Life Cycle Assessment – A Review

Nkosinathi Madushela

***Abstract*— With ever increasing concerns about the type of planet that generations to come stand to inherit, Life Cycle Assessment initiatives are carried-out to quantify the amount of impact that different sources of pollution have on the environment. Life Cycle Assessments have evolved over the last few decades, and the paper primarily focuses on what have been achievements, areas of improvement, barriers, and what still needs to be done to ensure that scares natural resources are preserved for future generations.**

***Index Terms*— Eco-branding, Global Warming Potential, Life Cycle Assessment, Life Cycle Management**

I. Introduction

Life Cycle Assessment (LCA) is a field of science that has been predominantly driven by the changing global climate. The carbon dioxide (CO_2) levels in the world have been rapidly increasing, as indicated by Al Gore in his documentary "An inconvenient truth" [1]. It is believed that the increase in average global temperatures stems from the increase in CO_2 emissions. It is through this belief that a number of LCA initiatives find themselves predominately concentrating on the Global Warming Potential (GWP) measure. However LCA is applicable to a number of environmental impacts ranging from ecotoxicity (e.g. water chronic), acidification, radioactive waste, etc. as it will be indicated later [2].

A. History

During 1979 the Society of Environmental Toxicology and Chemistry (SETAC) was founded on the basis that it will serve as a multidisciplinary organisation aimed at tackling environmental issues [3]. Life Cycle Assessment was then developed as a tool that will marry the product developments in industry with the environmental impacts resulting from the aforementioned products. Over the years different methodologies were developed to relate the products produced (be it electricity, petroleum, beverages, etc.) with the resulting consequences (e.g. ecosystem quality, natural resources; human health).

B. Paradigm Shift

Eco-branding is a marketing endeavor to match eco-friendly products with consumers. Listed below are the chronological phases that eco-friendly products have experienced over the years [4]:

- Eco-ugly,
- Eco-cool,
- Eco-chic;
- Eco-iconic.

In the early years of LCA initiatives efforts were made to recycle products, and because the technology back then was not as developed as it is today, a number of products produced through recycling were perceived as being ugly hence the name eco-ugly. As more people got aware of the importance of using natural resource sparingly, those who supported LCA initiatives were perceived as being cool, hence the name eco-cool. However the aesthetic perspective of clothes in-particular from eco-friendly materials was still less favourable, and it is during this time that the clothing industry took advantage by redesigning clothes which were more aesthetically pleasing hence the name eco-chic. Finally now we are in an exciting era where entrepreneurs such as Elon Musk are driving for eco-friendly products such as his Tesla car, and this is the dawn of an era known as eco-iconic - where efficient, and aesthetically pleasing products across a number of industries are being embraced.

C. Importance

Irrespective of whether the products are eco-ugly or eco-iconic, Life Cycle Assessment studies are crucial, as they provide us with quantifiable impacts that industrial products have on the environment. This is important as it allows us to be able to measure the amount of damage that we are causing in the world and it also pin-points the major contributors in environmental impacts. These environmental impacts aid in the better understanding of the changes in our ecosystem and consequently the type of planet that we will leave for generations to come.

II. LCA and complimenting fields

With what has been said thus far, Life Cycle Assessment is yet to be defined. Life Cycle Assessment (LCA) is defined as a tool used to assess potential environmental impacts of a product, process or service coupled with the extraction of raw materials, transport, processing, production, distribution, use, reuse, recycling, and final disposal. Thus LCA is a tool used to assess a product's, service or process impact on the environment from cradle to grave [5].

A. Life Cycle Management

LCA is a subset of a broader discipline known as Life Cycle Management (LCM). Life Cycle Management is comprised of three sub-disciplines indicated below [6]:

1) Environmental Management,
2) Environmental Communication;
3) Life Cycle Assessment.

Manuscript received February 29, 2016; revised April 13, 2016. N. Madushela is an assistant lecturer and a PhD candidate in the Department of Mechanical Engineering Sciences, University of Johannesburg, Auckland Park Kingsway Campus, Johannesburg, South Africa, 2006. Phone: +2711-559-4378, (E-mail: nmadushele@uj.ac.za).

