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COMMENTARY AND DISCUSSION ARTICLE

Moving towards an Egyptian national life cycle inventory database

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Abstract
Purpose Life cycle inventory (LCI) data are region-specific because energy fuel mixtures and methods of production often differ from region to region. LCI database examples include US LCI, Ecoinvent v.2, and NIST, each of which is country-specific. Thus, the main aim of this study is to show that Egypt is in need of an Egyptian National LCI (ENLCI) database and to focus on the means of developing a database specific to Egypt.
Methods Arab countries have thus far engaged in virtually no life cycle assessment (LCA) studies, and a significant neglect of this matter is in evidence for the continent of Africa and, in particular, Egypt. Thus, this study suggests an organizational and managerial framework for the development of a national LCI database and sheds light on the required LCI database categories and data quality for practical solutions reflecting who is equipped to do what in order to keep pace with the world.
Results The results from this review are useful to standardize the study of the life cycle assessment concept in Egypt; to form a foundation for development of an Egyptian database for facilitating a cleaner environment; to encourage stakeholders, such as the environmental agencies, Egyptian Housing and Building Research Center, and the Ministry of Industry; to propose an organizational framework in which they play a central role; and to provide investment to initiate development.
Conclusions The analysis indicates that the development of a LCI database specific to Egypt is difficult because Egypt has various technical and organizational challenges, but a roadmap of actions to be taken to move ahead is provided. The success of this roadmap depends on the capacity for developing the necessary technical and financial support and on strong partnerships with industry, government, LCA professionals, and academia.

Keywords Life cycle assessment · Life cycle inventory requirements · National life cycle inventory database development

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1 International literature studies of building life cycle assessment

Since the start of the twenty-first century, interest in life cycle assessment (LCA) has been rapidly increasing, as evidenced by numerous case studies. Life cycle thinking is also growing in importance within European policy as, for example, demonstrated by the communication from the European Commission on Integrated Product Policy (IPP) (Commission of the European Communities 2003). A direct result of the IPP is the development of the International Reference Life Cycle Data System (ILCD) Handbook, a practical guide published in 2010 for LCA according to the current best practices, complementary with the international standards organization (ISO) 14040 (European Commission-Joint Research Centre-Institute for Environment and Sustainability 2011).

Cabeza et al. (2014), in agreement with Buyle et al. (2013), argued that various case studies found in the literature are difficult to compare because of their specific properties such as building type, climate, comfort requirements, local regulations, etc. A comparison from Cabeza et al. (2014) can be seen in Table 6, which includes most of the case studies considered in the present review. Many important phases of LCA were compared, such as the scope, the lifetime, the functional unit considered, the system boundaries, the location, and the building typology.

Ramesh and Prakash (2010) conducted a literature survey on the life cycle energy use of buildings based on 73 case studies from 13 countries. The survey included both office and residential buildings. Data was collected for wood, steel, concrete, and other building materials.

Included within a life cycle inventory (LCI) database are the energy and raw materials used; the emissions to atmosphere, water, and soil; and different types of land use, and these factors are quantified for each process, combined in a process flow chart, and related to the functional basis (Cabeza et al. 2014). In other words, an inventory of all the inputs and outputs to and from the production system is prepared in this step. As an example, the inputs may include water consumption and the outputs may include sulfur oxides (SOx). Thus, products and processes can be compared and evaluated using LCI results. If the results of the LCI are consistent, a product performance with respect to its environmental burden can be determined, as illustrated in Fig. 1.

