus River aquifers are being depleted at rates faster than they are being replenished, in some cases dropping 10 metres in one year (Pengra 2012).

Box 1: Heavy Metal concentrations in vegetables and fruit - Lahore, Pakistan
(Khan, Javid et al. 2013)

In Pakistan, there is a shortage of surface water supply, with ground water used to irrigate cereals and urban wastewater used for growing vegetables. The large amounts of organic material and inorganic elements in the water generally produce good yields.

A recent study in Lahore found that wastewater concentration of Cu, Mn, Ni and Cd were higher than the legally prescribed safe limits. In the soil, concentrations of Zn, Cu, Fe, Mn, Pb, Ni and Cd that could be extracted by plants were within safe limits.

The study found that 100 % of the leafy vegetable and fruit samples were contaminated and the accumulation of heavy metals was higher than the WHO/FAO recommended levels. The study suggested heavy metals might be absorbed directly from wastewater whereas accumulation in soil is relatively slow.

Water pollution: Polluting sources include sewage, rubbish, industrial waste discharge and agricultural runoff containing fertilisers and pesticides. Groundwater geogenic contaminants such as arsenic and fluoride are also often aggravated by the over-extraction from wells. Around 70% of India's surface water is polluted (Murty and Kumar 2011) and only around 10% of wastewater is treated while the rest is discharged untreated into water bodies (Auditor General of India 2012). Vegetables can absorb heavy metals from contaminated irrigation water (European Union 2013) (refer to Box 1). Arsenic groundwater problems have emerged in a number of Asian countries including China, Bangladesh, India, Mongolia, Nepal, Cambodia, Myanmar, Pakistan and Afghanistan, (Mukherjee, Sengupta et al. 2006) largely as a result of arsenic-rich bedrock that filters water pumped to the surface through millions of tube-wells. A USAID study has found high levels of arsenic in irrigated rice and vegetables. Contamination in leafy vegetables such as amaranthus and spinach can be double or triple the levels found in rice (FAO 2006).

3.1.2 Soil degradation and loss of biodiversity

Soils provide a substrate, ecological processes, and living organisms that support plant growth. They aid in the filtration and retention of water and the sequestering and conversion of nutrients. Biodiversity helps to regulate pests and disease while bees and other wildlife are vital for pollination.

Land degradation and urban spread: Centuries of poor agricultural practices have disrupted and damaged the ecosystem services provided by soils. This includes land clearing and fragmentation, excessive tillage and poor soil cover, the introduction of pests and the mismanagement of irrigation, fertilisers, herbicides and pesticides. It is estimated that currently 20% of the planet's land is degraded (UNCCD 2012). Furthermore, calorie increases per capita between 2003 and 2030 will require an additional 130 million ha of food production (an area the size of South Africa) (UNCCD 2012). This is of great concern for Asia where 30% of the world's land area is currently home to 60% of the world's population (World Population Statistics 2013). In addition, cities are expanding into prime rural land used for the production of perishable vegetable and fruit production. Growers will be pushed into less productive areas resulting in further degradation (Box 2).

Box 2: Asia's growing urban areas
(Muller 2013), (UN Habitat 2011)

It is expected that 55% of Asia's population will live in urban environments by 2030 (2.7 billion) (Muller 2013). Cities like Bangkok in Thailand will expand for another 200 km from its current centre by 2020, replacing valuable agricultural land with industrial and residential land (UN Habitat 2011).

Loss of genetic diversity in fruit and vegetable crops: The FAO estimates that around 75% of the genetic diversity of agricultural crops has been lost due to an over reliance on a limited number of highly marketable varieties along with natural or human induced land use changes (FAO 2003). Indigenous knowledge associated with the production of many of these crops has also been lost. The genus Malus (apples), for example, has lost 85% of its 7000 cultivars with the industry now based around only two varieties (Menini 1998).

The risk of diminishing the gene pool is a threat to food supplies as it is vital for:

- maintaining pest and disease resistance;
- developing desirable traits including drought resistance, heat and salt tolerance; and
- improving nutritional quality.

Box 3: Human Pollinators of Fruit Crops - Sichuan, China
(Partap and Ya 2012)

Chemicals emitted by flowers are affected by pollutants which hamper the ability of pollinators to locate food. Four decades of insect spraying (around 4-10 sprays per season) and reduced numbers of polliniser trees in orchards (due to their low market value) has meant that Maoxian growers now have to employ human pollinators to pollinate 100% of their apples. Human labour has proven uneconomical and beekeepers are reluctant to allow their bees into the area because of the overuse of pesticides. Farmers are now turning to produce that doesn't require human pollination.

Loss of pollinators: Pollinators (bees, butterflies, bats and birds) contribute around US$206 billion globally to agricultural crops (Gallai, Salles et al. 2009). While many stable crops are wind pollinated, many fruit and vegetables rely on pollinators. The FAO estimates that the 71 out of 100 crop species that feed 90% of the world are bee-pollinated (UNEP 2010). The decline of pollinators is associated with habitat loss, excessive pesticide use and exposure to disease and pathogens such as mites. China's six million bee colonies have suffered significant losses of which some have been attributed to Varroa mites (UNEP 2010). Box 3 provides an example of the impact of years of unsustainable use of pesticides on pollinators.

Organic farming: Asia has 8.5% of the world's 3.2 Mha of organic agricultural land, of which 1.9 Mha can be found in China, followed by India with 1.2 Mha (Willer and Lernoud 2014). While still gaining acceptance, the high value associated with organic products can be seen in the level of government interest. Seven countries have implemented organic labelling regulations (China, India, Japan, South Korea, Philippines, Taiwan and Malaysia), while two have established accreditation systems (Thailand and Indonesia) (Willer and Kilcher 2011).

However, the debate regarding the greenhouse gas benefits of organic farming and its impact on yields continues. Some LCA studies suggest that gains in reduced emissions from less synthetic fertiliser use in organic systems can be offset by field work and the delivery of organic fertilisers (Venkat 2012), while others suggest organic farming results in less fossil fuel use per hectare. One study found that synthetic fertilisers and pesticides accounted for 40% of the energy used in all of US agriculture. Given the high levels of pesticide and fertiliser use in Asia, energy use per hectare is also likely to be similar or higher. This suggests additional fuel use for mechanically controlling pests and the delivery of organic fertilisers may be outweighed by the embodied energy of synthetic pesticides and fertilisers. (Kaltsas, Mamolos et al. 2007) and (Nielsen, Nielsen et al. 2003).

Low energy inputs into organic systems also equates to a lower carbon footprint. El-Hage Scialabba and Hattam suggest 48-66% lower carbon dioxide emissions on a per hectare basis (El-Hage Scialabba and Hattam 2002). Of course all of these studies are impacted by the lower yields typically found on organic farms. A recent study that compared 316 organic and conventional crops across 34 species from 62 study sites, suggests that this gap is closing. It found that while overall organic yields were 25% lower than conventional yields, when best management practices were used, overall yields were only 13% less (Seufert, Ramankutty et al. 2012).

3.1.3 Excessive pesticide use

Pesticides include insecticides, herbicides, rodenticides, fungicides and miticides. Around one-third of all agricultural products are grown using pesticides (Liu 2002) resulting in 4.6 million tons of pesticides being sprayed into the environment every year (Zhang, Jiang et al. 2011). Without pesticides, fruit losses have been estimated at 78% and vegetables at 54% (Cai 2008). Whilst vital for crop protection, it is reported that only 1% actually reaches its target while the remainder finds its way into the atmosphere and non-target water bodies and soils where ist toxicity threatens the health of the environment (Zhang, Jiang et al. 2011).

China is the second largest consumer, after Europe, of pesticides in the world, as well as the largest producer and exporter of pesticides (Zhang, Jiang et al. 2011). Pesticides are often used indiscriminately and excessively. For example, a survey of pesticide use in Bangladesh found that insecticides were applied excessively-up to 180 times annually-to protect eggplant crops from an eggplant fruit and shoot borer, while tomato crops in India received in excess of 50 pesticide applications each year (Srinivasan 2012).

3.1.4 Management of nitrogen fertiliser to reduce N2O emissions

Nitrogen is the key limiting nutrient for most agricultural systems. Excessive nitrogen use via fertilisers directly and indirectly contributes to increased N2O emissions and climate change. Excess nitrogen in a water-soluble form can also leach from soils and flow into water bodies. The increased nutrient loads can create algal blooms which consume large amounts of oxygen needed by aquatic life to survive. Asia is the largest consumer of fertiliser in the world (59%), with the bulk of consumption being in East Asia and South Asia.

3.1.5 Depletion of phosphorous stocks

Phosphorus is essential for biological growth. Plants take up phosphorous from solutions in the soil; however, the concentration of soluble phosphate is often very low. The agricultural industry has become heavily reliant on applying phosphate fertiliser made from finite reserves of rock phosphate to make up for the shortfall. However, only one fifth of the applied mined phosphate ever actually ends up in the food produced (Schroder, Cordell et al. 2010). This is unsustainable given the serious environmental impacts associated with the production and use of phosphate fertiliser. These impacts include: the production of toxic and radioactive waste and greenhouse gas emissions during mining and manufacturing; the eutrophication of rivers associated with phosphate leaching and runoff and the associated cadmium pollution to soils (Schroder, Cordell et al. 2010).

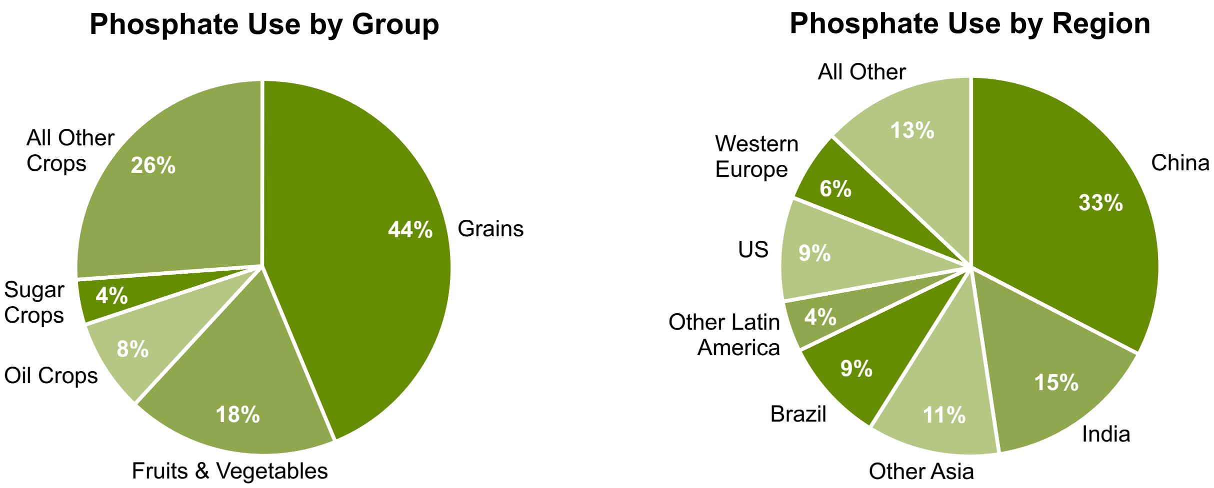

Figure 2: Phosphate Fertiliser Use by Crop and Region

In 2012, Asia consumed 60% of the world's phosphate fertiliser (Figure 2). World production is likely to peak in 2030 with the consequences exacerbated by biofuel production (Rhodes 2012). Already the price of rock phosphate has tripled since 2006 (PotashCorp 2013).

3.2 Processing

In Asia, it is estimated that only around 5% of produce is processed into value added (including minimally processed) products. Resources that are important for processors are sufficient supplies of clean water; energy for operation of processing equipment; and chemicals for cleaning and packaging to protect the final products. Competition for water and general availability can be an issue for some processors, depending on their location. Wastewater from fruit and vegetable processing can generally be treated using relatively simple methods of separation (pulps), followed by simple primary treatment and, if required, some secondary treatment. These are discussed further in processing. Where possible, processors should use renewable sources of energy in order to minimise greenhouse gas emissions and their carbon footprint. Organic residues e.g. pomace or biogas, can potentially be a source of renewable energy within the industry and will also reduce the generation of waste. Resources used for packaging should be minimised as far as possible and prevented from ending up in waste streams e.g. by minimising weight, recycling and via resource efficient design.

3.3 Retail, distribution and consumption

The impacts of retail, distribution and consumption are generally related to greenhouse gas emissions from fossil fuel sources of energy; water consumption, particularly if water scarcity is an issue for the region; and also wastewater generation and risk of polluting waterways. Solid waste generation in this section of the value chain is included in the discussion on 'supply chain losses'.

In developed regions, in order to meet consumer demand, it is common practice to store produce for long periods, which could extend up to several months. This can have a significant effect on the levels of energy consumption and the resulting carbon footprint. There is also increasing awareness amongst consumers in regards to 'food miles' as well trends towards sourcing local produce that is grown in season. This will serve to reduce the need for long-term storage of produce and thus greenhouse gas emissions.

3.4 Supply chain losses

In the developing regions of Asia, more than 50% of total fruit and vegetables produced are wasted, with 40% occurring during production, post-harvest and processing, and 10% during the distribution and consumption stages (Figure 3). This is more than solid waste as the produce embodies resources such as water, energy and raw materials accumulated across the entire supply chain.

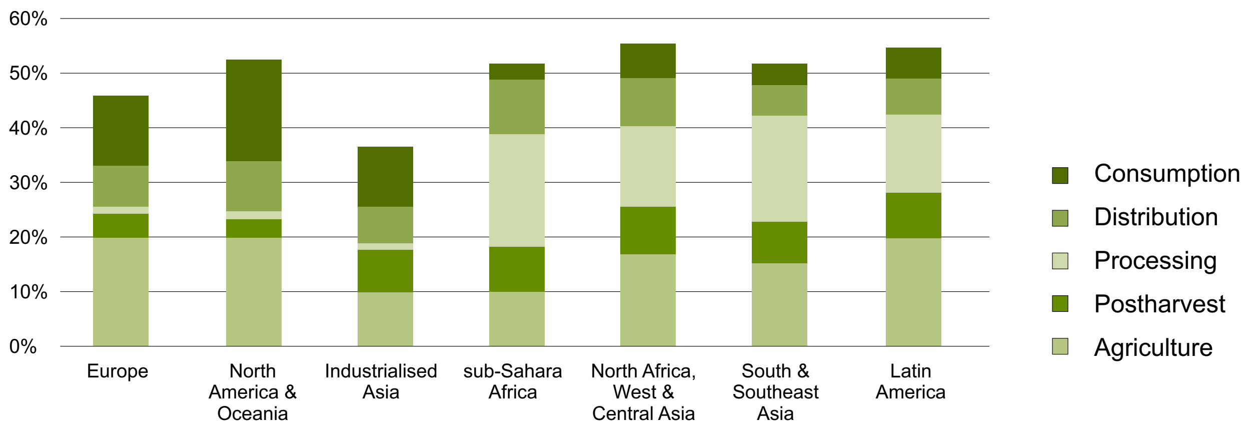

Figure 3: Food losses – Fruits and Vegetables
(Gustavsson, Cederberg et al. 2011)

Environmental stress is a major cause of crop losses during production; i.e. the impact of unseasonal and extreme variations in climate; reduced water availability; drought; flooding; soil erosion and salinity. Excess waste during the post-harvest stage is largely due to insufficient access to technologies, particularly cold chain infrastructure, and an overall lack of coordination and communication across supply chains (APO 2006,FAO 2009, IBIS World 2013).

4 A CLOSED-LOOP APPROACH TO GREENING

Where possible throughout this report, greening opportunities are considered in the context of achieving a 'closed-loop', whereby waste streams from one process can be used as a resource for another. This is illustrated in Figure 4. The implementation of closed-loop fruit and vegetable processing will require the cooperation and interaction of farmers and their suppliers, processing companies, distributors, communities, governments, unions, legislators, associations and research bodies. Innovative regional cooperation can help to identify appropriate solutions to improve value chains from processing fruits and vegetables. Opportunities presented in this report include:

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- The use of solid waste from harvesting or processing to produce compost as a fertiliser (Section 7.3).
- The use of post-harvest waste to create income and produce by-products such as biopolymers functional food, phytochemicals, a variety of pharmaceuticals, cosmetics and natural dyes (Section 7.3).
- The use of processing wastewater to irrigate fields (Section 7.2).
- The extraction of by-products from processing waste or to generate biogas to be used for cogeneration, heating (for processing companies or communities) or for transport (Section 7.1).
- The use of renewable energy (Sections 5.6 and 7.1.2).
- The use of processing by-products for animal feed (Section 7.3).
- The use of processing by-products to produce packaging materials (Section 7.5).
- The production of packaging which is recyclable, compostable, produced with renewable energy or which is even edible (Sections 7.3 and 7.5).
- Educational initiatives on food waste prevention to reinforce the perception of the value of fruits and vegetables to minimise food waste from household by conscious procurement, management of storage and appropriate cooking (Section 9.3).

