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Alexandria Research Centre for Adaptation to Climate Change
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Potential Applications of Life Cycle Assessment in Climate Change Arena

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Glossary

GHGs: Greenhouse gases

LCA: Life Cycle Assessment

GWP: Global Warming Potetials

IPCC: Intergovernmental Panel on Climate Change

1. Introduction

Evaluation of potential climate impacts of a given technology or mitigation measure requires identifying, quantifying and aggregating the emissions of mutiple greenhouse gases (GHGs) associated with such a technogology or mitigation measure (Mallapragada and Mignone, 2017). For this purpose, Life Cycle Assessment (LCA) can be employed. LCA was defined as an objective evaluation of the environmnetal burdens associated with a product, process or activity. This is typically undertaken through identifying and quantifying energy and materials used and waste released to the enviornmnet (Mahmoudkhani et al., 2014, Ozeler et al., 2006).

Such an assessment usaully analyzes a certain product from resource to final waste disposal (Reijnders, 2012). Upon identifying the inputs and outputs from each phase, the potential environmental impacts of each input and output are evaluated. Accordingly, a holistic portray about the environmental impacts of a certain product or service can be depicted.

For example, LCA can be applied to assess environmental impacts of a cotton T-shirt. In such a case, different phases of producing this T-shirt manufacturing will be considered including; Raw Material, Processing, Manufacturing, Packaging, Transportation, Use, as well as End of life in terms of disposal, Reuse, or Recycle (Figure 1). LCA usually starts from the Raw Materials phase where fertilizers, energy, and water are used as resources.

The outputs from this phase will be: a) “cotton”; the end product of this phase that will be used as a raw material in the next phase (the processing phase), b) emissions to air as GHG are generated from burning fossil fuels used during agricultural practices, c) solid wastes and d) liquid discharge from the extra irrigation water (Worldwatch Institute, 2003).

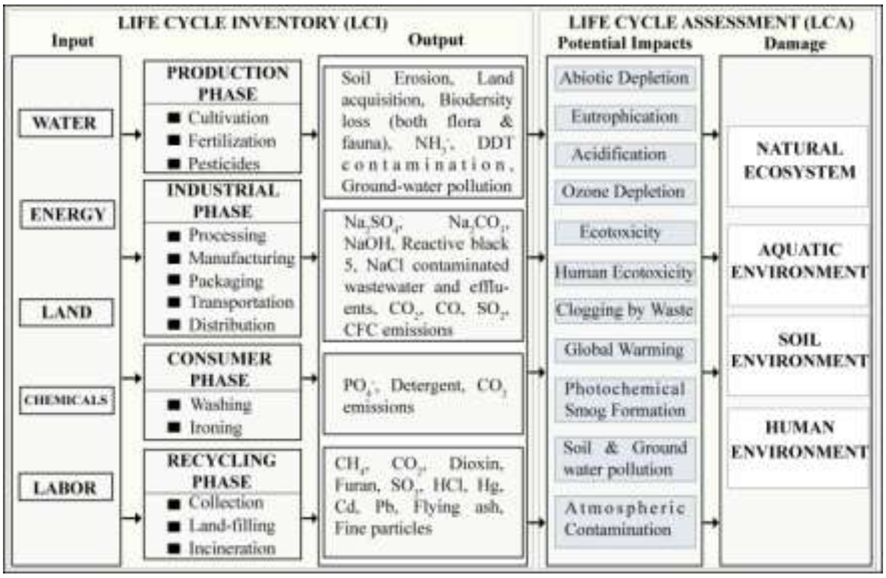

Figure 1: Framework of T-Shirt LCA
(Source: Hossain, 2015)

LCA has been commonly used as an effective environmental management tool (Ozeler et al., 2006). In order to ensure the proper application of LCA the international standards ISO14040 (2006) and ISO14044 (2006) were developed. The standards provide the principles and frameworks of life cycle assessment and serve as guidelines when conducting the studies. ISO14040 (2006) presents the four main phases of conducting an LCA (Figure 2): Goal and scope definition, Life cycle inventory, Impact assessment, Data interpretation.