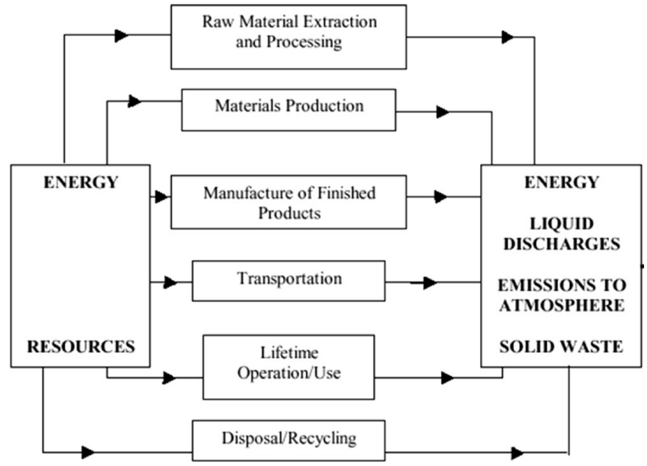

Fig. 1 The framework of the LCI database stage

2 International LCI databases

Tharumarajah and Grant (2002) pointed out that LCI databases have been developed in various regions of the world over the past decade or so. Some countries are more advanced in their development than others. Countries in Western Europe and Canada are considered to be pioneers, having invested heavily in the development of national LCI databases since 1980. In recent times, Asian countries and Australia have also begun developing databases. In other countries, development is focused largely on separated processes or products.

Curran and Notten (2006) demonstrated that regional networks are also being established to share experiences and data mostly among countries that have mutual trade between them. Examples of these are the Asia Pacific Roundtable for Sustainable Consumption and Production and LCA researcher network, North American Database, the African LCA Network (ALCAN), and the Latin American LCA Network (ALCALA—*Asociación LCA de Latinamerica*). Network development in Western Europe is indirect through sharing of publicly available country-specific databases (such as the Swiss database BUWAL) and/or through the use of commercial LCA software tools that incorporate many of the public databases. A global LCI project is also underway to address the critical need to organize and centralize a worldwide knowledge base of LCI data sources that will ease identification and acquisition of available data (Yung et al. 2013). A summary of developments appears in Table 1.

From the distribution of LCA studies around the world given in Fig. 2, Sweden clearly has undertaken the largest number of studies, and Arab countries have clearly engaged in no studies, except for the single study in Bahrain; significant neglect is indicated for the continent of Africa and, in particular, Egypt. Sweden is considered to have engaged in numerous studies because it has a well-established database for conducting LCA.

Cabeza et al. (2014) summarized the literature studies of LCA approaches up until 2014, and their findings are shown in Fig. 3. These findings indicate that LCA studies in America have been predominantly focused on the building industry or on buildings, whereas, in Asia and Oceania, most studies have focused on life cycle energy assessment (LCEA). Europe presents a similar number of LCA and LCEA studies. Finally, only a single life cycle cost assessment (LCCA) of a building could be found.

This analysis begs the question, what about Africa and, especially, Egypt? Because South Africa is a major exporter of raw materials, the external demand for life cycle inventory data from South Africa is increasing (Lippiatt 2007). As such, there is an increasing potential for greater coordination of LCA efforts in South Africa. Although a few South African universities and research institutes have been active in LCA for over 10 years, South African industry and government have been slow to realize the benefits of LCA.

Attia and Wanas (2012) introduced a study that aimed to describe the influence of building construction on energy consumption through a survey that was conducted in Cairo and its surrounding residential neighborhoods, referred to as the Database of Egyptian Building Envelopes (DEBE). This study is a good start towards creation of an Egyptian database, which includes the data concerning the thermal properties of 13 Egyptian building materials.

Table 1 Summary of LCI database activities worldwide

Level of database activity	Countries
Significant database/s development and efforts to coordinate/exchange data at national level	Italy, Switzerland, Australia, Canada, Chinese Taipei, Japan, Korea, Sweden, USA
Significant database development but no coordinating/exchange effort	Austria, France, Germany, UK
	Western European countries not listed above
Database development for separated process chains only	China, India, Argentina
Very little database development but use of LCA	Thailand, Malaysia, Vietnam, Eastern European Countries, Brazil, Philippines, Indonesia, Singapore, Chile, Mexico, Taiwan

Yung et al. (2013) emphasized that in developing countries in general, LCA activity is low, and interest from industry and government is also typically low. LCA activity typically occurs only at the academic or research institute level. Because many developing countries supply resources to developed countries, there is an increasing recognition that LCI databases must include products and services from developing countries (Tharumarajah and Grant 2002).

