Journal of Cleaner Production 107 (2015) 291–309

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Risk based life cycle assessment conceptual framework for energy supply systems in large buildings

Nasser Ayoub [a, c, *], Farayi Musharavati [a], Shaligram Pokharel [a], Hossam A. Gabbar [b]

[a] Department of Mechanical and Industrial Engineering, College of Engineering, Qatar University, Doha, Qatar
[b] Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Ontario, Canada
[c] Faculty of Industrial Education, Helwan University, Cairo, Egypt

ARTICLE INFO

Article history:
Received 19 October 2014
Received in revised form
6 February 2015
Accepted 21 April 2015
Available online 30 April 2015

Keywords:
Risk based-LCA
Energy conservation
Hybrid energy supply systems
Large buildings
IDEF0
Risk indicators

ABSTRACT

This paper proposes an environmental assessment framework that integrates the conventional life cycle assessment (LCA) with risk assessment for the purpose of evaluating energy conservation systems in buildings from environmental and societal perspectives. The inclusion of the potential risks raised by the different stakeholders in this framework will help the LCA professionals to identify accurate system boundaries of their study. This research addresses some limitations of frameworks presented so far by providing process activity modeling, using Type-zero method of integrated definition language, IDEF0, as a tool to describe each phase of its application. The proposed framework considers the LCA risk-based analysis in three modules namely; (i) establish of the life cycle stages, (ii) identify risk indicators and perform risk assessment, and (iii) manage risks through applying the risk assessment results to the life cycle of building's energy system. The risk based life cycle assessment (RBLCA) framework proposed here is further explained in a case study of performing RBLCA for a hybrid energy supply system (HESS) that supplies power to a hotel building. This approach allows us to investigate unfavorable impacts and risks of using HESS as way for energy conservation.

1. Introduction

Construction and operations of large buildings and industrial facilities produce pollutants that increase human and environmental health risks (Bhutto et al., 2014; Marafia, 2001). In construction phase, energy can be conserved through effective material supply chains as well as resources management. In the operation phase, energy can be conserved either through; (a) customer demand reduction based on behavioral or control mechanisms, or (b) through supply replacement based on the use of efficient technologies and renewable energy supply technologies. In order to assess the maximum potential for reducing environmental consequences, life cycle assessment (LCA) of each stage of energy supply system need to be thoroughly analyzed (Ayoub, 2007). In this work we focus on the energy supply side of a large building and develop a framework for risk based life cycle analysis (RBLCA) by investigating the life cycle stages of the energy supply system of a large building based on potential risks. By combining environmental assessment and risk assessment in our approach, we can control and manage risks more effectively (Darwish et al., 2013). This leads to various design options with better operational efficiency. The following subsections present the theoretical background of RBLCA frameworks followed by a literature review and research objectives.

1.1. Risks, life cycle assessment and RBLCA definitions

Risks can cause adverse effects and consequences in terms of losses that can be economical or environmental (Gabbar et al., 2012). Risks in buildings can be caused by natural disasters, human faults, management failure, and design error (Chen and Huang, 2008; Marhavilas et al., 2011). Other risks are associated with the use of hybrid energy supply systems (HESS). These risks are usually due to supply fluctuations, seasonal changes and/or climatic variations. Such risks are more prominent in situations where renewable energy supplies are part of the energy mix. Other forms of risks related to HESS operations are the lack of technical knowledge on repairs and maintenance, safety of workers and emissions.

* Corresponding author. Department of Mechanical and Industrial Engineering, College of Engineering, Qatar University, Doha, Qatar. Tel.: +974 4403 4325.
E-mail address: n.ayoub@qu.edu.qa (N. Ayoub).

http://dx.doi.org/10.1016/j.jclepro.2015.04.075
0959-6526/

In the literature, life cycle analysis (LCA) has been recognized as a useful tool for identifying the environmental impacts of products and making comparisons between products based on their environmental performance (Basson and Petrie, 2007). Therefore, the ideal case would be to address the identified adverse effects based on the life cycle stages of the investigated building. In other word, operational, environmental and economic risks analysis must be incorporated in the life cycle analysis of a building development project. In this perspective, risk-based life cycle assessment can be defined as "the life cycle assessment process that contemplates assessing and managing risks along the life cycle".

1.2. Life cycle assessment and RBLCA literature

Life Cycle Assessment studies are currently applied in a very limited extent in the building sector (Buyle et al., 2013). The reason for this is the requirement of a large dataset and specific tools to analyze the dataset. Current literature focus on building retrofits with modified lightening and HVAC systems (Ardente et al., 2011; Li et al., 2013; Rasouli et al., 2014) to whole building life cycle (Bilec et al., 2010; Buyle et al., 2013; GORD, 2010; Kua and Wong, 2012; Newell and Pizer, 2008). Many studies have been conducted on evaluating the environmental performance of fossil fuel based and renewable electricity production systems (Chen et al., 2013; Fthenakis and Kim, 2012; Kannan et al., 2007; Nugent and Sovacool, 2014; Peng et al., 2013). Despite such and similar studies, there is a general lack of research work devoted to investigating the LCA of HESS in buildings.