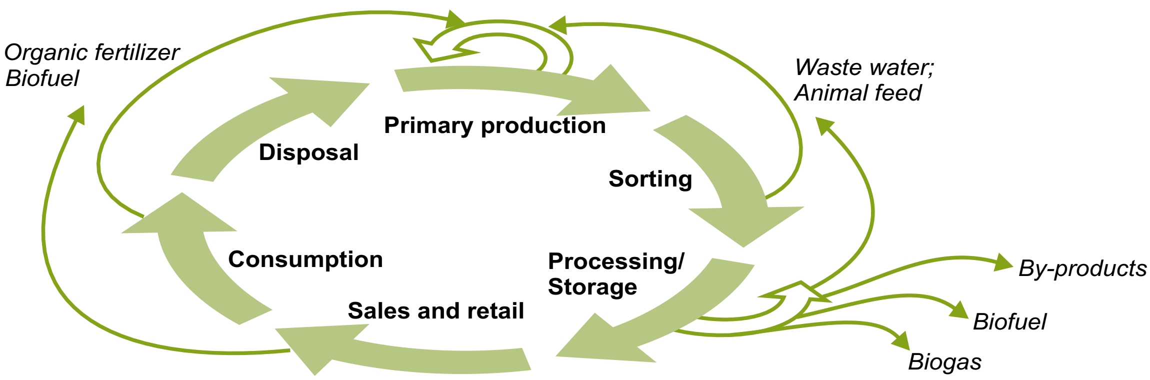

Figure 4: Simplified closing the loop value chain model for fruit and vegetable production
(FAO 2010)

5 GREENING IN FRUIT AND VEGETABLE FARMING

Growing demand along with food safety concerns and shortages in major inputs such as water and arable land has made greening production a priority for many Asian governments. In general, fruit and vegetable farms are small (on average around ½-2 ha), are heavily reliant on manual labour and are technology poor. Greening the supply chain is compatible with many other Asian Government policies around production, including increasing food supply for greater self-sufficiency, improving food safety, raising the incomes of farmers and growing greater varieties of produce. As discussed in Chapter Two, greening the supply chain is vital if Asia is to address its dramatically declining water supplies. There are a myriad of pressures exerted on this valuable resource, including growing demand for fruit and vegetables and higher quality food products; trans-boundary water conflicts; unregulated and excessive groundwater extraction; climate change impacting on monsoons and snow/glacier melts; water pollution and competition for water with the energy sector. Greening also has an important role to play in combating centuries of land degradation and to manage the spread of urban growth into arable lands. The rate of biodiversity loss at both the genetic and at the species level (pollinators) also requires urgent greening interventions. Education on green approaches on the management of pesticides and nutrients has also been proven to be an effective method to reduce the level of pollutants reaching environments. Awareness-raising is also being undertaken in regards to declining phosphate stocks and greenhouse gas emissions associated with nitrogen use.

A number of the greening opportunities described in this section have been recognised by the FAO as being 'Good Agricultural Practice' as described in Box 4.

Box 4: The FAO Good Agricultural Practices (GAP)
(FAO 2008)

The FAO GAP are a collection of principles for on-farm production and post-production processes that take into account economic viability, environmental sustainability, social acceptability and food safety and quality. They may be applied to a range of different scales and farming systems including fruit and vegetable production systems. They are not a rigid set of principles, instead the FAO provides countries and stakeholders with independent information on existing private and public GAP programmes, practices and standards to assist the implementation of locally agreed GAPs. Assistance includes inventories and studies on existing GAP, along with the benefits and costs, challenges, scope, drivers and incentives to adopt them. They provide technical advice for the application of GAP at the farm level and information on existing regulatory requirements. Training resources and an information database can be found on the FAO GAP website: (www.fao.org/prods/gap/home/database_en.htm).

5.1 Growing regions and climate

Fruit and vegetable production in Asia can be broadly broken into tropical, sub-tropical and temperate climate zones.

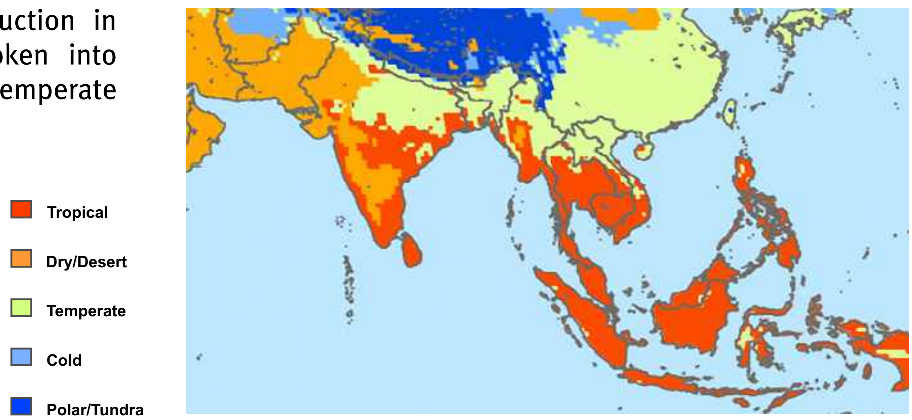

Figure 5: Climate Zones of Asia
(CIESIN 2007)

Tropical fruit and vegetables: There is no dry season in countries such as Indonesia, Singapore and Malaysia where the climate is humid and rainfall is evenly distributed throughout the year. Vegetables suited to this climate are mostly root crops and some leafy vegetables. Fruits grown in the region include exotics and evergreens such as mango, sapota, papaya, pineapple and banana. Farmers generally practice mixed-cropping systems where fruits, vegetables, rice or planation trees are grown on the same land or harvested from forests. Excess produce to their own needs is sold at traditional retail outlets and markets (Fonsah, Roshetko et al. 2007). Most of these countries are reliant on fresh vegetable and fruit imports although many are exploring innovative production systems to become more self-sufficient. For example, Sime Darby, a Malaysian multinational is using aeroponic technology (where the roots are sprayed with a cooled nutrient mist) for the commercial production of premium temperate vegetables (Yee, Chuen et al.) Singapore, which produces only 7% of its own fresh food, is now seeing the emergence of urban vertical hydroponics farms such as Sky Greens whose farm sits on 3.2 acres and produces half a tonne of fresh greens daily (Urban Growth 2013).

Subtropical fruit and vegetables: In areas of China, India and Indo China, Korea and the Philippines where there is a definite diversity in the seasons with a cool and dry season, a hot season and a rainy season, farmers can grow a wide variety of fruit and vegetables and, in some cases, multiple crops annually. Farmers in these areas rely on monsoon rains as well as irrigation schemes and aquifers to sustain high levels of production. Fruits grown there include mangoes; guava; grapes; citrus; jackfruit; pomegranates; litchis; dates and figs; along with some typical tropical wet fruits such as bananas. Vegetables suitable for monsoon climates include tomatoes; leafy greens; Chinese cabbage; Asian broccoli; eggplants; cucumbers; chilli; and zucchinis. Many Asian governments believe organic farming is one way small landholders can secure price premiums and thus have been supporting farmers to enable them to gain access to organic markets as discussed in Section 5.2.1.

Temperate fruit and vegetables: The lower temperatures found at higher latitudes, such as those found in Northern China and India, are suited to growing fruits such as apples and prunes, peaches, pears, plums, persimmons, cherries and strawberries. Solar greenhouses are used extensively in China in order to grow vegetables over the long winter months. New innovations in the design of greenhouses are allowing production of greater varieties of vegetables.

5.1.1 Improving irrigation management

Between the 1950s and 1970s, many Asian countries invested in large-scale centralised gravity fed surface irrigation schemes to help overcome the uneven distribution of water and arable land. In the case of China, over half of the nation's croplands are now irrigated (Zhu, Li et al. 2013) and producing 90% of its vegetables and fruits (Kai, Bu et al. 2006). However, many are in decline and disrepair due to poor design, operation and maintenance, with some exceptions in China (Mukherji, Facon et al. 2010). As a result, many farmers have opted out and invested in their own energy intensive, groundwater irrigation systems, fuelled by cheap pumps and often government subsidised electricity. Water scavenging irrigation in South Asia, the North China plains and some parts of Southeast Asia has resulted in over-exploitation and deterioration in water quality. On-farm greening initiatives will not be sufficient unless deficiencies in the management of large-scale water infrastructure are also addressed.

Participatory Irrigation Management (PIM): Policies aimed at increasing farmers' involvement in the management of public irrigation schemes through PIM have been of mixed success, with a review by the International Water Management Institute finding only 40% of 108 large PIM schemes in Asia were successful in terms of improving performance. Although the study did find that performance was higher in non-rice-paddy systems (Mukherji, Fuleki et al. 2009). Both PIM and IMT (see below) are only likely to be successful where there is strong political will and governance (especially in an environment of ethnic or caste differences), and an ability to enforce penalties. Farming also needs to be profitable and water relatively scarce (Mukherji, Facon et al. 2010). Furthermore, Water User Associations (WUA) should not just collect fines, but they should also be involved in agricultural extension to improve delivery, technology transfer and promote irrigation best practice (Asian Development Bank 2012) (refer to Box 5).

Irrigation Management Transfer (IMT): IMT in the irrigation sector of Asia has been slightly more successful, especially in China (Mukherji, Fuleki et al. 2009) (refer to Box 6). IMT involves the transfer of all or components of publically owned irrigation schemes to joint management boards, private enterprises or farmer groups. In order for IMTs to perform better than the public sector contracts, output performance standards need to be clear and rigorous.

Cost Recovery: In many regions, the price of water does not reflect its scarcity, nor is it priced for full cost recovery of supply. Problems with pricing include the impact of full cost recovery (for financial and resource sustainability) on low farm incomes; the difficulties of collecting fines; corruption and lack of motivation when revenue is not reinvested back into maintaining or improving water delivery. In India, many states have not revised the price of water in two decades (Varma, Dhingra et al. 2013) and collection rates are very low (Mukherji, Facon et al. 2010) (refer to Box 7). In some cases allocation, rather than price may be a better way to manage demand with peer pressure ensuring efficient and fair use (Cornish 2004).

Water efficient irrigation systems: Flood, basin or farrow irrigation is usually less efficient than sprinkler or micro-irrigation systems such as drips and mates. Non-pressurised, simple and affordable irrigation employed by subsistence growers include gravity drip bucket irrigation systems and clay pots or clay nozzles inserted into the soil and supplied water by inverted recycled bottles. Pressurised systems currently equip 15% (44 million ha) of the world's irrigated area (Faurès, Hoogeveen et al. 2011). The necessary initial high investment of water efficient technology is being supported through policies

Box 5: Participatory Irrigation Management - Waghad Irrigation Scheme Maharashtra, India
(Belsare, Desai et al. 2011)

The scheme's cultivable area is 9642 ha belonging to 15926 small farmers with an average land holding of 0.6 ha. The farmers were grouped into 24 Water User Associations (WUAs) and devised an innovative way to share water on a time basis, which has led to a 100% utilisation of irrigation potential, water savings, crop diversification, and a 100% collection rate of water charges. Farmers have diversified away from rice to high-value crops such as grapes and vegetables. They have constructed water conservation structures, such as ponds, which have resulted in the recharging of about 2523 wells and invested in drip irrigation for 4300 ha.

Box 6: Irrigation Management Transfer Management in China
(Chen 2012)

Since the 1980s, the management of some of China's large to medium-scale schemes has been transferred to Irrigation Associations or business-oriented Farmers' Organisations. Similarly, many small schemes have been transferred to farmers or collective groups such as WUAs. The transfer of management between1980-2011 has resulted in a zero increase of irrigation water withdrawal while the functional irrigation area has increased by 11.5 Mha and food production by 250 MT. Irrigation efficiency also increased from 30% to 51%.

Box 7: Groundwater Automated Irrigation Charge Collection System – Shangdong, China
(Easter and Liu 2005)

Integrated cards are inserted into an automated server that control the release of water and to provide a receipt stating the amount of water used and the cost based on a volumetric charging system. The system not only reduces administration costs, it also gives the farmer full control of their consumption and averages around 5 billion m3 of water annually.

Box 8: Deficit irrigation of fruit trees – Australia
(FAO 2011 b)

In Australia, irrigation deficit has been applied to fruit trees and found to increase water productivity by 60% while not impacting on fruit yields or quality.

State Council - The People's Republic of China 2006). For example, the uptake of water saving irrigation practices in China increased from 27% in 2000 to 42% of China's effective irrigation area by 2009 (Zhu, Li et al. 2013).

On-farm precision irrigation scheduling: There are a range of decision support systems to prevent over-irrigation, these range from simple soil moisture probes (tensiometers) and rain gauges to complex information and communication technology that combine online weather reports with real time farm data to run simulation models and provide farm specific irrigation advice.

5.1.2 Sustainable crop intensification

Intensification aims to achieve higher yields by reducing the negative impacts of factors that are limiting productivity. It is seen by the FAO as a sustainable strategy to meet growing food demands in the future (FAO 2011 a). Reducing the impacts of limited water can be achieved by implementing practices that:

- encourage crops to increase their root potential (particularly in areas suffering from leaching). Irrigation deficit controls the amount of water applied at critical growth stages in plants to encourage deeper root growth;
- rotate deep rooting crops;
- reduce soil disturbance and improve water infiltration and holding capacity while reducing evaporation; for example, via organic mulching or ground covers/fallowing, intercropping and deep or minimum tillage; and
- enable off-season vegetable production such as greenhouse cultivation, hoop houses or high tunnels, hydroponics and aeroponics.

Table 7: Yield Increases and water saving under drip irrigation

(Magal and Hefer)

Crop	Yield (tons/ha)			Water Use (mm)		
	Conventional	Drip	% Yield	Conventional	Drip	Water Saving (%)
Bananas	57.5	87.5	52	1760	970	45
Grapes	26.4	32.5	23	532	278	48
Sweet Lime	100	150	50	1660	640	61
Pomegranate	55	109	98	1440	785	45
Papaya	13.4	23.5	75	228	74	68
Tomato	32.0	48.0	50	300	184	39
Watermelon	24.0	45.0	88	330	210	36
Okra	15.3	17.7	16	54	32	40
Cabbage	19.6	20.0	2	66	27	60
Chilli peppers	4.2	6.1	44	110	42	62
Sweet potato	4.2	5.9	39	63	25	60
Beetroot	46	49	7	86	18	79
Radish	70.0	72	2	46	11	77

5.1.3 Water harvesting and groundwater recharge

Water harvesting is particularly important for dryland farmers. The type of water harvesting in Asia depends on the amount and intensity of rainfall and the size and characteristics of the catchment. Harvesting includes deep or strip tillage; tanks; ponds; cisterns; jars; fog netting; contoured bunds; terraces and planting pits; rainwater; percolation or sub-surface (sand) dams; stream diversion; and artesian wells. As discussed earlier, micro harvesting of groundwater in particular can be over-exploited if not monitored and governed, and the potential for increased withdrawal is limited. In some cases, rainwater is being harvested to recharge aquifers. In India, check dams, recharge wells and percolation ponds are used for recharge. (Karimov, Smakhtin et al. 2013). In China, groundwater is recharged through small pits and ponds; wells are injected with upstream water; and large underground dams are constructed with grouting or with clay walls (Karimov, Smakhtin et al. 2013). In arid and semi-arid countries such as Kuwait and Qatar, tertiary or advanced treated wastewater is used to recharge water aquifers (Hamoda, Derish et al. 2012).

Box 9: Vertical farms – Singapore, US and Japan
(Marks 2014) (Cho 2011)

Asia is home to several successful examples of vertical farming. These farms are two-dimensional and grow crops all year round using hydroponic and aeroponic technology (where roots are suspended in air and exposed to a fine mist of nutrients). Aeroponics at Singapore's AeroFarms uses 80% less water than hydroponics while producing 60 times more product, on 3% of the land than would have been produced using conventional agriculture techniques. Whilst seen as a possible solution to urban expansion, vertical farms do consume a lot of energy. Technological innovations include the use of biogas, as seen at Chicago's latest vertical farm where brewery waste, sent to an anaerobic digester, powers the entire facility. Another example is Japan's, Kyoto-based Nuvege windowless indoor farm which produces 6 million lettuces annually. Energy efficient LED lighting is especially tuned to the needs of plant chlorophyll and is used extensively in the AeroFarm.

5.1.4 Use of wastewater

Wastewater is used extensively throughout Asia for irrigation in urban and peri-urban areas and is essential for the livelihoods of many poor farmers, in particular in China, where at least 1.3 Mha of land is irrigated with wastewater (Jimenez 2006). A recent study in Beijing found that irrigated (sprinkler system) wastewater used to grow cabbage, broccoli and lettuce exceeded the WHO standard for acceptable disease burden (Mok and Hamilton 2014). Sustainable use of wastewater requires a country specific risk management approach that proactively considers, manages and regulates risk and water quality standards along with the method of irrigation, buffer zones, and withholding periods etc. (Mok and Hamilton 2014).

5.2 Land management and biodiversity

5.2.1 Organic farming

Organic farming aims to minimise detrimental environmental impacts by means of production methods that maintain biodiversity, ecological processes, water quality and soil fertility with minimal use of resources. This includes crop rotations; limited use of synthetic pesticides and fertilisers; no use of genetically modified seeds or plants; use of onsite resources such as manure; and the selection of plant species that are locally adapted and disease resistant (European Union 2014). Success of organic ventures is often dependent on organised or dedicated market channels, sound scientific management advice, accreditation or standards and supportive government policy.

5.2.2 Germplasm conservation and utilisation

Genebanks and vaults ensure germplasm is collected, conserved and evaluated so that valuable traits can be identified and used to improve genetic lines (see Box 10). For fruit crops that are vegetatively propagated, conservation options can be costly. These include in situ methods, such as conservation on- farms, botanical gardens, agro tourism parks and ex situ methods such as field genebanks, in vitro conservation and cryopreservation (storage of living cells, tissues or organs at ultra-low temperatures) (Ramanatha 2002).