3 Developing an Egyptian National LCI database

The ultimate requirement of a national LCI database is to serve the needs of a wide spectrum of potential users. Criteria for the requisite data must include (Tharumarajah and Grant 2002), but are not necessarily limited to, the following:

- Conformance to the ISO
- Meeting the requirements of specific transparency, screening, quality, and peer review
- Consistent treatment of materials and products
- Regional differentiation to the extent required to properly reflect critical variations within and across industry sectors
- Full accessibility in format(s) and software platforms designed to maximize use
- Adequate database coverage of sectors to reflect the priority needs of the users

3.1 Goals of the Egyptian National LCI database

The Egyptian National LCI (ENLCI) database will be a recognized source of Egypt-based, quality, and transparent life cycle inventory data and will become an integral part of the rapidly expanding use of LCA as an essential environmental analysis and decision-making tool. As such, the authors define the following points to be the goals of the ENLCI:

- Maintain data quality and transparency
- Incorporate commonly used materials, products, and processes in Egypt with up-to-date, critically reviewed LCI data
- Create LCI databases involving many individuals (teams of novices and experts) aiming at (1) practical involvement, (2) job training (training the decision makers), (3) capacity building, (4) operational “field tests,” and (5) assistance in establishing funding
- Support the expanded use of LCA as an environmental decision-making tool
- Maintain compatibility with international LCI databases
- Provide exceptional data accessibility
- Be fully and sustainably supported
- Support the competitiveness of Egyptian industry

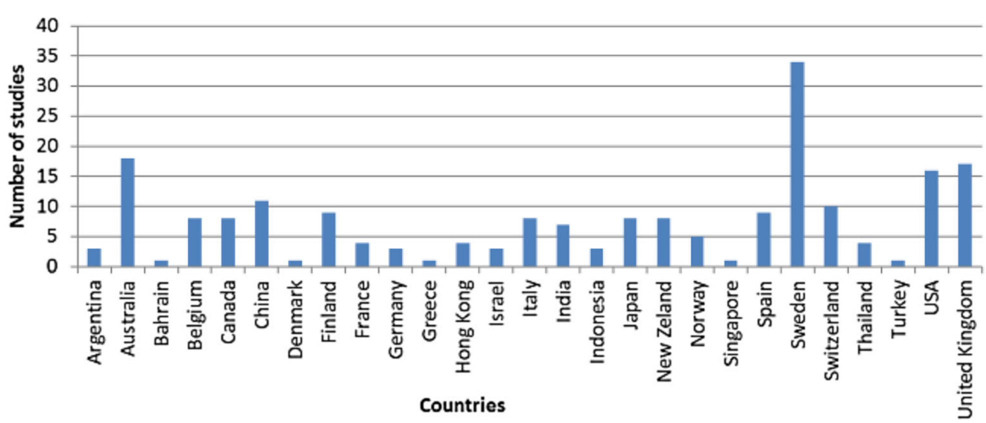

Fig. 2 A summary of the number of case studies of 27 countries from around the world (collected by the authors from 205 international case studies)