ISBN: 978-988-14048-3-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The current paper primarily reviews Life Cycle Assessment; however it is imperative that one should mention the other two disciplines of LCM, simply because the aforementioned disciplines are not autonomous.

Environmental Management has to do with ISO standards, and focuses on standardizing the work conducted in LCM to the international community. The standards are put in place to ensure that the global village is moving towards a common goal, and that in-turn allows researchers, policy makers, and the general public to be able to set a global benchmark on their LCA initiatives.

Environmental Communication on the other hand ensures that irrespective of the different languages, and methodologies; the understanding and interpretation thereof of the standards needs to remain consistent. One such consistent measure is the Environmental Product Declaration (EPD) which is an ISO label given to a certain product upon a conclusion of the Life Cycle Assessment initiative. The label indicates the environmental impact of the product transparently and through quantifiable measures independent of a given region's legislation or environmental impact limits.

B. Pillars of Sustainability

Although Life Cycle Assessment is a sub-discipline of Life Cycle Management, it (LCA) also has its three fundamental complementing disciplines given below [7]:

1) Environmental Life Cycle Assessment (eLCA),
2) Life Cycle Costing (LCC);
3) Social Life Cycle Assessment (S-LCA)

The current paper primarily focuses on the Environmental Life Cycle Assessment (eLCA). However a comprehensive review on Life Cycle Assessment will have to include the feasibility (economic value) for a product to be produced in an environmentally friendly manner (Life Cycle Cost), such that businesses can still operate while being cognisant of the environment. On the other hand human beings are constantly improving their living standards, and that in-turn translates to an altered social system (S-LCA). Thus it is crucial to also understand the human behavior to the morphing world, in-order to ensure that LCA studies and eco-designs are carried out to full-fill the expectations of the changing social system.

C. Legislation and Political Influences

Over the years governments across the globe have been heeding the call as adopted in the Kyoto Protocol on climate change [8]. An increasing number of countries primarily in Europe are moving towards more eco-friendly products as stipulated by the Integrated Pollution Prevention Control (IPPC) directive [9], even countries in Africa, such as South Africa also derived sections from the IPPC as contemplated in the South African National Pollution Prevention Act [10]. However there still remains a challenge in the developing world to integrate environmentally friendly technologies in their industries, with one of the drivers being the economic viability of such initiative. One measure developed to nor-malise such situations is the Best Available Technique (BAT) tool [9]. However because the bulk of the research work done on LCA initiatives is from the first world coun-tries, governments in the developing countries are struggling to implement and control pollution limits, simply because the bench mark pollution limits in literature are derived from first world countries.

Al Gore also makes mention of political influences that are acting as constraints in the promotion of preserving the environment. In his (Al Gore) documentary "an inconvenient truth", he makes mention of political leaders who are not proactive in addressing the issue of global warming, and consequently jeopardizing industries that will be affected by the more eco-friendly products such as the automobile industry, as well as the oil and gas industry [1].

D. Eco-Confusion and Greenwashing

In the information age we live in, people are constantly bombarded with information that might be misleading at times, with one of the drivers being the sheer volume of information available. Misinformation comes from companies and organisation that use a variety of labels that do not necessarily mean that the products are eco-friendly, but rather provide the perception that they are. It is due to this reason that Environmental Communication was mentioned earlier in the current paper. Organisations primarily communicate their commitment towards eco-friendly initiatives through eco-labels as branded in their products. There are three types of eco-labels that are currently used by organisations, and consumers that are not well informed might think that they are supporting eco-friendly products, whereas the organisation is merely greenwashing as explained later in the current paper. The three main eco-labels are classified as follows [11]:

1) Ecolabel Type 1 (ISO 14024): This type of label is what all products should be moving towards, as products with such a label are deemed to be eco-friendly, and do not compromise the environment. One such label is the European Flower.
2) Ecolabel Type 2 (ISO 14021): This type of label is the one that commonly misleads consumers, as it is a self-declared and non-certified eco-label.
3) Ecolabel Type 3 (ISO 14025): Type 3 labels promote the spirit of openness and transparency, as they indicate the environmental impact of the product as it currently is i.e. the label leaves it to the consumer to decide as to whether they would support a particular product given the facts about the eco-friendliness of the product as indicated in the ecolabel.

