Environmental Impacts of Packaging Materials

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Abstract When humankind began to store food or other items for next-day use, packaging in its primitive form emerged. In ancient times, leaves and bushes were used. By using high-end lightweight, durable, and cheaper material, today's packing industry has evolved exponentially. The industry is continuously searching for packaging solutions that have better strength, are easier to handle, are hygienic, are lightweight, and, most importantly, are sustainable. The major packaging materials are plastic, polystyrene, cardboard, etc. All of these materials are low in cost, light in weight, and durable. The world's growing population has led to large amount of packaging waste, which further contributes to the problem of its disposal and other environmental issues. High-energy consumption (embodied) and environmental problems are associated with packaging materials, which underscores the need to regard the proper use of packaging materials from an environment point of view. To analyse and quantify the environmental impacts associated with various packaging materials, an effective methodology is required. Life-cycle assessment (LCA) is an effective tool that can be utilised to evaluate various environmental impacts of packaging materials. This chapter discusses the environmental impacts associated with packaging materials and the use of LCA to evaluate these impacts so that they can be reduced considerably.

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1 Introduction

As people's lifestyles have changed, so has the environment. There have been significant changes in our ecosystem. Currently many problems are associated with the disposal of waste. It can clearly be seen that during the growing phase of packaging, no attention was being paid to sustainable solutions to waste. Now it is responsibility of humankind to contribute toward a greener environment. As an initial step, some regulatory bodies have been set up that regulate pollution from different industries and force them to reduce emissions. In addition, a few companies are taking sustainability into consideration and are performing environmental analyses of their manufacturing techniques. This analysis is the most important process used in almost all areas of activities from that of a small needle to those of massive aircraft parts. Packaging has many applications in transportation, preservation, and storage, etc. and provides protection to goods from moisture, breakage, dust, and contamination, etc. The medical, food, and beverage industries are almost completely dependent on packaging. In ancient times, bags, boxes, cases, etc., were made of natural materials, which were commonly used for packaging; however, with the passage of time, more effective materials were developed that protect goods not only from contamination but also maintain the characteristics and properties of the goods. For example, beverages packed in sealed bottles have the same taste and effectiveness as when they were packaged.

As the packaging sector continues to grow, its mammoth contribution toward environmental hazards is continuously increasing. Products come to the consumer in different packages. Because the consumer market is growing, packaging waste is exceeding standards set by regulating bodies. Industry is moving toward greener solutions for packaging, and the amount of waste from packaging is expected to be stable by the year 2021 (www.transperancymarketresearch.com). Packaging materials differ depending on their use and include paper, plastic, metal, and glass. Examples of reusable packaging include drum sand (reusable steel drums for storing liquids i.e. oil etc), plastic containers, etc. On the basis of application, the sustainable packaging market can be bifurcated into food and beverage packaging, personal care packaging, appliance packaging, etc.

As the consumption of packaging materials has increased throughout the world, the problem of packaging waste and its disposal is now looming. Excessive use of packaging materials is creating many environmental problems. Large amounts of packaging material waste raises the requirement of effective waste-management systems. In addition, many packaging materials, e.g., polyethylene, are not suitable for disposal in the environment. However, some packaging materials can be recycled, but the environmental impacts associated with their manufacturing and transportation, as well as their disposal, leads to various environmental problems. Therefore, it is important to control the environmental impacts associated with packaging materials. The initial step in this task is to evaluate the environmental impacts of different packaging materials. A tool is required to evaluate these impacts in the form of various sustainability indicators. LCA is one of the most effective tools to measure and study the environmental impacts associated with a product's packaging. LCA helps us study the environmental impacts of different products during their entire life cycle. This chapter begins with the introduction and discussion of various packaging materials along with their environmental impacts. The main features of LCA as a methodology to evaluate environmental impacts, as well as its applicability to reduce the environmental impacts of packaging materials, are discussed. In addition, some case studies on LCA of packaging materials are presented.

2 Packaging Materials and Their Environmental Impacts

The availability of food and beverages is highly dependent on their packaging. Advances in packaging materials have made the preservation and transportation of food items possible around the world. The shelf life of products has increased with better packaging. In addition, demand for quality food has lead to packaging innovation, and these innovations in packaging have helped to create new food categories and added convenience (Risch 2009). The primary functionality of packaging is not limited to simply containing the product. With the development of different lifestyles, more people require quality foods that can be preserved for longer periods of time. Currently packaging has become multifunctional. It involves protecting the product from external gases; blocking light to protect foods and their nutrients, colour, and texture; and preserving the product by maintaining specific ambient conditions around the food inside a container (Risch 2009).

Original packaging materials consisting of natural materials, such as skins, bark, leaves, and woven twigs, worked marginally well because foods were preserved by drying, smoking, salting, or fermenting. Deficiencies in these materials led to the development of textile, wood, ceramic, and glass containers, although they also have limitations in protecting food adequately. The development of lithography in 1798 saw the rise of low-cost printing and the development of labels. Canned tomatoes were introduced around the time of American Civil War. Heat sterilisation of spoilable foods in metal and glass containers was introduced in the early nineteenth century. This was important step in the area of packaging. Following a century later was the development of frozen foods in paperboard packages that maintained the nutrition, taste, and convenience of perishables all year long. To protect pulverized tobacco from ambient moisture, metal cans were used during the period of the Industrial Revolution (James et al. 2005; Risch 2009). Later, Nicholas Appert developed the idea of using cans to preserve food for the French army. Glass bottles were then replaced by metal cans. The use of heat processing was increased when using metal cans compared with glass. In the 1890s, individual packaging was utilised for biscuits. Before this, biscuits were packaged in large containers, and customers were filled their bags with biscuits to take home. Liners inside the bags protected the biscuits from moisture. In the history of packaging, it was important step when customised packaging was invented for a product. For a tight seal of glass bottles, the metal cork was developed by William Painter in 1892. It reduced the influx of oxygen into the bottle. The packaging of food items was also influenced by the development of how customers shopped for those items (Verghese et al. 2011).

