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Life cycle assessment of food

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ABSTRACT : Life cycle assessment is an effective tool in assessing the environmental performance of product or process or service. Life cycle assessment is a "cradle-to-grave" approach for assessing industrial systems. It means that assessment starts from the extraction of raw material from the ground and end at a point where final waste or used product is returned to the ground; therefore cradle-to-grave approach avoids 'problem shifting'. Global warming is a serious and far-reaching challenge facing us. Global temperature is increasing and human activities are the primary cause. The food industry is one of the world's largest industrial sectors and hence, a large consumer of energy which leads to environmental pollution. It is, thus, essential to evaluate the environmental impact and the utilization of resources in food production and distribution systems for sustainable consumption. The review involves the identification of best available practice in establishing a database for the life cycle inventory phase, and a list of environmental impact categories and accompanying factors to address these impact categories.

KEY WORDS : Life cycle assessment, Environmental impact, Inventory phase

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We are witnessing a scenario where overexploitation of natural resources and degradation of environment in the developmental process has brought our planet earth at the verge of losing its balance which posing a threat to human survival. Therefore, sustainability in the development process has become the core issue and has assumed a global dimension.

Scientific opinion also holds that the threat posed will become more severe over coming decades (Intergovernmental Panel on Climate Change 2001) from both the greenhouse gases we have already emitted and from those we are continuing to emit. It is vitally important that governments, business and the community act now to reduce greenhouse emissions and adapt to climate change.

Although the environment sustainability aspects of food production have different imperatives in developing and developed countries, they are facing certain similar challenges like conservation of soil and nutrient status wise utilization of fertilizers, selection and preservation of productive gene stock, careful use of agents for controlling diseases, efficient use of resources especially water and energy, minimization of waste, careful disposal of waste and productive use of by- products. The food industry is one of the world's largest industrial sectors and, hence, a large consumer of energy which leads to environmental pollution. It is, thus, essential to evaluate the environmental impact and the utilization of resources in food production and distribution systems for sustainable consumption. Consumers in the developed countries demand safe food of high quality that has been produced with minimal adverse impact on the environment.

Life cycle assessment had its beginnings in the 1960's. In 1969; researchers initiated an internal study for The Coca-Cola Company that laid the foundation for the current methods of life cycle inventory analysis in the United States. Life cycle assessment is a "cradle-to-grave" approach for assessing industrial systems. It means that assessment starts from the extraction of raw material from the ground and end at a point where final waste or used product is returned to the ground; therefore, cradle-to-grave approach avoids 'problem shifting'. Most important, a cradle-to-grave analysis involves a 'holistic' approach, bringing the environmental impacts into one consistent framework, wherever and whenever these impacts have occurred, or will occur. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle. In ISO 14040 (see below) LCA is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle".

The main applications of Life cycle assessment are in:

– Analyzing the origins of problems related to a particular product;

– Comparing improvement variants of a given product;

– Designing new products;

– Choosing between a numbers of comparable products.

International developments:

Its history goes back to the early seventies, though in the past, it went by different names such as resource and environmental profile analysis (REPA), energy analysis or product ecobalance.

SETAC :

SETAC (the Society of Environmental Toxicology and Chemistry) was the first international body to act as an umbrella organization for the development of LCA. It is a scientific organization with its roots in academia, industry and government. SETAC's involvement with LCA dates from 1989, when its first workshop was held in Smugglers Notch, Vermont.

ISO:

ISO (the International Organization for Standardization) is a world-wide private organization, including national bodies from both industrialized and developing countries, which aims to standardize a wide range of products and activities.

The 14000 series of ISO standards includes the standard 14001 on environmental management systems, as well as a series of standards relating to LCA (the 14040 series). These ISO activities began in 1994 and aimed to produce the first complete series of LCA standards.

The ISO LCA standards concern the technical as well as organizational aspects of an LCA project. The organizational aspects mainly focus on the design of critical review processes, with special attention to comparative assertions disclosed to the public.

UNEP:

A third international player in the field of LCA is UNEP (the United Nations Environmental Programme), represented by its Department of Technology, Industry and Economics in Paris. UNEP's focus is mainly on the application of LCA, particularly in developing countries. The task involves the identification of best available practice in establishing a database for the life cycle inventory phase, and a list of environmental impact categories and accompanying factors to address these impact categories.

Frame work:

The LCA process is a systematic, phased approach and consists of following four components (Fig. 1).

