12
Environmental Aspects of Food Processing

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12.1
Introduction

Waste is inevitably produced in all human endeavours; and its volume is proportional to the resources consumed. Waste is generally thought of as something that is no longer needed by the original user and is subsequently discarded. It is defined in UK legislation as: "any substance which constitutes a scrap material or an effluent or other unwanted surplus substance arising from the application of any process" [1]. It is further defined as: "any substance or article which requires to be disposed of as being broken, worn out, contaminated or otherwise spoiled" [1], or "that the holder discards, intends to or is required to discard" [2] (based on the definition of waste in EC Directive 91/156/EEC) [3].

The increased culture of consumerism within our societies has escalated the problem of waste because of the use of disposable goods. Processed food wastes constitute one of the largest fractions of municipal waste these days. Manufacturing processes operate under strict quality control and retailing has stringent 'sell by' date regulations, which has resulted in the generation of large volumes of food and packaging waste. The food industry is facing increasing pressure to reduce its environmental impact, both from consumers and regulators. Initial results from the study of Environment Agency indicate that the food, drink and tobacco sector contributes $8–11\times10^6$ t year^{-1} to the industrial/commercial total of $70–100\times10^6$ t year^{-1}. This partly reflects the importance and size of the food and drink industry within the UK [4].

Transferring food from the field to the plate involves a sophisticated production and supply chain, but for the purposes of waste production this can be simplified into three main steps: agriculture, food processors/manufacturers and the retail/commercial sector. Each of the sectors generates waste and wash water. Given the complexity of the food chain, environmental impacts can occur at various points in the chain, even for a single food product. It is therefore necessary to take a holistic systems-based approach to tackle the problem. This, however, demands that the entire food chain be considered in the context of

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dealing with environmental issues. Since such an approach would become too unwieldy in the context of this book, this chapter merely aims to identify key environmental issues relating to food processing and manufacture; and it discusses food waste characteristics, the relation between processing operations and the types of waste generated, waste processing options, energy issues in food manufacture, the environmental impact of refrigerants and packaging wastes.

12.2
Waste Characteristics

The quality and quantity of wastes produced depend on the type of food being processed. There are big differences from sector to sector, and even site to site: generalisation is not only difficult, but could also be misleading. Food wastages levels are often inferred from mass balances. It is estimated that about 21% of food product at the farm gate is lost, much due to spoilage, and only about 7%, on an average, is lost during processing [5]. From the data cited in [5] (see Table 12.1), it can be inferred that, although the percentage loss during food processing is low, wastage mass or volumes are very high. The wastes produced in any food industry depend mainly on the type of food being processed.

Food processing operations produce many varied types of wastes that can be categorised into solid, liquid and gaseous wastes.

Table 12.1 Solid wastes generated in selected processes [5].

Processed food waste	Total solids ($g\ kg^{-1}$)	Liquid volume ($m^3\ kg^{-1}$)
Vegetables		
Kale	16	0.004
Spinach	20	–
Mustard greens	16	–
Turnip greens	15	–
Potatoes	66	0.012
Peppers (caustic peeling)	65	0.020
Tomatoes (caustic peeling)	14	0.010
Dairy		
Cheese whey	–	9.00
Skim milk	–	0.07
Ice cream	–	0.08
Meat		
Red meat	0.440	25.00
Poultry	0.270	50.00
Eggs	0.111	–

12.2.1
Solid Wastes

Solid wastes emanating from food processing plants may include: the unnecessary leftover from the preliminary processing operations, residues generated as an integral part of processing, wastes resulting from processing inefficiencies, sludge produced from the treatment of wastewater, containers for the raw materials and finished products. Table 12.1 summaries typical solid wastes generated from a selection of food processes [7, 8]. In general, solid wastes are poorly characterised, both in terms of quality and quantity; and estimates of solid wastes are usually inferred from mass balances [7, 8].

12.2.2
Liquid Wastes

Wastewater from the processing industry is the main stream that is produced. It includes: wastewater resulting from using water as a coolant, water produced by different processing operations like washing, trimming, blanching and pasteurising and a large amount of wastewater produced from cleaning equipment [8].

12.2.3
Gaseous Wastes

The gaseous emissions from the food processing industry are mainly manifested in terms of emanating odors and, to a lesser extent, in terms of dust pollution. Other emissions include solvent vapors commonly described as volatile organic emissions and gases discharged by combustion of fuels.