According to ISO14044 (2006) LCA studies are globally used in:

a) Identifying environmental aspects of process production, minimizing products negative impacts on the environment and turning it into an eco-friendly product
b) Assisting decision makers in industry during process or product design and assist policy makers at different levels during strategic planning and priority setting.
c) Selection of environmental performance indicators and environmental measurements.
d) Marketing of environmental products

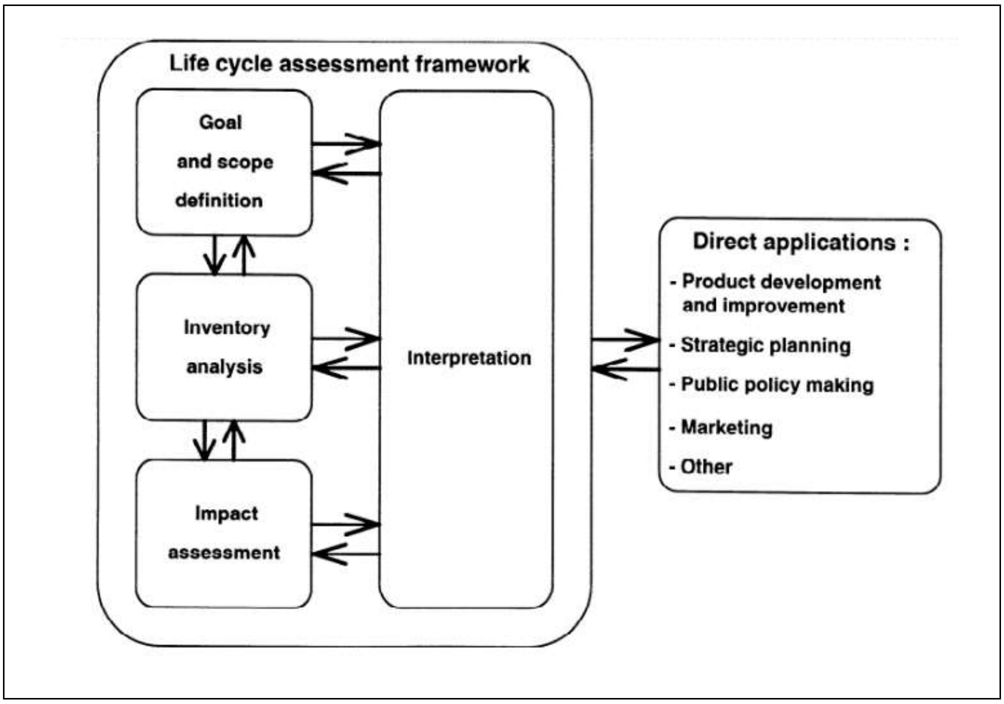

Figure 2: Life Cycle Assessment phases
(Source: ISO14040: 2006)

The standards (ISO14040) provide the principles and frameworks for LCA and serve as guidelines when conducting the studies. According to ISO14040 (2006), LCA is conducted through four main phases including: defining goals and scope, life cycle inventory, impact assessment and interpretation (Figure 2) (Bird et al., 2011). Each of these phases is described below.

- Goal and scope definition: This phase involves defining the object of the analysis, dscussing assumptions and identifying system boundaries in addition to environmental effects to be considered.
- Life cycle inventory: This phase entails gathering data necessary for all processes involved in the product life cycle. The output of this phase is represented in an inventory of all inputs and outputs in the form of elementary flows to and from the environment.
- Impact assessment: This phase evaluates the impacts of considred goods, services or technology. one additional impact category that can be incorporated in this phase is the global warming impacts that can be

evaluated through summing up GHGs emissions, which are usually expressed in CO_2 equivalent. One of the metrics that are commonly used for global warming impacts in LCA of different products and technologies is Global Warmng potentials (Mallapragada and Mignone, 2017).

CO_2 equivalent as an output of LCA can be quite sufficient to guide mitigation poloicies as it refelcts the contribution of the product, technology or system under assessment to climate change (Reijnders, 2012).

- Data interpretation: this phase involves interpreting various impacts in relation to the objective of assessment.

2. Objective

This working paper is intended to review the state of LCA and its potential applications in climate change arena. In order to attain this objective, the paper cover the following sections.

- Introducing Global Warming Potetials (GWP) as the most common climate metrics used for LCA of different products and technologies.
- Identifying current status of LCA research in Egypt focusing on main gaps and challenges.
- Exploring potential applications of LCA in climate change research in Egypt.