Box 10: Genebanks for improved vegetable lines
(AVRDC World Vegetable Center 2014)

The AVRDC World Vegetable Centre genebank maintains the world's largest public vegetable germplasm collection from 156 countries. The Centre distributes around 10 0000 seed samples to researchers across the globe each year.
Major breeding successes include the development of high-yielding, heat-tolerant tomatoes and brassicas and disease resistance in tomatoes, peppers, cucurbits, onions, mung bean, soybean, and eggplant. The Centre's improved mung bean varieties are planted over millions of hectares throughout Asia. The Centre also works to improve the nutritional value of vegetables with high beta-carotene tomatoes providing 3-6 times as much vitamin A as normal tomatoes.

5.2.3 Agroforestry and mixed cropping

Agroforestry and intercropping are based on ecological principles that optimise the benefits of biophysical interactions created when trees or shrubs are combined with crops. Trees, shrubs and undercover crops exploit different layers both above and below the ground, resulting in greater resource efficiency. As well as increasing land productivity, storing carbon and increasing income security, trees provide organic matter, shade to reduce soil temperature and moisture loss, and help to minimise soil erosion. They create habitat for pollinators and promote biological pest control. Intercropping banana, for example, with beans and sweet potato reduces the incidence of weevils and nematodes (Ouma and Jeruto 2010). Mixed cropping with legumes can also reduce the need for fertilisers through the biological fixing of nitrogen. However, more research is needed in the area of row orientation and light interception for horticultural crops (Ouma and Jeruto 2010). Box 11 provides an example of a policy to tackle food security and associated environmental issues.

Box 11: Agroforestry Policy – India
(Langford 2014).

In 2014, India became the first nation in the world to adopt a national agroforestry policy to tackle food security, climate change, deforestation and to improve water quality. The policy will be backed with US30–40 million which will be used for incentives programs, insurance schemes and greater access to markets for agroforestry products. The policy aims to increase tree cover to 33%.

5.3 Pesticide management

5.3.1 Integrated pest management (IPM)

Integrated pest management uses the best combination of chemical and biological controls along with cultural and mechanical practices to manage pests and diseases. The approach involves monitoring and understanding the pest to establish thresholds from when action should be taken. Less toxic options for pest control are utilised, with non-specific broad scale spraying only being a last option. Refer to Box 12 for an example.

Box 12: IPM Farmer Field Schools – China
(van den Berg 2004)

The Food and Agriculture Organisation runs a Regional Vegetable IPM Programme in South & Southeast Asia. Results have shown graduates of IPM Farmer Field Schools in Indonesia have changed from preventative spraying to observation-based pest management, reducing insecticide use by 61% (a decline in insecticide use from 2.8 to 0.02 applications per season). The project in selected IPM sub-districts has seen a 21% yield increase.

5.3.2 Cultural Management

Cultural management practices are often very cost effective. They are typically of little risk to the environment and help to reduce the pest's survival, dispersal and initial establishment. Practices include choosing tolerant or pest resistant varieties, crop rotations, planting pest free rootstock and good field sanitation. Good sanitation includes the removal and correct destruction of fallen or damaged product and using a rake or plough to expose pupae in the soil to sunlight or predators at appropriate intervals. Cultural management is particularly important in the management of Tephritid fruit flies which can result in 90-100% yield losses and can impact on trade due to tight restrictions imposed by importing countries (ACISAI 2012).

5.3.3 Mechanical controls

Mechanical controls include barriers, traps and even the physical removal of problem pests. The controls have proven very effective in the management of the Brinjal Shoot and Fruit Borer Leucinodes orbonalis (refer to Box 13).

Box 13: Cultural and mechanical control of Brinjal Shoot and Fruit Borer – Bangladesh
(Alam, Hossain et al. 2006)

The Brinjal Shoot and Fruit Borer has resulted in yield losses up to 86% in Bangladesh and 95% in India. In Bangladesh, pesticides used to control the borer constituted up to 32% of the total production costs with 60% of farmers spraying 140 times or more each season. The erection of barriers around borer infestation to restrict the movement of adult borers along with good field sanitation was found to reduce shoot damage by 62.7%.

5.3.4 Bio-pesticides

Bio-pesticides are derived from natural materials such as bacteria, minerals, animals, pheromones and plants. They are usually less toxic than conventional pesticides, do not have a residue and affect only the target species. When they are used as part of an integrated pest management strategy they can be as effective as conventional pesticides (Kuma 2012).

Although the use of bio-pesticides is increasing, the development of stable formulas and standardisation of delivery methods must be carefully addressed (Srinivasan 2012). China is a bio-pesticide producer and an important bio-pesticide exporter.

5.3.5 Bio-pesticides

Biological control is a long-term solution that uses the naturally occurring enemies of pests. The approach does require considerable research to ensure released biological control agents do not pose a threat to non-target species. Refer to Box 14 for an example.

Box 14: Biological control of Papaya Mealybug - Tamil Nadu, India
(Myrick, Norton et al. 2014)

The papaya mealybug Paracoccus marginatus was first identified in 2008. The parasitoid Acerophagus papaya was imported from Puerto Rico and released in 2010. Within five months the papaya mealybug was under control and pesticide usage reduced. The annual economic benefits for the five most important crops affected by the program over five years is between $524 million to $1.34 billion.

5.4 Nutrient and carbon management

5.4.1 Precision farming

Precision farming is based on reducing environmental impacts through the management of in-field variability, in soil fertility and crop conditions. It utilises technologies such as Global Positioning Systems (GPS), and Geographical Information Systems (GIS) sensors, satellites and aerial images to ensure precise amounts of inputs, such as water and fertiliser, are only applied where needed. In France, aerial mapping of nitrogen and chlorophyll levels are taken by drones (Fresh Plaza 2014). Box 15 outlines the benefits of precision farming of tomatoes in India.

Box 15: Precision tomato farming – India
(Ravindran, Kendra et al. 2012)

Training on precision farming and hi- tech agricultural practices was provided for 3,000 farmers by the Tamil Nadu Agricultural University to promote market-led horticultural production. Precision farming was shown to reduce the use of water and chemical sprays while also lowering residues left in the soil and water. There was also a substantial increase in quality and average yields compared to traditional techniques with tomato production improving from 35 to 100 tons/ha, onions 11 to 21 tonnes/ha and banana 40-120 tonnes/ha. Farmer incomes increased two-to three-fold in spite of high water soluble fertiliser prices.

5.4.2 Organic nutrient recycling and carbon sequestration

Mhe storage of organic carbon in the soil is vital for soil fertility and also reduces the loss of CO2 to the atmosphere. However, the release of carbon has been greatly accelerated in recent decades due to the application of mineral fertilisers and intensive tillage. The addition of organic matter not only enhances soil fertility, moisture and physical structure, but also has a greenhouse gas mitigating effect. Carbon can be sequestered in the fields of vegetable and fruit growers by:

- The direct application of manures and composts, fish emulsions and proteins, seaweed and blood meal, biochar, or other soil amendments;
- green manures or cover crops incorporated back into the soil;
- agroforestry; and
- reduced tillage.

5.4.3 Micro-dosing

Micro-dosing involves small quantities of inorganic fertilisers being sown into a hole with the seed. It may be a viable option in regions where fertiliser is expensive and where access to manure and crop residues is limited. Limited micro-dosing is widely practiced in Burkina Faso, Mali, Niger and Zimbabwe and has been found to help crops mature more rapidly and increase yields by 50-100% (Oasis 2006).

Box 16: Carbon credits for soil carbon sequestration – Australia
(Australian Ministers Office 2014)

Australia's Federal Environment Minister announced in March 2014 that soil carbon storage would be added to the list of approved projects under the Carbon Farming Initiative (CFI). This will allow Australian vegetable producers to acquire carbon credits by storing carbon which can then be sold to companies that need to offset their emissions.

5.4.4 Nitrogen fertilisers and reducing nitrous oxide emissions

Methods that can be employed by fruit and vegetable producers to reduce emissions from nitrogen fertiliser use include:

- reducing the amount of fertiliser applied by applying the 4Rs of Nutrient Management Stewardship - Right Rate, Right Placement, Right Timing, Right Form (Box 17);
- managing the timing and amount of irrigation for maximum efficiency while minimising runoff;
- rotations with legumes such as beans and peas to fix atmospheric nitrogen in the soil, reducing the need for inorganic nitrogenous fertilisers whilst also helping to break pest host cycles and increasing biodiversity;
- direct drilling techniques rather than conventional cultivation; and
- using enhanced efficiency fertilisers (EEFs) that combine fertiliser and breakdown inhibitors that slow down the chemical conversion of nitrogen compounds to ammonium and nitrate which are precursors to N2O (Australian Government Department of Agriculture 2014).

Box 17: Economic and environmental gains of reducing fertilisation rates – China
(Norse 2010).

Scientists in China have reported 30-60% overuse of nitrogen fertiliser on crops as a result of poor information transfer, poor quality fertiliser and the lack of soil testing facilities. This overuse accounts for a staggering 10-15% of total GHG emissions from agriculture. It is believed that applications could be reduced by 30% without affecting food security to not only bring about economic savings, but also to reduce China's total GHG emissions by more than 2% and nitrous oxide emissions by 30% within 10 years.

5.4.5 Nitrogen fertilisers and reducing nitrous oxide emissions

Fruit and vegetables account for 18% of global phosphate consumption (PotashCorp 2013). Best practice to reduce phosphate loss from fruit and vegetable farms include:

- the recovery and reuse of organic fertilisers (e.g. manures, composts);
- the use of green manures; reduced tillage, irrigation management to reduce runoff; and
- leaching and promoting good soil health (phosphorus will become less viable if the pH is not optimal).

Among a range of greening options, the 4Rs principle (Right Rate, Right Placement, Right Timing, Right Form) should be applied to all phosphate fertiliser applications. Phosphate should be recovered from wastewater where possible or used for biofuels such as algae.

5.5 Improving resilience

5.5.1 Grafting to improved stress tolerance

Grafting has been traditionally used in vegetable and fruit production against soil borne diseases; however, tolerant rootstocks are now being investigated for soil-related environmental stresses such as salinity, flooding and water stress. For example, commercial tomato hybrids have been successfully grafted onto the roots of tomato genotypes with the ability to exclude saline ions (Estan, Martinez-Rodriguez et al. 2005).

5.5.2 Breeding climate resilient vegetables

Many previous breeding programs have focused on species adapted to high inputs; however, the focus may need to change to those traits suitable for low inputs and harsher environments. Box 18 provides an example of breeding for heat and drought tolerance.

Box 18: Breeding of heat and drought tolerant vegetables – Asia
(The World Vegetable Centre 2014)

Over the last 25 years the World Vegetable Centre has developed more than 100 heat and drought tolerant tomato lines that have been released in 37 countries along with a variety of sweet pepper that can only be grown in the lowland tropics because of its heat-tolerance.

5.6 Energy use in farming

Energy is mainly used in the farming sector for operation of farm machinery and harvesters, transport vehicles and irrigation pumps. Information on energy efficiency and alternative energy fuels for vehicles is provided in Section 8 (Transport).

There are many opportunities to reduce energy consumption and the reliance on non-renewable fuels in the farming sector. Some examples are provided below.

Precision agriculture: As the use of draft animals declines in Asia, the reliance on non-renewable fuels for powering farm machinery and their associated greenhouse gas emissions is also likely to increase. The use of GPS systems on tractors to control traffic can considerably reduce fuel consumption as shown in Box 19.

Box 19: Control traffic and conservation tillage – China
(Andersen 2010)

Research on China's dryland Loess Plateau found runoff from controlled traffic was 20% lower than from conventional tillage plots with soil erosion declining by 16% (Zhang 2001). Furthermore, random field traffic was found to increase fuel consumption by 26-30% compared with controlled traffic practices.

Solar pumps: Currently substantial amounts of energy are used to pump and deliver water to crops. Groundwater can be 25% more energy intensive than pumping surface water (ADRET 2012). In India lifting water accounted for 6% of all India's total CO_2-e emissions (94 million tonnes CO_2-e/yr), while in China electricity intensity (MWh/m^3) to produce and supply water increased by 20% between 1997 and 2005 (ADRET 2012). Refer to Section 5.1.1 for opportunities to reduce irrigation energy consumption through effective irrigation management and water efficient pressurised irrigation systems. India is looking to use solar pumps to reduce power and to diesel subsidies to ensure reliability in supply (Box 20).

Box 20: Solar pumps – India
(ADB 2012)

Over the next five years India will invest $1.6 billion to convert electrical and diesel pumps to solar to save $6 billion a year in power and diesel subsidies. Crop production is also expected to improve with farmers no longer reliant on volatile fuel costs and the overburdened archaic power-grid built in the 1960s which suffers from regular blackouts. In exchange for accepting subsidies to purchase solar water pumps, farmers must agree to use water-saving drip irrigation.

Box 21: Greenhouses heated using thermal energy – Beijing China
(APO 2006)

Two hours out of Beijing, the Tianjin Dashun Group is building a hothouse complex to cover 100ha. The houses will be heated using hot thermal water in the ground and a heat exchanger.

Greenhouse designed to optimise renewable energy sources: New innovations in greenhouse design are allowing vegetable producers in China to grow more varieties and greater volumes with fewer impacts on the environment (Box 21). The single-slope solar greenhouses for example, are built to face south with insulation walls on the north, east, and west sides. The energy efficient greenhouses use solar energy for lighting and heat over the winter to grow warm season crops such as tomatoes and cucumbers (Aguilera, Lassaletta et al. 2013).

6 GREENING IN POST-HARVEST HANDLING

The post-harvest handling stage of the value chain consumes energy for harvesting, cooling and storage; water and chemicals for washing and sanitising produce; significant amounts of packaging; and, in turn, generates associated greenhouse emissions, wastewater and solid wastes. Greening opportunities for this stage of the value chain are discussed below.

In the developing regions of Asia, more than 50% of total fruit and vegetables produced are wasted with 10% occurring at the post-harvest stage (Gustavsson, Cederberg et al. 2011). Care must be taken during post-harvest handling to prevent damage and deterioration to produce and to minimise waste. Careless or poor handling techniques can cause moisture loss, damage and internal bruising or splitting. Ideally, in order to extend shelf life, fruit and vegetable produce should be cooled and kept in cold storage. Basic steps for post-harvest handling (Dauthy 1995) are to:

- keep products in the shade, without any possible direct contact with sunlight;
- avoid dust;
- avoid excessive heat;
- avoid any possible contamination; and
- protect produce from attack by rodents, insects, etc.

In developing regions, fruit and vegetables are frequently transported whole with minimal packaging or pre-treatment (washing, sanitising and cooling). As a result, large volumes of the inedible portions of vegetables are transported to wholesale markets, where they are discarded instead of being used to generate value added by-products or reintegrated into the land (Box 22). Stations where fruit and vegetables are trimmed, sorted, graded, packed in cartons or crates and cooled are uncommon.

The application of proper post-harvest treatment technologies extends shelf life, helps to retain product quality and reduces losses. In developed supply chains, such operations include fumigation, fungicidal dipping, surface coating with wax, ripening and conditioning, vapour heat treatment and others. Exposure to fungi and bacteria leads to product loss. For example, contaminated field boxes and dirty water used in the washing process can be as harmful as damaging the products during transport (Kader 2005). Modified atmosphere storage and packaging markedly enhances the shelf life of fruits and vegetables when combined with refrigeration (Box 23). This involves modifying the atmosphere surrounding the stored product by removal of O_2 or addition of CO_2 as well as ensuring products are stored in a moist environment in order to minimise water loss.

Box 22: Waste reduction by working with suppliers (Queensland State Government 2010).

Harvest Freshcuts are fresh salad producers in Brisbane. They work closely with their fresh produce suppliers to reduce the amount of organic waste arriving on-site to the benefit of both farmer and processor. The outer leaf is removed on-farm, keeping organic material on-farm for reuse and reducing waste production at the processing plant. The organic waste generated at the processing plant is sent to a dairy farm to be used for feed. An added benefit for the processor is the reduction in cleaning requirements as the removal of the outer leaf also removes the majority of dirt. Harvest Freshcuts are currently investigating options to remove more waste on-farm for continued benefits.

Box 23: Modified atmosphere packaging, Vietnam (UNEP 2013)

Viet Lien, a producer and retailer of organic vegetables, has adopted Modified Atmosphere Packaging (MAP) technology with a view to improving the preservation of vegetables during transit. MAP also helps eliminate the need to use harmful chemicals to prolong shelf life. Prior to applying MAP, Viet Lien's organic vegetables were packed in ordinary plastic bags that prevented ventilation and caused vegetables to rot quickly – even after just one day during the hot summer months. MAP works by slowing the growth of aerobic organisms and decreasing oxidation reactions. As a result, the shelf life of vegetables packed using MAP is up to two times longer compared with the plastic packaging or leaving the vegetables open. MAP is used in four organic farm projects in the suburbs of Hanoi.

Where there is access to a cold supply chain and some level of treatment prior to processing, there can also be significant use of energy and water for the operation of washers and coolers. However, this is offset by the reduction in product loss and the energy and water that goes into production in the first place. Box 24 gives an example of waste reduction from the development of a cold supply chain in the Philippines. Box 25 describes energy and water savings gained through adopting a technique of hydrocooling. In hydrocooling, fruits and vegetables are cooled using chilled water just prior to freezing to reduce the cooling demand on freezers. It is reported that using hydrocooling to cool fruits and vegetables down to just above freezing is much more energy efficient than using the evaporators in freezers to perform the same service (Hacket et al.2005, cited in Masanet, Worrell et al. 2008). In addition, the use of recirculated water will significantly reduce water consumption.