Even though the characteristics of food wastes can be discussed in terms of their physical states, it is necessary to note that solid wastes contain a substantial proportion of water, just as liquid wastes may contain a significant proportion of solids. It is therefore absolutely critical to note that food wastes are not only multicomponent but also multiphase in nature [8].

12.3
Wastewater Processing Technology

Treatment of the wastes produced from food industries is an important concern from the environmental point of view. As discussed earlier, the waste products from food processing facilities include bulky solids, wastewater and airborne pollutants. All of these cause potentially severe pollution problems and are subject to increasing environmental regulations in most countries. Generally, wastewater is most common, because food processing operations involve a number of unit operations, such as washing, evaporation, extraction and filtration. The wastewaters resulting from these operations normally contain high concentrations of suspended solids and soluble organics, such as carbohydrates, proteins and lipids, which cause disposal problems. To remove these contaminants from water, different technologies are adopted in the food industry, which are described in detail in Chapter 13 and in [9, 10].

12.4 Resource Recovery From Food Processing Wastes

The wastes from food industry, after recovery and further processing, can be used for different purposes: the recovered materials can either be recycled, or be used to recover energy by incineration or anaerobic digestion. Recycling not only reduces the environmental impact of the material, but also helps to satisfy the increasing demands for raw materials. In addition, it also reduces disposal costs, a key driver of recycling technologies. For instance, fruit, vegetables and meat processors generate large quantities of solid wastes. Table 12.2 lists examples of useful materials which can be recovered from fruit and vegetable wastes.

Recovered materials can be used in various ways. Solid food wastes can be used as animal feed after reducing their water content. A good example of this practice is soybean meal, a byproduct of soybean oil extraction, which was simply discarded previously but is now used as animal feed on account of its high nutritive value [11]. Solid wastes can also be upgraded by fermentation. A number of fermented foods are produced this way. Composting and ensilaging are also examples of solid waste fermentation process [6]. Solid wastes rich in carbohydrate can also be converted to sugars by enzyme-assisted hydrolysis: an example is the enzymatic hydrolysis of lactose and galactose sugar using β-galactosidase [12]. Solid wastes rich in sugar can be fermented to produce carbon dioxide and ethanol. The latter a valuable product, and has also been earmarked as an alternative fuel for the future [13].

As mentioned above, solid wastes can also be utilised as fuel directly or converted to methane by anaerobic digestion in a bioreactor. Biological hydrogen is produced by fermentation of both glucose and sucrose in food processing wastes under slightly acidic conditions in the absence of oxygen. This can be achieved by using a variety of bacteria through the actions of well studied anae-

Table 12.2 Some examples of products which can be recovered or made from fruit and vegetable wastes [8].

Source of waste	Product
Apple pomace	Pectins
Apple skin	Aromatics
Tomato pomace	Pectins, tomato seed oil, colour from skin
Stalk of paparika and pumpkin seeds	Natural colouring agents
Green pea pods	Leaf proteins, chlorophyll
Stones from stoned fruits	Active carbon, kernels (after debittering)

robic metabolic pathways and hydrogenase enzymes. Hydrogen has 2.4 times the energy content of methane, i.e. on a mass basis; and its reaction with oxygen in fuel cells produces only water, a harmless byproduct. Hydrogen gas has valuable potential for producing clean and economical energy in the near future [14].

12.5 Environmental Impact of Packaging Wastes

Packaging is acknowledged to perform a number of useful functions. It acts as a physical barrier between a product and the external environment, thereby protecting it from external contamination and maintaining hygienic conditions, it protects and preserves the product during handling and transportation, it serves to attract the attention of consumers thereby giving the product a good market value and it also serves to provide information on the product and instructions on how to use it (see also Chapter 9). Despite these advantages, the environmental impact of packaging wastes is considerably high and, in many cases, outweighs their benefits. Recent studies have shown that, in Europe, packaging forms ca. 16% of municipal solid waste (MSW) and 2% of nonMSW [15].

The key environmental issues related to packaging are:

- the use of packaging materials like plastics and steel which are either nonrecyclable or uneconomic to recycle (a large amount of such wastes invariably end up in landfills);
- the use of material intensive packaging, which requires an energy-intensive process to manufacture;
- the use of substances in the packages having high chemical and biological oxygen demand (some even hazardous and toxic to the environment) which cannot be discharged safely into natural water streams.