In the United States, the first supermarket came into existence in 1920. Essential requirement for the development of packaging and stores was goods in packages at that time. In New York, the concept of the "economy store" was introduced in 1907, and it was commercially successful. Due to this success, the first supermarket—named Piggly Wiggly—was opened in Memphis, Tennessee, USA, in 1916. In this type of store, customers could purchase items that were stored on shelves in aisles. In Houston, another company provided trolleys (shopping carts) to customers (Lewis 2011). The development of new distribution and packaging techniques increased during World War II. These developments include plastic films and thin metal foils and sheets. The most frequently used packaging material midway through the nineteenth century was polyethylene. The manufacturing of ethylene packaging material was patented by Imperial Chemical Industries. The process involved compressing ethylene gas and heating it to a high temperature. During the mid–twentieth century, single-use packaging containers were introduced into the marketplace to replace refillable containers to some extent. The dynamics of the distribution chain were changed by this development (Verghese et al. 2011).

Today a variety of packaging materials, such as bottles, cellophane, cartons, plastics, cans, etc., are available; however, with the development of new packaging materials, the problem of their waste management has also increased. The consumption of packaging materials is increasing drastically in almost all nations of the world. Many environmental impacts are associated with the production, operations, transportation, and disposal of packaging materials. Packaging industries play a large role in the contamination of land, air, soil, and water. Therefore, it becomes important to analyze the environmental impacts of packaging materials in terms of moving toward a sustainable future. This is due to the fact that packaging materials cannot be removed from daily life because they have become an important part of all areas of human activities; however, their environmental impacts can be controlled considerably. This can be done by evaluating the environmental impacts of packaging materials using effective methodologies that evaluate environmental indicators in quantitative terms.

3 Life Cycle Assessment (LCA) and Sustainability

LCA is an effective tool used to evaluate the environmental effects associated with a product, process, or service during its entire life cycle i.e., "cradle to grave." The concept of LCA was introduced in the early 1880s by an economist, Patrick

Geddes, who proposed efficiency improvements to the product life cycle of coal as an energy source (IPCC 2001). At an early stage, the focus of life-cycle analysis was on energy balance, technology, and society's dependency on alternate energy sources such as nuclear energy (Hulme et al. 2002). Later, LCA methodology became standardised and rapidly developed as a practice within the ISO 14040 environment standard series (Sartori and Hestnes 2007; Sayal et al. 2006). Now LCA is seen as a tool that measures the variable inputs and outputs of any consumer product, buildings, packaging, etc. One of the largest achievements of LCA is becoming a part of the sustainable decision-making process in multinational companies such as Toyota (Energy Information Administration 1997). The initial step in such companies is to develop a sustainable corporate strategy that clarifies specific business cases for sustainable development. Determining the environmental life-cycle impacts of the company's products and services will lead toward more sustainable products and services. A recent development has been seen in the life-cycle initiative wherein the United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) collaborated to develop an understanding and practice of life-cycle thinking (California Energy Commission 1998).

The term "sustainable development" came into being when the World Commission on Environment and Development published its landmark report, *Our Common Future*, in 1987. "Sustainability" can be defined as development that meets current demands without compromising the ability of future generations to meet their demands. This term represents the environmental, economic, and social balance of products and services. In 1997, John Elkington (United States Department of Energy 1999) popularized the term "triple bottom line (TBL)." TBL can be explained as a concern for "people, profit' and planet." TBL became a term to represent a common ground for sustainability following the debate over sustainable development, wherein economics must be balanced with the current and future needs of society and the environment (Arena and De Rosa 2003).

3.1 LCA Methodology

Life-cycle assessment (LCA) is a methodology that acts as a tool using qualitative assessment of materials, energy flows, and environmental impacts associated with materials and processes. It is used for systematically estimating the environmental impact of each material and process. LCA is a technique used for evaluating different parameters and aspects, e.g., greenhouse gas (GHG) emissions, associated with the fabrication of a product and its impacts throughout the lifetime (i.e., cradle to grave) of a product, e.g., extraction of raw materials, manufacturing, consumption, and disposal (Kim 1998). Life-cycle analyses are also associated with the evaluation of energy and materials used and waste material discharged into the environment during the product's life cycle. The technical framework of LCA consists of four key components that play an important role in assessment. They

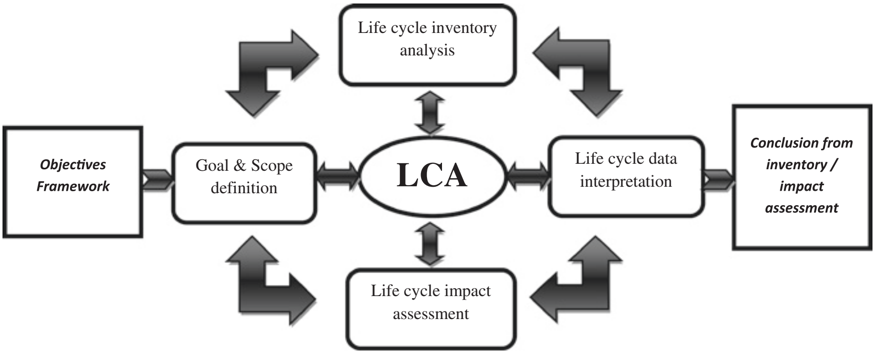

Fig. 1 Stages of life cycle assessment (Sharma et al. 2011)

are interrelated throughout the process and in accordance with the terminology of ISO (International Standards Organization). LCA methodology consists of four stages: goal and scope definition, life-cycle inventory (LCI) analysis, life-cycle impact assessment, and life-cycle interpretation (Fig. 1).