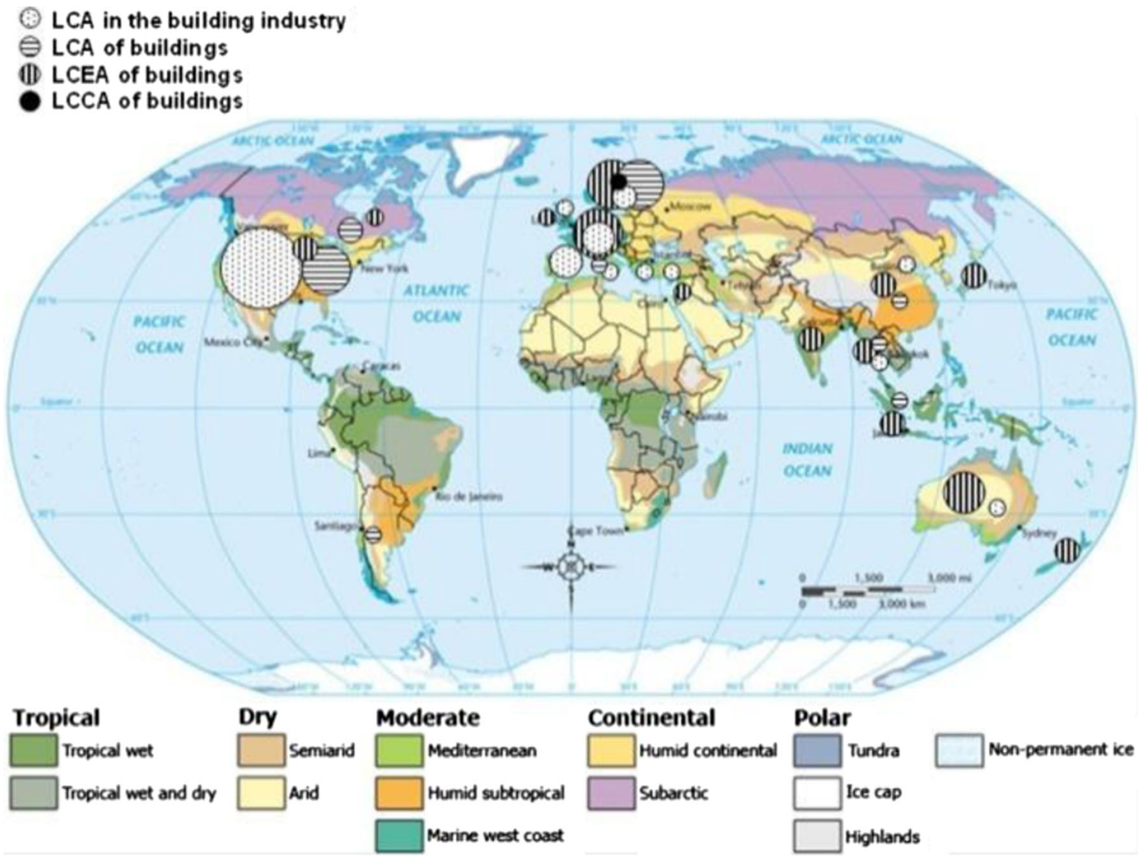

Fig. 3 A summary of studies organized by area of assessment and type of study carried out, where the *area of the circles* represents the number of studies conducted (Cabeza et al. 2014)

3.2 Challenges to developing the ENLCI database

The challenges to developing an ENLCI database that addresses the above established requirements are both technical and organizational. The technical challenges include acquiring the necessary data; modeling and transforming this data into LCI data; and assuring its quality, reliability, accessibility, and maintenance in a well-developed database. The organizational challenges include organizing and managing the numerous stakeholders in industry and academia as both users and suppliers of data; promoting the use and growth of the database; planning and coordinating the development tasks; and addressing issues concerning the provision of resources, expertise, and funding in order to grow and sustain the database. These challenges are further elaborated in the following subsections.

3.2.1 Technical challenges

The quality, reliability, relevancy, and coherence of data are at the core of a nationally accessible and usable database (Asdrubali et al. 2013). Data quality (or, simply, quality) by its very definition characterizes the distinctiveness or degree of excellence of data. In this respect, ISO 14041 (Erixon and Carlson 2003) lists a number of indicators of data quality: coverage (the relative age of the data and the applicable region and technologies for which it is valid), its measure of the prevailing variability, extent of life cycle stages covered, consistency with respect to the unit definition and system boundaries, and the degree to which data reflects the true population of interest (EPA 1993).