Fruit and vegetable produce can be stored for up to months at a time in controlled atmospheric conditions, making a significant impact on a product's carbon footprint. This presents opportunities to minimise energy requirements for refrigeration and air-conditioning which are outlined in the section on processing.

Packaging not only protects product from damage, but also provides an essential link between producer and consumer for marketing purposes. Produce may be packed in wooden crates, bamboo baskets, plastic crates, plastic bags, or nylon sacks, and there are numerous opportunities to reduce the impacts of such packaging. For example, wooden crates are commonly used in transporting fresh produce, although timber conservation is critical. One alternative is corrugated fibre board (CFB) containers which reportedly consume one third of the wood required for producing timber boxes of the same size. CFB boxes can also be fabricated from kraft paper produced from bamboo, long grasses and many other types of agricultural residues like bagasse, paddy, cotton stalk, jute stick, wheat straw and recycled paper and cardboard (APO 2006). Another alternative is the use of reusable plastic crates (Box 26). Further information on reducing environmental impacts can be found in the packaging section of this report.

Box 24: Lettuce Clustering in the Philippines
(APO 2006)

Small vegetable growers in different villages of the province of Bukidnon, Mindanao were producing vegetables (lettuce, carrots peas) for local traders at a vegetable trading post, situated 75 km away from the farms. An additional market (a vegetable processor supplying large fast food outlets in the metropolis) was identified, and approximately 400 kg of lettuce was transported by air on a weekly basis to Manila. Apart from the high cost of airfreight, lettuce delivered to the processor did not meet the 61% yield specified in the marketing contract, owing to the need for excessive trimming. Attaining the high quality standards of the fast food processor was a challenge for the grower; however, they were determined to succeed. The processor offered technical advice on the improvement of production and post-harvest practices, in particular, recommendations regarding the use of refrigeration and shipping to reduce freight costs.

The requirement to supply a 20ft refrigerated van with 3.5 Mt of lettuce on a weekly basis, led to the formation of a cluster of lettuce growers. The lettuce cluster shared production technologies to come up with a common quality standard, and began making weekly shipments to the processor in Manila. With the use of refrigerated transportation, the trimmings were significantly reduced to a maximum of 10% and the processor's yield recovery specification of 61% was achieved. The supply chain was facilitated by equipment inputs in the form of cold chain infrastructure from the government. Its successes have also provided the impetus for other independent, small lettuce growers to join in the cluster.

Box 25: Hydro-cooling of freshly harvested fruit and vegetables
(Smart Water 2008)

An example of the benefits of hydrocooling is a hydro-cooler built in partnership with Victoria University of Technology, Australia and Wobelea Pty Ltd. Water recirculating has reduced the water use from 60,000 L/tonne of broccoli cooled to around 75 L/tonne. When round fruit such as apples, are cooled, the water use is estimated to be about 35 L/tonne. Electrical use is estimated to be 20 kWh and 16 kWh per tonne of produce when the throughput is 4 t/hr and 6 t/hr respectively. If the water was not recirculated, the running cost would be about 300kW per tonne.

Box 26: Use of plastic crates in food supply chains in Asia
(UNEP 2013)

The FAO Regional Office for Asia and the Pacific promotes the use of reusable plastic crates in fresh produce supply chains with small farmers through technical training and information (including cost-benefit analyses). The shift requires government support through provision of incentives and facilities for the recycling and management of the crates. Private companies also have a role to play by providing crate-leasing arrangements. The objectives are to reduce the environmental impact of the use of plastic film and reduce post-harvest losses. Farmers that have switched from plastic packaging to re-usable crates consistently report reductions in losses.

7 GREENING IN FRUIT AND VEGETABLE PROCESSING

The fruit and vegetable value chain in Asia is more geared towards the production and consumption of fresh and minimally processed products. Of the 794 million tonnes of vegetables and 310 million tonnes of fruit produced in Asia, it is estimated that in the order of 5% is further processed via formal channels as explained in the sector overview. In addition to this is the amount processed via informal channels, e.g. cottage industries, which is more difficult to quantify. Fruit and vegetable processing consumes significant amounts of energy, water, chemicals and packaging, in turn generating greenhouse emissions, wastewater and solid wastes which must be managed. Greening opportunities are presented below. The significance of these opportunities across the value chain can only be highlighted through further research into processing efficiencies and, in particular, life cycle assessment.

Processed fruit and vegetable products can be categorised as follows:

- Fresh, minimally processed/prepared portions
- Canned or bottled products
- Frozen products
- Juices and concentrates

Figure 6 shows overall simple process flow diagrams for fruit processing. Generally, fruit and vegetables are processed to preserve nutritional value, to produce value added products such as drinks, jams and sauces, or to extract valuable compounds e.g. proteins. Processing of whole fresh fruits and vegetables usually consists of sorting, washing, portioning, and then packaging. Additional processing technologies are undertaken with a view to preserve product or add value. These include canning, bottling, freezing, drying, and fermentation and may be applied at various scales (cottage, small, medium and large). Such preservation techniques create an environment that prevents harmful microorganisms from multiplying.

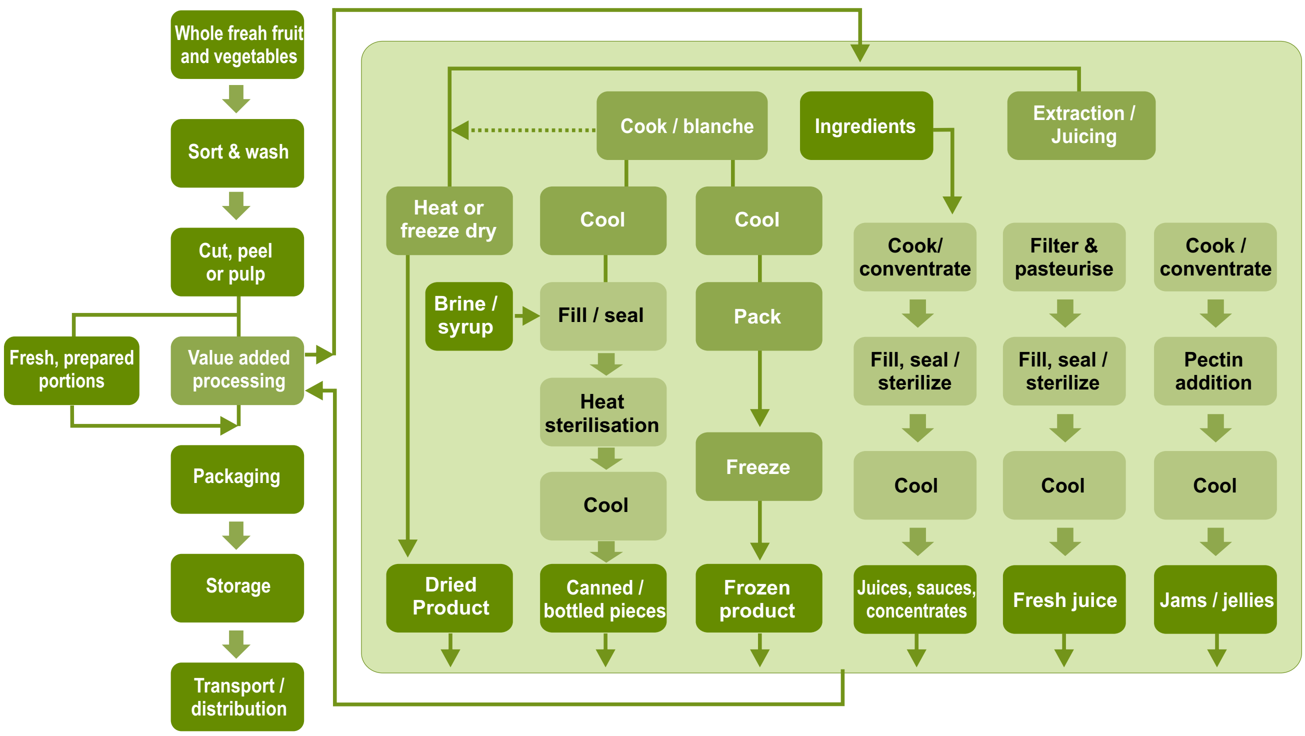

Figure 6: Fruit and vegetable processing steps

Fruit and vegetable processing can be categorised as those occurring at ambient temperature (e.g. sorting, size reduction); those requiring application of heat (cooking, pasteurising); those requiring removal of heat (chilling, freezing); and post-processing operations (packaging, storage) (Rosier 2010). Each of these processes requires various levels of resource inputs of energy, water and chemicals and also generates various types of waste (solid, liquid, heat). The majority of processors throughout Asia are relatively small-scale fruit and vegetable processors that use domestic or light industrial sized equipment such as pressure cookers, fridges, freezers, deep fryers, gas burners, heat sealers, pulpers and crushers. An extensive list of equipment can be found in 'Small-scale Fruit and Vegetable Processing and Products' (Fellows 2004).

The processing of fresh leafy vegetables requires an array of water and energy intensive equipment such as chilling systems, conveyor belts, slicers, continuous washing flumes, conveyors, spin driers and packing machines (James and Ngarmsak 2010). As with other segments of the supply chain, there are significant challenges in capacity building, gaining access to markets, obtaining finance and justifying capital investment. This applies particularly to the thousands of small-scale producers that use outdated technology; are not well-connected and who often operate in isolation from other actors in the supply chain (FAO 2009, Singh, Tegegne et al. 2012). Opportunities for greening fruit and vegetable processing in small to large scale operations are discussed in the following sections. Engaging staff and encouraging good housekeeping practices will also make a significant difference in reducing resource consumption.

Table 8: Fruit and Vegetable Processing Operations

Processing at ambient temperature
• Raw material preparation (cleaning, sorting, grading, peeling)
• Size reduction
• Mixing and forming
• Separation and concentration of food components
• Fermentation and enzyme technology
• Irradiation
• Processing using electric fields, high hydrostatic pressure, light or ultrasound
Processing by application of heat
Heat processing using steam or water
• Blanching
• Pasteurisation
• Heat sterilisation
• Evaporation and distillation
• Extrusion
Heat processing using hot air
• Dehydration
• Baking and roasting
Heat processing using hot oils
• Frying
Heat processing by direct and radiated energy
• Dielectric, ohmic and infrared heating
Processing by removal of heat
• Chilling
• Controlled or modified-atmosphere storage packaging
• Freezing
• Freeze drying
Post processing operations
• Coating and enrobing
• Packaging
• Filling and sealing of containers
• Handling, storage and distribution

7.1 Energy use in processing

Energy, most often electricity and natural gas, is used in fruit and vegetable processing to provide heat for steam and hot water systems; to remove heat in the process of chilling or freezing; or to operate various items of processing equipment and utilities. The overall split of energy use is generally similar regardless of the scale of operation, with heating and refrigeration consuming the majority of energy followed by the operation of processing equipment. Figure 7, 8 and 9 give an indication of the breakdown of energy use in a large-scale fruit and vegetable canning facility. Similarly, Figure 10, 11 and 12 provide a breakdown of energy use in a large-scale frozen fruit, juice and vegetable manufacturing facility.

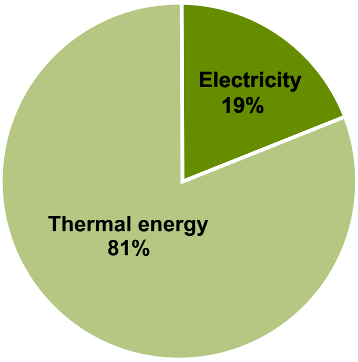

Figure 7: Typical energy split in a large-scale fruit and vegetable canning facility

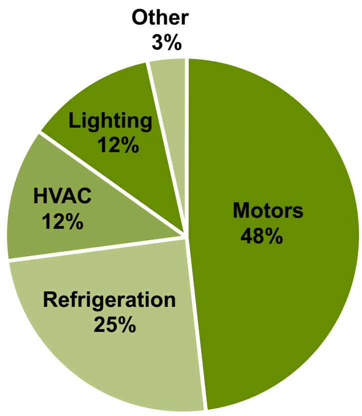

Figure 8: Typical electricity split in a large-scale fruit and vegetable canning facility*

*HVAC – Heating, ventilation, air conditioning

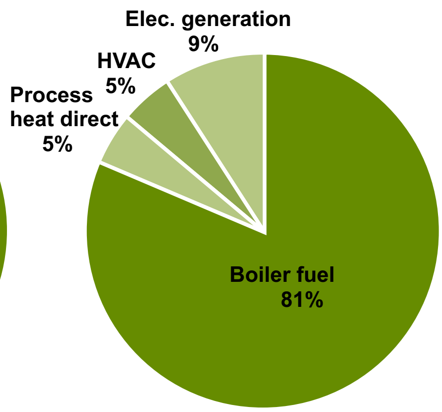

Figure 9: Typical thermal energy split in a large-scale fruit and vegetable canning facility*

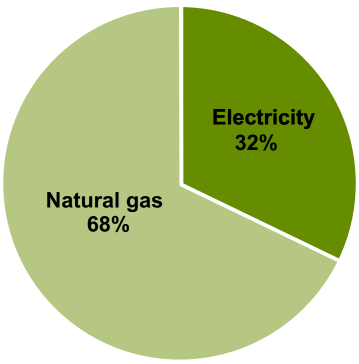

Figure 10: Typical energy split in a large- scale frozen fruit, juice and vegetable processing facility

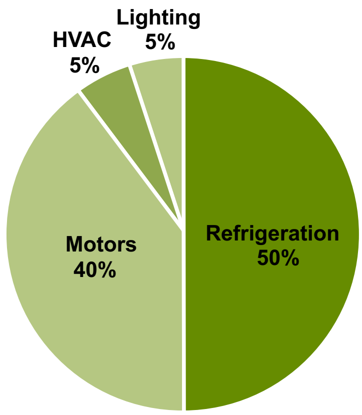

Figure 11: Typical electricity split in a large-scale frozen

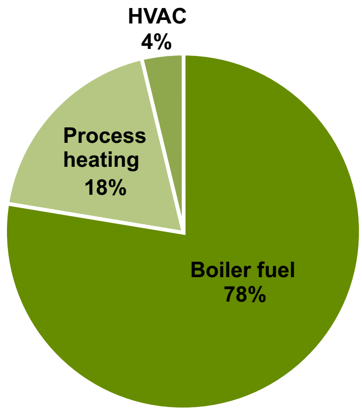

Figure 12: Typical thermal energy split in a large-scale frozen fruit, juice and vegetable processing facility

Compiled from (Masanet, Worrell et al. 2008)

The initial processing of fruit and vegetables generally occurs in a chilled environment; this can be followed by additional energy intensive processes of further chilling or heating, blanching and cooking. As shown in the charts, for chilled, as opposed to canned products, the majority of the electricity in fruit and vegetable processing plants is consumed by refrigeration. Electricity is also used in large facilities for lighting, compressed air systems, hydraulic pumps and other process drive motors. In most cases, fossil fuels are used to generate steam for processing (blanching, sterilisation) and sanitation.

7.1.1 Energy efficiency

The integrated analysis and optimisation of energy efficiency in industrial fruit and vegetable processing plants offers great potential for reducing resource use and lowering costs. Optimising the energy input requires an exact knowledge of the internal energy consumption in terms of amounts and costs, as well as the respective flows through the operation. Interrogation of each aspect of energy flow is known as pinch analysis. An energy management system, such as that according to ISO 50001 (International Organization for Standardization), can be implemented to assist companies to achieve systematic energy management and highlight where savings can be made.

Opportunities for reducing energy consumption in fruit and vegetable processing are shown in Table 9. A detailed evaluation can be found in the US EPA 2008 Energy Star Guide (Masanet, Worrell et al. 2008)

A study of seven fruit and vegetable processing plants in California indicated an electricity cost savings potential of up to 7% for larger plants and up to 16% in smaller sized plants, and a fuel cost savings potential of 5 to 12% (Hackett, Chow et al. 2005). Again, this was mostly due to improvements in the cooling and heating systems.

It is expected that similar or even greater savings could be achieved by fruit and vegetable processing facilities in Asia. For the thousands of cottage and small-scale industry processors throughout Asia, savings can be made possible by means of implementing simple measures such as preventing heat loss, repairing leaks, regular maintenance of equipment, good process layout and design (as described in James and Ngarmsak 2010), and by simply ensuring that equipment is not left on unnecessarily or turned on before being required (Table 9). The upgrade to new energy efficient technology and equipment will also lead to significant savings (see Box 27, Box 28 and Box 29).