Definition of the LCA goal and scope establishes the functional unit usually focusing on the most important impact categories, system boundaries, and quality criteria for the inventory data. Common examples of LCA environmental indicators are shown in Fig. 2.

LCI analysis is associated with the accumulation and processing of data on materials and energy flows during various stages of the product's life cycle. In life-cycle impact assessment (LCIA), the environmental impacts of various flows of material and energy are assigned to different categories of environmental impact. Finally, life-cycle interpretation involves the interpretation of results from both LCI analysis and life-cycle impact assessment. It includes the identification of significant issues by pinpointing them as well as the evaluation of results, which are based on the data collected. The ISO has defined LCA as "a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (Fig. 3).

3.2 *Strength of LCA*

LCA considers all environmental hazards caused by the release of emissions to any environmental compartment. It starts from the extraction of raw materials and energy used to manufacture a product through the product's consumption or use phase to final disposal of the product. LCA encourages companies to take a better approach toward protecting the environment by choosing better methods or processes for product development. LCA acts as an "alarm" by highlighting types of environmental hazards in developing a product or process and at which stage of

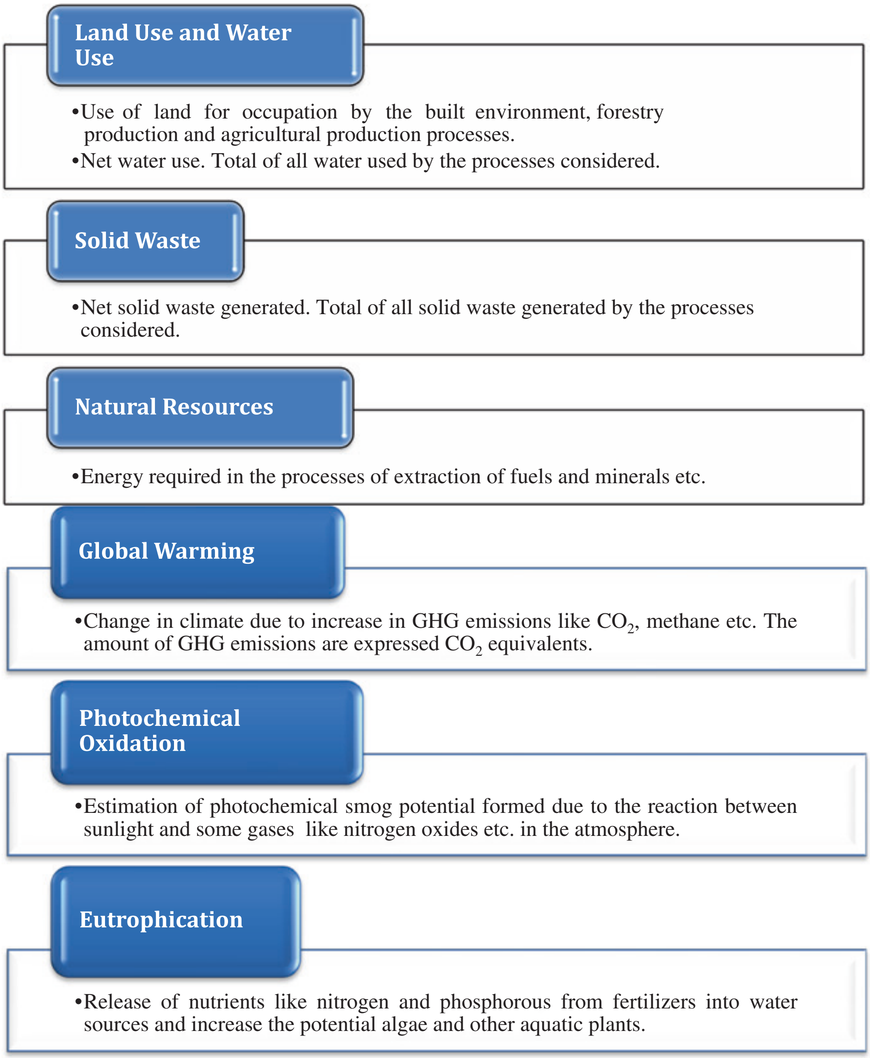

Fig. 2 Some common LCA environmental indicators

production, use, or disposal the hazard(s) will most affect the environment. LCA prioritizes products or processes that are highly likely to deteriorate the environment, and promotes ways to change that item or process to decrease its environmental impact.

Sometimes LCA can also be used as a tool for the decision maker when he or she is seeking a better alternative by comparing all of the environmental impacts caused by the production of a product. The results of LCA can help the person to choose the optimum production process as well as benefit the company from

