Food Industry Wastes

Assessment and Recuperation of Commodities

Edited by

Maria R. Kosseva and Colin Webb

Food Science and Technology, International Series

FOOD INDUSTRY WASTES
ASSESSMENT AND RECUPERATION OF COMMODITIES

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ASSESSMENT AND RECUPERATION OF COMMODITIES

Food Science and Technology
International Series

A complete list of books in this series appears at the end of this volume.

I dedicate this book to my family

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Preface

Large quantities of food waste are generated all over the world. They are generated largely by the fruit-and-vegetable, vegetable oil, fermentation, dairy, meat, and seafood industries. In the world's leading economies, such as the USA, United Kingdom, and Japan, approximately 30% to 40% of the food 'consumed' is actually discarded. Waste is generated at every stage in the process chain: agriculture (pre- and postharvest), food manufacturing, packaging, retail/catering, and consumer/household; up to 50% of produce can be wasted only along the supply chain. Food industry waste is therefore a significant global problem, with impacts on economic, environmental, and food security systems. In addition, wasting food, while millions around the world suffer from hunger, raises questions of ethics and morality and could well lead to future food crises. There are also environmental impacts associated with the inefficient use of associated natural resources, such as water, energy, and land. The disposal of food wastes to landfill causes pollution and produces methane, a powerful greenhouse gas. Government efforts are currently focused on diverting such wastes away from landfill through regulation, taxation, and public awareness. However, rather than dwelling entirely on the environmental challenges posed, governments would do well to realise that such food waste streams represent considerable amounts of potentially reusable materials and energy.

This book is a concise presentation of a variety of important aspects involved in dealing with food wastes. The main aim is to emphasize trends in food waste management techniques and processing technologies. Providing a number of case studies and examples, some emerging environmental technologies suitable for development towards a sustainable society are illustrated. The book consists of 5 major commodity-oriented sections. The first looks at the *Problems and Opportunities* associated with food wastes and considers current waste regulations, the variability of food wastes, and green production strategies. Next, *Treatment of Solid Wastes* is presented, with chapters considering waste bread, fruit-and-vegetable wastes, and others, for the production of fermentation products, functional foods, biogas, and fertilizer. We then look at improved biocatalysts and innovative bioreactors for *Enhanced Bioprocessing of Liquid Wastes* including a mathematical modeling approach and a case study of thermophilic aerobic digestion. In the fourth section, *Impact Assessment of Water Footprint and Rehabilitation of Food Industry Wastewater*, addressing water conservation/use/reuse/waste, is introduced along with the benefits of electricity generation from wastewater. Finally, food chain management and the *Assessment of Environmental Impact of Food Production and Consumption* are considered through the application of life cycle assessment (LCA). The food industry uses LCA to identify the steps in the food chain that have the largest impact on the environment in order to target improvement efforts. It is then used to choose among alternatives in the selection of raw materials, packaging material, and other inputs as well as waste management strategies.

Key features of the book are that it provides guidance on current food process waste regulations and disposal practices and understanding of waste beneficial reuse and bio-processing. It is written by experts from around the globe, providing the latest information on international research and development of novel green strategies and technologies for coping with food wastes. The book includes both theoretical and practical information providing, we hope, inspiration for additional research and applications to recover energy and niche coproducts including water use and reuse. Food intake is a vital source of energy for human beings. In the same way, food wastes should be seen as a vital source of energy and a feedstock for novel manufacturing processes. We have therefore provided a strong focus on environmental and bioprocess engineering methodology for the simultaneous treatment of food wastes, reduction of water footprints, and production of valuable products. We are sure that the book will raise awareness of sustainable food waste management techniques and their appraisal *via* Life Cycle Assessment. Finally, the book will contribute to the state of the art in waste management and valorisation of food by-products, providing novel concepts in the conversion of waste to resource.

We would like to take this opportunity to acknowledge and thank the contributors to this book for their excellent collaboration in bringing a comprehensive range of topics together in a single volume. We would also like to thank Nancy Maragioglio, the senior acquiring editor for the Food Science and Technology book program at Academic Press, and the production team at Elsevier, in particular Carrie Bolger and Colin Williams for their helpful assistance throughout this project and for keeping us to time (almost) and ensuring everything came together properly.

At last but not least, we are grateful to our families for their current and continued support.

Maria R. Kosseva
Colin Webb

Introduction: Causes and Challenges of Food Wastage

Maria R. Kosseva

1. SUSTAINABILITY OF THE FOOD SUPPLY CHAIN

At the global level, there appears to be sufficient food available to feed the world's population. This total, however, hides a wide distribution of food consumption that stretches from acute hunger crises to excess food consumption and large quantities of food waste.