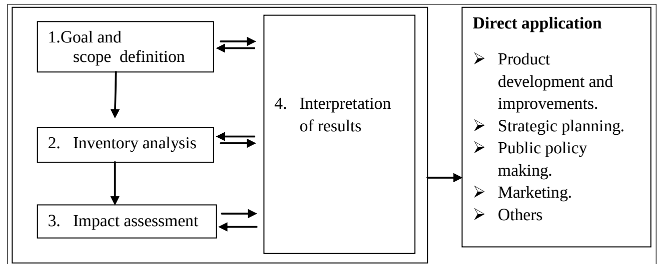

Fig. 1 : Phases in life cycle assessment and applications

Goal definition and scoping (ISO 14041):

Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment. The goal establishes 'Function and Functional Unit'. Careful selection of the functional unit to measure and display the LCA results will improve the accuracy of the study and the usefulness of the results. In comparing two or more product, functional unit selection is useful.

The goal must be revisited periodically as the study progresses to ensure consistency of data collection with end use of the results. In this phase following information is determined: the type of information which adds value to final decision, how accurate result must be to add the value and how the result must be interpreted and displayed in order to be meaningful and usable. Goal definition and scoping of LCA project will determine the time and resources needed and it will also guide the entire process to get the meaningful results.

The primary goal is to choose best process, product or service which has least effect on human health and environment. Conducting LCA can also help to guide the development of new process, product or service. There may be secondary goals in conducting the LCA which vary depending upon the project. e.g. to support public policy, to support product certification, to rank the relative contribution of individual steps or process, to identify the data gaps, to guide the product and process development.

Inventory analysis (ISO 14041):

A life cycle inventory is a process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, process, or activity. Following four steps of a life cycle inventory:

Develop a flow diagram of the processes being evaluated:

A flow diagram is a tool to map the inputs and outputs to a process or system. The “system” or “system boundary” varies for every LCA project. The goal definition and scoping phase establishes initial boundaries that define what are to be included in a particular LCA; these are used as the system boundary for the flow diagram. Unit processes inside the system boundary link together to form a complete life cycle picture of the required inputs and outputs (material and energy) to the system.

Develop a data collection plan :

Defining data quality goals – No pre-defined list of data quality goals exists for all LCA projects. The number and nature of data quality goals necessary depends on the level of accuracy required to inform the decision-makers involved in the process.

Identifying data sources and types – It determines if data quality requirements have been met. There is no pre-defined list of data quality indicators for all LCIs. Examples of data quality indicators are precision, completeness, representativeness, consistency, and reproducibility.

Identifying data quality indicators – For each life cycle stage, specify the necessary data source and/or type required to provide sufficient accuracy and quality to meet the study’s goals. Defining the required data sources and types prior to data collection helps to reduce costs and the time required to collect the data.

Developing a data collection worksheet and checklist:

The next step is to develop a life cycle inventory spreadsheet that covers most of the decision areas in the performance of an inventory. A spreadsheet can be prepared to guide data collection and validation and to enable construction of a database to store collected data electronically. The spreadsheet is a valuable tool for ensuring completeness, accuracy, and consistency. It is especially important for large projects when several people collect data from multiple sources.

Collect data :

Data collection efforts involve a combination of research, site-visits and direct contact with experts, which generates large quantities of data. As an alternative, it may be more cost effective to buy a commercially available LCA software package.

A second method to reduce data collection time and resources is to obtain non-site specific inventory data. Several organizations have developed databases specifically for LCA that contain some of the basic data commonly needed in constructing a life cycle inventory.

Impact assessment:

This step should be completed as part of the initial goal and scope definition phase to guide the LCI data collection process and requires reconsideration following the data collection phase. The items identified in the LCI have potential human health and environmental impacts.

For an LCIA, impacts are defined as the consequences that could be caused by the input and output streams of a system on human health, plants, and animals, or the future availability of natural resources. Three main categories: human health, ecological health, and resource depletion.

Classification :

The purpose of classification is to organize and possibly combine the LCI results into impact categories. For LCI items that contribute to only one impact category, the procedure is a straightforward assignment. For example, carbon dioxide emissions can be classified into the global warming category.

Characterization :

Impact characterization uses science-based conversion factors, called characterization factors, to convert and combine the LCI results into representative indicators of impacts to human and ecological health. Characterization provides a way to directly compare the LCI results within each impact category. In other words, characterization factors translate different inventory inputs into directly comparable impact indicators. For example, characterization would provide an estimate of the relative terrestrial toxicity between lead, chromium, and zinc.

Normalization:

Normalization is an LCIA tool used to express impact indicator data in a way that can be compared among impact categories. This procedure normalizes the indicator results by dividing by a selected reference value.