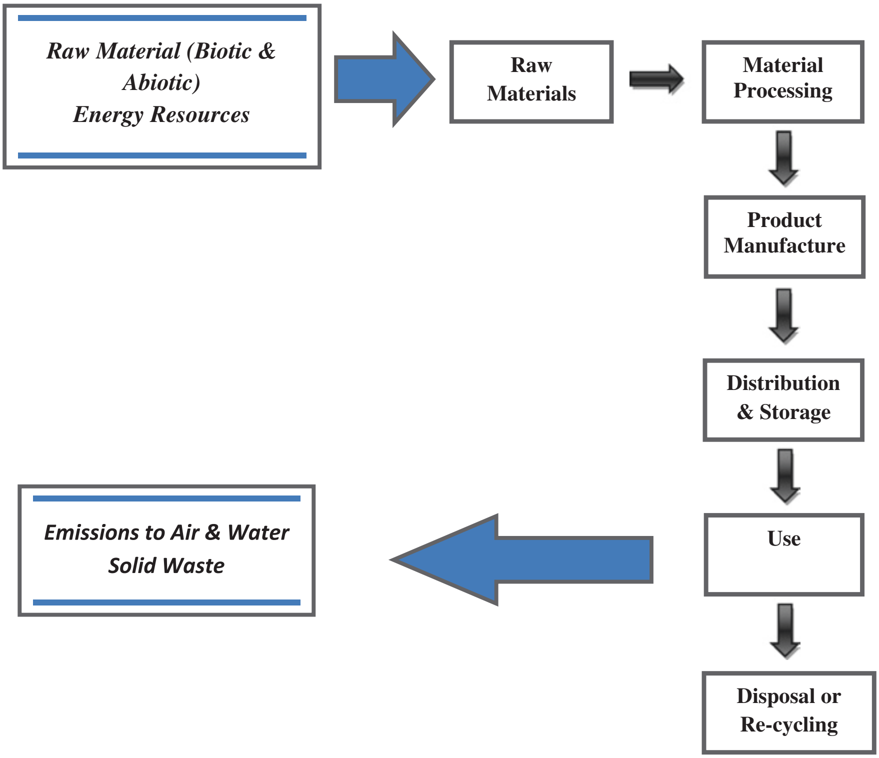

Fig. 3 Life-cycle system concept (Verghese 2008)

economic and social points of view. Although LCA has its own benefits, sometimes it can also mislead if the database is compromised; therefore, there is a need for transparency in LCA modelling (Finnveden et al. 2009).

3.3 Potential Gaps

LCA is not an easy task to perform; rather, it requires many resources, and in some cases it may consume a lot of time. If the user wants to examine all of the information in detail, data compilation may be an issue. As mentioned previously, compromising the database can lead to inaccurate or misleading results. Therefore, before performing LCA, the availability of a data source, financial resource, and time for completing the analysis must be determined. The role of LCA is to provide correct information to the user so that environmental impacts associated with the health of our environmental surroundings are correctly estimated. However, it does not account for the performance and social acceptance of the product. It is

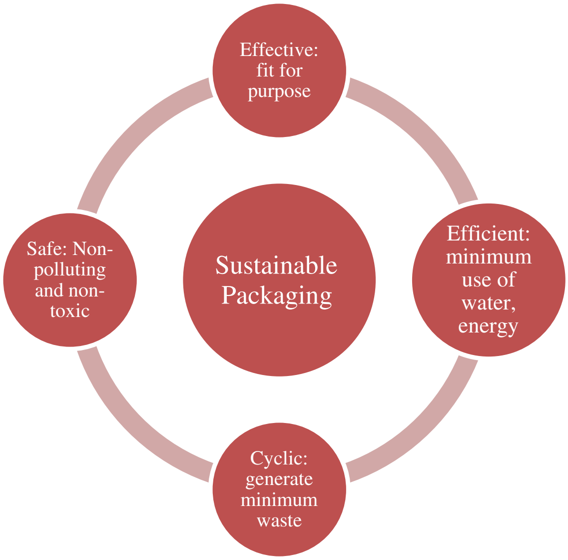

Fig. 4 Sustainable Packaging Alliance framework for packaging sustainability

not a cost-estimating analysis; hence, these factors must be assessed separately or accounted for within the company. The final decision is always made by the user; hence, the results of LCA help a decision maker make fact-based decisions.

For enhancing definitions, many sustainable packaging frameworks have been developed globally. The Australia-based Sustainable Packaging Alliance (SPA) in 2002 proposed that sustainable packaging must consider the following (Lewis 2002):

- Entire product life cycle;
- Triple bottom line (TBL); and
- Minimise environmental impacts of packaging

SPA has optimised their approach over time by adding a series of key performance indicators (KPIs) to four strong pillars of a framework for sustainable packaging (Fig. 4) (Lewis 2011).

4 Life-Cycle Assessment (LCA) in the Packaging Industry

A considerable number of LCAs were performed during the 1980s and 1990s on food packaging due to new packaging formats. For packaging of carbonated beverages, aluminium cans were used after tin-plated steel cans in the 1950s. A can opener was used for opening metal-can packaging. After 1963, the ring pull was introduced, and the stay tab was introduced in 1975. In recent times, application of modified-atmosphere packaging has increased. Due to such types of packaging, the shelf life of the product has lengthened. The speed of oxidation decreases when using gases, such as nitrogen or carbon dioxide, and reduces the growth of aerobic bacteria growth. Compared with bulk packaging, single-serve packaging has grown more in recent years. Single-serve packaging does not contain food in bulk quantities; only a defined quantity of food or beverage is contained by such packaging.

There exists a balancing act between appropriate serving size and changes in demographics and lifestyles. In Western society, as households become smaller and working hours outside the home increase, manufacturers are introducing smaller serving sizes and ready-to-go meals. As lifestyles continue to change, packaging is also trying to meet the challenge of delivering product. One must not forget that this rapid demand for packaging comes with environmental consequences that must be acknowledged, managed, and balanced (Verghese 2008).