Food insecurity is a harsh reality for one billion people. At the other end of the spectrum, overeating and food waste is common among more than one billion people, too (Lundqvist, 2010). The problem of being overweight and obesity in adolescents and children mainly reflects increased energy intake. Long-term trends indicate marked increases in availability of added oils, meat, cheese, frozen dairy products, sweeteners, fruit, fruit juices, and vegetables, which may have influenced the prevalence of childhood obesity. Combined per capita chicken and turkey availability increased more than six-fold overall, from 5.1 kg/year in 1909 to 33.5 kg/year in 2007. Meat, poultry, and fish availability exceeded 90 kg/year in 2002 and in subsequent years, which represented a 60% increase over values from early in the 20th century. Estimated losses due to spoilage, waste, and cooking processes are as high as 57% for the meat food group (Barnard, 2010). In a loss-adjusted analysis, total meat, poultry, and fish availability rose from 48.3 kg/year in 1970 to 54.4 kg/year in 2007. According to USDA estimates, these data correspond to an increase in per capita energy availability from red meat, poultry, and fish, adjusted for losses, from 367 kcal/day in 1970 to 387 kcal/day in 2007 (US Department of Agriculture, 2007).

Lack of availability of empirical data hampers the analysis of the low efficiency in the food chain. Lundqvist (2010) compares the variation and trends in the food supply and norms of food intake requirements for *an active and healthy life*. For food supply reference is made to the international norm, which is usually set at 2,700–2,800 kcal/day per person (Molden, 2007). It was found that in many countries the food supply is much higher than the international norm and very much higher than the food intake requirements. If a comparison is made between the amount of food produced in the field and food intake requirements, the gap is even wider, since losses and conversions are substantial (Lundqvist, 2010). In parallel, calculations imply a steady increase in body weight among US adults over the past 30 years and a progressive increase in food waste, from 900 to 1,400 kcal/day per person between 1974 and 2003 (Hall et al., 2009). When supply of food increases and food is perceived as relatively cheap and easily accessible, the risk for a dual problem increases: the public health situation deteriorates and the waste increases, with negative repercussions on resource pressure, environment, and productivity in society (Lundqvist, 2010).

One-third of all food produced for human consumption on the planet, about 1.3 billion tonnes, is lost or wasted each year, according to the Food and Agriculture Organization report of the United Nations prepared by the Swedish Institute for Food and Biotechnology (Gustavsson et al., 2011). Food is wasted throughout the food supply chain (FSC), from initial agricultural production down to final household consumption. In medium- and high-income countries, food is to a great extent wasted, meaning that it is thrown away even if it is still suitable for human consumption. Significant food loss and waste do, however, also occur early in the FSC. It has been estimated that between 25% and 50% of food produce is wasted along the supply chain. In low-income countries, food is mainly lost during the early and middle stages of the FSC; much less food is wasted at the consumer level. Food losses represent a waste of resources used in production, such as land, water, energy, and other inputs. Producing food that will not be consumed leads to unnecessary CO_2 emissions in addition to loss of economic value of the food produced.

How much food is lost and wasted in the world today and how can we prevent food losses? It is impossible to give precise answers to these questions, and there is not much ongoing research in the area.

This is quite surprising as forecasts suggest that food production must increase significantly to meet future global demand. Insufficient attention appears to be paid to current global FSC losses (Gustavsson et al., 2011).

Historically, people secured food through two methods: hunting and gathering, and agriculture. Today, most of the food energy consumed by the world population is supplied by the food industry, which is operated by multinational corporations that use intensive farming techniques and industrial agriculture to maximize system output. While the European food system is undergoing remarkable change—spreading eastwards, concentrating, globalizing, altering internal relations—evidence for the food industry's impact on environment, health, and social inequalities has mounted. The two EU discourses—one on economic efficiency and high technological innovation (competitiveness) and the other on environmental and social progress (sustainable development)—are now in a state of tension. At the member state and EU level, there is recognition that both goals will either have to be addressed by the powerful industrial and retail conglomerates or those combines will themselves become policy targets (Rayner et al., 2008).

One feasible frontier in this "food crisis" has been identified as the environment. The shift in demand from local and seasonal toward imported, non-seasonal fruit and vegetables increases transportation, cooling, and freezing inputs, with a corresponding increase in energy. Greater processing of food leads to increased energy and material input and associated packaging waste. While energy in producing food has decreased, the environmental cost of acquiring food has risen with greater use of cars required to transport foods from supermarkets.