In most countries, regulations are in place for reducing the impact of packaging and packaging wastes on the environment. This is mostly done by limiting the production of packaging wastes, enforcing the recycle of packaging material and reuse of packages where possible and encouraging the use of minimal packaging at source.

12.5.1 Packaging Minimisation

The foremost strategy in packaging waste management is to reduce the use of packaging to a bare minimum level at all stages of production, marketing and distribution. This can be achieved by: (a) decreasing the weight of material used in each pack (known as lightweighting or downgauging), (b) decreasing the size or volume of the package or using less material in the first place, e.g. reducing the thickness of the packaging material, (c) using consumable or edible package and (d) modifying the product design, e.g. avoiding unnecessary multiple wrapping of a product with different materials [16].

12.5.2
Packaging Materials Recycling

The purpose of recycling is to use a material as raw material for the production of a new product after it has already been used successfully. If recycling is done properly and in conjunction with good design, many materials can be recovered after their first useful life is over. The two major objectives should be to conserve limited natural resources and to reduce and rationalise the problems of managing municipal solid waste disposal [15].

Recycling is defined as the reprocessing of the waste material in a production process either for the original purpose or for other purposes. The EU definition [17] also includes organic recycling, i.e. aerobic or anaerobic treatment of the biodegradable part of the packaging waste to produce stabilised organic residues or methane. In general, recycling involves physical and/or chemical processes which convert collected and sorted packaging, or scrap, into secondary raw materials or products. Secondary raw material is defined as the material recovered as a raw material from used products and from production scrap.

Before sending packaging materials for recycling, they should be properly sorted (i.e. separated from other packaging materials) and cleaned (i.e. free from any contamination). Sorting and cleaning are two important operations before processing, since they affect the quality of the input stream which finally determines the quality and value of the secondary materials. The materials commonly used for food packaging are: paper and board, plastic, glass, aluminum and steel.

Given the widespread use of paper and board as packaging material, their recycling is critical from the environmental point of view as well as resource recovery. Recycled paper is a major source of raw material for the paper industry. About 44.7×10^6 t of waste paper were recycled in Europe in 2003, which is substantially higher than 10 years ago, when only ca. 26×10^6 t were recycled. This represents 53.2% of the total paper used in Europe [18]. Packaging is the largest sector; and it uses almost two-thirds of the recycled paper in Europe to manufacture case materials, corrugated board, wrapping, etc.

The total consumption of plastics in Europe was about 36.8×10^6 t in 2000, of which 13.7×10^6 t (37.3%) were used for manufacturing packaging materials. Plastics account for 17% of the total packaging usage in Western Europe [1]. The most widely use packaging plastics include low and high density polyethylene (LDPE, HDPE), linear low density polyethylene (LLDPE), polypropylene (PP), polystyrene (PS), polyethylene tetraphthalate (PET) and polyvinyl chloride (PVC). After collection, the material is sorted, to separate the plastics from other materials like paper, steel, aluminum, etc. The sorting step also includes the separation of plastics by their resin type (like PET, HDPE, etc.). The sorted plastics are then recycled by different technologies, such as mechanical, feedstock and chemical recycling [19].

Mechanical recycling involves processes like extrusion, coextrusion, injection, blow moulding, etc. (see also Chapter 9). Feedstock recycling includes pyrolysis, in which plastics are subjected to high temperature in the absence of oxygen which enables the hydrocarbon content of the polymer to be recycled. Pyrolytic processes have been studied extensively for the last two decades. However, most of this research has been undertaken using pure and clean plastics, or mixtures of pure plastics. There is a strong need to develop processes capable of dealing with wastes that have plastics attached to other contaminants, such as paper, metals or bioproducts. Microwave-induced pyrolysis of plastics is a novel process in which microwave energy is applied to carbon mixed with plastic waste [20].

Chemical recycling involves depolymerisation of PET, resulting in the monomers terepthalic acid and ethylene glycol which, after purification, can be reused to produce new polymers.

Another method, called the 'super clean recycling process', uses mechanical and nonmechanical procedures to recycle high quality postconsumer material, producing polymers suitable for use in monolayer application, i.e. use in direct contact with food. The processes are proprietary, but they are believed to involve a combination of standard mechanical recycling processes with nonmechanical procedures such as high-temperature washing, high-temperature and pressure treatments, use of pressure/catalysts and filtration to remove polymer-entrained contaminants [21].