4.1 Case Studies

During the last five decades, one of the main applications of LCA has been in the food- and beverage-packaging industry. For the packaging of food and beverages, the most commonly used packaging materials used today are glass, tin cans, and plastic. In 1969, Coca Cola was the first company to undertake such a study; at the time it was known as “resource and environmental profile analysis” (REPA). This was at the time when single-use packaging containers were being introduced to the market, and Coca Cola was interested in knowing the environmental profile of such types of packaging material compared with refillable containers. Since then, LCAs have been undertaken on many different packaging formats across the world to better understand the dynamics of materials selection, inform the design of packaging formats, and argue for better waste-management practices of used packaging (Lewis 2011). Packaging is designed in the most efficient manner to serve its purpose. Various LCA studies were performed to understand the impacts of packaging on the environment by considering it as a part of a product’s life cycle. In most cases, approximately 2–5 % of overall environmental impacts are from packaging in the case of foods and 25 % in the case of beverages (Verghese et al. 2013).

Numerous packaging materials are available globally for food and beverage packaging. A study performed by Huang and Ma (2004) showed that the most common and popular packaging materials are polyethylene terephthalate (PET) containers, high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), steel containers, aluminum containers, glass, cardboard boxes, liquid paperboards (LBP), etc. The study was performed using an integrated approach involving a combination of qualitative and quantitative methodologies. In an LCA approach, which is quantitative, aluminum and glass containers are considered to be less environment friendly because of the carcinogen and heavy metals emitted during their production; however, in a qualitative approach, the results are the opposite (Huang and Ma 2004). Therefore, a material cannot be judged as better compared with another material until the former performs well in all of the environmental measures, i.e., from packaging production, including raw material extraction, to the end its life.

According to Sebastien et al. (2009), in a comparison was performed between two baby food alternatives, i.e., glass jar versus plastic pots, plastic pots were deemed more beneficial than glass jars (Sebastien et al. 2009). The methodologies included in the study were IMPACT 2002+ and CML 2001. The environmental impacts reduced with the use of plastic pots instead of glass jars were 14–27 % of energy, 28–31 % for global warming potential, 31–34 % for respiratory inorganics, and 28–31 % for terrestrial acidification/nitrification. These benefits are due to production process, the light weight of the plastic, and the preservation process.

An LCA was performed on beer to calculate the environmental impacts and to determine possible betterment in the production and distribution phases. The stages included were the agriculture phase to the product delivery phase, but the consumption phase was excluded. The functional unit used was 505 multipacks of bottled beer. For calculation of KCL-ECO and for impact assessment, the DAIA 1998 method was used in the life-cycle assessment phase. Raw-water treatment, energy production, and contribution of oxygen depletion, eutrophication, summer smog, climate change, and acidification were also taken into consideration. In terms of both economic and environmental benefits, it was further recommended to optimize transport and to determine ways to diminish waste generation and save electricity.

As previously discussed, one of the major problems associated with packaging is waste management. After their use, many packaging materials end up in landfills. This problem can only be solved if the packaging material decays or decomposes along with the food item stored in it so that both can be disposed of together. The preferred option in the UK for dealing with organic waste is composting (www.defra.gov.uk). Composting is an environmentally responsible waste-management option involving the biodegradation of organic materials under aerobic conditions (Song et al. 2009).

Biodegradable polymers can be developed from renewable or nonrenewable (fossil) energy resources (Scott 2000). In a United States–based study performed in a school of packaging, the Michigan State University assessed the environmental profile of PET (polyethylene terephthalate), PS (polystyrene), and PLA (polylactic acid) containers. The methods used were ISO standards 14040, 14044, and 14049 as well as ASTM standard 7075. In this study, processes from corn-harvesting to corn-cracking were considered. The data of study were taken from Europe, North America, and the Middle East, and 1000 containers having a 1-pound capacity served as the functional unit. The environmental impacts measured were global warming, aquatic ecotoxicity, aquatic eutrophication, ozone depletion, aquatic acidification, respiratory organics and inorganics, nonrenewable energy, and land occupation. The results of the study showed that PLA (biodegradable) had a smaller environmental footprint than the petroleum-based PS, PP, and PET; among all choices, PET had the greatest impact value in terms of the respiratory inorganics, nonrenewable energy, and global-warming categories except for respiratory organics and aquatic acidification (Madival et al. 2009).

To know the complete performance of a packaging material, it is necessary to see the recycling phase of LCA. An Italian-based joint research team (CONAI) studied the Italian system of plastic packaging recycling and collected and mechanically recycled PET and PE liquid containers. The "basket-of-products" method is used for the comparison of resource consumption and environmental pollution by different management scenarios producing different products. It was concluded that the tool used is beneficial for the comparison of political waste-management scenarios. The amount of energy used for the production of 1 kg of recycled PE and PET is the lowest amongst all of the material compared in the study (Arena et al. 2003). However, other studies have given importance to the comparison of waste disposal with recycling (Craighill and Powell 1996). The methodology used is "life-cycle evaluation" (a combination of life cycle assessment plus economic evaluation). One tonne each of glass, paper, steel, aluminum, HDPE, PET, and PVC plastic waste were analysed separately, and comparison was made between the recycling system and its management by a waste-disposal system. It was found that the waste-disposal system contributed more to global warming than does recycling.

Toniolo et al. (2013) performed a study to determine to what degree the recycling of packaging is environmentally friendly. Comparison was made with the environmental effects of plastic food packages (multilayered plastic tray, PET tray), and how much the end-of-life treatment affects the environment was measured quantitatively. For multilayer film, the treatments are land-filling and incineration; for mono-material the treatments are recycling, land-filling, and incineration. The methods used were ReCiPe 2008, IMPACT 2002+ for impact assessment, CUT OFF approach for recycling, and Monte-Carlo technique for uncertainty analysis. Result shows that packaging by using recyclable material is preferable over the packaging material which is not recyclable.

