Review article

Assessing status of life cycle assessment studies in Egypt

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Abstract

One of the tools used worldwide nowadays for achieving sustainable development is "Life cycle assessment". This tool is being used to assess and compare environmental impacts of products or services through their entire lifetime. Researchers and environmental experts in both academia and industry are using Life cycle assessment (LCA) as it presents a quantitated and qualitative tool that reflects the environmental impacts. In spite of this, it was noted that limited studies employed this important tool in Egyptian cases. The goal of this review paper was to identify potential usage of LCA in Egypt. This was done by evaluating the conducted studies concerning this area in Egypt and main gaps and challenges were determinined, accordingly. Improvement options and future requirements for using LCA in Egypt would then be recommended.

In order to assess the statues of the LCA studies in Egypt, the published documents by both national and international scholars related to LCA cases conducted in Egypt during the period of 2006 till 2019 were collected and reviewed. It was found that 39 documents were published concerning this area. The published documents covered seven main area of studies namely: building and construction materials, aquaculture farming, energy, industrial manufacturing, transportation, water treatment and waste handling. Top publications were in the building and construction materials field accounting for 44% of the total publications followed by energy, aquaculture farming, waste handling strategies, and industrial manufacturing of textile and packing materials (13%, 13%, 13 and 8% of the total publications, respectively). The main benefits as well as gaps of the conducted studies were discussed for each area. Current concerns, need of future studies as well as related recommendation and suggestions were also presented.

Keywords: Life cycle assessment, sustainable development, Egypt
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1. Introduction

In view of the increasing awareness concerning environmental issues worldwide, several techniques were developed to assess the environmental impacts and assist in mitigating and minimizing the negative impacts. Life cycle assessment (LCA) is one of techniques developed for these issues. LCA is employed to estimate the environmental impacts of products, services or systems considering all inputs from raw materials, water, energy and outputs from end product, air emissions, liquid discharge and solid wastes. LCA studies are used to identify the main points of environmental

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concern in a product or service life cycle to improve them. They can also assist decision makers in the industrial sector as well as policy makers in setting priorities, strategic planning and product design [1].

LCA methodology was introduced for the first time to the research community in the late 1960s, then developed by many countries [2]. International standards on "Environmental management of life cycle assessment" were developed for understanding and frame working usage of this important tool. ISO 14041:1998 [3] was the first developed standard and it clarifies what is meant by LCA goal and scope. In addition, it explains how to design the system model, the inventory analysis and data collection. It was followed up in 2000 with ISO 14042: 2000 [4] which served as a guide to understanding the life cycle impact assessment phase and its relation to other phases and ISO 14043 [5] that helps in explaining the results and data obtained from previous phases. Furthermore, ISO14040: 2006 [1] describes the principles and frameworks of life cycle assessment including its four main phases; the goal and scope, life cycle inventory, impact assessment, and data interpretation. As presented in Figure (1). ISO14044: 2006 [6] is the last version of the standards. This ISO combines the three previous ones [3 – 5] and in combination with [1] replace them by presenting the requirements and guidelines for conducting LCA study.