The second frontier is cultural: the impact on European food traditions and consciousness about food. A study across 15 European countries has suggested that three core attributes, or types of approach, guide Europeans in the selection of food products (Rayner et al., 2008):

- Food as a source of pleasure and sensations. Products are judged by taste, sight, smell, point of origin, trustworthiness of producer/retailer, etc.
- Food as a matter of price, convenience, or ease of use.
- Food as a consideration for health.

If the environment is not nurtured, it cannot yield wholesome food. On the other hand, if the food is not produced, processed, and distributed equitably, and if food cultures are irreversibly damaged by product marketing, it becomes a vehicle for social conflict, inequality, and worsening patterns of health. Europe's dilemma is all too common: how to balance food production for large populations accustomed to unparalleled choice and cheapness with sustainability in both natural and human-ecological terms—managing supply chains in a manner that enables both them and the earth to sustain future generations (Rayner et al., 2008).

As a result, food waste is a significant global problem for economic, environmental, and food security reasons. The experts argue that, unless more sustainable and intelligent management of production and consumption are undertaken, food prices could indeed become more volatile and high in a world of seven billion people, rising to over nine billion by 2050, as a result of escalating environmental degradation. Up to 25% of the world food production may become 'lost' during this century as a result of climate change, water scarcity, invasive pests, and land degradation. These are environmental impacts associated with the inefficient use of natural resources such as water, energy, and land (e.g., causing deforestation and land degradation). World food production has already risen substantially in the 20th century, primarily as a result of increasing yields due to irrigation and fertilizer use as well as agricultural expansion into new lands, with little consideration of food energy efficiency. At the same time the world price of food is estimated to become 30–50% higher in the coming decades and to show greater volatility. Increased food prices have had a dramatic impact on the lives and livelihoods of those already undernourished or living in poverty and spending 70–80% of their daily income on food. Key causes of the current food crisis are the combined effects of speculation in food stocks, extreme weather events, low cereal stocks, growth in biofuels competing for cropland, and high oil prices (Nellemann et al., 2009).

The recommendations in the United Nations Environmental Programme were to capture and recycle postharvest losses/waste and to develop new technologies, thereby increasing food energy efficiency by 30–50% at current production levels. New strategies are needed that respond to the intimidating challenges posed by climate change mitigation and adaptation, water scarcity, the decline of petroleum-based energy, biodiversity loss, and persistent food insecurity in growing populations. There is also an economic impact of throwing food away, which ultimately affects all the organizations and individuals involved in the supply chain, including the final consumer (Ventour, 2008). Rather than focusing solely on increasing production, we can increase food security by enhancing supply through the optimization of food energy efficiency. Food energy efficiency is our ability to minimize the loss of energy in food from harvest potential, through

processing, to actual consumption and recycling. By optimizing this chain, food supply can increase with much less damage to the environment, in a manner similar to improvements in efficiency in the traditional energy sector (Nellemann et al., 2009).

2. QUANTITY OF FOOD WASTES

Large quantities of food waste are generated all over the world. One of the key findings is that industrialized and developing countries dissipate roughly the same quantities of food. In developing countries more than 40% of the food losses occur at postharvest and processing levels, while in industrialized countries, more than 40% of the food losses occur at retail and consumer levels. Food waste at consumer level in industrialized countries (222 million tonnes) is almost as high as the total net food production in sub-Saharan Africa (230 million tonnes) (Gustavsson et al., 2011). The study also claims that fruits and vegetables, as well as roots and tubers, have the highest wastage rates.

In the UK, 8.3 million tonnes of food and drink are thrown away every year with a carbon impact exceeding 20 million tonnes of CO_2 equivalent emissions (WRAP, 2010). Most of this is avoidable and could have been eaten if only we had planned, stored, and managed it better. Less than a fifth is truly unavoidable—things like bones, cores, and peelings, which can be used as resources for other manufactured goods. The amount of food wasted per year in UK households is 25% of that purchased (by weight). The avoidable food and drink wastes are thrown away for two main reasons: 2.2 million tonnes is thrown away due to cooking, preparing, or serving too much; and a further 2.9 million tonnes because it was not used in time. For example, the avoidable food and drink waste consists of:

- 860,000 tonnes of fresh vegetables and salads
- 870,000 tonnes of drink
- 680,000 tonnes of bakery
- 660,000 tonnes of home made and pre-prepared meals
- 500,000 tonnes of fresh fruit
- 290,000 tonnes of meat and fish
- 530,000 tonnes of dairy and eggs
- 190,000 tonnes of cakes and desserts
- 67,000 tonnes of confectionery and snacks.

All this wasted food is costly; in the UK people spend £12 billion every year buying and then throwing away good food. This works out to £480 for the average UK household, increasing to £680 a year for households with children—an average of just over £50 a month.