Recycled plastics have been used in food contact applications since 1990 in various countries around the world. To date, there have been no reported issues concerning health or off taste resulting from the use of recycled plastics in food contact applications. This is due to the fact that the criteria that have been established regarding safety and processing are based on extremely high standards that render the finished recycled material equivalent in virtually all aspects to virgin polymers [22].

Various food contact materials and constituents can be used, provided they do not pose health concerns to consumers, which may occur when some substances from the food packaging migrate into the food. To ensure the safety of such materials, food packaging regulations in Europe require that the packaging materials must not cause mass transfer (migration) of harmful substances to the food, by imposing restrictions on substances from the materials itself that could migrate into the food. Consequently, food packaging materials must comply with many chemical criteria and prescribed migration limits. The migration of substances from the materials into the foodstuffs is a possible interaction that must be minimised or even avoided, since it may affect the food or pose longer-term health concerns to the consumer [23] (see also Chapter 9).

With regard to recycled PET, there is strong need to have relevant analytical data on the nature and the concentration of the contaminants that can be found in the recycled material, in order to ascertain the safety of reusing PET for food purposes. Knowledge of the contaminants and information on practical and effective test methods would help in the formulation of future legislation [24].

With a view to make packaging from sustainable materials, a number of biodegradable alternatives have been developed. Traditionally, biobased packaging materials have been divided into three types, which illustrate their historical development. First generation materials consist of synthetic polymers and 5–20% starch fillers. These materials do not biodegrade after use, but will biofragment, i.e. they break into smaller molecules. Second generation materials consist of a mixture of synthetic polymers and 40–75% starch. Some of these materials are fully biobased and biodegradable [25]. The market value of biobased food packaging materials is expected to incorporate niche products, where the unique properties of the biobased materials match the food product concept [26]. Packaging of high-quality products such as organic products, where extra material costs can be justified, may form the starting point. Biopolymer-based materials are not expected to replace conventional materials on a short-term basis. However, due to their renewable origin, they are indeed the materials of the future [27].

According to [4], targets for recovery and recycling have been set by EU as follows: 50–65% by weight of packaging waste to be recovered, 25–45% to be recycled, and 15% to be recovered by materials. These targets refer to packaging composed of plastics, paper, glass, wood, aluminum and steel. Further, the combined content of lead, mercury, cadmium and chromium (VI) has been limited to 100 ppm. The law also ensures that packaging materials are introduced in the marketplace only if they meet 'essential requirements', i.e. characteristics that include minimisation of weight and volume, and suitability for material recycling.

12.6 Refrigerents

Refrigeration systems are essential for the production, storage and distribution of chilled foods. The commonly used refrigerants in these systems are chlorofluorocarbons (CFC) and hydrofluorocarbons (HCFC). Although highly efficient, these refrigerants have been shown to be responsible for severe environmental threats like global warming and depletion of the ozone layer.

CFCs are organic compounds containing chlorine, fluorine and carbon atoms and having ideal thermodynamic properties for use as refrigerants. But their chlorine content is mainly responsible for the depletion of the ozone layer in our environment. When CFCs are released into atmosphere, they dissociate in the presence of ultraviolet (UV) light to give free chlorine. This free chlorine atom decomposes ozone to oxygen and regenerates itself by interacting with a free oxygen atom, as follows [28].

$$CF_2Cl_2 \rightarrow CF_2Cl + Cl$$

$$Cl + O_3 \rightarrow ClO + O_2$$

$$Cl + O \rightarrow Cl + O_2$$

The regeneration of chlorine sustains the process and depletes the ozone layer. This layer is known to protect life on earth from UV radiation, by absorbing a large portion of it and allowing only a small fraction to reach the earth. But its depletion will expose us, causing skin cancer, damage to eyes, damage to crops, global warming, climate change, etc. [28]. Besides this effect, such refrigerants are also known to contribute to global warming, along with CO_2 and other gases such as methane, nitrous oxides, chlorofluorocarbons, and halocarbons.

The extent to which a substance can destroy the ozone layer is measured in terms of a parameter called ozone-depleting potential (ODP). The ODPs of CFCs are significantly greater than ODPs of hydrofluorocholorcarbons (HCFC) and hydroflurocarbons (HFC). Hence, CFCs are gradually being replaced by these other two. It may be noted that HFCs have zero ODP, since they do not contain any chlorine atoms. However, the F-C bonds in CFCs, HCFCs and HFCs are very strong in absorbing infrared radiations escaping from the earth's surface. Their absorption capacity is much more than CO_2 [29]. To measure the contribution of different gases to global warming, a scale called the global warming potential (GWP) has been set up. Table 12.3 lists the ODP and GWP of different refrigerants. It is quite obvious from the table that CFCs have high ODP and GWP compared to HCFCs and HFCs [30].