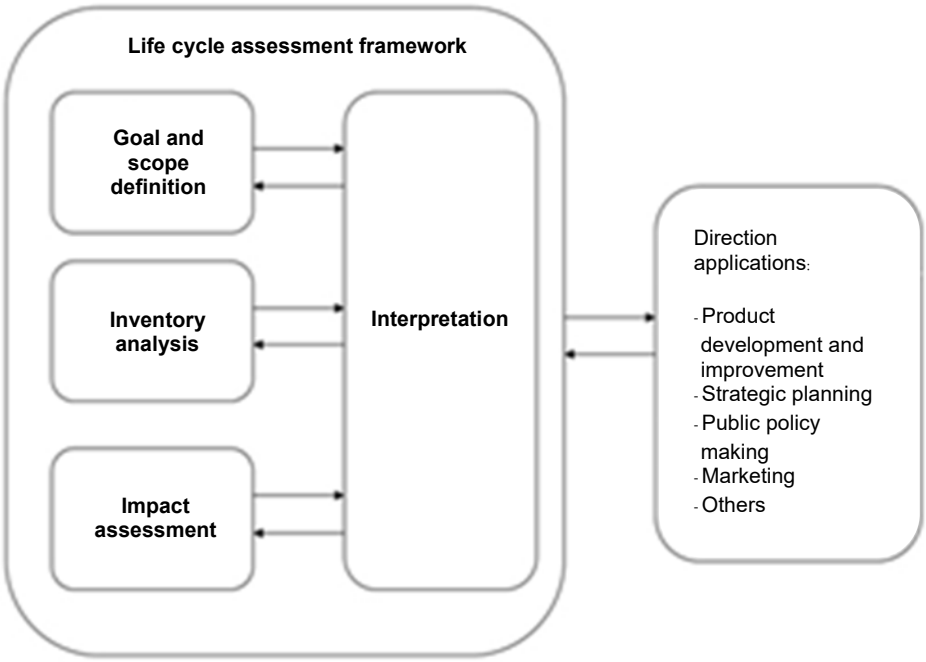

Figure 1. Conceptual framework on LCA [1]

Nowadays many organizations have adopted the life cycle thinking and LCA studies are being conducted worldwide by researchers in universities, research centers and industrial plants. In Egypt, in spite of the increasing awareness and concern about environmental issues, there are limited studies on the use of LCA as a tool for environmental sustainability.

This review article will attempt to evaluate the current status of LCA studies conducted in Egypt and to identify potential usage of LCA in future investigation. The main objectives are to:

- Identify conducted LCA studies in Egypt,

- Determine main gaps and challenges in conducted LCA studies in Egypt,
- Recommend improvement options and future requirements for using LCA in Egypt.

Data Assessment

In order to assess the conducted LCA studies in Egypt, the published literature was collected, classified and evaluated following the adopted methodology by various researchers [7- 9] as shown in Figure 2. The methodology consists of the following steps:

a) Setting a time frame of required data. Data were collected from published documents related to LCA in Egypt from 2006 when the final international standard of LCA [1] was released till date 2019.

b) Framing questions, three main questions were taken into consideration; How many documents were published related to LCA in Egypt?, What type of documents? and Which topics were covered?

c) Identifying search criteria and conducting search. Search was done on "ISI Web of Science", Science direct", "Scopus", "Google", "Google scholar" and "Research gate" using the keywords " Egypt", "Life cycle assessment" and "LCA".

d) Screening records, classification and evaluation of collected data. The classification and evaluation would consider published documents such as "research papers" and "review papers" published in local journals, international journals or conference proceedings. Documents should be related to LCA in Egypt published during the period from 2006-2019.

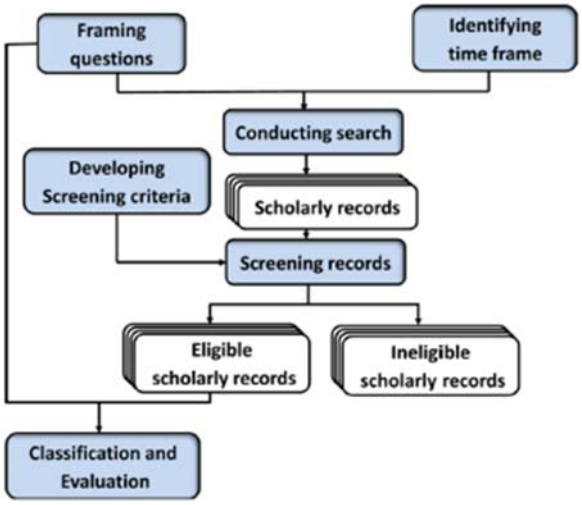

Figure 2. Data collection and evaluation methodology [7-9]

Overview on LCA publications related to Egypt

Summary of the published documents related to LCA in Egypt is presented in Table 1 and 2. It was found that 39 publications were concerned about LCA studies in Egypt. Thirty-three were case study investigations using LCA as an environmental assessment tool and the rest were working papers or review papers. Most of the documents (85%) were published in international peer- reviewed journals, a few in conference proceedings (13 %) and only one (3%) in a national paper. Most of

the conducted studies were done by national universities and research centers and only one research study by one holding company. This reflects the need to promote LCA as an environmental sustainable tool within the private sector in Egypt.