3. LCA Applications in Climate Change

LCA is usually used for identifying climate change mitigation benefits associated with alternative products, services or technologies. This means that application of LCA in the field of climate change is mainly to evaluate different technologies, measures and acrtivities that emit one or multiple GHGs. Such an evlautation usually involves utilizing a number of climate metrics to quantify and aggregate emitted GHGs. Among these metrics GWP is one of the most widely used (Mallapragada and Mignone, 2017). GWP represents the weighted sum of life cycle GHG emissions (Plevin et al., 2014). GWP is simply a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). GWP was developed to allow comparisons of the global warming impacts of different gases, and it is calculated in carbon dioxide equivalents (CO_2-Eq). The larger the GWP, the more that a given gas warms the earth compared to CO_2 over a certain period of time. The total result of GWP is expressed in CO_2 Eq. (Table 1) (Goedkoop et al., 2008a; EPA 2017). GWP was developed to compare the global warming potentials of different gases. For instance, Methane (CH_4) is estimated to have a GWP of 28, while Nitrous Oxide (N_2O) GWP is 265 for a 100-years timescale. This means that the contribution of releasing 1 kg of methane or Nitrous Oxide to climate change is equivalent to 28 or 265 kg of CO_2, respectively.

Table 1 : Some Global warming potential (GWP) values relative to CO_2

Gas	Chemical Formula	GWP values for $100^{\text{-year}}$ time horizon according to IPCC Fifth Assessment Report (AR5)
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265

(Source: IPCC, 2014)

The time period for GWP can be 20, 100 or 500 years, however, most studies use 100 years as a time period according to the model developed by the Intergovernmental Panel on Climate Change (IPCC). GWP proved to be a common unit of measure that allows analysts to add up emissions estimates of different gases and helps decision and policy makers to compare emissions and identify reduction opportunities of GHGs (EPA, 2017).

It should be noted that calculation of the potential GHGs emissions depends on a wide range of parameters that can be obtained from LCA databases such as ECOINVENT*, ELCD†, GEMIS‡, the Chinese National Database, JEMAI, Spine or US LCI§. These databses contains estimates of emissions associated with resource extraction and the use of fossil fuel use as well as many agricultural and industrial activities (Bird et al., 2011, Reijnders, 2012).

GWP is calculated through a number of methods (Table 2). These methods can be divided into two main categories: multiple indicator methods and single score methods. The multiple indicator methods calculate different impact indicators and compare them. As for single score methods, they are methods that calculate only one indicator in this case GWP. Almost all the previous methods calculate the GWP based on the developed methodology of the Intergovernmental Panel on Climate Change (IPCC).

It is worth mentioning that some of these methods were developed to be implemented for a specific geographical region. For example, TRACI 2 was initially developed by the U.S. Environmental Protection Agency for LCA studies to be conducted only in US context (Bare and Gloria 2006; Frischknech et al., 2007)

Table 2 : Most common methods of calculating GWP and Carbon Footprint in LCA studies

Methods	Type of methodology	Calculation model	Reference
CML 1992	Multiple indicators	Greenhouse effect (kg) = (GWP 100 x airborne emission (kg))^3, GWP is calculated over a 100-year	(Heijungs et al, 1992), Goedkoop*et al.,* (2008b)
CML 2001		Calculation is done over a 100-year , model as developed by IPCC	Frischknech*et al.,* (2007)
Eco-indicator 95			Goedkoop*et al.,* (2008b)
EDIP 2003			Frischknech*et al.,* (2007); Hauschild and Potting (2003)
EPD 2007			Goedkoop et al., (2008b);
Impact 2002+			Goedkoop*et al.,* (2008b); Frischknech*et al.,* (2007)
IPCC 2001 GWP	Single score indicator		IPCC(2001); Frischknecht*et.al.* (2003)
IPCC 2007			IPCC(2007)
TRACI 2	Multiple indicators		Bare and Gloria (2006); Frischknech*et al.*, 2007)

LCA can be used in comparing between the different process, materials, infrastructure alternatives and indentifying those alternative with less GHGs emissions (Nygren and Antikainen, 2010).

In the field of energy, LCA was applied to estimate the GHG emissions from the different systems. For example, LCA was employed in estimating the GHGs emissions as a result of using biofuel vs fossil fuels in transportation in an attempt to evaluate climate change mitigation measures and reduce associated costs (Eriksson and Ahlgren, 2013). Bird et al., (2011) suggest a mothodology for LCA of typical energy ssyetsm (Figure 3).