To control the production and consumption of substances which cause ozone depletion, the 'Montreal protocol on substances that deplete the ozone layer' was signed in 1987 and has been effective since 1989 [31]. The purpose of this agreement was to phase out CFCs by the year 2000 and to regularly review the use of transitional ozone-safe alternative refrigerants, which are scheduled to be replaced by 2040. Similarly, though HCFCs are used as replacements for CFCs,

Table 12.3 Refrigerant characteristics [30].

Refrigerant	Ozone-depleting potential	Global warming potential (CO_2 = 1.0)	Stratospheric lifetime
CFC 11	1.0	4100	55.0
CFC 12	1.0	7400	116.0
CFC 113	1.07	4700	110.0
CFC 114	0.8	6700	220.0
CFC 115	0.5	6200	550.0
HCFC 22	0.055	2600	15.2
HCFC 123	0.02	150	1.6
HCFC 124	0.022	760	6.6
HCFC 141b	0.11	980	7.8
HCFC 142b	0.065	2800	19.1
HFC 125	0.0	4500	28.0
HFC 134a	0.0	1900	15.5
HFC 143a	0.0	4500	41.0
HFC 152a	0.0	250	1.7

they are still responsible for ozone depletion and need to be phased out by 2020 as specified by the amended Montreal protocol [15]. HCFCs are expected to be replaced by HFCs.

12.7 Energy Issues Related to Environment

The energy consumed by the food and drink industry, in most countries, is a significant proportion of the total energy used in manufacturing industries. For instance, this proportion within UK is around one-tenth [32]. Energy is consumed by the food industry to keep food fresh and safe for consumption. This is achieved by different processing operations (boiling, evaporation, pasteurisation, cooking, baking, frying, etc.), safe and convenient packaging (aseptic packaging) and storage (freezing, chilling). The energy required for these processes is obtained from either electricity or burning fossil fuel. When the cost of energy consumption is considered, it has received very low priority in many organisations because it accounts for only 2–3% of the total production cost [32]. But considering the other side of the coin, i.e. the environmental effects, the energy consumption cannot be ignored. The food industry will be affected by all international measures aimed at reducing industrial energy consumption. The background to some of the international measures is discussed below.

The burning of fossil fuel results in emission of large amounts of CO_2, the most important greenhouse gas, which is responsible for about two-thirds of potential global warming. CO_2 produced from burning fossil fuel is responsible for 80% of the world's annual anthropogenic emissions of CO_2. Methane (CH_4), the second most important greenhouse gas, is responsible for about 15% of the build up, and nitrous oxide (N_2O), which also has a high stratospheric lifetime, is responsible for 3% of the build up [33]. Other greenhouse gases, e.g. CFCs, HCFCs, Perfluorinated Carbons (PFCs), sulfur hexafluoride (SF_6), etc., are produced from various sources, which include the refrigeration systems used in food processing. The average temperature rise experienced by the planet on account of greenhouse emissions has been estimated to be approximately 0.5 °C over the past 100 years. But sophisticated computer models solely based on CO_2 emissions are predicting a temperature rise of 5 °C over the next 200 years [34]. The average rate of warming due to emission of these gases would probably be greater than ever seen in the last 10 000 years. This increasing temperature may cause many catastrophic events, like melting of the polar ice cap, rising of global sea levels and unbearably hot climates all over the world. The global sea level has risen by 10–25 cm in the last 100 years and it is expected to increase in between 13 cm and 94 cm by the year 2100, which might cause widespread flooding [34]. Burning of fossil fuels also gives rise to SO_2, which is converted to sulphate in the atmosphere, known as sulphate aerosols. These aerosol particles absorb and scatter solar radiation back into space and hence tend to cool the earth. But, due to their shorter lifespans, it is difficult to assess the impact of aerosols on the global climate. However, it has been concluded that the increase in sulphate aerosols has had a cooling effect since 1850 [34].

To minimise the chances of catastrophic events occurring in the future, we must slow down the emission of greenhouse gases. This can be achieved by limiting the combustion of fossil fuels, which ultimately leads to reduced energy demand by increasing the drive for energy efficiency and improving its use.