Table 9: Energy saving opportunities for fruit and vegetable processors

(Pagan, Prasad et al. 2004, Hackett, Chow et al. 2005, Masanet, Worrell et al. 2008)

Energy management (for medium-to large-scale processors)
• Appointment of energy manager
• Conduct an energy assessment
• Use of production-related indicators for energy use
• Monitoring and control of energy use and sub-meters
• Power factor correction and load management
• Use directly fired systems (e. g. in dryers)
• Investigate cogeneration
• Investigate alternate energy sources e.g. solar, biofuels
Boilers (for medium to large-scale processors)
• Control of air to fuel ratio
• Lower steam pressure
• Increase condensate recovery & repair condensate traps
• Optimise boiler blow down system
• Recover energy off flash steam
• Monitor exhaust gas temperature
• Recover energy of exhaust gas by economiser
• Improve insulation of steam pipes
Refrigeration (for medium to large-scale processors)
• Use ammonia as refrigerant
• Reduce temperature lift
• Clean condensers and optimise defrosting
• Limit air movement (e. g. by curtains)
• Recover heat from desuperheaters to preheat water
• Investigate absorption chilling, geothermal cooling, hydrocooling
Process specific (relevant to all processors)
• Blanching – heat recovery, heat and hold, steam recirculation
• Drying – heat recovery, insulation, mechanical de-water, direct-fired dryers
• Evaporation – multi-effect evaporators, membranes, freeze concentrate, mechanical/thermal recompression
• Frying – heat recovery from exhaust, use of spent oil
• Pasteurising/sterilising – insulation, helical or compact immersion exchangers, induction heating of liquids
• Peeling – heat recovery, abrasive or caustic peeling
Other electrical and thermal equipment (relevant to all processors)
• Upgrade to more energy efficient processing equipment
• Use variable speed drives on motors (pumps, fans)
• Optimise sequencing of air compressors
• Leak detection and repair program for compressed air
• Acquire energy efficient motors
• Use efficient lights (T5 or LEDs) and daylight control
• Use daylight control
• Auto-switches on equipment not in use e.g. conveyor belts
• Good maintenance and housekeeping practises

Box 27: Shifting to hygienic and eco-friendly production in the tofu and tempe industry in Indonesia
(Switch Asia 2013)

Indonesia's soy-based food-processing industry generates around €57 million per year and serves as a source of income for 85,000 businesses. The industry supports 285,000 workers, of whom 40-50% are women. Indonesia's tofu and tempe industry, with its vast number of micro, small, and medium-sized enterprises (MSMEs), still uses environmentally damaging production practices. Issues include general inefficiency, inadequate waste disposal, lack of hygiene, insufficient access to credit, and a low awareness about new technologies. The project Scaling SCP in the Soybean Processing Industry seeks to address the inefficient usage of energy in the soy-based food industry. The project includes the establishment of a tempe demonstration factory which is demonstrating the use of a biogas and liquid waste filtering system. In the first year, 104 producers upgraded equipment, most of them reducing the use of firewood. By switching to sustainable technologies, 800 small food-processing factories in Indonesia will save approximately 260,000 tonnes of carbon emissions per year.

Box 28: Reducing refrigeration costs in fruit processing and storage, India
(The Energy and Resources Institute 2013)

Fruits and vegetables are often ripened by keeping them in artificially controlled atmospheres. Maintaining temperatures and constant monitoring are energy intensive processes. Instead of ripening the fruits and vegetables using traditional refrigeration, Jain Irrigation installed poly houses with semi-automated cooling fan pads (evaporative cooling). This requires relatively less energy for air circulation and cooling and maintaining desired temperatures. This initiative has substantially reduced the cost of installation and operation of the refrigeration units. The investment in incorporating this initiative was Rs.3.87 Crores. The savings accrued from this initiative were Rs. 72 lakhs per annum.
Other energy saving initiatives were:

- Installation of a vapour absorption chiller to utilise the waste heat from the biogas engines
- An air cooled dehumidifier was changed to water cooled with reduced energy consumption
- Other heat recovery initiatives.

These investments cost Rs. 1.83 Crores with savings of Rs. 84 lakhs per annum.

Box 29: Reducing lighting energy and costs, India
(The Energy and Resources Institute 2013)

Fruit and vegetable processor Jain Irrigation has installed skylights in their processing hall to take advantage of natural light. The installation cost Rs 7.5 lakhs and has resulted in savings of 26,400 KWh/yr and Rs 1.98 lakhs/yr.

7.1.2 Alternative energy sources and heat recovery

It is imperative to look for opportunities to reduce dependence on fossil fuels and reduce carbon emissions. Fruit and vegetable processing has relatively high heating demands, but requires low to medium processing temperatures. For example, the operations of washing/cleaning, pasteurisation and drying usually occur at temperatures around 40-110°C. Solar heat energy is therefore a feasible and proven alternative to fossil or electric supply. Solar energy is used for drying fruits, herbs, vegetables, and spices in a variety of installations in India (Box 30).

Box 30: Solar drying of fruits and vegetables, India
(PEN 2013).

Sanga Dal Mill has adopted solar heat to reduce diesel consumption. The south facing roof of the factory has been covered by a 167 m2 solar collector panel. On a normal sunny day the collector delivers hot air above 6500c. A 3 Hp power blower is used to deliver the hot air from the solar panel to the point of usage. Insulated metal ducts are used to avoid temperature loss. The system, installed in 2001, saves 60 to 90 L/day of diesel.

PEN, Planters' Energy Network in India, has installed 8 large solar drying units in the Ladakh and Kargil region. The roofs of the processing houses have 55 to 90 m² solar collectors where hot air is passed to a re-circulation drier placed inside the room. Numerous small driers of 70 kg capacity with photovoltaic panels have been also installed in Ladakh. The dryers have been used for various fruit and vegetables including mangoes, apricots, tea leaves and spices.

For advanced processors, electricity and fossil fuel use can also be reduced by utilising cogeneration systems e.g. micro-turbines to produce electricity and vapour absorption chillers for cooling (Box 31).

Box 31: Cogeneration and absorption refrigeration for a fruit and vegetable processor, Austria.
(Capstone 2013)

Austrian company Marchland Fruit and Vegetable Delicacies GmbH processes 17,000 tonnes of fruit and vegetables per year. They were coping with operating an antiquated plant as well as severe grid failures. The decision was made to install a micro-turbine system with exhaust used as feed to the steam boiler. An additional benefit of the micro-turbine is the option to operate in stand-alone mode in case of grid failure. During cold periods, recovered heat from the plant's pasteurisation process and waste heat from the micro-turbine produces hot water through a secondary heat exchanger that supplies heat to the warehouse and office. On hot days, an absorption chiller uses the micro-turbine's waste heat as energy to produce cool water for air conditioning. The cogeneration facility generates 200kW/yr of electricity reducing overall electricity costs. Energy efficiency ranges from 90%–96% and system utilisation is greater than 40%.

Vapour absorption chillers operate by using a heat source (solar or waste heat) to drive the cooling system. Another opportunity is the use of geothermal cooling (Box 32).

Box 32: Geothermal cooling for a jam manufacturer, Japan
(JPS 2005)

A Japanese jam manufacturer, Aohata Corporation, began operating a new geothermal cooling system that provided its facility with 260 kW of additional cooling capacity. Water is circulated below ground through a series of pipes placed in 37 holes that are drilled to a depth of 100 meters. The company reported that the system uses only about 25% of the electricity required by a traditional refrigeration system.

Where available, biofuels can be an excellent alternative or supplementary fuel in regions where they can be sustainably sourced. Examples include pomace, coconut husk and rice husk (Box 33 and Box 34).

Box 33: Apple pomace as fuel, Germany
(Stiefel 2013)

After successful pelleting and combustion trials, the fruit juice producer Steifel built an apple pomace drying and pelleting plant as well as a storage silo. Since Autumn 2010, the pelleted apple pomace is the sole source of heat in the company and is used in the production of long shelf life fruit juices.

Box 34: Resource efficiency and Cleaner Production at the Rathkerewwa Desiccated Coconut Industry, Sri Lanka
(UNIDO and UNEP 2010)

The desiccated coconut factory reduced its overall energy use by 12%, water use by 68% and solid waste by 76% through the adoption of resource efficiency and cleaner production techniques. Initiatives included:

- Reduction of rejects due to mishandling
- Encouraging reduction in waste via education of employees regarding value of waste product
- Savings in water consumption and wastewater generation through improved cleaning methods
- Recovery of coconut oil from wastewater pits
- Fuel switching in the boiler from fuel oil to coconut shell

The company saved USD 50,000 during the initial phases of the programme and, after the implementation of all the options identified, the savings were in excess of USD 200,000 for an investment of less than USD 5,000. RECP enabled the company to simultaneously decrease waste quantities and reduce the amount of greenhouse gas emissions to almost zero through the utilisation of waste for energy.

7.2 Reducing water consumption and wastewater generation

The main water-consuming steps in processing fruit and vegetables include:

1. Preliminary cleaning and dirt removal
2. Removal of leaves, skin, and seeds
3. Blanching or cooking
4. Washing, cooling and sterilising e.g. flumes and water baths
5. Packaging (including canning/bottling)
6. Clean up and sanitation

Figure 13 shows an example of the breakdown of the water use of a vegetable processor which does not include water in the final product. Typically, the bulk of the water is used in process operations and cleaning, with a smaller percentage used in utilities, such as boilers and cooling towers. Table 10 gives an indication of the typical water usage per tonne, per product (note, however, that the World Bank data is quite dated and there is a general lack of information for benchmark data on water use for the sector).

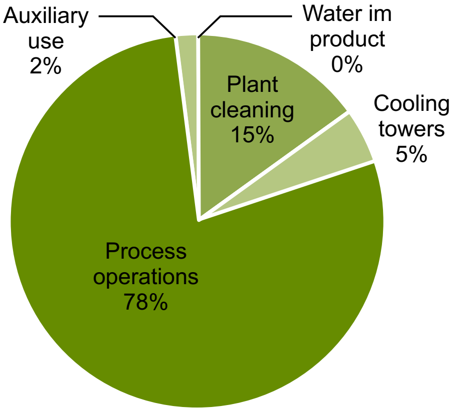

Figure 13: Water use for a vegetable processor (Pagan, Prasad et al. 2004)

Table 10: Water usage in fruit and vegetable processing (kL/tonne product)

Product category	Source: (World Bank 1998)	Source: (AFGC 2007)	Source: (NB 2013)
Canned fruit	2.5-4.0		
Canned vegetables	3.5-6.0		
Frozen vegetables	5.0-8.5		
Fruit juices	6.5		
Jams	6		
Baby food	6.0-9.0		
General fruit & vegetable processing	-	2.4	1.57 - 4.8

Table 12 lists the potential opportunities for reducing water use in the sector. The use of shut-off valves, low-flow or air-injected taps and spray cleaners, switching to mechanical peeling, and converting from hydraulic to the mechanical transport of raw materials through a production line, are simple and low-cost measures to reduce water demand. Dry peeling methods can reduce the effluent volume by up to 35% and pollutant concentrations can reduce organic loads by up to 25% (World Bank 1998). Similarly, the removal of the outer leaf of some vegetables on the farm can result in the majority of dirt being retained at the farm and correspondingly reduce washing requirements (Box 22). Although there is potential to replace some wet processes with dry processes, consideration needs to be given to the overall effect of energy consumption. Examples of water saving and other clean technology case studies are shown in Box 35-37.

The key environmental issues for the fruit and vegetable wastewater streams are the biochemical oxygen demand (BOD), suspended solids (TSS), and the excessive nutrient loading, by nitrogen and phosphorus compounds in the wastewater of processing industries. Table 11 gives an indication of typical wastewater generation per ton of product. Wastewater treatment methods in fruit and vegetable processing often only include primary treatment i.e. the mechanical removal of gross,

Table 11: Wastewater discharge from fruit & vegetable processing

(NCDENR 2009)

Crop	Flow (kL/ton) min.	Flow (kL/ton) mean	Flow (kL/ton) max.
Vegetable Products			
Asparagus	7.2	32.2	109.8
Bean, snap	4.9	15.9	42.4
Broccoli	15.5	34.8	79.5
Carrot	4.5	12.5	26.9
Cauliflower	45.4	64.4	90.8
Pea	7.2	20.4	53.0
Pickle	5.3	13.2	41.6
Potato, sweet	1.5	8.3	36.7
Potato, white	7.2	13.6	25.0
Spinach	12.1	33.3	87.1
Squash	4.2	22.7	83.3
Tomato, peeled	4.9	8.3	14.0
Tomato, product	4.2	6.1	9.1
Fruit Products			
Apple	0.8	9.1	49.2
Apricot	9.5	21.2	53.0
Berry	6.8	13.2	34.4
Cherry	4.5	14.8	53.0
Citrus	1.1	11.4	35.2
Peach	5.3	11.4	23.8
Pear	6.1	13.6	29.1
Pineapple	9.8	10.2	14.4
Pumpkin	1.5	11.0	41.6

suspended and floating solids (dirt) using screens, cyclones, settling pits, clarifiers and dissolved air flotation tanks (SA Water 2013). Some secondary or biological treatment may be necessary to remove high levels of dissolved organics e.g. in tomato paste production or starch from potato processing. Wastewater production should firstly be minimised through reductions in water use. It is optimal to separate and treat waste process streams at source in order to maximise recovery of by-products. If properly managed, irrigation is an excellent end-use of the wastewater stream depending on wastewater quality and

Table 12: Water saving opportunities in fruit and vegetable processing

(Pagan, Prasad et al. 2004, Masanet, Worrell et al. 2008, Fresner, Waltersdorfer et al. 2014)

Water management
● Appointment of water manager
● Use of production-related indicators
● Monitoring and controlling (install sub-meters)
● Conduct a water assessment
Water pre-treatment
● Control of chemical consumption
● Optimise backwash cycles on sand filters & ion exchangers
Refrigeration
● Avoid once-through cooling
● Reuse cooling water e. g. for site cleaning
Cleaning and housekeeping
● Remove solids without the use of water
● Use foam cleaning
● Use efficient spray nozzles & spring loaded valves
● Repair leaks
● Install smooth, cleanable surfaces
● Use high pressure rather than high flow
● Use of cleaning in place (CIP) plants and pigging
● Collect water from final rinse for pre-rinse
● Minimise water use cleaning floors and machines
Processing operations & utilities
● Reuse concentrated wastewaters and solid wastes for production of by-products or for the generation of biogas
● Procure clean raw fruit and vegetables, thus reducing the concentration of dirt and organics (including pesticides) in the effluent
● Use dry methods such as vibration or air jets to clean raw fruit and vegetables
● Convert to dry peeling
● Separate and recirculate water used for transport or for washing (after sedimentation of solids)
● Use counter current cascaded systems where washing is necessary
● Use steam blanching instead of water blanching
● Use air cooling after blanching
● Use dry rather than wet conveying systems
● Recycle evaporator condensate
● Recycle can and bottle cooling water, blanching and cooking water
Reduce cooling tower bleed and boiler blowdown
● Recycle compressor cooling water
● Stormwater collection e.g. for cooling towers

proximity to suitable land. If irrigation is unfeasible, treated wastewater streams should be discharged to municipal systems, however this often does not occur in developing regions and discharge to waterways or open drains is not uncommon.

Box 35: Transfer of Environmentally Sound Technology in Mediterranean Countries (MED TEST), Edfina Fruit and Vegetable Processing, Egypt
(UNIDO 2012)

Edfina is a large size food enterprise producing approximately 2,282 tons/year of frozen vegetables, juice, fruit nectar, canned food such as jam, tomato paste and legumes for the local market and for export (50%). The MED TEST project identified annual total savings of $US 888,993 in water, raw materials and fuel against an estimated investment of $US 257,518 (4 month payback). Savings included:

- Water costs were reduced by 32% through good housekeeping, water reuse for raw materials washing and blanching, utilisation of a water monitoring and control system, dry cleaning of floors in different units and improved techniques for equipment washing.
- Electricity costs were reduced by 10% by improving power factor, measuring harmonics, installing soft starters for compressors, blancher heat recovery and switching to natural gas.
- Wastewater pollution loads were reduced by 50% in BOD, 25% in COD and 15% in TSS through good housekeeping and upgrading packaging, thereby reducing loss to drains.

Galina Frozen Fruit and Vegetables, Egypt

Galina is a medium-sized joint stock food enterprise. The company produces approx. 10,000 tons/year of frozen vegetables and fruits for export. The MED TEST project identified annual total potential savings of $US 113,499 in water, raw materials and fuel with an estimated investment of $US 32,500 (< 3 month payback). Savings included:

- Water costs were reduced by 50% through good housekeeping; preventive maintenance; improved water monitoring and control; dry cleaning of floors; and improved techniques for equipment washing.
- Electricity costs were reduced by 10% through preventive maintenance programs for compressors and cooling towers; improved lighting, measuring harmonics, and implementing heat recovery at the blancher.
- Wastewater pollution loads were reduced by 55% BOD5, 40% COD and 15% TSS from good housekeeping, water conservation and upgrading packaging units to reduce product losses from entering the drain.

Box 36: Clean Technology in Tapioca Starch Industry, Thailand
(Chavalparit and Ongwandee 2009)

Eight Tapioca starch plants were selected for an assessment of clean technology development and adoption. The study found that:

- only one company had implemented water recycling in their production processes;
- two companies had replaced a centrifugal screen with a more efficient Dutch State Mines Screen (DSM);
- four companies had installed motor load control at a dehydration drying machine and grinding machine;
- four companies had replaced incandescent lamps with two-tube, 36W fluorescent lamps;
- two companies had used exhaust air from a drier stack for preheating fresh air; and
- five companies had recovered biogas to replace fuel oil for a burner.

Paybacks ranged between immediate and 2.3 years with the highest period being 5.2 years for the motor load control project.

Box 37: Recycling of brine water in Kimchi processing, Korea
(Yi, Kim et al. 2001)

In the Kimchi (a salt-pickled and fermented food) manufacturing industry, the process of brining and rinsing the raw vegetable produces a large amount of highly saline wastewater. A new brining wastewater reuse system was developed using a hybrid chemical precipitation/microfiltration process. The trials were successful with continued production of a quality product, increased recovery of magnesium used in processing and reductions in wastewater discharged to sewers.