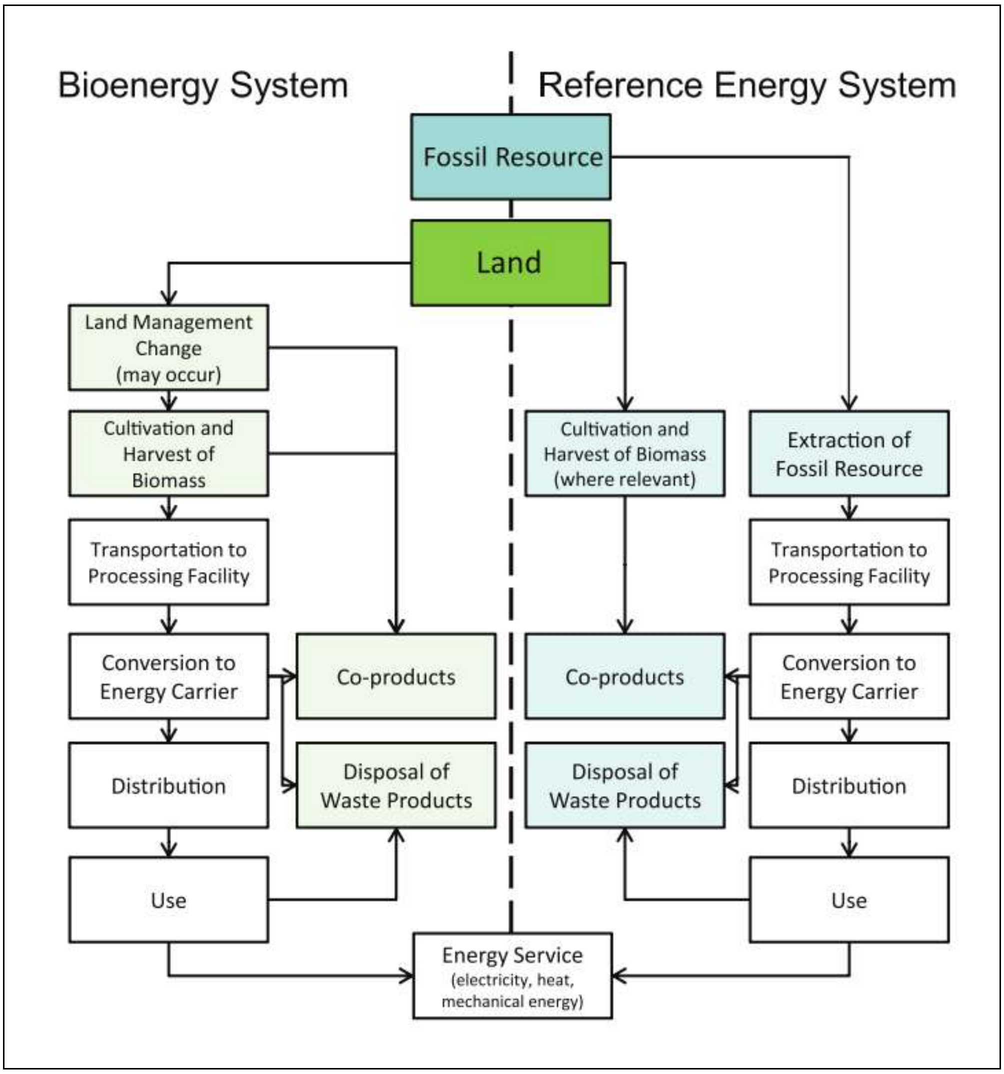

Figure 3: Life cycle stages of typical energy system

Source: (Bird et al., 2011)

Also, LCA was used in comparing different applied technologies in the manufacturing processes in terms of their emission of GHGs. In this respect, LCA revealed that textile industry, for instance, releases usually high levels of GHGs, as carbon dioxide is mainly released during the usage of fossil fuels in steam and electricity generation consumed in different processes. Furthermore, it was suggested that the production of synthetic fiber has more emissions of GHGs compared to natural fiber due to the energy consumed in both raw material production and finishing process phases (BSR 2009; Beton et al., 2014;Yacout et al., 2016).