Companies tend to make use of Ecolabel Type 2. This enables the organisations to perform unethical acts in marketing their products, through what is referred to as greenwashing. Greenwashing can be defined as a practice of giving misleading information about products or services in order to present a sustainable/environmentally friendly public image [12]. Companies conduct greenwashing for a number of reasons, and literature summaries such reasons as "the seven sins of greenwashing" [13]:

1) Sin of the hidden trade-off,
2) Sin of no proof,
3) Sin of vagueness,
4) Sin of worshiping false labels,
5) Sin of irrelevance,
6) Sin of lesser of two labels;

ISBN: 978-988-14048-3-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

7) Sin of fibbing.

Irrespective of which of the seven sins of greenwashing a company utilizes it does not change the fact that the company is unethical in its representation.

III. Life cycle assessment methodologies

There are a number of LCA methodologies, however as stipulated earlier the most prevalent of such methodologies are those that measure the carbon dioxide equivalence, as it is perceived to be the major impact on eco-system through global warming. It should be noted that although LCA methodologies are predominantly utilised to measure CO_2 equivalence, they are also capable of measuring other environmental impacts stated earlier. Table 1 Indicates methodologies that are predominantly utilised and their capabilities [14] [15]:

TABLE 1:
LCA METHODOLOGIES AND THEIR CAPABILITIES

Methodology	Capabilities
CML	Abiotic depletion
	Land use
	Climate Change
	Ozone Depletion
	Human toxicity
	Ecotoxicity
	Smog formation
	Acidification
	Eutrophication
Ecoindicator 99	Depletion of minerals
	Depletion of fossil fuels
	Land use
	Climate Change
	Ecotoxicity
	Ozone Depletion
	Ionising radiation
	Acidification
	Carcinogenic substances
	Respiratory effects
	Eutrophication
EDIP	Global Warming
	Ozone Depletion
	Acidification
	Eutrophication
	Human toxicity
	Ecotoxicity
	Resources
	Hazardous waste
	Slags/ashes
	Bulk waste

The aforementioned methodologies do not only help the consumer purchase eco-friendly products, but they also assist both the private and public sector in ensuring that their products are designed efficiently (eco-design), products are effectively communicated to the end-user (Ecolabels), and finally that the entire supply chain of a product is performed in a manner that promotes green procurement, because ultimately the entire system should be balanced and not selected processes in the system.

IV. Framework

The structure of a Life Cycle Assessment is as follows [16]:

1) Defining the goal and scope of the assessment,
2) Inventory analysis;
3) Impact Assessment.
4) Interpretation of the results

It should be noted that since LCA is an iterative process, the steps in the aforementioned structure might need to be revised more than once as the direct applications of the LCA initiative might be revised due to public policy revisions, strategic planning, product improvement, etc.

A. Goal and Scope Definition

The goal and scope should be clearly defined, and the anticipated application coupled with a particular target audience should be stated unambiguously. Within the goal and scope the following should be contemplated:

1) Functional unit,
2) Peer review,
3) System boundaries;
4) Data quality requirements.

The functional unit quantitatively defines the functions of a product, thus should be measurable and well defined. The functional unit measures the function of the studied system and it provides a reference that compares the inputs and outputs e.g. the functional unit for an electricity generation system can be identified as 1 kW-h.

Peer review is important as LCA initiatives are normally comparative in nature, thus inputs of peers in the field are important to ensure that the initiative addresses what it meant to address.

System boundaries are primarily where one considers the starting and end point of the LCA initiative. It should be noted that when performing an LCA one should not concentrate on flows that have negligible impact, while also keeping in mind not to narrow the scope significantly as that might also lead to the omission of crucial contributors. It is for this reason again that peer reviews are imperative.