Table 13: Fruit and vegetable processing effluent requirements for direct discharge to surface waters (mg/L, except for pH) (World Bank 1998)

Parameter	Maximum value
pH	6-9
BOD	50
COD	250
TSS	50
Oil and grease	10
Total nitrogen	10
Total phosphorus	5

7.3 Solid waste management and by-product usage

Fruit and vegetable processing produces by-products and residues, which could be reused as product input or potential energy sources in the same or different production systems. Large quantities of these potential by-products are disposed of as waste, which is a loss of valuable materials, is costly for business and impacts on the environment. By-products include product rejects, cores, culls, evaporated volatiles, oil, peels, pulp and seeds. Table 14 lists opportunities for by-product use. Some solid wastes, particularly from processes such as peeling, coring and pulping, typically have a high nutritional value and organic content which should be utilised e.g. as animal feed stock or in producing quality composts which replenish soil carbon stocks. Box 38 provides an example of by-product recovery for a potato chip manufacturer.

Table 14: Opportunities for closing loops and value utilisation

By-product	Use
All plant parts	Enzymes, phytochemicals
Culls	Natural colours and flavours
Cores	Animal feed
Evaporated volatiles	Essence, detergents
Peels	Pectin, flavours, essences
Pulp	Confectionery, drinks, concentrates
Rejects	Fuel, feed, fertiliser, ethanol
Seeds	Oil, animal feed, fuel
Shells and husks	Fuel
Solid waste	Fertiliser, compost, fuel

7.3.1 Minimising solid wastes

Prevention of solid waste is largely a combination of good process design, good housekeeping practices and education and involvement of staff. It is about raising awareness of employees, by creating responsibility and providing procedures to minimise wastes at source. Such opportunities can often be quickly and easily implemented, require little capital, and provide immediate payback. Examples include:

- addressing supply chain management issues to ensure appropriate quality is delivered on time in full;
- improving inventory management to minimise disposal of expired materials;
- storing materials in dry conditions and in appropriate containers, properly labelled and at appropriate temperatures;
- preventing vermin ingress;
- improving process control, operation and maintenance of machines ;
- installing drip trays to stop food hitting the ground from conveyors, feeding points and machines;
- minimising cleaning frequency by increasing batch size;
- minimising cleaning waste by thoroughly collecting product before actual cleaning starts;
- avoiding shut-down losses by collecting fruits and vegetables from tables and machines;
- avoiding the combination of different waste streams; and
- reusing wastes on-site or use as feed for another process (SEAM Project 1999, Pagan, Prasad et al. 2004).

Process design has a significant effect on waste generation. For example, Table 15 gives an indication of vegetable losses as a result of different peeling methods. However, consideration must be given to further processing requirements and final product. Abrasive peeling is reported to be more destructive than manual peeling and leads to greater deterioration (discolouration), which is an issue for fresh cut products (Garcia and Barret 2002). Process equipment maintenance is also important. For example, dull knives and blades will contribute to greater levels of bruising which will affect storage life and overall waste.

Table 15: Example of losses at vegetable peeling for different peeling methods (%)

Vegetables	Manual	Mechanical	Chemical
Potatoes	15 - 19	18 - 29	-
Carrots	13 - 15	16 - 18	6 - 10
Beets	14 - 16	13 - 15	9 - 10

7.4 Chemical use

Chemicals are used in fruit and vegetable processing for cleaning and sanitising of operating equipment and surrounds. Table 7 shows the typical chemicals used and their purpose. Chlorine is commonly used in the decontamination of fresh cut fruit and vegetable products. However, its use has been called into question due to potential health issues with chlorine residues, hence alternatives are being promoted such as chlorine dioxide, sodium chlorite and ozone (Rico, Martin-Diana et al. 2007, James and Ngarmsak 2010). Opportunities for reducing chemical usage include:

- undertaking dry cleaning as far as possible;
- review and rationalising use of cleaning and sanitising agents;
- use of automatic dosing systems and clean-in-place (CIP); and
- use of environmentally friendly cleaning agents (Pagan, Renouf et al. 2002).

Box 38: By-product recovery in the production of potato chips, Portugal
(Catarino, Mendonça et al. 2007)

A potato chip manufacturer applied cleaner production principles to reduce wastewater generation and costs and improve by-product recovery. Various process streams were separated at source and then treated. The project achieved the following results:

- Hydroclones were used to recover starch produced in potato processing. The concentrated starch was used as a raw material in paper manufacturing, contributing to additional business profit and has reduced wastewater loads and costs.
- The implementation of water reuse circuits inside and outside the production area reduced dependency on fresh water supplies.
- Recovered oil and grease has reduced wastewater discharge loads. The recovered materials are sold to soap manufacturers.
- The wastewater reduction initiatives allowed the overall downsizing of the treatment plant

Table 16: Cleaning and sanitising chemicals used in fruit and vegetable processing

(Pagan, Prasad et al. 2004, CSIRO 2011, ChemStation 2013)

Type of chemical/agent	Application	Function
Cleaning agents		
Multi-purpose	Easy to remove soil	Manual, pressure and foam cleaning all surfaces
Alkaline	Fats, protein, organic soil	Clean-in-place and soak tank. Breaks down fats to suspend in solution. Breaks down fats to form soaps. Forms colloidal solutions
Acidic	Protein, metal corrosion	Controls mineral deposits. Softens water
Enzyme assisted	Protein, fats, oils	Used in conjunction with mild detergents to break down and solubilise difficult-to-remove soils
Complex phosphates	Fats, proteins	Displaces soil. Disperses of soil. Softens water. Prevents soil re deposition
Disinfectants		**Comments**
Chlorine	Process equipment and also directly on product	Kills broad spectrum of microorganisms. Corrosive. Concentrations of 50-200 ppm have been used in processing. Can lead to retention of chlorine odour on freshly cut product. Has been banned in some European countries (FAO, 2010).
Chlorine dioxide	Processing equipment (200 ppm) and approved for use in flume waters (3 ppm)	Oxidising power is 2.5 times that of chlorine. Effective against many microorganisms at lower concentrations than free chlorine. Reactivity is reduced by the presence of organic matter. Approved by the US Food and Drug Administration (USFDA) (FAO,2010).
Acidified sodium chlorite	Used directly on product	Approved by the USFDA. Spraying or dipping of fresh-cut produce (500-1200 ppm).
Quaternary ammonium compounds (QUATS)	Used for surfaces. Effective in acidic environment	Stable, long shelf life, less corrosive. Leaves residues, high foaming e.g. in CIP.
Iodine based compounds	Wide-ranging. Used for surfaces and equipment	Stable, long shelf life, less corrosive. Can stain. Less effective against bacterial spores than chlorine.
Hydrogen peroxide and peroxyacetic acid	Wide ranging	Biodegradable. Hazardous in concentrated form. Is an irritant and corrosive.
Ozone	Used on product	Wash (0.5-4ppm) and flume water (0.1 ppm).
Electrolysed water	Freshly cut produce	Bactericidal power higher than that of a 5-ppm ozone solution in the decontamination of freshly cut lettuce.
Organic acids (e.g. lactic acid, citric acid,	Directly on freshly cut produce	Various concentrations

7.5 Packaging of processed product

Packaging serves many functions, including the preservation of produce as well as a being a vehicle for marketing. It can be categorised as (Queensland State Government 2010 c):

- Primary – that which is used around the product at the point of sale e.g. bottles.
- Secondary – that which groups the product until it is sold e.g. boxes.
- Tertiary – that which enables the product to be handled and transported e.g. pallets, pallet wrap and strapping.

Table 18 provides a list of the types of packaging used in fruit and vegetable processing. Table 17 lists opportunities for reducing the negative impacts of packaging. Producers can improve the environmental compatibility of their products by using bio-based resources (Box 39 and Box 40), choosing alternative packaging, as well as by rethinking and modifying the whole product design (Box 41). Eco-design presents a good opportunity for reducing impacts. It is the focus of the Sustainable Product Innovation in Packaging (SPIN) Project which involves working with 500 small to medium enterprises in the countries of Vietnam, Cambodia and Laos in the areas of food supply, processing and packaging (UNEP 2013).

Table 17: Reducing impacts of packaging
(Pagan, Prasad et al. 2004)

Avoid unnecessary packaging	
Eliminate unnecessary packaging via design	
Order bulk delivery of products e.g. chemicals, food additives	
Review handling and distribution measures e.g. clean-in-place systems, conveyors for bulk	
Reduce packaging	
Light-weighting of packaging	
Minimise use of adhesives e.g. tapes, glues	
Optimise packing lines e.g. canning, box construction, vacuum packing to minimise waste	
Optimise receiving, handling and storage to prevent contamination and/or damage	
Reuse packaging	
Return to supplier for re-use e.g. drums, cartons, plastic containers	
Reuse within the plant operation	
Pass to third party for reuse	
Avoid damage to promote reuse	
Recycle packaging	
Use recyclable packaging	
Separate recyclable waste	
Adopt purchase policy that includes recyclables	
Use bio-degradable packaging	
Disposal	
Dispose in a manner that minimises environmental impact	

Table 18: Packaging used in fruit and vegetable processing
(Pagan, Prasad et al. 2004)

Use	Type	Recycle Potential
Cans	Aluminium, tin, steel	commonly recycled
Bottles and jars	Glass polyethylene terephthalate (PET)	commonly recycled
Boxes/ cartons	Cardboard Virgin or recycled compostable, combustible Non-coated or coated Single or corrugated Combined with plastic or foil — liquid-proof	commonly recycled
Crates	Wood, plastic	commonly recycled
Trays	Polystyrene — expandable	difficult
Flexible wraps	Cellophane (regenerated cellulose) , polypropylene	difficult
Bags or sacks	Poly-vinyl chloride (PVC) Polypropylene Polyethylene Aluminium foil Poly-amide Nylon	difficult

Box 39: Flexible packaging from potato starch and PLA
(UNEP 2013)

2GFlexWrap is a flexible packaging material that is produced using reclaimed potato starch and poly-lactic acid (PLA) re-granulate (a sheet extrusion industry waste). Products include bio-plastic resin and stretched plastic film which can be used as food packaging. The product is being developed and tested in northwest Europe.

The essential component, Solanyl, is reported to require one third less energy to produce and has a 35% less carbon footprint when compared to the traditional flexible packaging material produced from polypropylene. Solanyl is biodegradable and compostable and, unlike other bio-plastics, does not affect recycling processes.

Box 40: Paperboard produced from agri-waste
(UNEP 2013)

The BulleShah Packaging Company is one of the first specialised packaging companies in Pakistan. Paper and liquid paperboard packaging is produced from agri-waste such as wheat straw, corn stalk and cotton buds. The company also produces paper from used beverage cartons. By sourcing agri-waste from poor farmers, the company is helping improve the livelihoods of around 8,000 people.

Box 41: Plastic crates reduce losses
(Kitinoja 2013)

The Institute of Postharvest Technology in Sri Lanka, introduced plastic crates to farmers, collectors and wholesale traders for the transportation of fruits and vegetables under the "Fresh Produce Chain" concept that was initiated in 2001. The crates cost about US$5.00 with the government providing a 50% subsidy to the buyers. An exchange system has been developed wherein the farmer or trader who delivers a full crate of produce to the buyer gets an empty crate in return. In a study on RPC use conducted in Sri Lanka, the quality and safety of vegetables reaching the consumer were improved appreciably. In the case of mangoes and avocados, the use of plastic crates for handling and transportation resulted in a reduction of losses from 30% to 6%.

8 GREENING IN TRANSPORT

Resource use in transport is mainly comprised of energy consumption (transport fuels and refrigerated storage) along with some relatively insignificant consumption of water for equipment cleaning. Greening opportunities can be pursued by improving infrastructure transport efficiencies and through the use of alternate fuels.

The urbanisation of more than 55% of the population in Asia by 2030, will increase the demand for food in urban areas (Choe and Roberts 2011). Transport infrastructure will need to improve to meet these demands as the distances between production and urban areas are vast. The majority of domestic fruit and vegetable produce is currently transported via road in refrigerated or non-refrigerated trucks, with this contributing significantly to greenhouse emissions and other pollutants.

Between 1995 & 2008, the demand for freight transport in the Asia and Pacific region grew by 84% (UN 2011) and, by 2030, Asia will account for 31% of total worldwide transport-sector related CO_2 emissions (ADB 2012). In addition, the lack of investment in improving and maintaining existing roads increases operating and transport costs and affects the overall regional economy (Donnges, Edmonds et al. 2007). Access to imported fruit and vegetables is also being facilitated by the fact that almost half of the world's population lives within coastal zones, including 60% of China's population. Many Asian countries have prioritised investment in modernising port facilities in, or near, large coastal urban areas for this reason (Armbruster and Coyle 2004). The distribution steps considered in this report are shown in Figure 14.

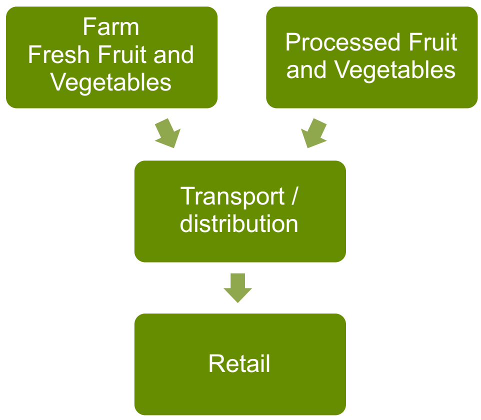

Figure 14: Fruit and Vegetable distribution steps

In the developing regions of Asia, losses and abandonment of fruit and vegetables post-farm gate are estimated at between 30-40% (APO 2006). These losses result in poor returns for farmers and are a result of constraints such as poor handling and transportation, inefficient technologies for storage, processing and packaging; inefficiencies due to the involvement of too many intermediaries and a lack of infrastructure (APO 2006) and (FAO 2011)).

A lack of adequate infrastructure leads to distribution delays, product damage and ultimately, to a lack of access to markets. A lack of refrigerated transport increases spoilage rates through overheating, particularly when inappropriately stacked. Poor loading, unloading and stacking practices damage goods before they make it to the factory or supermarket shelf.

Railway transportation is an efficient means of transport, especially over longer distances. Countries such as India currently use the railway system for the transport of fruit and vegetables. However, improvements are required to upgrade storage facilities and access to cold storage (APO 2006). Box 42 provides an example of the benefits of tramlines in remote areas.

Box 42: Tramline makes inaccessible regions accessible
(D.A.A.N. 2014)

The Philippine Centre for Postharvest Development and Mechanisation developed a tramline to facilitate the transportation of produce from small farms in remote areas to market and reduce post-harvest losses. Produce often took days to reach markets from these hilly and inaccessible areas using means of transport including bamboo rafts, foot travel and sleds pulled by carabao, cows and horses. Distances that took hours now take only minutes with less product damage, meaning more produce reaching the markets in a saleable condition giving farmers a larger profit.

8.1 Energy and GHG emission

8.1.1 Alternate fuels

Asian biofuel blends accounted for 12% of global biodiesel production in 2010, with the majority originating from first generation biofuels such as palm oil in Indonesia and Thailand (Larson 2008). While first generation biofuels produce less greenhouse emissions than fossil fuels, there is serious competition with food and livestock feed sources. Policies encouraging the use of second-generation biofuels, i.e. those which do not compete with food crops, are being widely adopted. China is set to become a world leader in the production of second-generation biofuels that do not compete with food crops as part of its plan to reduce CO2 emissions by 40-45% by 2020. India's biofuels policy also recommends that biodiesel be produced only from non-edible oil seeds such as jatropha that can grow in arid marginal lands (Chand, Kumar et al. 2007).

The combustion of dirty fuels such as diesel not only emits greenhouse gases, but also contributes to air pollution. Urbanisation results in an increase in fuel use which in turn increases air pollution. Cities such as New Delhi have some of the worst air quality in the world, due in part to diesel fuel combustion which produces carcinogenic particulate emissions ten times higher than gasoline emissions (Pearson and Katakey 2014). These fuels, which are government subsidised, also have lower quality standards than elsewhere in the world.

The switch from diesel to cleaner LNG fuel and even electric or hybrid engines can reduce emissions of both greenhouse gases and other air pollutants from vehicle transportation. Manufacturers in China are already producing alternative truck designs (Box 43).

8.1.2 Alternate fuels

There are numerous means by which the energy efficiency and carbon emissions of transport can be improved. Initiatives for road transport are shown below in Table 19. Box 44 provides an example of how a combination of energy efficiency opportunities can result in savings.

Box 43: Alternative truck design reduces emissions
(China Trucks 2009)

China Trucks have developed heavy duty trucks that can use liquefied and compressed natural gas as sources of fuel. These trucks greatly reduce emissions and particulate discharge compared with diesel engines.

Hybrid electric trucks use a mixture of electric battery storage and LNG and can reach speeds of up to 100km/hr. Similarly, slightly lighter purely electric trucks have also been developed.

Box 44: Fleet emissions slashed by 30%
(Murray 2013)

A three year trial by Volvo saw a 30% reduction of emissions in a fleet of 400 trucks in Gothenburg. The Climate Smart City Distribution project used a combination of cleaner fuels, more efficient engines and smarter logistics to achieve the emissions reduction. A 14% savings was achieved by replacing diesel with a mix, including 30% biofuel, while gas-driven light vehicles achieved an 83% reduction and hybrid rapeseed-based biofuel engines achieved an 84% reduction. Additional savings were made by optimising fleet travel through actions such as opening up bus lanes to distribution trucks and working with the supply chain to co-ordinate logistics for neighbouring businesses.

8.1.2 Transport efficiency

There are numerous means by which the energy efficiency and carbon emissions of transport can be improved. Initiatives for road transport are shown below in Table 19. Box 44 provides an example of how a combination of energy efficiency opportunities can result in savings.