ISO 2006 provided a faremwork to quantify GHGs emissions from a product system and evaluate the impacts on climate change (Figure 4). Such a framework was usually employed in planning for mitigation. Meanwhile, Nakano (2015) proposed LCA framework for assessing vulnerability and planning for adaptation (Figure 5). According to the proposed framework, various environmental drivers induced by climate change are firstly identified. This is followed by quantifying different impacts of these drivers on human health and social assets. Therafter, an elementary flow affected by each environmental driver is identified, where a large elementary flow related to a climate change refers to high exposure to climate impact (Nakano, 2015)

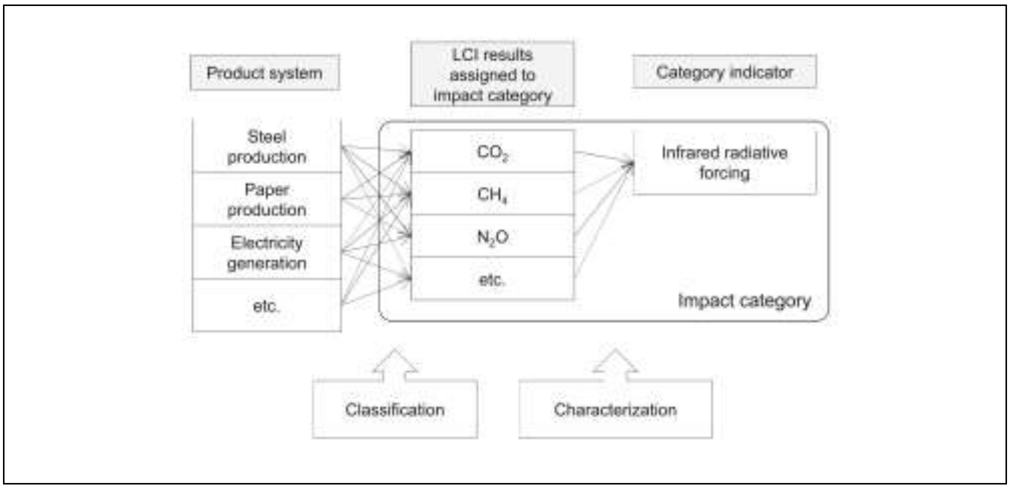

Figure 4: Life cycle assessment framework to quantify GHGs emissions from a product or a system
Source: (Nakano, 2015)

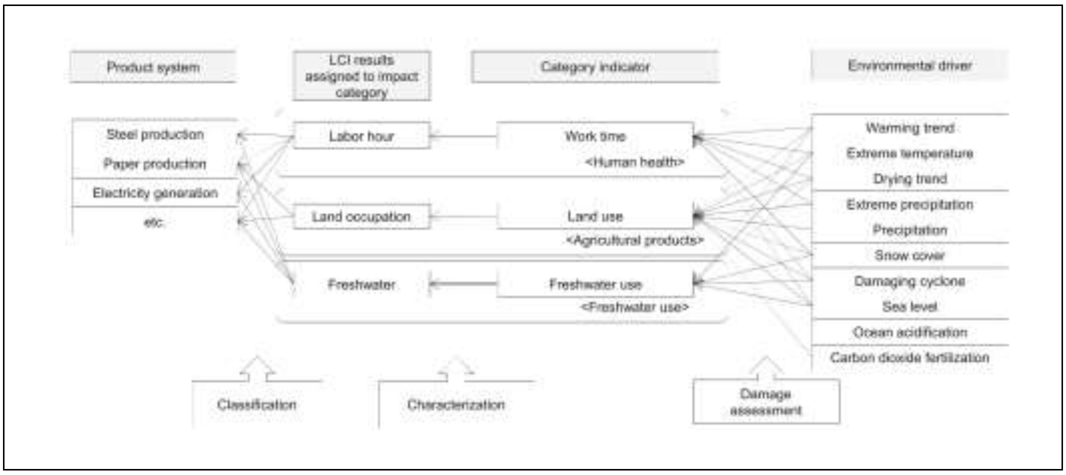

Figure 5: LCA framework of vulnerability assessment and adaptation planning
Source: (Nakano, 2015)

In construction and building materials field, LCA was employed, for example, to estimate the carbon footprint of building materials (Gonzalez and Navarro, 2006; Monahan and Powell, 2011; Costa, 2012; Muñoz et al.,2012; Gonçalves de Lassio and Haddad, 2016). At the same time, other studies assessed energy consumption and GWP of residential buildings and constructions (Gustavsson and Pingoud, 2006; Estokova et al., 2017). LCA studies in building and construction sector argue that the sector is one of the major consumers of raw materials and fossil fuels, with high GWP (Zabalza et al., 2011; Pacheco-torgal et al., 2014; Gonçalves de Lassio et al., 2016).