By analogy with the UK, in Japan approximately 20 million tonnes food garbage is generated every year (Minowa et al., 2005). This means that as much as ¥11 trillion worth of food is lost to waste annually. In 2008, 70% of the wasted food in Japan was recycled, half of which was turned to animal feed, 30% converted to fertilizer, and 5% to methane. The rest of the food waste was mostly incinerated or sent to landfills (Sugiura et al., 2009). In Taiwan, approximately 16.5 million tonnes of food waste is produced annually (Mao et al., 2006). In the Republic of Korea, more than 22% of the municipal solid waste is reported to be food waste, and the generation rate for food waste is around 0.24 kg/person/day (Kim et al., 2008). Annually this is equivalent to 4.3 million tonnes of food waste.

The amount of food wasted in the USA is staggering. According to the US Environmental Protection Agency, the USA generates more than 34 million tonnes of food waste each year. Food waste is more than 14% of the total municipal solid waste stream. Less than 3% of the 34 million tonnes of food waste generated in 2009 was recovered and recycled. The rest—33 million tonnes—was thrown away. Food waste now represents the single largest component of municipal solid waste reaching landfills and incinerators. Currently in the USA, over 97% of food waste is estimated to be buried in landfills. When food is disposed in a landfill it quickly rots and becomes a significant source of methane—a potent greenhouse gas with 21 times the global warming potential of carbon dioxide. Landfills are a major source of human-related methane in the USA, accounting for more than 20% of all methane emissions, which can be used as an energy source. There is nonetheless interest in strategies to divert this waste from landfills as evidenced by a number of programs and policies at the local and state levels, including collection programs for source-separated organic wastes. Jones has estimated that overall food losses in the USA amount to US$90–100 billion a year, of which households throw away US $48.3 billion worth of food each year (Jones, 2006). The amount of food loss at the household level in the USA was estimated to be 14%, costing a family of four at least US$589.76 annually (Jones 2004).

Studies made in other OECD countries show broadly similar figures, but also that the magnitude of waste varies significantly. Norway has about the same level of waste as the UK (i.e., 71 kg/year per person) (Hanssen and Olsen, 2008). For Holland, Thoenissen (2009) reports that 43–60 kg of edible food is wasted per household annually. The Netherlands is throwing away €2.4 billion per year on food waste, representing

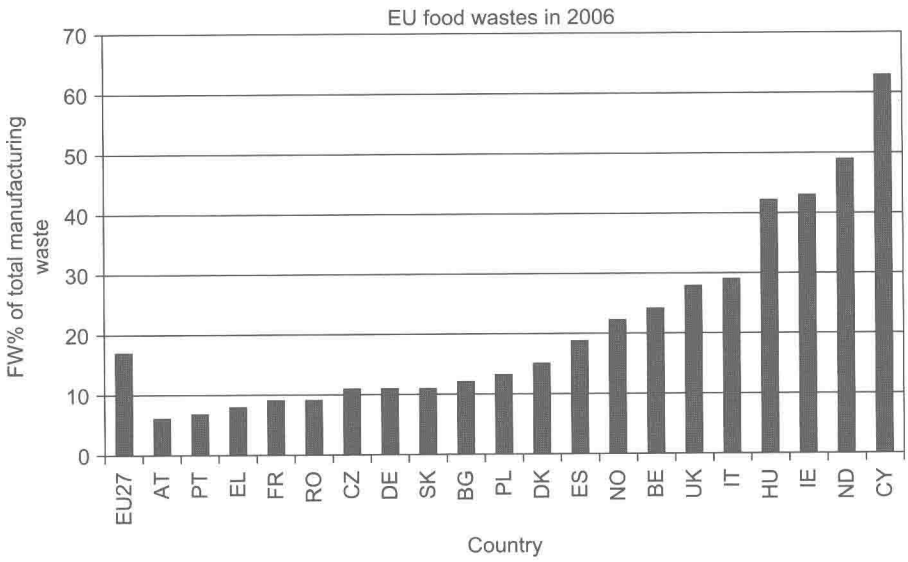


FIGURE 1 Waste generated by food industry in Europe in 2006 (percent of total waste generated in manufacturing). *Data from EUROSTAT (2009).*

more than 20% of the total food in the market (EUROSTAT, 2009). In the USA, the estimates vary significantly from about 25% to 50% (Jones, 2006; Schiller, 2009), and in Australia an average household annually throws out an estimated AUD$ 239 per person, or US$ 222 (Baker et al., 2009). The surprisingly large differences between societies that apparently have similar socioeconomic and cultural characteristics may partly depend on methodological differences and difficulties in defining the boundaries for the measurements (Lundqvist, 2010).