3.2.2 Organizational challenges

Addressing the technical issues alone would scarcely be sufficient to establish a national LCI database (Buyle et al. 2013). The ENLCI must be progressively developed to widen the scope of its coverage as well as its use. In this respect, the combined efforts of many stakeholders, including industrial users, data providers, developers, government, and other participants, will be required to ensure its robust development. The important issue possibly is how to facilitate this engagement (EPA 1993).

To solve these challenges, the present study suggests the following points:

- Capacity building and training of the decision makers of the Egyptian LCA community in order to establish a

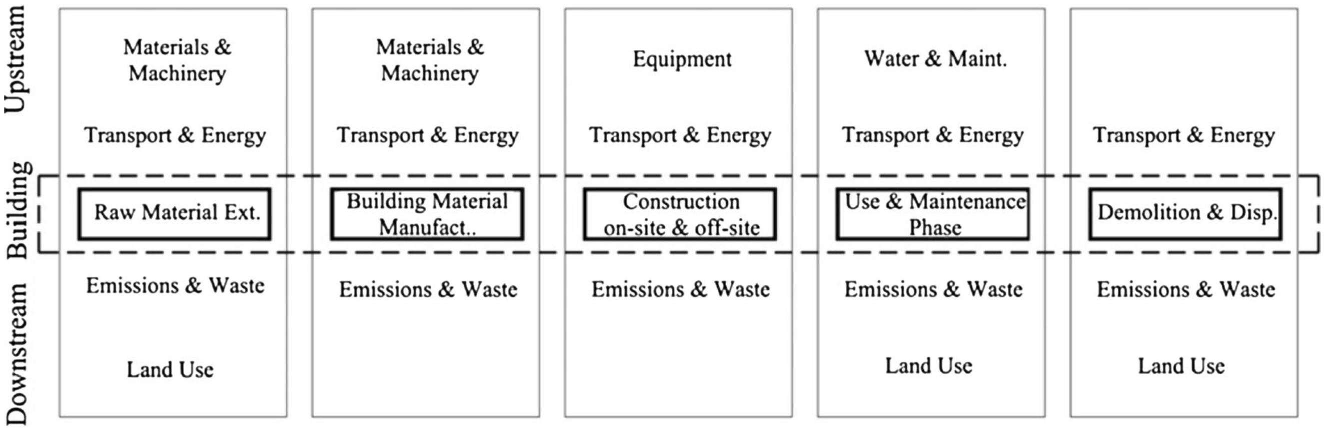

Fig. 4 A proposed system boundary for a building (Ries 2001)

national LCI database comprising aggregated as well as nonaggregated datasets

- Transfer of the technical system used for European LCI databases, such as the Swiss Ecoinvent LCI database, to organizations responsible for developing the ENLCI database
- Censorship of Egyptian industry and the establishment of limitations on the air, soil, water, and other pollutants

Also, the organizational structure for this first step towards developing an ENLCI database comprises the following participants:

- Industry and the concerned governmental ministries are in direct contact with the dataset producers and deliver the necessary information in order to facilitate the establishment of the respective datasets.
- The second coordinator, the Egyptian Housing & Building Research Center (HBRC), is in charge of the technical aspects, including the database related to the LCA building stages.
- The predominant role of Egyptian environmental agencies is monitoring and censorship of the materials, the product manufacturing processes, and the building energy consumption stage.
- Most LCI data is developed within projects carried out by state government agencies, universities, national research organizations, and industry. Data is employed by many sectors including energy and fuels, packaging, minerals, metals, building products, office equipment, and others.