With limited use of electricity and fuel, the energy efficiency can be achieved by the use of combined heat and power (CHP) or renewable energy. CHP is a fuel-efficient energy technology in which a major part of the heat that is being wasted to the environment is recovered and used in other heating systems. CHP can increase the overall efficiency of fuel use to more than 75%, compared with around 40% from conventional electricity generation. CHP plays an important role in the UK Government's new energy policy, whose ambition is to achieve a 60% reduction in CO_2 emissions by 2050 [35]. Following good process design practices can also make a difference [36]: for instance, insulating valves, flanges, autoclaves, heated vessels, pipes, etc. during steam production can prevent leakage of steam and hence reduce heat loss; also, using the optimum air-fuel ratio prevents unnecessary burning of fuel, etc. Renewable sources of energy like solar radiations, wind, sea waves and tides, biomass, etc. and the use of fuel containing low or no carbon (e.g. hydrogen) can reduce the emission of greenhouse gases to a significant extent. Another option is to capture the CO_2 emitted by a burning fuel and then utilise it or store it for later use [37]. CO_2 could be captured by various methods like adsorption onto molecular sieves, absorption into chemically reacting solvents (e.g. ethanolamines), membrane separation methods, etc. After separation, it can be used as a feedstock for the manufacture of chemicals which enhance the production of crude oil in the growth of plants or algae which could be used as a biofuel. Several methods of storing the CO_2 have been proposed, such as storing it inside ocean beds, in deep saline reservoirs, in depleted oil and gas reservoirs, etc. [38]. All these options may not be economically viable at this stage, but technology may need to be improved so that these options could be exercised more easily.

It is evident from the above discussion that environmental problems resulting from energy consumption cannot be resolved by nations unilaterally. A number of international treaties and agreements have been formulated to protect the environment from the hazards of greenhouse gases, such as the Kyoto protocol. During the 1992 'Framework convention on climate change' (FCCC), the first formal international statement of concern and agreement was formulated to take a concerted action for stabilising atmospheric CO_2 concentrations. In this context, the 1997 Kyoto protocol was negotiated (which includes several decisions such as reducing greenhouse gas emissions, based on 1990 levels, by 5.2% in the period 2008 to 2012) by the industrialised countries [39]. The UK voluntarily committed to reducing emissions by 12.5% by 2010. Other measures include enhancement of energy efficiency in different sectors, increased use of new and renewable forms of energy, advanced innovative technology for CO_2

separation and the protection and enhancement of sinks and reservoirs of greenhouse gases. In addition, there was a commitment to reduce fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas-emitting sectors that ran counter to the objective of the Convention [40]. The European Union aimed to control the environmental impacts of industrial activities by formulating an 'integrated pollution prevention and control' (IPPC) directive (Directive 96/61/EC of 24 September 1996), which sets out measures to ensure the sensible management of natural resources. These provisions enable a move towards a sustainable balance between human activity and the environment's resources and regenerative capacity [4]. The 'climate change levy' (CCL) was introduced as a tax on fuels or energy sources used by industry on 1 April 2001. The levy package aims to reduce CO_2 emissions of at least 2.5×10^6 t year^{-1} by 2010. The levy does not apply to waste used as fuel. To encourage the reduction of fuel consumption, the UK government has also announced that a discount of 80% from the levy will be given to companies who agree to reduce the CO_2 emission by reducing their energy consumption [41]. Food processing industries will be expected to work within the above parameters and there is no doubt that manufacturing practices will continue to change for the foreseeable future to comply with national and international regulations formulated to protect our environment.

12.8 Life Cycle Assessment

The life cycle assessment (LCA) is a tool standardised by the International Standardisation Organisation (ISO) to evaluate the environmental risks associated with a product from 'cradle' to 'grave'. It takes into account the environmental impact associated with its production starting from the raw materials and energy needed to produce it, to its disposal, along with processing, transportation, handling, distribution, etc. in between [42]. LCA studies have been carried out for a variety of products, including food. The first LCA studies on food products were undertaken at the beginning of the 1990s [43].

LCA identifies the material, energy and waste flows associated with a product during the different stages of life cycle and the resulting environmental impact. For example, if we consider the production of orange juice, the LCA analysis will involve: the weight of oranges and energy associated with transporting raw materials, the amount of wastes produced (both processing and packaging wastes), the energy or power consumed during processing, the mass and energies associated with the use of utilities like cleaning water, steam and air, the emissions released into air, water and land from the processing site and other relevant factors depending on the operating technology and regional location of the processing facility.

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