In Europe an estimated amount of approximately 50% of the food produced is wasted (EUROSTAT, 2009). This varies from country to country and from sector to sector, but in the best case approximately 20% of our food ends up as waste. At the same time more than 50 million Europeans are at risk of relative poverty. This is simply unacceptable from social, economic, and environmental points of view. In 2006 the manufacture of food accounted for 17% of total waste generated in manufacturing in the European Union (EU27) and over 40% in Cyprus, the Netherlands, Ireland, and Hungary (Figure 1). In Sweden, an average household is estimated to throw away 25% of food purchased. An average Danish family with 2 adults and 2 children wastes food worth €1341 a year (€2.15 billion for the whole country). Each French citizen throws away 7 kg of food still in the original package every year, when in the same country 8 million people are at risk of poverty.

Avoidable food waste in Finnish households is about 20–30 kg/person/year. This accounts for about 120,000 to 160,000 tonne/year for all households, or about 5% of all purchased food. In food service institutions, on average about 20% of prepared food is wasted, which amounts to about 75,000 to 85,000 tonne/year of avoidable food waste. In retail about 65,000 to 75,000 tonne/year of food products are discarded (due to the study methods, the result includes also some inedible parts like peels and bones). Households appear to be the biggest source of avoidable food waste in Finland. Edible food wasted in all households per year is worth about 500 million Euro (Koivupuro, 2011).

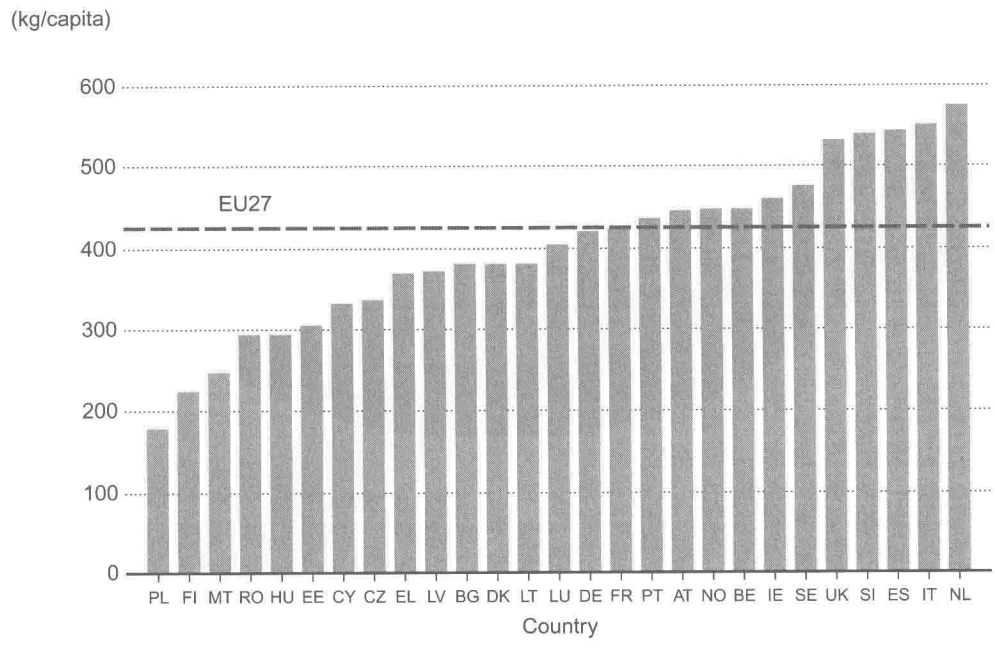
The waste produced by households ranged from 181 kg per capita in Poland to 576 kg per capita in the Netherlands in 2006, with an average of 423 kg per capita in the European Union (EUROSTAT, 2009) as shown in Boxes 1 and 2.

Food wastage depends largely on the society in which it was grown and consumed (Figure 2). In poor countries most food is lost at the producers' end: food gets lost in the fields or due to lack of storage and cooling systems or poor transport mechanisms. In the developing world, lack of infrastructure and associated technical and managerial skills in food production and postharvest processing have been identified as key drivers in the creation of food waste, both now and over the near future (WFP, 2009). For example, in India, it is estimated that 35% to 40% of fresh produce is lost because neither wholesale nor retail outlets have cold storage (Nellemann et al., 2009).

In developed countries, most food waste continues to be generated postconsumer, driven by the low price of food relative to disposable income, consumers' high expectations of food cosmetic standards, and the increasing disconnection between consumers and how food is produced. Similarly, the increasing urbanization within transitioning countries will potentially disconnect those populations from the sources of food, which is likely to further increase food waste generation.