Table 19: Road transport initiative

(ADRET 2012)

Vehicle modification	Fuel reduction
Alternative fuels e.g. CNG, LPG, hydrogen, hybrid electric	
Hybrid powertrain technology which harnesses the kinetic energy of braking	
Automated manual transmission to ensure optimum gear shifting	25-50%
Reduced rolling resistance tyres	
Automatic tyre monitoring/inflation systems	1-13%
Idle-management technologies with potential	2-4%
Improved aerodynamics and drag reduction	5-8%
Light weight trailers using aluminium, metal alloys, metal composites and other	3-25%
Longer combination vehicles (multiple trailers or double stacking).	5-10% per 10% weight decrease
Low friction engine lubricants	
More efficient and innovative refrigeration e.g. liquid nitrogen technology	3-5%
Efficient equipment and ancillary systems e.g. high intensity discharge lamps (HIDs)	
and light-emitting diodes (LEDs), efficient alternators, power steering	
Driver practices and logistics	
Improved driver practices	14-20%
Regular preventative maintenance	Up to 5%
Improved logistics (strategic route practices)	

8.1.3 Refrigerated Storage

Development of cold supply chains will significantly decrease product losses. As well as more advanced and traditional refrigerated storage, the use of simple methods can be effective e.g. the use of low-cost, low energy cooling chambers (Box 45).

Room or forced-air cooling with cold air can reduce spoilage rates, although proper stacking of produce is necessary to allow air flow around all of the produce (FAO 2009 a). Cooling with water is appropriate for commodities that are not subject to wetting such as celery and peas. It can be used, for example, as ice to rapidly drop the temperature. It can also be used during transport, distribution and storage (FAO 2009 a). Vacuum cooling can be used where air or water cooling is inappropriate, such as where there is produce with high surface-to- volume ratios such as brussels sprouts, carrots and spinach. However, these cooling methods must be properly managed to prevent damage to the

Box 45: Low cost, low energy cooling chambers
(APO 2006)

Several countries have developed low-cost, low-energy cooling chambers consisting of simple materials which can increase shelf life and reduce losses of both vegetables and fruit.

A Nepalese brick and sand structure made from a double wall of brick filled with sand can maintain an internal temperature of between 7-10 oC and relative humidity above 85% when the sand is frequently dampened with water.

A similar structure was developed in Sri Lanka and used by retail traders to store unsold produce reducing losses down from 20% to 5%.

Box 46: ENBED technology improves cold chain system (UNEP 2013)

ENBED (Environmental benefits through the decrease of food products' loss and waste) is a low-cost technology for monitoring products through the entire cold chain sector of transport, distribution and retail. Its real time monitoring and feedback allows swift intervention if human error or machinery malfunction occurs. It reduces spoilage due to handling and transit errors. Its feedback from every stage of the chain allows improvement of the cold chain system and provides greater accuracy in estimating the shelf life of monitored products.

ENBED is a co-operative project funded by the Competitive and Innovation Framework Eco-Innovation Programme in the food and drink sector.

Box 47: Nitrogen fuelled refrigeration units – UK (Commercial Transport Publishing Ltd 2011) and (Ricklefs and Xhunga 2010)

ASDA (one of the UK's largest supermarket chains) is replacing its entire fleet of diesel-fuelled fridge units with liquid nitrogen units. The nitrogen is separated from air and produces zero CO_2 emissions (25 - 30 tonnes of CO_2 emitted by a diesel-fuelled refrigerated truck). Its minimal temperature variance is between 0.1°C and 0.7°C which reduces food spoilage, (diesel systems vary by up to 3.3°C). It retails for 10% more than diesel-fuelled refrigerated systems. When estimating the overall energy consumption from extraction to consumption, liquid nitrogen systems reduce carbon emissions by a factor of 4.

product such as chilling or freezing injury (FAO 2009 a). Similarly, temperature, relative humidity and hygiene also need to be managed in these facilities to prevent degradation and then loss of produce (FAO 2009 a). New technology is being developed that can monitor all stages of the cold chain system and provide real-time feedback to allow quick repair of faults in the system (Box 46).

Alternative refrigerant fuels can also provide environmental benefits (Box 47).

9 GREENING IN RETAIL AND CONSUMPTION

The retail and consumption section of the value chain primarily consumes energy through refrigeration; water for washing and cold storage; and the generation of substantial amounts of waste. The significance of this resource consumption and resulting impacts for the fruit and vegetable value chain is not easily quantified; however, they can be more closely examined through analysis such as life cycle assessment.

In middle and high-income countries, food loss and waste is greatest at the consumer level. However, for the fruit and vegetable industry, significant losses occur at the post-harvest phase due to out of specification fruit and vegetables being rejected by retailers. Consumers in developed countries discard between 15-30%, by mass, of all purchases made (Gustavsson, Cederberg et al. 2011). In low-income countries, including South and Southeast Asia, the greatest losses occur at the early stages of the food chain during the production, processing and distribution stages with much less waste occurring at the level of the consumer (Gustavsson, Cederberg et al. 2011). As supply chains become more advanced, and demand increases, there is likely to be similar levels of waste at the consumer end as seen in developed countries. This high level of waste comprises significant levels of embodied energy and water in the final product. The adoption of efficiently operated cold chain systems coupled with consumer education is therefore a key intervention point to reduce losses (FAO 2011). The retail and consumption steps considered in this report are shown in Figure 15.

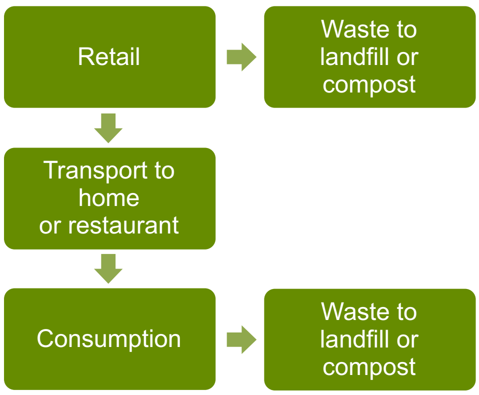

Figure 15: Retail and consumption steps

Traditional supply chains involve farmers selling directly to markets or consumers. However, with the growth of supermarkets and more complex supply chains there can now be several intermediary steps between the farmer and the consumer (Srimanee and Routray 2012). Fresh-cut fruit and vegetables in Asia are sold in open-air markets and food stands and increasingly in supermarkets. However, limited refrigeration is used for displays and so fresh-cut fruit and vegetables rarely have a shelf life beyond the display date (James and Ngarmsak 2010)

Fruit and vegetables are seen as a “destination category” for supermarkets, that is, a product that draws customers to the shop, building customer loyalty (FAO 2005). However, this brings with it a demanding quality system, fierce competition, reduced margins, and generally a preferred suppliers list (FAO 2005). Many small farmers struggle for market share in supermarkets due to their lack of capital and inability to maintain consistent supply throughout the year (Srimanee and Routray 2012). The development of intermediaries such as co-operatives can give smaller farmers better bargaining power and, as a result, a better market share.

Box 48: Pran Fresh collaboration reduces losses (UNEP 2013)

Pran Fresh is a Thai medium-sized enterprise with around 450 staff. It has its own organic farm and collaborates with 10 growing partners to deliver fresh vegetables to retailer Tesco, in the hope to extend the shelf life of the produce.
An experimental pre-cooling process is being used to reduce post-harvest losses of fresh leafy vegetables.
A QR code has been developed by Tesco and Pran Fresh to provide customers with information on sourcing and nutritional information.
This pilot program has already reduced rejections by over 7,000 trays, and when proven successful will be implemented throughout Tesco's sourcing facilities.

A 'direct marketing' strategy could be employed by individual farmers or cooperatives thereby reducing the number of players in the supply chain and offering good quality product to consumers at potentially premium prices. This should result in faster access to the market and hence fresher fruit and vegetables for the customer and less wasted food. Box 48 provides an example of the benefits of collaboration to reduce losses. The use of the concept of food miles and the promotion of food that is produced locally and in-season can also help reduce waste and greenhouse emissions. However, it should be reviewed on a case-by-case basis as there are instances where product that is not produced in the local area and is transported in from outside, can actually have a smaller carbon footprint.

9.1 Energy

Refrigeration is the most significant user of energy in retail and consumption. Traditional markets and street vendors in countries such as Thailand generally store and display fresh fruit and vegetables at ambient conditions. However, the growth of air conditioned supermarkets is increasing the amount of energy used in fresh fruit and vegetable refrigeration (FAO 2011). Maintaining the integrity of the cold chain system is critical to minimise losses to produce that is transported or stored for any length of time.

In many Asian countries many of these crucial intermediary links between the producer and consumer have not kept pace with consumer demand and expectations in food quality. Increased refrigeration will profoundly affect distribution costs and will exacerbate environmental impacts such as fugitive refrigerant emissions and energy consumption with its associated carbon emissions. However, these disadvantages should be weighed against the reduction in produce loss and improved quality of produce reaching the consumer.

To minimise the environmental impacts of increased refrigeration and space cooling systems, the most efficient system available should be installed where possible and maintained at optimum operating conditions. Greening opportunities for new and retrofit situations include:

- installing doors on fridge/freezer display stock gives a load reduction of between 5 and 50% (Rees 2011);
- reducing heat loads – effective roof and wall insulation, sealing to reduce air leaks, reduction in incidental heat loads from fans and pumps, lighting, people and machinery;
- defrosting on demand rather than timer;
- optimising compressor and system operations including the use of variable speed drives on fans, pumps and compressors and floating head pressures (allowing the system to take advantage of lower ambient temperatures to reduce refrigerant temperatures);
- correctly sized condensers;
- temperate control and energy management systems;
- planned maintenance to ensure effective heat transfer across surfaces;
- use of natural refrigerants;
- recovery of compressor waste heat for space or water heating; and
- effective use of cold space such as pallet racking.

Additional measures for refrigeration display cases in retail stores include optimising the hours of operation of anti-sweat heater controls and night covers (aluminium shields can reduce consumption by 8%) (Carbon Trust 2001). Similarly, new monitoring systems and energy efficient technology can reduce losses from the display cases as shown in Box 49.

Box 49: Presto Supermarket reduces refrigeration costs
(Ng 2012)

Presto supermarket at Citta Mall in Kuala Lumpur, Malaysia has implemented Hussman Tempcool energy efficient technology on their semi-height merchandiser to reduce the loss of cool air. A secondary curtain of hot air keeps the cold air within the cabinet. The mechanical control system has been replaced with a flexible electronic control system which is centrally controlled using real-time data which is fed to the store managing director.

Whilst initial investment in refrigeration was approximately 45% higher than the original budget, the energy savings are already estimated at RM20000 per month with the initial expenditure estimated to be recovered within the year.

The remote access to real-time data also provides savings by reducing the number of times the service contractor is called for minor problems as trouble shooting can be done remotely saving call-out fees. Similarly, savings are made by minimising breakdowns due to the system's ability to analyse real-time data against predicted data which allows the prediction of equipment failure before it happens.

9.2 Water

In retail and consumption, significant volumes of water are used for cooling reject heat from refrigeration and air-conditioning units using evaporative condensing units (cooling towers) as well as for cleaning. Opportunities to reduce water consumption include:

- reducing the cooling load of cooling towers and air conditioning – reducing temperature set point and only operating when necessary;
- reducing unnecessary water loss – excessive flow from overflow and blowdown (effective water treatment to reduce number of concentration cycles), splashing, drift or leaks;
- use of water efficient equipment e.g. taps, use of trigger mechanisms on hoses, maintenance of water equipment, shop design (surfaces and drains) and increasing staff and consumer awareness; and
- dry cleaning techniques, e.g. soaking and using high pressure, low volume cleaning hoses. (Prasad, Price et al. 2013)

9.3 Waste and consumer behaviour

Along with efficient refrigeration systems and maintenance of the cold chain system for produce, waste can be prevented through the use of effective and innovative packaging, which has the greatest opportunity for recycling and reuse. This is discussed further in Section 7.5 (Packaging).

Waste resulting from the retail sector of the supply chain is often interlinked with consumer behaviour. The perception in many supermarkets is that customers want a homogenised colour, weight and size of their fruit and vegetables. This can lead to fit-to-eat produce being rejected at the farm or turned back at the supermarket door (Gustavsson, Cederberg et al. 2011). Often this produce is used for animal feed instead of human feed and the energy, water and resources used to make it are wasted. Surveys of customers have found that this perception is unfounded and that they would be willing to purchase out of specification produce as long as the taste is not affected (Gustavsson, Cederberg et al. 2011). Education of both retailers and consumers about the nutritional value of non-homogenised fruit and vegetables could result in less rejected produce.

Increasing incomes, higher food quality and safety expectations, and urbanisation in industrialised Asia have led to increased levels of consumer waste. Up to 30% of all food cooked is thrown away in Europe, North America and industrialised Asia (Gustavsson, Cederberg et al. 2011). The FAO estimates that if the food wasted or lost globally could be reduced by just one quarter, this would be sufficient to feed the 870 million people suffering from chronic hunger in the world (FAO 2013 c).

In August 2013, the FAO launched the 'Save Food Asia-Pacific Campaign', which will be an on-going advocacy initiative. Another consumer awareness campaign is “Love Food Hate Waste” (Box 50). This program focuses on information about shopping habits, food storage, cooking and effective use of leftovers. The target audience is households and businesses such as the hospitality and retail sectors. Partnerships have been formed with food retailers, manufacturers, not-for-profit organisations and local government. Furthermore, a food waste reduction scheme through a user-pays system is being trialled in South Korea (Box 51).

Box 50: Awareness campaigns – UK
(Lipinski, Hanson et al. 2013)

More than 300 local authorities in England run localised “Love Food Hate Waste” initiatives to encourage and assist residents in reducing waste. Worcestershire County Council undertook a three-month campaign to reduce food waste in Worcester City (9,000 households). Partnerships were formed with more than 70 local businesses, community organisations, and schools, who displayed posters and distributed leaflets. The University of Worcester also hosted free cooking classes focused on effective reuse of leftovers. Food waste reduced by 14.7 %.

Box 51: South Korea food waste recycling
(Borowiec 2014)

New technology is being trialled in a pilot study in Seoul, South Korea to reduce food waste. Each household accesses new food waste bins using an individualised radio frequency chip embedded in an access card. The new system allows the waste to be weighed and disposal cost of food waste allocated to individual households. Previously each household paid a flat rate for disposal. It is hoped this new system will assist households to consider their food waste and reduce it where possible. The goal is to reduce food waste nationally by 20% of the current level.

Demand for out of season fresh fruit and vegetables puts pressure on the transport and storage systems and results in higher energy use as cold storage is generally required to keep food fresh (Andersen 2010). Retailers should work with consumers to promote seasonal fruit and vegetable consumption.

10 DIRECTION FOR POLICY MAKERS AND OTHER PLAYERS

There are many opportunities for greening the fruit and vegetable value chain outlined in this report. Whilst some actors use the latest technology and maintain control over the whole supply process, there are many more small farmers and processors striving to maintain access to local markets while relying on age-old farming practices and simple technologies. The current state of the individual businesses within each supply chain will determine where the best intervention point occurs. Successful policy making will require the co-operation, interaction and integration with actors along the value chain (as appropriate) including government and non-governmental agencies, entrepreneurs, industry associations, research bodies, technical associations, producers and suppliers.

To provide further direction, a review of existing policy recommendations from a number of leading organisations, and relevant to the fruit and vegetable value chain, was undertaken for this report. The recommendations are shown in Table 20 and linked with the corresponding section of this report where technical detail is provided on opportunities to consider. It is envisaged that this will provide guidance on greening opportunities along the value chain to policy developers, non-governmental organisations and other organisations that provide assistance to the fruit and vegetable processing industry.

The recommendations are grouped into categories of regulation (RG); economic arrangements and incentives (E); capacity building, education and extension (CEE); and research (RS), all of which are important in promoting and supporting the uptake of greening opportunities. Particular points to consider as a way forward in developing policy directives include:

- identification of suitable indicators for resource use across the supply chain;
- monitoring and benchmarking to identify best practice;
- rigorous validation of greening practices/technology, particularly those that might be considered to be high-risk in a developing region where there is little scope for 'trial and error';
- research support to develop the methodologies needed at the ground level to take advantage of payment for environmental services and carbon trading;
- demonstration that sustainable practices/technology/new breeds suit local conditions;
- extension and technical support in sustainable farming practices;
- investment in efficient processing technologies and cold chain infrastructure; and
- education across the supply chain through to consumers to help minimise waste.

In addition, perverse subsidies that encourage consumption of limited or polluting resources need to be removed and replaced with incentives to implement greening initiatives.