Grouping :

Grouping assigns impact categories into one or more sets to better facilitate the interpretation of the results into specific areas of concern. Typically, grouping involves sorting or ranking indicators (ISO, 1998).

Weighting :

The weighting step (also referred to as valuation) of an LCIA assigns weights or relative values to the different impact categories based on their perceived importance or relevance.

Evaluate and document the LCIA results:

Now that the impact potential for each selected category has been calculated, the accuracy of the results must be verified. The accuracy must be sufficient to support the purposes for performing the LCA as defined in the goal and scope. When documenting the results of the life cycle impact assessment, thoroughly describe the methodology used in the analysis; define the systems analyzed and the boundaries that were set, and all assumptions made in performing the inventory analysis.

Interpretation (ISO 14043) :

Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

ISO has defined the following two objectives of life cycle interpretation:

Analyze results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the LCA, and to report the results of the life cycle interpretation in a transparent manner.

Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study (ISO, 1998b).

The purpose of conducting an LCA is to better inform decision-makers by providing a particular type of information (often unconsidered), with a life cycle perspective of environmental and human health impacts associated with each product or process. However, LCA does not take into account technical performance, cost, or political and social acceptance. Therefore, it is recommended that LCA be used in conjunction with these other parameters.

Conclusions, recommendations and reporting :

The objective of this step is to interpret the results of the life cycle impact assessment (not the LCI) to determine which product/process has the overall least impact to human health and the environment, and/or to one or more specific areas of concern as defined by the goal and scope of the study.

If an LCIA stops at the characterization stage, the LCIA interpretation is less clear-cut. The conclusions and recommendations rest on balancing the potential human health and environmental impacts in the light of study goals and stakeholder concerns.

Limitations of conducting an LCA:

Performing an LCA can be resource and time intensive. Depending upon how thorough an LCA the user wishes to conduct, gathering the data can be problematic, and the availability of data can greatly impact the accuracy of the final results. Therefore, it is important to weigh the availability of data, the time necessary to conduct the study, and the financial resources required against the projected benefits of the LCA.

LCA will not determine which product or process is the most cost effective or works the best. Therefore, the information developed in an LCA study should be used as one component of a more comprehensive decision process assessing the trade-offs with cost and performance, e.g., Life cycle management. The life cycle inventory (LCI) analysis quantifies the resources use, energy use, and environmental releases associated with the system being evaluated. It has been reported that agricultural LCAs often exclude production processes of pesticides, machines, buildings, and roads because of lack of data (Cederberg and Mattsson, 2000). In this study, environmental impact of agricultural chemicals was considered, but that related to the construction of packaging and storage facilities, transport, and other machinery used was not, because of lack of data; emissions from tomato waste were not considered either.

As mentioned earlier, an LCA can help identify potential environmental tradeoffs. However, converting the impact results to a single score requires the use of value judgments, which must be applied by the commissioner of the study or the modeler. This can be done in different ways such as through the use of an expert panel, but it cannot be done based solely on natural science.

Environmental supply chain management:

One of the most significant paradigm shifts of modern business management is that individual no longer compete as solely autonomous entities, but rather as supply chains (Christopher, 1998). Executives are becoming aware that the successful co-ordination, integration and management of key business processes across members of the supply chain will determine the ultimate success of the single enterprise (Vorst van der, 2000).

Recently, more attention has been given to environmental supply chain management (ESCM) defined as "the set of supply chain management policies held, action taken, and relationship formed in response to concerns related to the natural environment with regard to the design, acquisition, production, distribution, use, reuse and disposal of the firm's goods and services" (Zsidisin and Siferd, 2001). Life cycle assessment (LCA) can be seen as main instrument of ESCM. LCA is a context-dependant tool.

Environmental care strategies, type of LCA and supply chains (Fig. 2):

Different organizations strive for different goals, which impact the type of LCA that is most suitable in a specific situation. Following care strategies applicable to individual companies and supply chains (Vermaak, 1995; Spliethoff and van der Kolk, 1991; van Koppen and Hagelaar, 1998):

Process oriented strategy: strive for control of the environmental burden caused by the production process by means of production integrated measures that achieve both

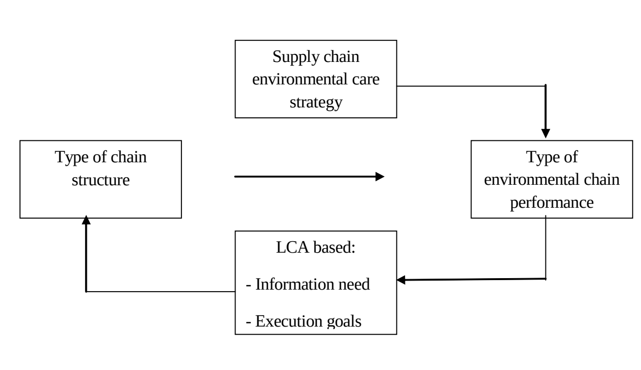

Fig. 2 : Research model- environmental supply chain

compliance with governmental rules and regulation and a better return. Examples are new technologies to save water or raw materials.