Table 1. Summary of local LCA studies in Egypt published during 2006 -2019

Area of study	Aim of study	Reference	Publication Type	Affiliation
Aquaculture	Analyze the environmental impact of tilapia production in different production systems	[10], [11], [12]	International paper	Stockholm Resilience Center / WorldFish
		[13], [14]	International paper	Alexandria University
Building and construction materials	Assessing the environmental impacts of residential buildings and construction materials	[15]	Local paper	Tanta University
		[16], [24], [25], [26]	Conference paper	Egypt-Japan University of Science and Technology (E-JUST)
		[17], [18], [19], [20], [21], [22], [23], [27], [28]	International paper	
		[29]	International paper	Cairo University
		[30]	International paper	Menoufia University
	A framework for incorporation of green building materials	[31]	International paper	Housing and Building National Research Center
Transportation	Estimating the environmental impacts of vehicles tires	[32]	International paper	E-JUST
Water treatment	Assessing the environmental impacts of water systems	[33]	International paper	Technische Universität Berlin, Germany
Waste handling		[34]	International paper	National Water Research Center
	Assessing the sewage sludge treatment process	[35]	Conference paper	Technische Universität Braunschweig, Germany
		[36]	International paper	Mansoura University
	Comparing the waste handling scenarios of synthetic fiber waste	[37]	International paper	Alexandria University

Table 1. (cont.) Summary of local LCA studies in Egypt published during 2006 -2019

	Assessing the potential use of some agro and industrial wastes as building materials	[38]	International paper	National Research Center
	Identifying the impacts of different waste management strategies for recovery of used lubricating oil	[39]	International paper	Alexandria Petroleum Company (APC)
Industrial manufacturing	LCA of aluminum foil packaging material	[40]	International paper	Alexandria University
	Evaluating the environmental impact of textile materials	[41]	International paper	
		[42]	International paper	Università Politecnica delle Marche, Italy
Energy	Evaluating energy infrastructure and their impacts	[43]	International paper	School of Engineering, Kyushu University, Japan
		[44]	International paper	University of Hamburg, Germany
		[45]	International paper	E-JUST
		[46]	International paper	Beni-Suef University
	Assessing the environmental impact of renewable energy materials	[47]	International paper	Riga Technical University, Latvia
Others	The interplay of environmental assessment methods; and characterizing the institutional backgr ound in Egypt	[48]	International paper	The British University in Egypt (BUE)

Table 2. Summary of local LCA studies in Egypt per type and affiliation

Affiliation		International Journal	National Journal	Conference proceedings	Total	%
Name	**Country**					
Alexandria University	Egypt	5			5	12.8
Egypt-Japan University of Science and Technology (E-JUST)		11		4	15	38.5
Menoufia University		1			1	2.6
Mansoura University		1			1	2.6
Alexandria Petroleum Company (APC)		1			1	2.6
Cairo University		1			1	2.6
National Research Center (NRC)		1			1	2.6
Environment and Climate changes Research Institute National Water Research Center		1			1	2.6
Tanta University			1		1	2.6
Beni-Suef University		1			1	2.6
British University in Egypt (BUE)		1			1	2.6
Housing and Building National Research Center		1			1	2.6
Technische Universität Braunschweig,	Germany			1	1	2.6
Technische Universität Berlin		1			1	2.6
University of Hamburg		1			1	2.6
Stockholm Resilience Center / WorldFish	Sweden	3			3	7.7
Riga Technical University	Latvia			1	1	2.6
Università Politecnica delle Marche	Italy	1			1	2.6
School of Engineering, Kyushu University	Japan	1			1	2.6
Total (Number)		32	1	6	39	100.0

As per the covered topics, Table 3 summarizes the number and percentage of publications per area of studies. Seven areas of studies were addressed in this study namely; aquaculture, industrial manufacturing, building and construction materials, transportation, energy, water treatment and waste handling.

Table 3. Number of local LCA publications per covered area of studies

Area of study	Number of Publications	%
Aquaculture	5	13%
Industrial manufacturing	3	8%
Building and construction materials	17	44%
Transportation	1	3%
Water treatment	1	3%
Waste handling	6	15%
Energy	5	13%
Other	1	3%
Total	39	100%

Cover Areas of Study, Related Challenges and Gaps

6) Building and construction materials

LCA publications related to building and construction materials were the major area of publications, accounting for 44% of the total published documents. Publications in this area include several case study assessments that aimed to estimate the carbon emissions or evaluate the environmental impacts of local building construction in several locations across Egypt [19, 24, 29] when compared between the environmental impacts of various construction materials such as cement, bricks [16, 18, 21-23, 25-26], sidewalk pavement [27, 30] and pile foundation [28]. One study employed LCA as a support decision tool in green building design [20]. The concerns about the impacts of the building and construction sector on the environment arose recently due to the continued expansions and constructions by both private and public sectors in the different areas across Egypt. However, the conducted LCA studies in this area until now have focused only on modeling the environmental impacts of the cases in question without taking the cost analysis or social impacts into consideration. The sustainability of this expanding sector should be taken into consideration.