3.3 Selection criteria of the ENLCI database

Hammond and Jones (2008) presented the criteria used to estimate the embodied energy and carbon in their Inventory of Carbon & Energy (ICE), and these are discussed below. Due to the difficulties experienced when selecting these values, the criteria need to be flexible and yet maintain an ideal set of conditions. One of the main difficulties is inconsistent and poor specification of data in the literature, i.e., different and incomplete boundaries (Dixit et al. 2013).

For developing the ENLCI database to ensure consistency of data within the inventory, the following five criteria are applied for data selection:

- Compliance with approved methodologies/standards: preference is given to data sources that comply with accepted methodologies. In the case of modern data, an ideal study would be ISO 14040/44 compliant (the ISO guideline for environmental LCA).
- System boundaries: system boundaries are adopted as appropriate for "cradle to gate" embodiment. Feedstock energy is included only if it represents a permanent loss of valuable resources, such as fossil fuel use. As an example, fossil fuels utilized as feedstock for petrochemicals used in the production of plastics are included (although identified separately).
- Origin (country) of data: ideally, the data incorporated would be restricted to that emanating from Egypt. However, in the case of most materials, this is not feasible, and the best available data from foreign sources must be adopted (using, for example, European and worldwide averages).
- Relative age of data sources: preference is given to modern data sources, especially in the case of embodied carbon where historical changes in fuel mixtures and carbon coefficients associated with electricity generation give rise to greater uncertainty in the embodied carbon values.

3.4 System boundaries of the required data for creating the ENLCI database

Ries and Mahdavi (2001) formulated and proposed a boundary definition that incorporates land use attached with life cycle stages in addition to the energy embodied in the required capital infrastructure, as described in Fig. 4.

Table 2 Required LCI data categories

Data category	Description
Material inputs (kg per functional unit)	
Primary materials	Actual materials that make up the final product for a particular process. These can be individual materials or a combination of materials that comprise a component part
Ancillary (process) materials	Materials that are used in the processing of a product for a particular process. Process materials from monitor manufacturing could include, for example, etchants used during photolithography, which are washed away and are not a part of the final product, but are necessary to manufacture the product
Energy inputs (MJ per functional unit)	
Process energy	Energy consumed by any process in the life cycle
Precombustion energy	The energy expended to extract, process, refine, and deliver a usable fuel for combustion
Transportation energy	Energy consumed in the transportation of the materials or products in the life cycle
Natural resource inputs (kg per functional unit)	
Nonrenewable resources	Materials extracted from the ground that are nonrenewable, or stock, resources (e.g., coal)
Renewable resources (e.g., water)	Water or other renewable, or flow, resources (e.g., limestone) are included in the analysis. Renewable resource data values are presented in mass of water consumed for a particular process
Emissions outputs (kg per functional unit)	
Air	Mass of a product or material that is considered a pollutant within each life cycle stage. Air outputs represent actual gaseous or particulate releases to the environment from a point or diffuse source, after passing through emission control devices, if applicable
Water	Mass of a product or material that is considered a pollutant within each life cycle stage. Water outputs represent actual discharges to either surface or groundwater from point or diffuse sources, after passing through any water treatment devices
Solid wastes	Mass of a product or material that is deposited in a landfill or deep well
	Represent actual disposal of either solids or liquids that are deposited either before or after treatment (e.g., incineration, composting), recovery, or recycling processes
Products (kg of material or number of components per functional unit)	
Primary products	Material or component outputs from a process that are received as input by a subsequent unit process within the display life cycle
Coproducts	Material outputs from a process that can be used, either with or without further processing, but are not used as part of the final functional unit product