In India, the All India Glass Manufacturers' Federation (AIGMF) engaged with PE sustainability solutions Pvt. Ltd. (PESSPL) to perform LCA of glass containers compared with alternative packaging (PET, aluminium can, carton, and pouch). The objectives of the study were (1) to evaluate the environmental footprint of glass containers compared with the alternatives and (2) to help AIGMF member companies project a "green image" of their product among consumers and stakeholders. CML 2001 method was used for the evaluation of environmental impacts. The functional unit was taken as 180 ml of liquor in a glass, PET, carton, or pouch container. The study found that emission, material inputs, and energy were affected over time by increasing the use of an abatement system, efficiencies, rebuilds, and cleaner technologies. It was recommended that for improvement in light-weighting, a "narrow-neck press-and-blow" technique should be used to package the liquor. In addition, importance was given to increasing the use of natural gas and renewable energy as well as the reuse of secondary materials (www.packagingconnections.com).

Table 1 Summary of examples of food and beverage packaging LCAs

Food/beverage item	Packaging type	Outputs
Retail packaging		
Milk	Glass HDPE, LLDPE, and PC pouches	Refillable HDPE preferred
Baby food	Glass jars versus plastic pots	
Coffee and butter	Flexible packing	Single-serving packaging; plastic preferred
Beer	Aluminium beverage cans	
Industrial packaging		
Large cartons	Reusable plastic pallets versus wooden pallets	Reusable plastic pallets have lower environmental impacts compared with wooden pallets

Detzel and Monckert (2009), Busser and Jungbluth (2009), Humbert et al. (2009), Madival et al. (2009), Falkenstein and Wellenreuther (2010), Keoleian and Spitzley (1999), Lee and Xu (2004)
HDPE high density polyethylene; *LLDPE* linear low density polyethylene

Most studies have been focused on the retail packaging level, whereas some have looked at industrial packaging (Table 1). There is no straightforward answer to which packaging format is best. The answer depends completely on geographical situation, functional, data quality, assumptions made, system boundaries selected, available waste-management practices, capture rates of materials, and the context of the situation.

The assessment of a packaging system is focused, but it does not consider the effect of foods and beverages. This is due to government and consumer concerns regarding environmental impacts of the actual packaging materials themselves without significant attention being paid to what is within the packaging (Williams et al. 2008). As the results of agricultural and food-production system studies have shown, the greater environmental impact of the product-packaging system involves the food or beverage contained within the packaging, not just the packaging materials themselves (Roy et al. 2009; Erlov et al. 2000; Jungbluth et al. 2000). For example, the overall resource efficiency of a coffee-packaging system is increased by packaging the coffee in a single-serving packet by decreasing material losses incurred during other coffee life-cycle stages such as production and use. Impacts associated with the production of the product itself are greater than the impacts related to the packaging production. A framework provided by LCA methodology can be utilised to measure the environmental impacts created by producing the product as well as the packaging (Busser and Jungbluth 2009).

Humbert et al. (2009) studied the comparative primary energy and greenhouse-gas emission impacts of glass jars versus plastic pots for baby food. Given the same mode of transportation, 14–27 % less primary energy is needed to transport plastic pots, and the production of plastic pots generates 28–31 % less global warming potential impact than the glass option. To influence the final impacts of the two alternatives, the actual material production, packaging weight, and on-site preservation parameters were identified. Keoleian and Spitzley (1999) compared HDPE, linear low-density polyethylene (LLDPE), glass paperboard carton, pouches, and polycarbonate packaging systems for the delivery of 1000 gallons of milk. Refillable HDPE, polycarbonate bottles, and flexible pouches were identified as preferable by the study. To understand the environmental impacts of three clamshell-packaging options made of PLA, PET, or PS, all three materials were evaluated by applying a life-cycle framework. PET was the least preferred option due to the greater weight of the containers. Resin production and transportation contributed to the environmental impact exerted by the packaging option (Madival et al. 2009).

Utilising multiple indicators as recommended by Roy et al. (2009) was used to compare the different environmental impacts of food options. All trade-offs associated with one specific mode of production compared with another could not be captured using a single indicator. For example, organic production is the preferred option when comparing conventional with organic agricultural practices. However, a more complete life-cycle study must also consider arable land use as a metric when comparing both agricultural practices because greater amounts of arable land are consumed by organic production to deliver the same service.

Shopping bags are also popular for the temporary packaging of items. Due to their ease of use, they are widely employed throughout the world. Muthu et al. (2011) performed a study to evaluate the carbon footprints of various shopping bags, e.g., plastic, paper, nonwoven, and woven type, using LCA technique with SIMAPRO 7.2. The study was performed for bag-users in Hong Kong, India, and China. The results showed that the carbon footprints of shopping bags are high in the absence of proper use and disposal options. In addition, the reuse of bags was found to be an important measure to significantly reduce carbon footprints. Another study was performed by Muthu et al. (2009) on plastic and paper bags, and their environmental impacts were compared using LCI data. Data on energy consumption and emissions during the manufacturing phase were used for LCI data. Plastic bags were found to be better than paper bags from an environmental point of view.

Muthu et al. (2013) has discussed a novel test instrument to estimate the eco-functional properties in terms of the reusability, impact strength, and weight holding–capacity of shopping bags. Result shows that paper bags were found better than plastic bags for single use category, whereas plastic bags were found superior in reusable category.