BOX 1

EU WASTE GENERATED BY HOUSEHOLD IN 2006



European waste generated by households in 2006 (in kg per capita) (EUROSTAT, 2009).

The lack of infrastructure in many developing countries and poor harvesting/growing techniques are likely to remain major elements in the generation of food waste. Less than 5% of the funding for agricultural research is allocated to postharvest systems (Kader, 2003), and yet reduction of these losses is recognized as an important component of improved food security (Nellemann et al., 2009). Irrespective of the global region, there is a need for successful introduction of culture-specific innovations and technologies across the FSC to reduce losses.

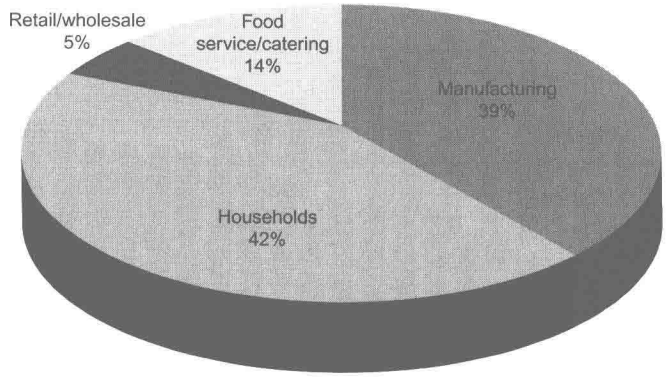
There are clearly fundamental factors affecting postconsumer food waste worldwide, some of which may require solutions that involve direct communication and awareness raising among consumers of the importance of reducing food waste. Others require government interventions and the support and cooperation of the food industry itself, such as improving the clarity of food date labeling and advice on food storage or ensuring that an appropriate range of pack or portion sizes is available that meets the needs of different households (Parfitt et al. 2010).

Undoubtedly, agricultural and food production losses are particularly high between field and market in developing countries, and wastage (i.e., excess caloric intake and obesity) is highest in the more industrialized nations. The loss of, or reduction in, other primary ecosystem services (e.g., soil structure and fertility; biodiversity, particularly pollinator species; and genetic diversity for future agriculture improvements) and the production of greenhouse gases (notably methane) by decomposition of the discarded food are just as important to long-term agricultural sustainability the world over (Nellemann et al., 2009).

The qualitative approach of Mena et al. (2011) helped to identify the main root causes of waste in the supplier–retailer interface, which were categorized into three groups: (1) mega trends in the market place, (2) natural causes related to the products and processes, and (3) management root causes on which practitioners have a direct impact. The results revealed that levels of waste are, to a large extent, dependent on the natural characteristics of the product, such as shelf life, temperature regime, and demand variability, and on mega trends in the markets, such as the increasing demand for fresh products and products out of season. Despite the natural constraints, it was found that there are many opportunities for reducing waste by

BOX 2

PERCENTAGE BREAKDOWN OF EU27 FOOD WASTE GENERATED BY MANUFACTURING, HOUSEHOLDS, WHOLESALE/RETAIL, AND FOOD SERVICE/CATERING SECTORS (BEST ESTIMATE)



The main estimate of this study (EC DG ENV, 2011) relies more heavily on EUROSTAT data to estimate manufacturing, household, and "other sector" food waste: households produce the largest fraction of EU food waste among the four sectors considered, at about 42% of the total or about 38 Mt; manufacturing food waste was estimated at almost 35 Mt per year in the EU27 (70 kg per capita). The wholesale/retail sector accounts for close to 8 kg per capita (with an important discrepancy between Member States) representing around 4.4 Mt for the EU27; the food service sector accounted for an average of 25 kg per capita for the EU27, at 12.3 Mt for the EU27 overall. There is a notable divergence between the EU15 at 28 kg per capita (due to a higher trend of food waste in the restaurant and catering sector) and 12 kg per capita in the EU12. *Source: 2006 EUROSTAT data (EWC_09_NOT_093), various national sources.*