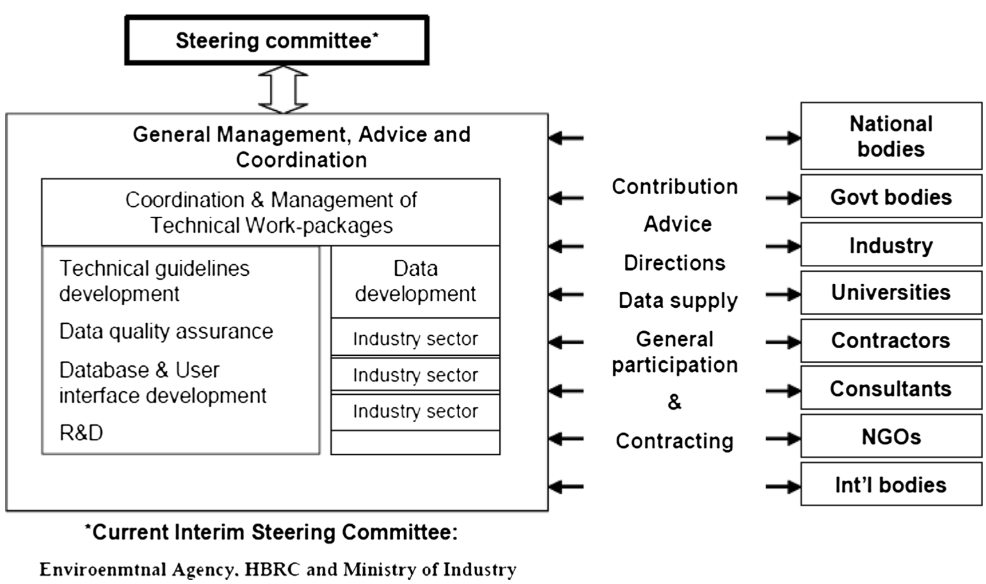

Fig. 5 Proposed organizational and managerial framework for the development of a national LCI database

Table 2 describes the data categories required for inventory, including material inputs, energy inputs, natural resource inputs, emission outputs, and product outputs. Inventory data must be uniformly normalized in accordance with the mass per functional unit (in the case of material and resource inputs and emission or material outputs), megajoules (MJ) per functional unit (in the case of energy inputs), or the number of components per functional unit (in the case of display components).

Data should include the final disposition of emissions outputs, such as whether outputs are recycled, treated, and/or disposed. This information helps determine the calculated impact for a particular inventory item.

4 Moving towards an ENLCI database (the roadmap)

While the above discussion regarding technical and managerial aspects/challenges encompasses the treatment and focus on tasks for implementing a national LCI database, it does not offer a practical solution as to who is equipped to do what. Establishing these details can be difficult, given the numerous stakeholders and LCA/LCI developers occupying the different sectors (see Fig. 5) and the different levels of interests, participation, and capacities for contributing to development of a national LCI database.

5 Conclusions

Interest in LCA is growing internationally. Many countries understand the importance of using LCA to identify and evaluate opportunities for minimization of resource consumption and air, water, and land pollution. Providing a transparent, consistent, accessible, and reliable national LCI database for Egypt has many potential benefits to industry as well as other institutional users. The ENLCI database can become a single source of reliable Egyptian inventory data for undertaking life cycle impact studies on a wide range of products and services, as well as serving as a repository of information to reduce environmental burdens in product supply chains.

There is an absence of an explicit organizational or project entity that has political recognition to draw and engage a wider group of stakeholders in their multiple roles as development partners, and as both users and suppliers of data. In addition, the start-up phase of a national LCI project is critical for instilling confidence and trust in the various stakeholders.

Thus, developers of an ENLCI database must be cognizant of this factor and take appropriate measures to rectify the situation. Additionally, the development should incorporate wider user requirements for providing accessibility, efficient database design, conformance to standards, accounting for regional differences, and so on. Not properly adjusting to changing needs and requirements could result in the data becoming less and less attractive to users.

The results from this analysis can be used to standardize the study of the LCA concept in Egypt and to lay a foundation for an ENLCI database. The results presented also highlight the importance of the role of stakeholders, such as environmental agencies, the HBRC, and the Ministry of Industry, in building and developing a national LCI database specific to Egypt and to use the LCA approach as an environmental impact tool.

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