The energy flows associated with packaging are low when comparing the amount of energy invested in the various sectors involved in food production. According to previous investigations, total primary energy consumption is in the range of 7.3–10 units to produce 1 unit of food energy in the United States (Hall et al. 1986; Heller and Keoleian 2003). Manufacturing packaging material contributes 9 % of the total energy invested to produce food. Manufacturing packaging material consumes 1000 PJ out of the 11,000 PJ consumed yearly by the United States food sector (Pimentel and Pimentel 1996). In addition, the rapid conversion of prime farmland, the political problem of illegal workers, the depletion of topsoil, and the rate of groundwater withdrawal were identified as the key parameters posing a significant risk to the long-term sustainability of the United States food sector. In food production, the impacts of manufacturing packaging materials are less than impacts contributed by other sectors such as transportation, processing, and agricultural production.

5 Improvement in Sustainability Packaging Using Life-Cycle Thinking

Numerous environment-evaluation tools help in making the quick decisions that can be required in selection, design, and packaging system formats. The development of tools extend from guidelines and paper-based checklists to Internet-accessible evaluation tools and interactive and life-cycle based analytical tools incorporating life-cycle methodology as a fundamental component (Verghese and Lockrey 2011). A summarized detail of available tools is tabulated in Table 2. A series of packaging objectives is presented in the table along with a tool that could be helpful in addressing the objective concerned. Information about the results obtained from each tool, along with a description on how to find more information on the particular tool, is briefly presented. An in-depth detail of tools describing their features, data sources, ease of use, types, timing of use, and rationales can be found in the available literature.

To render these tools effective, it is vital to have in place well-documented and -communicated processes that guarantees implementation. The important requirements to be considered for the selection and implementation of decision-support tools for a new product-development process are as follows (Verghese 2008):

- The tool must enable a simple work flow for the user by being instinctual, easy to communicate, and logical.
- The tool should fit into the company's culture.
- The tool should require the least amount of set-up time to make use of it.
- The tool should require less data-input requirements so as to make it user-friendly (i.e., the user should easily understand the benefits and features of the tool).
- The tool should present the results in a visually appropriate layout that is easily adoptable.
- The tool should include matters that relate to users on a day-to-day basis.

Table 2 Selection of packaging evaluation tool

Packaging objective	Suitable tool to use	Type of result
Obtain a general idea of the supply chain of a packaging system	Life-cycle map	Provides the design team with high-level scan of key materials and processes and allows the team to become familiar with potential environmental impacts across the supply chain
Design a new packaging system or update an existing design and begin an assessment of environmental impact and credentials of the design	Guidelines	Contains questions relevant to the materials and design of packaging and highlights particular areas, e.g., material selection and end-of-life issues, where additional information may be required
	Sustainable Packaging Alliance—packaging sustainability framework	Relates the four guiding principles of packaging sustainability (efficient, effective, cyclic, and safe) and identifies design strategies per principle and performance indicators (Sustainable Packaging Alliance 2010)
	Australian Sustainable Packaging Guidelines	Assessment of environmental impact and credential of packaging design and criteria (APCC 2009)
	Sustainable Packaging Coalitions–Design Guidelines For Sustainable Packaging	DfS background and strategies based on packaging environmental-impact credentials and criteria (Design guidelines for sustainable packaging 2006)
	WRAP–Guide to evolving packaging design	DfS data on consumer views, law, brand, innovation, tools, technique, and materials consideration; provides further links and glossary
	Envirowise–packaging design for environment	General packaging information, regularity data, material figures, and links to further reports (Envirowise 2008a)
	Envirowise–pack guide; a guide for packaging eco-design	Design-focused information on material regularity data and link to further resources (Envirowise 2008b)
Evaluate the environmental profile of several different packaging material combination	Packaging-specific analytical tool	Provides life cycle-based environmental information

(continued)

Table 2 (continued)

Packaging objective	Suitable tool to use	Type of result
Perform a quick scan of industry benchmark for packaging weight by material/formal		Provides industry average data on packaging-material weight for a range of packaging applications
Screen packaging design against alternatives	EDIT	Generates comparative graphical/tabular results for a range of environmental indicators for up to six different designs (Envirowise 2010)
	Wal-Mart–Package Modelling	Life cycle–based environmental impact metrics including comparative analysis and report exporting (Walmart 2008)
	Toyota–EPIC	Toyota packaging environmental indicator comparison, life-cycle cost comparison, life-cycle stage analysis, and life-cycle inventory
Screen packaging design against alternatives	Packaging-Specific LCA-based analytical tool	
	PIQET	Rapid streamlined environmental-impact assessment including comparative, tabulated graph- and inventory-based reporting; reports a range of packaging-sustainability metrics (Verghese et al. 2010)
	COMPASS	Reports include component contribution, comparative life-cycle assessments, and packaging attributes that are important to a designer (COMPASS 2009)
Model in detail the life-cycle environmental impacts of primary and alternative packaging systems and/or publish results	Life-Cycle Assessment Software	
	SimaPro	Detailed and flexible quantitative life-cycle environmental impact of a packaging system's full comparative and sensitive capability
	GaBi	Detailed and flexible quantitative life-cycle environmental impact of a packaging system's full comparative and sensitive capability

Certain things that should be taken into consideration include the following (Verghese and Lockrey 2011):

1. Who is the person in the organization using LCA as a tool?
2. The amount of detail required by the person performing LCA must be defined.
3. Why is LCA needed, and when is the right time to perform it?

5.1 Answering to Supplier Demands

Several suppliers are currently looking to apply sustainability initiatives through their supply chain, which often translates to food producers following new protocols and using new tools to attain these goals. Any place where environmental metrics are concerned, measurements are often underpinned by LCA data or methodology. Sustainable innovation products have an enhanced and improved environmental profile in which the enhancements are substantial and evident. To meet the requirements for sustainability, a product must show at least 10 % improvement throughout its life cycle in one of the crucial indicators—such as consumption of energy and/or water, total materials used for the product and its packaging, transport, or the application of renewable energy sources (instead of nonrenewable resources)—along with no noticeable worsening in any of the other indicators (White 2009).