– Compliance oriented strategy: Comply with rules and regulation with the help of end-of-pipe technique. Perfect examples are a water clearance installation and filters on chimneys to diminish a particular kind of emission.

– Market oriented strategy: Aim for the reduction of environmental burden caused by the design of the product to achieve competitive advantage. In this stage of environmental care the R & D department also incorporates the environmental aspects in the design process.

LCA of some foods (Table 1).

Table 1 : Life cycle assessment of some foods

Sr. No.	Product	Impact on environment	Reason	Suggestion	References
1.	Bread	Photo-oxidant formation, Eutrophication	Baking process and nitrogen fertilizer used in wheat cultivation	Organic production of wheat	Andersson and Ohlsson, 1999; Holderbeke *et al.*, 2003; Braschkat *et al.*, 2003.
2	Beer	Emission of GHG (Global warming)	wort production followed by filtration and transportation	Reusable glass bottles	Takamoto *et al.*, 2004
3.	Tomato ketchup	Acidification	Geographical location and type of tomato paste	Prepare less concentrated tomato paste	Andersson *et al.*, 1998; Andersson and Ohlsson, 1999
4.	Dairy products	High consumption of water and energy, the discharge of effluent with high organic components (eutrophication)	Pesticide use for feed growing, water for cleaning and drinking	Reduce nutrient surplus in farms, less use of pesticide in imported concentrated feeds, and on-farm fodder production, a greater use of concentrated feed,	Williams *et al.*, 2006; Cederberg and Mattsson, 2000
5.	Rice	Greenhouse gas (GHG) emissions (global warming)	Cultivation process, parboiling of rice by local small processors, transportation	Use good variety of rice, large industries for parboiling process, sea transporting.	Kasmaprapruets *et al.* 2009; Breiling *et al.*, 1999; Roy et al. 2005.
6.	Meals (wheat, soy, sugar, tomato, oil, cooked rice, meat)	CO_2 emission	Cultivation and processing	Higher emission for protein-rich products followed by carbohydrate- rich products.	Ozawa and Inaba, 2006.
7.	Potato	Global warming and Eutrophication	Cultivation and transportation	shifting from conventional to organic production	Williams *et al.*, 2006; Mattsson and Wallén 2003.
8.	Meat	Global warming, eutrophication, land use, human toxicity	Feeding length, feed production and type of feed, animal housing and manure storage	shorter feeding length, organic farming, Replacing soya meal feed by pea and rapeseed-cakes, Chicken is most efficient followed by pork and beef is the least efficient.	Ogino *et al.*, 2004; Williams *et al.*, 2006; Nemecek, 2006; Roy *et al.*, 2008
9.	Sugar beet	Eutrophication, resource depletion	Pesticides, acidification	Genetically modified herbicide tolerant variety	Haas *et al.*, 2001
10.	Coffee packaging	Resource depletion, global warming	Manufacturing of package and transportation	Use of polyaminate bags instead of metallic cans	Monte *et al.*, 2005
11.	Frozen orange juice	Global warming	Cultivation and processing	Good agricultural practices	Coltro *et al.*, 2008
12.	Waste management	Human and eco toxicity and resource depletion	Processing of food (raw material)	Incineration, incineration after bio-gasification, bio gasification followed by composting and composting	Hirai *et al.* (2000)

Conclusion :

Adding life cycle assessment to the decision-making process provides an understanding of the human health and environmental impacts that traditionally is not considered when selecting a product or process. This valuable information provides a way to account for the full impacts of decisions, especially those that occur outside of the site that are directly influenced by the selection of a product or process.

LCA has been done on large variety of food products across the world but it is least developed and studied in India. As we are bound voluntarily to reduce our carbon emission in the Copanhegan Summit, there is lot of scope for implementing the LCA.

Remember, LCA is a tool to better inform decision-makers and should be included with other decision criteria, such as cost and performance, to make a well-balanced decision.

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