Furthermore, the development or usage of green building materials as an ecofriendly alternative to conventional building materials was not addressed properly. The only study in this area was conducted by Garas *et al*. [28] who investigated the impacts of using some agricultural and industrial waste, i.e. rice straw cementitious bricks, rice straw bales and concrete mix with granite waste building materials as building materials for the construction industry. Based on their results they found that used waste for developing new eco-friendly building materials can significantly reduce the negative environmental impact of the construction industry. However, the related impacts differ for each case study. In agreement with Ay-Eldeen *et al.* [28] and Azouz [31], there is a need for database on alternatives for eco-friendly building. The usage of agricultural and industrial wastes as building materials will reduce the waste handling problems, reduce production costs and minimize negative environmental impacts of the construction industry. Future LCA studies in the area of building and construction materials should address this issue with more focus, on other agricultural and industrial wastes for different construction application (buildings and roads).

2) Energy

Due to the energy crisis worldwide and global interest in replacing the dependence on fossil fuels and ongoing attempts to replace it by renewable energy sources, LCA studies related to energy are gaining more and more importance. The published documents related to this topic and Egypt represents 13% of the total publications, these studies were done at different levels. The studies conducted by Aly and Managi [43] and Shaaban *et al*. [44] employed LCA to assist the policy decisions making by assessing the energy infrastructure and their impacts on societies' capital assets. The studies highlighted the positive potential of using different energy and renewable energy systems.

Technology oriented studies presenting the potential impacts of applying different energy sources were conducted by Armanuos *et al*. [45] and Menoufi *et al*. [46]. Armanuos *et al*. [45] compared between the environmental impacts of running an irrigation system for rice cultivation by diesel fuel pumps verses solar pumps. They declared that the usage of solar pumps was more ecofriendly and reduced the overall impacts. Their study took the cost analysis factor which would be of most importance when introducing such a technology. Menoufi *et al*. [46] compared between the potential impacts and energy performance of two photovoltaic systems "Building Added Concentrating Photovoltaic (BACPV)" and a "conventional Building Integrated Photovoltaic (BIPV)". They presented the novel design, related environmental impacts and payback. Their study reflected the potential of using novel solar energy systems and promoted its employment, which seems a promising solution for using renewable energy in Egypt.

The potential impacts of using novel materials for biodiesel production was addressed by only one study [47]. Fawzy *et al*. [47] conducted LCA study to model a novel Egyptian system for biodiesel production from Jatropha using waste water in unused desert land. Their results showed the environmental benefit of using Jatropha for biodiesel production. However, the cost analysis and social impacts were not addressed in this study. Similar studies using other novel materials including agricultural and industrial waste materials for biofuel production are strongly recommended for future studies. Using hybrid systems of biomass and solar energy can be a potential area of future studies as well.

3) Aquaculture

Egypt is considered as the top producer of farmed tilapia in Africa and one of the top ten worldwide [13-14]. Aquaculture farming is a very important industry in Egypt that has been expanding over the last few years [13-14]. Published LCA studies related to aquaculture in Egypt represented 13% of the total. Aquaculture farming of tilapia and environmental assessment of its production systems were the main concern of the studies in this area. "Nile tilapia" is considered as one of the most important sources of cheap protein in Egypt. The author of the studies [10 - 14] agreed that both energy consumption for fish feed production and aeration of aquaculture farming ponds together with the production of fish feed were the main contributors to the environmental impacts of this industry. In order to reduce the negative environmental impacts they suggested to adopt energy saving practices by better energy management of the aquaculture farm to reduce the overall energy consumption. In addition, they emphasized on the need to use novel fish feed formulas and new ingredients. In agreement with researchers [10 - 14], the use of local ingredients for fish feed will reduce the overall footprint of the aquaculture production cycle. The cost benefits as well as the impacts on the surrounding society has to be taken into consideration since it will be an opportunity for jobs' creation.