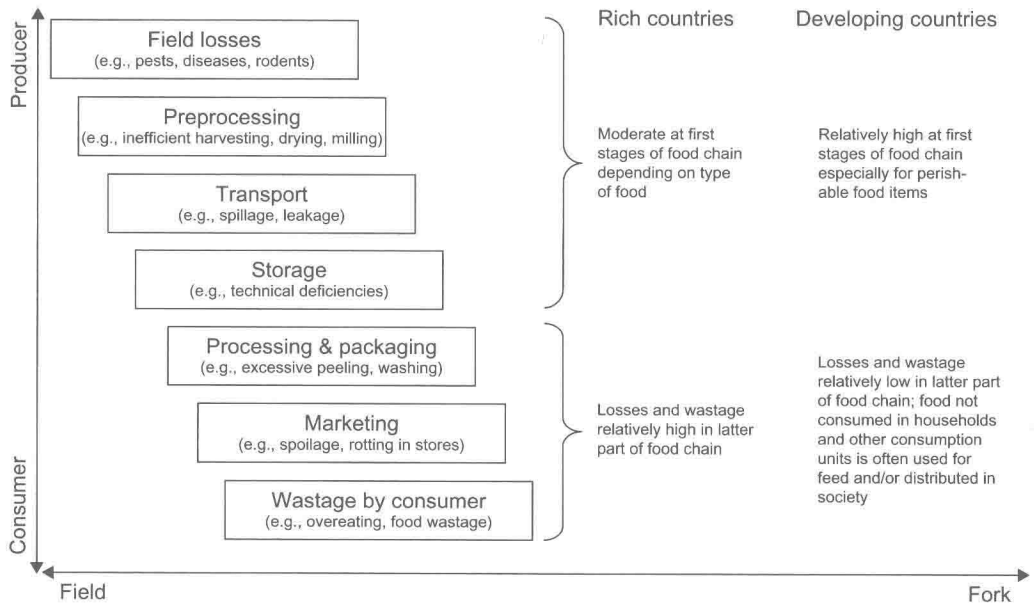


FIGURE 2 **Main types of food losses and wastage.** *From Lundqvist (2008).*

addressing the nine management root causes identified by the study. These root causes are: information sharing, forecasting and ordering, performance measurement, cold chain management, training, quality management, waste management responsibilities, promotions management, and packaging. This study was restricted to two countries (UK and Spain) and a limited range of products. It, however, identifies a number of common efficiency lapses at the supply-chain and management level, which can apply across the countries in the developed world. Despite the limitations, it could serve as a stepping-stone for future research trying to address the problem of food waste.

Ultimately, the most important reason for food waste at the consumption level in rich countries is that people simply can afford to waste food (Stuart, 2009).

3. WATER WASTE

Food waste is also water waste, as large quantities of water are used to produce the lost food. From the environmental perspective food waste accounts for more than one quarter of the total consumptive use of finite and vulnerable freshwater and more than 300 million barrels of oil per year. Globally, the amount of water withdrawn every year to produce the lost and wasted food could fill a lake of 1,300 km^3, about half the volume of Lake Victoria. In the US, annual food production consumes about 120 km^3 of irrigation water. People throw away 30% of this food, which corresponds to 40 billion liters of irrigation water. That is enough water to meet the household needs of 500 million people. Today, to meet global food demand some 7,100 billion cubic meters of water, equivalent to more than 3,000 liters per person per day, are used during crop production through evaporation and transpiration. In arid and semiarid countries, water is already a limiting factor in agricultural production. About 1.2 billion people, one-fifth of the world's population, live in basins where water is running out (Lundqvist, 2008).

Water losses accumulate as food is wasted before and after it reaches the consumer. In poorer countries, most uneaten food is lost before it has a chance to be consumed. Depending on the crop, an estimated 15–35% of food may be lost in the field. Another 10–15% is discarded during processing, transport, and storage. In richer countries, production is more efficient but waste is greater: people throw away much of the food they buy, and all the resources used to grow, ship, and produce the food are thrown away along with it.

The world water requirements for food production from 1960 to 2002 and its projection to 2050 are depicted in Box 3 (Nordpil, 2009).

By 2050, the demand for water for food production is predicted to double in order to cope with the needs of the growing human population (Rockström et al., 2005). The global need for energy production—and therefore water—is also projected to rise by 57% by the year 2030 (Hightower and Pierce, 2008). Clearly the time has come to address the central question: *Is there enough water to sustain our wasteful lifestyle?* (Cominelli et al., 2009). Therefore, the water footprint concept has been developed in order to have an indicator of water use in relation to consumption by people. The water footprint is more accurate and provides a more useful assessment of the water demands of a country than do the national figures for water consumption (Chapagain and Hoekstra, 2004).

4. ENVIRONMENTAL EFFECT OF FOOD WASTE

As carbon becomes the prominent form of measuring environmental impact, much attention is being given to determining the carbon impact of the UK food and drink retail supply chain. WRAP assessed the greenhouse gas emissions associated with food and packaging waste (Figure 3). WRAP's estimate of the carbon impact of the UK food and drink supply chain and household waste was performed to calculate the greenhouse gas emissions associated with grocery retail food and drink waste. Conversion factors were developed to convert the quantities of waste to quantities of CO_2 equivalent at each stage in the supply chain (a total conversion factor is 3.8 tonnes of CO_2 eq per tonne of waste) (WRAP, 2010). The greenhouse gas emissions of avoidable food waste from Finnish households roughly correspond to the emissions of 100,000 cars (Koivupuro, 2011).