Morover, LCA was applied to estimate the contribution of agriculture activities to GHGs. In this context, many studies used LCA in order to assess the environmental performance and production process for dairy farms (Berlin 2007; Eide 2002; Hospido et al., 2003; Berlin et al., 2008; Bartl et al., 2011; González-García et al., 2012; Djekic et al., 2014). It was reported that approximately 85% of the GHG and 40% of energy consumption in the agricultural sector are linked to dairy farms (IDF, 2009).

Also, LCA studies suggested that GHG emissions can be reduced by efficiently use of fossil fuel for cultivation machinery such as plough, planting, pesticide spray,harvesting, and nitrogen fertilizer application (Andersson and

Ohlsson 1999; Brentrup et al., 2004; Barker-Reid et al. 2005; Meisterling et al., 2009; Wang et al., 2009; Fallahpour et al., 2012; Boone at al., 2016;Fantina el at., 2017).

In waste management sector, LCA was utilized to assess various stategies for managing waste fabric (Schmidt et al., 2016; Yacout and Hassouna, 2016; Woolridge et al., 2006; Schmidt et al., 2016; Esteve-Turrillas and de la Guardia, 2017). These studies revealed that reusing, and recycling textile waste were the preferable strategies due to their crucial role in reducing GHGs emissions and energy saving.

At the same time, LCA was used in estimating GWP of different scenarios for Municipal Solid Waste (MSW) disposal included landfilling, incineration with energy recovery, anaerobic digestion before landfilling, landfilling plus recycling and composting. It was suggested that GWP of these scenarios differ widely according to the geographic location and considered scenarios (Mahmoudkhani et al., 2014).

In the transportation sector, LCA was employed as a transportation decision tool for reducing and mitigating GHG. In this Context, it was reported that European roads are responsible for more than 25% of GHG emissions (European Commission report 2014). Some studies addressed the potential reduction of GHG emissions by changing transportation modes like automobiles, buses, trains, aircraft, and oceangoing vessels (Chester et al., 2012; Eisenstein et al., 2012; Saxe et al., 2017). Others focused on adopting fuel-saving and renewable energy technologies (Nahlik et al., 2015; Wolfram and Wiedmann, 2017).

4. Current Statues of LCA Studies in Egypt

A search for literature on LCA in Egypt was undertaken through Google Scholar, which is one of open access web search engines that indexes the full text or metadata of large number of scholarly literature covering a wide range of disciplines. It was found that only 22 research work on LCA were reported in the case of Egypt. This indicated that the concept of LCA as an environmental managment tool is still limited in Egypt. However, this limited number of studies aimed mainly to assess environmental impacts of a product or system. Most of these studies considered applications of LCA in two topics: aquaculture and building materials (Figure 6). Meanwhile, 20% of the total scholarly documents were interested in waste hanldling topics. This is followed by manifacturing industry that was considered by 13% of total number of research work.

Applying LCA can have supported decision-making processes through providing estimates for the potential impacts of various alternatives on global warming. In spite the importance of LCA as a tool for decision-making process in the area of mitigation and adaptating to climate chnage. However, it is clearly noticed that none of the studies considred climate change issues.