The outcome of an LCA initiative strongly depends on the integrity of the data utilised and one should always bear in mind that for the method used the outcomes should be reproducible “as a litmus test for data integrity”

B. .Inventory

This is the most tedious part of LCA, and where a number of human errors normally occur. Inventory analysis is comprised of data collection and calculations which enable the quantification of the inputs and outputs. Thus relevant processes need to be described, and the assembly of the model defined. Also included should be the disposal scenarios.

C. .Impact Assessment

Impact assessment is divided into two sections in ISO 14040 which are as follows:

1) Mandatory elements: Selection of impact categories, category indicators and characterisation models.
2) Optional Elements: Normalising the results i.e. the magnitude of the category indicator results are calculated relative to reference information.

ISBN: 978-988-14048-3-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

D. Interpretation of Results

Results interpretation is to simply look back at the goals and aims set initially, and whether the results obtained address what was questioned prior to the commencement of the initiative. This reflection is also important in terms of suggesting recommendations to improve the product's environmental impact moving forward.

V. Moving Forward

The current paper has reviewed the history and the current condition of the Life Cycle Assessment discipline. A number of successes can be recorded with more researchers joining the discipline and subsequently developing papers which are published in LCA journals. The discipline has also made significant strides from the Kyoto protocol, and amidst some political forces that are still opposing LCA initiatives. There is still more that needs to be done however the progress made thus far is encouraging even with the development of LCA software such as SimaPro, and an ever increasing database for standard LCA models worldwide.

References

[1] D. Guggenheim, Director, *An Inconvenient Truth.* [Film]. United States of America: Paramount Pictures, 2006.
[2] eco-invent, "Implementation of Life Cycle Impact Assessment Methods," Dübendorf, Switzerland, 2007.
[3] SETAC, "Society of Environment Toxicology and Chemistry," SETAC, 24 November 2015. [Online]. Available: https://www.setac.org/?page=History. [Accessed 22 February 2016].
[4] M. E. Reed and D. T. Chiang, "Eco-Advantage Strategies and Supply Chain Effects," *Journal of Supply Chain and Operations Management*, vol. X, no. 1, pp. 212-225, 2012.
[5] EPA, "US Environmental Protection Agency," US Environmental Protection Agency, 12 September 2014. [Online]. Available: https://search.epa.gov/epasearch/epasearch?querytext=life+cycle+assessment. [Accessed 6 February 2016].
[6] S. M. Subramanian, Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing, Hong Kong: Woodhead Publishing, 2015.
[7] R. V. Reddy, M. Kurian and R. Ardakanian, Life-cycle Cost Approach for Management of Environmental Resources: A Primer,UK: Springer, 2014
[8] U. N. F. C. o. C. Change, "Status of Ratification of the Kyoto Protocol," UNFCCC, 7 January 2016. [Online]. Available: http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php. [Accessed 10 January 2016].
[9] A. Neubauer, *Integrated Pollution Prevention and Control,* Berlin: Ecologic, 2015.
[10] D. o. W. a. E. Affairs, "South African National Pollution Prevention Act," Government Gazette, Johannesburg, 2014.
[11] I. 1. 1. 14025, *Environmental labels and Declarations*, 2012.
[12] M. A. Delmas and V. C. Burbano, *The Drivers of Greenwashing,* California: University f California, Los Angeles, 2011.
[13] M. Spaulding, "The Seven Deadly Sins of Greenwashing," 8 May 2009.[Online].Available:http://sinsofgreenwashing.com/index94e4.pdf. [Accessed 20 January 2016].
[14] J. Foley and P. Lant, "Regional normalisation figures for Australia 2005/2006—inventory and characterisation data from a production perspective," *The International Journal of Life Cycle Assessment* , vol. XIV, no. 3, pp. 215-224 , 2009.
[15] L. C. Dreyer, A. L. Niemann and M. Z. Hauschild, "Comparison of Three Different LCIA Methods: EDIP97, CML2001 and Eco-indicator 99," *The International Journal of Life Cycle Assessment* , vol. VIII, no. 4, pp. 191-200, 2003.
[16] I. 14040, *Environmental management -- Life cycle assessment -- Principles and framework*, 2006.

ISBN: 978-988-14048-3-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)