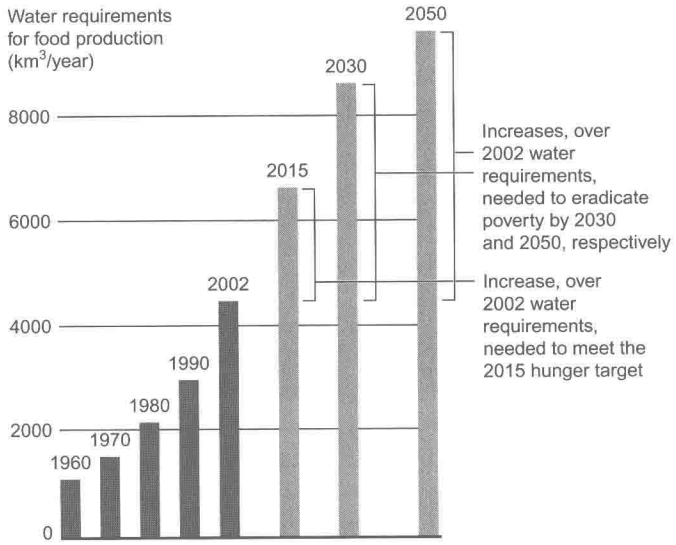
The combined carbon impacts in the UK of food and packaging waste in the supply chain totals 10 million tonnes of CO_2 eq, and in the household 26 million tonnes CO_2 eq. In addition, the greenhouse gas impact associated with by-product going to animal feed is 3.7 million tonnes of CO_2 eq. For household and manufacturing, most of the impact comes from food waste, whereas for distribution and retail most comes from packaging waste.

5. CONCLUSIONS

Roughly 30–40% of food in both the developed and developing worlds is lost to waste, though the causes are very different. In the developing world losses are mainly attributable to the absence of food-chain infrastructure and the lack of knowledge or investment in storage technologies on the farm, although data are

BOX 3

HISTORIC AND PROJECTED CHANGES IN WATER CONSUMPTION FOR FOOD PRODUCTION, 1960–2050



The requirements for water in agriculture will need to increase in order to meet the Millennium Development Goal of ending hunger. Boosting of water requirements is needed to meet this supply. *From Nordpil (2009)*

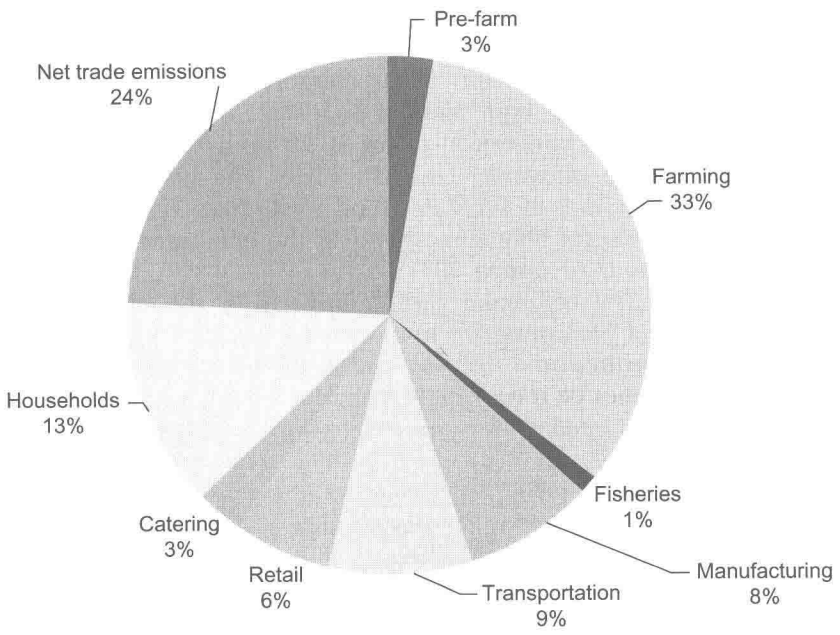


FIGURE 3 Greenhouse gas emissions associated with the UK food chain by sector in 2006. *From WRAP (2010).*

scarce. In contrast, in the developed world pre-retail losses are much lower but those arising at the retail, food service, and home stages of the food chain have grown dramatically in recent years (Nellemann et al., 2009; Stuart, 2009). Simultaneously, studies show that some Western countries, such as the USA, France, Sweden, and Brazil, are consuming every day a surplus of 1,400 calories per person for a total of 150