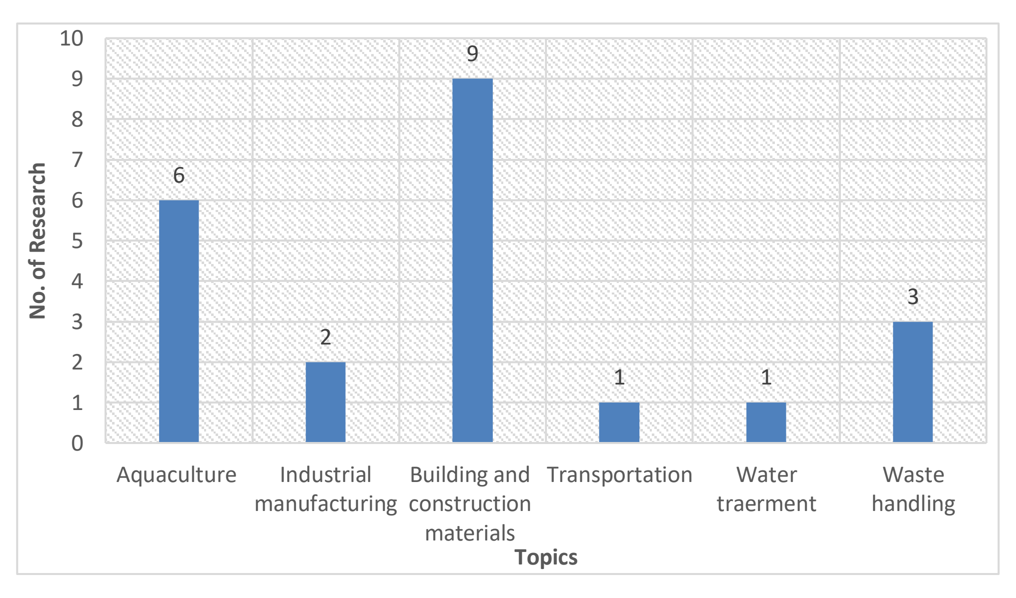

Figure 6 : Number of local LCA publications per covered topics

Generally, the limited number of research work on LCA in Egypt can be attributed mainly to:

- **Absence of local data and a national database:**

  Availability of accurate detailed and up-to-date data is one of the prerequists of LCA (McManus and Taylor, 2015). Such data is of great importance in providing baseline conditions and profiling various impacts in LCA. In this respect, there is a need to develop an Egyptian National life cycle inventory (LCI) database, which can contribute largely to standardize LCA studies in Egypt (Ali et al., 2014; Yacout et al., 2016; Azouz, 2018; Baker and Lepech, 2009). Alternatively, a database of a relatively similar countries could be employed, meanwhile.

- **Lack of expertise:**

  Limited number of potential users, including researchers, scholars and decidion makers, are familiar with LCA in Egypt. In this repsect, there is a need for awareness raising about and capacity building activities on LCA of researchers, scholars and decision makers. This may lead to promoting the usage of LCA as a tool for environmental sustainability and decision making at the national level.

5. Potential Applications of LCA Studies for Climate Change in Egypt

The importances of LCA was highlighted under the Egyptian Sustainable Development Strategy vision 2030, which considered the environment one of the main pillars for sustainability and climate action as one of the sustainable development goals (El-Megharbel, 2015). This, in turn, increased the need for the use of LCA in the field of climate change adaptation and GWP mitigation. In this context, further research work need to include, but not only be limited to:

- Evaluating adaptation and mitigation options in agriculture sector at local level. Future LCA studies should focus on:

  - identifying preferable practices of the different production systems for dairy production and processed food products.
  - Usage of fertilizers and pesticides are the major contributors to GHG emissions from agriculture farming.
  - Assessing the emissions of grains, fruits and vegetables farming at local level should be done and compared to same emissions from agriculture farming at the international level to find novel minimization options.
  - Reduction of GHG emissions by organic farming vs conventional farming is a very important issue to be addressed as well in order to encourage the adaptation of organic farming in Egypt.

- Energy saving and promoting renewable energy systems: Energy sector contributes by 95.4% of the total GHGs emissions in Egypt (EEAA, 2016). Therefore, any mitigation policy shoul consider energy sector, in this context, LCA can be employed in:
  - Assessing the environmental impacts of different biogas production systems relative to non-renewable energy systems.
  - Energy saving applications in intensive energy consuming industries such as chemical and pharmaceutical industries is one of potential areas for improvement.
- Supporting decision-making process in manging municipal solid waste: LCA can assist in selecting preferred and more eco-fiendly MSW management strategies with less GHGs emissions at city level.

6. Conclusion

LCA is usually an efficient tool for environmental management and has great potentials to be utilized in climate change arena. LCA can be employed in estimating greenhouse gases emitted from different technologies, measures or acivities, which in turn, may considerably support policy-making process in the field of mitigation and adaptation to climate change.

However, a few studies of LCA in Egypt were reported. Generally such limted number of research work on LCA in Egypt can be explained by lack of data and expertise. Up till now, major proportion of such limited number of research work was interseted in two main sectors; aquaculture and building materials. Meanwwhile, none of the previous resercah work considred climate change issues.

Nevertheless, LCA has great potentials in the field of climate change mitigation and adaptation in Egypt. For this purpose, a number topics in the field of agricultutre and energy sector were identified.

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