4) Water, wastewater treatment and waste handling

Mahgoub and colleagues conducted LCA study on the environmental impacts of water systems in Egypt [33]. For wastewater treatment, comparative studies for different handling strategies at industrial and city levels were covered by 15% of total LCA publications related to Egypt. At city

level, the conducted studies evaluated the environmental impacts of wastewater treatment processes in Alexandria city [35], and the different treatment technologies in relation to cost analysis were compared [34, 36]. The possibility of using new technologies can be considered in future studies.

At the industrial level, one study aimed to identify the preferable waste handling strategy for hazardous solid waste in synthetic textile industry [37], different waste management strategies for recovery of used lubricating oil were evaluated by Hassanain *et al.* [39] and Garas *et al.* [38] used some agricultural and industrial waste materials for production of building materials. The number of LCA studies related to waste handling is low in comparison to the number of industrial applications in Egypt. Further waste management options for different products can be evaluated for achieving a more eco- friendly and sustainable industry. Waste management strategies for handling different types of waste at city level can also be addressed. These waste management strategies can address the preferable options for handling municipal solid waste and household waste by landfill, incineration, recycle or reuse.

5) Industrial manufacturing

Topics related to industrial manufacturing represented 8% of the total publications. The conducted studies addressed the environmental impacts of textile production [41, 42] and packing materials manufacturing [40]. The studies suggested means for the improvement of current production process in order to obtain a more ecofriendly production, however, cost analysis and social impacts were not considered by any of these studies. Egypt is a major industrial country in the MENA region with many manufacturing facilities to meet the local demand and for exportation. The conducted studies only addressed the production of synthetic fabrics, cotton yarn and foil packing material, future LCA studies should focus on other products such as equipment manufacturing, different textile materials, food and dairy products, cement industry and so on.

6) Transportation

In spite of the important rule of transportation sector, huge impacts on environment and especially on energy consumption and climate change affected the society. Only one LCA was conducted related to this sector in Egypt [32]. Elkafoury and Negm [32] assessed the life cycle of vehicles tyres on Egyptian road network in order to estimate the environmental impacts of their production and consumption phases.

With only one conducted LCA study in this sector the area is open for further studies. The potential of reducing greenhouse gases (GHG) emissions and mitigating related climate change impacts using alternative routes and methods for products transportation can be addressed [49]. Furthermore, the potential of reducing fossil fuels consumption by using alternative renewable energies is a rich area for investigation as well.

Towards Promoting LCA Studies in Egypt

LCA proved to be an efficient tool for researchers, engineers who design products and decision-makers in the industry as well as policy makers [6]. This important tool should be employed in Egyptian studies more often. Main gaps of each area of study and related improvement and future need of studies were illustrated in the previous section. The main challenges that face further usage of LCA as a tool for sustainability in Egypt are the lack of local experts and awareness about this important tool limits its utilization [49]. In agreement with Yacout [49], capacity building workshops and scientific events such as conferences can be organized to promote benefits of this tool on how to employ it and to connect between international experts in this area and national researchers.

Data limitations, in terms of unavailability of recent local data for conducting the research and for benchmarking of results is a challenging point for consideration. The availability of data is a key factor for conducting any LCA [50]. In this case, data has to be collected from case studies by the research group that could be subjected to some uncertainty. In order to minimize bias, data analysis for uncertainty has to be taken into consideration [51]. Additionally, the absence of a local database, a National Egyptian Life Cycle Inventory (NELCI) database is required to standardize LCA research studies in Egypt. In Agreement with various researchers [17, 31, 41, 50-51], the development of a NELCI is a must to obtain more accurate results concerning LCA studies in Egypt.

2. Conclusions

Life cycle assessment is an efficient tool for environmental sustainability worldwide. However, limited investigations employed LCA in Egyptian studies. The current status of LCA studies conducted in Egypt was evaluated for potential usage of LCA in future investigations. Conducted LCA studies in Egypt were identified. Determination of main gaps and challenges and recommend improvement options and future requirements for using LCA in Egypt were also analysed by reviewing the published documents concerning LCA in Egypt. The covered areas of study were identified as well as the main gaps and challenges. Areas of concern and topic to address were suggested for future studies in each study area. Improvement options for promoting LCA usage as a tool for sustainable development in Egypt were presented as well.

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