Table 20: Summary of policy recommendations for Greening Fruit and Vegetable Value Chain

Greening opportunity	Reference	Policy type	Key stakeholders (In addition to governments)	Related section of this report
Production				
Support Payments for Ecosystem Services (PES) schemes, e.g. carbon offset schemes, payment for reduced tillage and cover crops, protection of endangered wildlife habitat, open space and/or wetlands, payment for delivering watershed services.	(FAO 2013 a)	E	Government	5.3
Phase out input subsidy schemes for agro-chemicals (fertiliser and pesticides), water and energy in favour of subsidy programmes to promote sustainable agriculture.	(ADB and IFFRI 2009, Curtis 2012)	E	Government	5.2, 5.4, 5.5, 5.7
Key areas for increased investment to build climate resilience are: irrigation; rural roads; information technologies; market support; and extension services.	(ADB and IFFRI 2009)	E	Government, private sector	5
Carbon trading will increase the value of sustainable farming practices and improve the likelihood that farmers will adopt practices such as minimum tillage, integrated soil fertility management, integrated pest, disease and weed management.	(ADB and IFFRI 2009)	E	Government, farmers, development agencies, financial institutions	5.7
Establish national regulations for sustainable farm management e.g. develop indicators, monitor and establish benchmarks for best practice and regulate practices that degrade natural resources.	(FAO 2013 b)	RG	Government, researchers, extension officers	5
Build capacity and provide learning opportunities (e.g. field schools) and technical support in 7 recommended management practices (minimum soil disturbance, permanent organic soil cover, species diversification, use of high yielding, adapted species, integrated pest management, healthy soils and efficient water management).	(FAO 2013 b)	CEE	Government, educators, farmers, extension officers	5
Strengthen the capacity of tertiary and secondary education to provide formal training in sustainable farming practices.	(FAO 2013 b)	CEE	Government, educators, students	5
Disseminate information on sustainable farming through traditional channels such as newspapers and radio as well as cellular phones and the internet.	(FAO 2013 b)	CEE	Government, media, educators, extension officers, farmers	5
Develop tools and undertake assessments to verify the impact of sustainable farming practices.	(FAO 2013 b)	CEE	Government, researchers, development institutions	5
Shift research to traits relevant to climate change e.g. drought and heat tolerance, insect and pest tolerance, nitrogen use efficiency, salinity tolerance.	(ADB and IFFRI 2009)	RS	Government, researchers	5.7
Invest in science, technology & innovation and support the commercialisation of biotechnology research.	(ADB and IFFRI 2009)	RS	Government, researchers, private sector investors, financial institutions	5.3, 5.6
Support targeted research in the field of Integrated Pest Management (IPM) in areas such as host plant resistance to pests and disease, practical monitoring and surveillance methods, use of selective pesticides and bio-controls.	(FAO 2013 b)	RS	Government, researchers, farmers	5.3
Increase investment in plant breeding at the biological and molecular level to enhance agricultural productivity. This includes advanced scientific expertise, equipment and long term funding.	(FAO 2013 b) (ADB and IFFRI 2009)	RS	Government, researchers, development institutions, private sector	5.6
Strengthen linkages between the conservation of plant genetic resources and the use of diversity in plant breeding.	(FAO 2013 b)	RS	Government, researchers, development institutions, private sector	5.3

Greening opportunity	Reference	Policy type	Key stakeholders (In addition to governments)	Related section of this report
Take greater steps to establish community banks for genetic material and involve farmers in crop improvement programs to increase the diversity of materials and to ensure plant varieties are suited to farming practices.	(Curtis 2012)	CEE	Government, researchers, development institutions, private sector, farmers	5.3
Integrate fertigation technology (including use of liquid fertilisers), deficit irrigation and wastewater reuse into irrigation systems	(FAO 2013 b)	CEE	Government, industry, private sector, farmers	5.2
Provide support for the expansion of teaching facilities to provide information on efficient irrigation technologies and farming techniques to improve on-farm utilisation of water such as irrigation timing and planning.	(Hasanain 2012 b)	CEE	Government, educators, development institutions, farmers	5.2
Support for projects that demonstrate the potential success and efficacy of new water efficient irrigation technologies.	(Hasanain 2012 b)	E	Government, extension officers, researchers, farmers	5.2
Selective subsidisation and adoption of modern irrigation technologies e.g. in areas with high value crops so the gain in net value can pay for the investment.	(Hasanain 2012 b)	CEE	Government, financial institutions, development institutions, farmers	5.2
Support full cost recovery for water; however, before prices are increased, credible alternatives should be provided, in the form of subsidised access to water saving technologies.	(Hasanain 2012 b)	E	Government, community groups, farmers	5.2
Support community organisations that have the potential to advise, educate, and manage the allocation of water amongst users.	(Hasanain 2012 b)	CEE	Government, community groups, farmers	5.2
Scale-up investment in underground storage techniques.	(ADB and IFFRI 2009)	E	Government, development institutions	5.2
Provide incentives for practices that reduce water runoff and local water harvesting.	(Curtis 2012)	E	Government, farmers, community groups	5.2
Reduce the distance between producers and consumers, and increase access to markets, e.g. support local processing units, invest in local infrastructure for transport and storage facilities, invest in local, regional and institutional markets, enhance business management and marketing skills (especially of women).	(Curtis 2012)	E/CEE	Government, development institutions educators, private sector, farmers	5.2
Harvesting and post-harvest handling				
Conduct education campaigns and training on appropriate methods and times of harvesting to prevent damage through rough handling and to promote understanding of the link between harvesting and the quality and shelf life of the product.	(APO 2006) (PEF 2013)	CEE	Government and development agencies	6
Development of efficient harvesting tools and equipment.	(APO 2006)	CEE	Development agencies, universities and research institutions	6
Education campaign for farmers and stakeholders on appropriate sorting, grading and packaging protocols to prevent damaged or spoilt food spreading decay through the food chain.	(PEF 2013)	CEE	Governments, institutions and co-operatives stakeholders and FAO	6
Promote investment in alliances/commodity based clusters to provide pre-cooling facilities.	(APO 2006)	E	Governments, private sectors, cooperatives.	6
Facilitate co-operation between farms to allow surplus from one farm solve the shortage at another farm.	(Gustavsson, Cederberg et al. 2011)	CEE	Development agencies, governments, co-operatives.	
Research and information programs into the benefits of pre-cooling technology at commercial scale.	(APO 2006)	RS	Development agencies such as FAO, UNIDO, USAID, EU, ADB	8.1.3
Reduction in premature harvesting can be reduced by development of co-operatives to share retail demands and possibly receive agricultural loans.	(Gustavsson, Cederberg et al. 2011)	CEE/E	Governments, co-operatives, retailers, financial institutions	9

Greening opportunity	Reference	Policy type	Key stakeholders (In addition to governments)	Related section of this report
Storage				
Promote investment in storage facilities on farm level and refrigerated storage at the market place.	(APO 2006)	E	Governments, local, private sector, development agencies	6 and 8.1.3
Education campaigns on appropriate storage conditions, including temperature, humidity, sanitation etc.	(APO 2006) (PEF 2013)	CEE	APO, NIPO, FAO	6
Processing				
Develop linkages between processors and farmers.	(Gustavsson, Cederberg et al. 2011)	CEE	Development agencies, governments, co-operatives and farmers	7
Promote cleaner production, increase the efficiency of the utilisation rate of resources, reduce and avoid the generation of pollutants, protect and improve environments, ensure the health of human beings and promote the sustainable development of the economy and society.	(ChinaCP 2006)	CEE	Government, processors	7
Packaging				
Commercialisation of suitable packaging technology to prevent damage during handling, transport and storage.	(APO 2006) (PEF 2013)	CEE	Governments	7.5
Education campaigns on appropriate packaging technologies.	(APO 2006)	CEE	Governments	7.5
Development of regulatory policies and regulations against the negative environmental impact of packaging.	(APO 2006)	RG	Governments	7.5
Development of regulatory policies and regulations against a lack of suitable labelling.	(APO 2006)	RG	Governments	7.5
Transport and handling				
Improved logistics and management to lower cost and increase efficiency in the distribution of fruit and vegetables.	(APO 2006)	CEE	Governments	0
Conduct education campaigns on temperature management, loading and unloading practices during transportation.	(APO 2006) (PEF 2013)	CEE	Governments	8.1.3
Develop knowledge of safe food handling practices along the food chain.	(Gustavsson, Cederberg et al. 2011)	CEE	Governments, co-operatives, development agencies	6 and 0
Retail and consumption				
Education campaigns for both retailers and consumers on the food waste resulting from 'appearance quality standards'.	(Gustavsson, Cederberg et al. 2011)	CEE	Retail and consumption Farmers, consumers, retailers, governments and co-operatives	9.3
Promotion and development of farmers' markets and farm shops to reduce losses from out of specification fruit and vegetables.	(Gustavsson, Cederberg et al. 2011)	CEE	Farmers, consumers, governments and co-operatives	9
Assistance to small farmers to enter the supermarket supply chain.	(Srimanee and Routray 2012)	E	Governments, co-operatives	9
Education campaigns to promote the provision of a variety of sizes of pre-packaged products to allow choice by customers and reduction in food wastage.	(FAO 2013 c)	CEE		9.3
Education campaigns to assist consumers to better plan their shopping and understand the meaning of the best before, used by and expiry dates and to understand storage and temperature control of food through to consumption.	(Gustavsson, Cederberg et al. 2011)	CEE	Governments	9.3

11 CONCLUSION ON OVERALL GREENING POTENTIAL

The fruit and vegetable value chain uses considerable amounts of resources (energy, water, chemicals, fertilisers, and packaging), generating significant amounts of solid and liquid wastes and emissions. This report presents a multitude of greening opportunities and supporting case studies which can be implemented across the fruit and vegetable supply chain in Asia and also, where appropriate, across the world.

The difficulty is in knowing where to apply efforts to achieve the greatest efficiencies and capitalise on greening potential. There is a lack of research regarding the impacts over the life cycle of fruits and vegetables grown in Asia. LCA studies undertaken in the US and Europe indicate that, for carbon emissions, the hot spots are in energy consumption, in greenhouses and also emissions due to freight, particularly air, for the distribution of produce. Both of these points are relevant to the developing regions of Asia as overall demand for seasonal and out of season produce increases.

Analyses of water footprints provide no simple indication of where to direct efforts as the footprints are regionally specific and dependent on crop type, climate and overall water availability. In addition to this, there is also a lack of sector benchmarking data which would help to identify where to focus efforts. For example, the most recent detailed water consumption data for fruit and vegetable processing was from a study undertaken in 1998.

In relation to fruit and vegetable growing, opportunities are regionally specific and dependent on factors such as climate, water availability, land use competition and general capacity/capability of producers with respect to maturity of market chains, access to reliable transport, cold chain infrastructure and general government support. In this regard, the particular issues for the region need to be evaluated and appropriate policy directives developed in areas of government regulation; economic arrangements and incentives; research; capacity building; education; and extension. A list of policy directives for each of these categories is presented in this report. Specific greening opportunities which have proved to be successful include the efficient management and application of irrigation water, nutrients and pesticides; plant breeding programs to improve yields; disease and pest resistance; and tolerance to local growing conditions. Innovation in areas such as hydroponics also show promise along with low carbon technologies (e.g. solar pumps) and carbon offsetting opportunities.

In relation to post-harvest handling and delivery of product to wider markets, investment in technology and infrastructure that will improve cold chain supply will go a long way to reducing wastes across the supply chain, which is currently reported as being as much as 50% of total produce. Reduced post-harvest losses will offset some increases in carbon emissions due to expanded cold supply chains. It is estimated that currently only around 5% of total fruit and vegetable produce in Asia is further processed into value added products. However, this is likely to increase over the coming years due to a rising middle class and increased demand for value added fruit and vegetables. Greening opportunities for processing and distribution will be well-served through the adoption of eco-efficiency assessments and practices included in this area of the value chain such as investment in more efficient equipment and technology, particularly refrigeration and heat supply systems.

Lastly, consumer education campaigns are needed which raise awareness of the impacts of food waste and the implications of demanding out of season produce that is also expected to be perfectly shaped and unblemished. Such high consumer expectations only exacerbate waste across the entire value chain, not only in the solid form but also as embodied energy and other resources consumed upstream.

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APPENDIX A. FRUIT AND VEGETABLE TRADE IN ASIA

Table I

Fresh Fruit (nes) exports			
Year	**Area**	**Value**	**Unit**
2011	Asia	1,915,797	tonnes
Fresh Fruit imports to Asia exports			
Year	**Area**	**Value**	**Unit**
2011	Asia	1,653,968	tonnes
Top 5 World Fresh Fruit exporters, 2012			
Country	**Item**	**Value**	**Unit**
Viet Nam	Fruit, Fresh nes	603,788	tonnes
Thailand	Fruit, Fresh nes	471,642	tonnes
China	Fruit, Fresh nes	390,545	tonnes
China, Hong Kong S	Fruit, Fresh nes	261,975	tonnes
Spain	Fruit, Fresh nes	140,828	tonnes
		1,868,778	tonnes
Top 5 World Fresh Fruit importers, 2012			
Country	**Item**	**Value**	**Unit**
China	Fruit, Fresh nes	1,068,982	tonnes
China ex. int	Fruit, Fresh nes	1,016,425	tonnes
China, mainland	Fruit, Fresh nes	738,173	tonnes
China, Hong Kong S	Fruit, Fresh nes	327,925	tonnes
Russian Federation	Fruit, Fresh nes	218,197	tonnes
		3,369,702	tonnes

Table II

Prepared Fruit (nes) exports			
Year	**Area**	**Value**	**Unit**
2011	Asia	1,968,500	tonnes
Prepared Fruit (nes) imported to Asia			
Year	**Area**	**Value**	**Unit**
2011	Asia	1,301,547	tonnes
Top 5 World Prepared Fruit (nes) exporters, 2011			
Country	**Item**	**Value**	**Unit**
China	Fruit, prepared nes	1,238,876	tonnes
China, mainland	Fruit, prepared nes	1,207,289	tonnes
China ex. int	Fruit, prepared nes	1,197,405	tonnes
EU (12) ex. int	Fruit, prepared nes	639,474	tonnes
EU (15) ex. int	Fruit, prepared nes	551,274	tonnes
Top 5 World Prepared Fruit importers, 2011			
Country	**Item**	**Value**	**Unit**
EU (15) ex. int	Fruit, prepared nes	1,391,875	tonnes
EU (12) ex. int	Fruit, prepared nes	1,365,084	tonnes
USA	Fruit, prepared nes	1,198,232	tonnes
EU (25) ex. int	Fruit, prepared nes	1,177,677	tonnes
EU (27) ex. int	Fruit, prepared nes	1,157,861	tonnes

Total fruit production in China = 122,000,000 tonnes in 2010 (Table 2 in report)

Total vegetable production in China = 540,000,000 tonnes in 2010 (Table 1 in report)

Total fruit exported from all China = 390545 + 1238876 = 1629421 tonnes = 1.63 million tonnes (Tables I and II in Appendix)

Total vegetable exported from all China = 515307 + 869206 + 963717 = 2,348,230 = 2.35 million tonnes (Tables III, IV and V in Appendix)

Total % of Chinese fruit and vegetable production that is exported = (1.63 + 2.35)/(122 + 540) million tonnes = 0.6%

Table III

Fresh Vegetables (nes) exports			
Year	**Area**	**Value**	**Unit**
2011	Asia	1,253,698	tonnes
Fresh Vegetables (nes) imports			
Year	**Area**	**Value**	**Unit**
2011	Asia	743,878	tonnes
Top 5 World Fresh Vegetables (nes) exporters, 2011			
Country	**Item**	**Value**	**Unit**
Mexico	Vegetables, fresh r	631,917	tonnes
China	Vegetables, fresh r	515,307	tonnes
China, mainland	Vegetables, fresh r	491,833	tonnes
USA	Vegetables, fresh r	252,975	tonnes
Netherlands	Vegetables, fresh r	240,783	tonnes
Top 5 World Fresh Vegetables (nes) importers, 2011			
Country	**Item**	**Value**	**Unit**
China	Vegetables, fresh r	216,895	tonnes
UK	Vegetables, fresh r	203,918	tonnes
USA	Vegetables, fresh r	196,051	tonnes
France	Vegetables, fresh r	178,951	tonnes
China, Hong Kong S	Vegetables, fresh r	178,688	tonnes

Table IV

Vegetables, frozen, exports			
Year	**Area**	**Value**	**Unit**
2011	Asia	1,081,161	tonnes
Vegetables, frozen, imports			
Year	**Area**	**Value**	**Unit**
2011	Asia	799,281	tonnes
Top 5 World Frozen Vegetables, exporters, 2011			
Country	**Item**	**Value**	**Unit**
Belgium	Vegetables, frozen	1,083,802	tonnes
China	Vegetables, frozen	869,206	tonnes
China ex. int	Vegetables, frozen	861,787	tonnes
China, mainland	Vegetables, frozen	834,333	tonnes
EU (12) ex. int	Vegetables, frozen	387,555	tonnes
Top 5 World Frozen Vegetables, importers, 2011			
Country	**Item**	**Value**	**Unit**
USA	Vegetables, frozen	677,688	tonnes
Germany	Vegetables, frozen	530,396	tonnes
EU (12) ex. int	Vegetables, frozen	526,772	tonnes
EU (15) ex. int	Vegetables, frozen	512,732	tonnes
France	Vegetables, frozen	486,618	tonnes

Table V

Vegetables, preserved, exports			
Year	**Area**	**Value**	**Unit**
2011	Asia	1,304,121	tonnes
Vegetables, preserved, imports			
Year	**Area**	**Value**	**Unit**
2011	Asia	957,378	tonnes
Top 5 World Fresh Vegetables (nes) exporters, 2011			
Country	**Item**	**Value**	**Unit**
China	Vegetables, preserved n	963,717	tonnes
China, mainland	Vegetables, preserved n	951,092	tonnes
China ex. int	Vegetables, preserved n	941,580	tonnes
Netherlands	Vegetables, preserved n	433,238	tonnes
EU (12) ex. int	Vegetables, preserved n	403,995	tonnes
Top 5 World Fresh Vegetables (nes) importers, 2011			
Country	**Item**	**Value**	**Unit**
Germany	Vegetables, preserved n	429,540	tonnes
EU (15) ex. int	Vegetables, preserved n	358,662	tonnes
EU (12) ex. int	Vegetables, preserved n	358,399	tonnes
Franxe	Vegetables, preserved n	353,416	tonnes
USA	Vegetables, preserved n	348,834	tonnes