While a RBLCA framework has not been given due attention by some researchers, it is envisage as an appropriate approach for providing better and more practical analysis to energy supply systems in buildings (Hossain et al., 2007). One reason for this anomaly could be the pragmatic nature of the generic approach implied in RBLCA. For example, in addition to the site-specific parameters, the RBLCA application involves the identification of potential exposure routes and probability of vulnerability that provide an effective decision-support (ABSConsulting, 2002). Over the years, RBLCA methods have been recently applied on various disciplines such as costing analysis (Padgett et al., 2010; Weiwei et al., 2012), maintenance strategies (Chiu et al., 2012; Khan et al., 2004), energy systems (Gabbar et al., 2012; Gabbar; and Bedard, 2012), decision making (ABSConsulting, 2002; He and Kua, 2013; Kikuchi and Hirao, 2009), and chemical process design (Hirao et al., 2008; Sugiyama et al., 2008). Albeit, risk-based studies that consider life cycle assessment and environmental impacts are still lacking in the public literature. For example, Khandoker et al., (Hossain et al., 2007), developed a robust risk-based environmental assessment tool for industrial processes. This tool was used to evaluate different process options at the early design or retrofit stage. The main limitation of applying this methodology in building systems is that it does not explicitly consider the role of stakeholders in the decision making process. Another RBLCA methodology relies on informing the affected public if certain hazards are expected to spread widely beyond certain level of exposure risk was presented in (Sheau-Ting et al., 2013). The authors suggested that a third party should be involved in risk assessment either for the analysis or for the independent review of the analysis.

Using IDEF0 as a base for detailed processes design, risk assessment and life cycle assessment is pioneered by several researchers (Hirao et al., 2008; Kikuchi and Hirao, 2009; Kim et al., 2003; Sugiyama et al., 2008, 2006) to enable detailed and transparent definition of the whole design process. The local risks of processes and environmental impacts throughout the products life cycle have been considered, by Yasonari and his colleagues, via systematic procedure models for risk-based decision making of small and medium-sized enterprises (SMEs) (Kikuchi and Hirao, 2009). They have integrated LCA and plant-specific risk assessment using hierarchical IDEF0 activity modeling approach. The process generation, evaluation, and decision making activity models were defined and visualized with their associated information flows and data that should be collected by on-site engineers. A case study is conducted on designing a metal cleaning process reducing chemical risks due to the use of a cleansing agent. This approach is analogous to our proposed framework in relying on providing detailed information for the users of the framework based on predefined objectives and available data resources. Another IDEF0 activity model approach on Life Cycle Assessment based process design and related activities such as multi-objective decision making has been presented (Sugiyama et al., 2006). The whole design process is described hierarchically starting from design chemical process as a top activity and LCA related activities are sub-activities. The economic performance of the designed processes is considered as an activity concurrent to LCA, enabling multi-objective evaluation and optimization of the process. A case study is presented on the design of chemical recycling processes of beverage PET bottles with focus on the multi-objective process assessment. The integration of Environmental, Health and Safety (EHS) risks using IDEF0 activity modeling in industrial process design is also presented in the literature (Hirao et al., 2008; Sugiyama et al., 2008). The different phases of early process design, i.e. process chemistry and conceptual design, with process evaluation indicators are identified in the activity model. The model uses EHS aspects as assessment criteria together with conventional economic and technical indicators. Similar to the framework presented here, the viewpoint of the activity model is that of the design framework user i.e. design-project manager who leads the team.

To the best knowledge of the authors of the present study, the cited works are the only works that consider a RBLCA approach for energy supply systems.

1.3. Problem statement and research objectives

About 19% of Qatar's electricity is consumed by large buildings and it has increased by about three times compared to that in 1999 (Ayoub et al., 2014). There is, therefore, a need to understand how energy is being consumed now so that measures to conserve energy in buildings can be developed. There are also risks associated with energy supply systems. For example, equipment failure, and degradation of indoor conditions constitute risks that affect human health. In the domain of large buildings sectors the hotel sector represents a concentrated energy using entity that provides the largest negative impacts on the environment. Therefore, a comprehensive study of energy supply systems in hotels is a crucial undertaking. Such an undertaking is important since it allows energy planners to implement long term energy management strategies that support sustainable development (Çakmaklı, 2007).

To approach the solution of the problem discussed above this research paper has the following objectives:

1. Develop a framework for RBLCA for buildings. This framework will derive inspiration from the work presented in (ABSConsulting, 2002; Kikuchi and Hirao, 2009; Sugiyama et al., 2006).
2. The framework is generic and hence can be applied to the whole building life cycle or the life cycle of one of its components from the viewpoint of the project manager and, thus, the information flows are based on his objectives and available data resources.
3. Identify potential risks through the life cycle of energy supply systems.