In this definition, it is now a prerequisite now for supply chains to report a number of environmental indicators through the newly introduced supplier environmental sustainability scorecard. A strong use of life-cycle thinking creates environmental improvement involving "trade-off" decisions so as not to damage one indicator for the sake of other (e.g., focusing on carbon emissions only to see water and land use increase). As an additional sign of proactivity, Walmart has established a packaging scorecard and, more recently, a software platform called "Package Modelling," which permits supplied groups to be ranked and aggressively improved by modelling various improvements in design and increasing their rank in real time. These tools are also incorporated along with Walmart's already tested supply chain-management system, which exploits life-cycle data, both primary and generic, throughout the ranking process.

Private-sector supply chain alliances, e.g., those from Walmart and Proctor and Gamble, complement industry-based initiatives such as the Sustainable Packaging Coalition (SPC) in the US and the Sustainable Packaging Alliance (SPA) in Australia. These organizations have designed procedures and protocols that reinforce life-cycle thinking and deliver a platform for companies via the supply chain to vigorously cooperate in decreasing the environmental influence of food- and beverage-packaging products.

6 Future Scope

Future challenges exist related to application of LCA in the packaging industry, and they mostly concern low-carbon economy. It has been suggested by the Intergovernmental Panel on Climate Change (IPCC) that a 50–85 % reduction in CO_2-equivalent gases is required by 2050 to prevent a 2–2.4 °C increase in global temperature (IPCC 2007). Application of LCA in the packaging industry has several implications as follows:

1. increased accountability to customers regarding the ecological impact of packaging;
2. assisting packaging designers to reduce the ecological impact of packaging by shifting LCA from a reflective tool to an action-orientated decision-making tool; and
3. consideration to including food in up-scaling the functional unit within the packaging industry due to substantial emissions from food production.

6.1 Increased Demands from Consumers

There is a growing trend for businesses to be accountable for their actions under the banner of "corporate social responsibility." Sustainable packaging strategies have recently been introduced by Marks and Spencer and Walmart. Various indicators—e.g., $CO_{2eq.}$/tonne and innovation to meet their target of 5 % reduction in packaging across the supply chain—are addressed in Walmart's packaging scorecard. Different brands. such as Cadbury and Coca-Cola. have good CO_2–reduction targets in place. For example, to reduce 50 % of absolute carbon emissions by 2020 and reduce packaging used per tonne of product by 10 %, Cadbury's "purple goes green" commitment is in progress (www.cadburyinvestors.com). In addition, 92 % of retail markets in the UK are signatories of the Courtauld Commitment. This commitment aims to improve resource efficiency and reduce carbon emissions and the broader environmental impact of the retail grocery sector. These types of strategies require the packaging industry to be accountable for its ecological impacts, and LCA is well suited to measure such.

The packaging industry is facing increased consumer pressure to counter its image as the "visible face of waste" within the household. LCA plays an important role in communicating the worth of packaging in preserving and protecting the product. For example, due to advanced packaging solutions, there is only 2 % food waste in the supply chain in Europe as compared with 30 and 50 % food waste in developing countries (PricewaterhouseCoopers LLP 2010). To counter consumers' perceptions, the objective approach of LCA will be increasingly required. Voluntary carbon-labelling schemes have been trialled for food (Hogan and Thorpe 2009) in various countries as follows:

- United Kingdom (Carbon Trust)
- United States (Carbon Fund)
- Germany (Product Carbon Footprint pilot labelling scheme)
- Sweden (Climate Marking) and the European Union (carbon footprint measurement toolkit),
- Japan (30 companies have participated in a pilot scheme funded and coordinated by the Japanese Ministry of Economy, Trade and Industry)
- South Korea (CooL Label)
- Thailand (carbon label being developed by the Thailand Greenhouse Gas Management Organisation)

In the United Kingdom, consumers of products associated with CO_{2eq} emissions are informed by the United Kingdom's Carbon Trust label across the entire life cycle of the product. The Carbon Trust label consists of four "sub-labels": (1) the footprint, (2) the carbon footprint estimation expressed in CO_2-equivalent terms, (3) an endorsement by the Carbon Trust, and (4) a commitment by producer to minimise emissions (Hogan and Thorpe 2009). An educational component is included as an optional element to explain how the carbon footprint is calculated. This provides the packaging industry an opportunity to communicate the worth of the packaging. In allowing customers the advantage of knowing a product's carbon impact during its life cycle, the combination of sub-labels in the Carbon Trust label gives the consumer a full picture of the environmental consequences of purchasing, using, and disposing of a particular product (e.g., water use or human toxicity).

7 Conclusion

The consumption of packaging materials is increasing at a high rate throughout the world. Packaging materials are used in almost all areas of activities and have become a basic need in various industries. Many packaging materials can be recycled, but many environmental problems are associated with doing so. Thus, it is important to evaluate the environmental impacts of packaging materials throughout their entire life cycle and to considerably reduce their harmful effects on the environment. LCA as tool gives us the opportunity to identify the "grey areas" that affect our environment and thus indirectly affect us. Considering the effects of environmental issues associated with packaging materials, global investors now must develop alternate means of packing. Increased awareness toward environmental hazards is one of the major factors fuelling the global demand for green packaging. Due to this, considerable efforts are being made to decrease toxic waste and GHG emissions. Green packaging results in fewer toxic emissions and causes less pollution. Moreover, initiatives to clean up the environment, as well as strict regulations and monitoring agencies, are being enacted by governments globally.

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