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Rr. Anggun Paramita Djati

School of Environmental Science, University of Indonesia, Jakarta, Indonesia | Health Research and Development Unit, Banjarnegara, Central Java, Indonesia, 53415, anggundjati@gmail.com

Sherafina Reni Cahayanti

School of Environmental Science, University of Indonesia, Jakarta, Indonesia, 10430

Ellyna Chairani

School of Environmental Science, University of Indonesia, Jakarta, Indonesia, 10430

Raldi H. Koestoer

School of Environmental Science, University of Indonesia, Jakarta, Indonesia, 10430

Djoko M. Hartono

School of Environmental Science, University of Indonesia, Jakarta, Indonesia, 10430

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WHEN LCA APPLIES TO HEALTH SERVICE INDUSTRY

Rr. Anggun Paramita Djati^{1,2,*}, Sherafina Reni Cahayanti¹, Ellyna Chairani¹, Raldi H. Koestoer¹, and Djoko M. Hartono³

¹School of Environmental Science, Universitas Indonesia, Central Jakarta 10430, Indonesia

²Health Research and Development Unit, Banjarnegara, Central Java 53415, Indonesia

³Environmental Engineering Study Program, Civil Engineering Department, Universitas Indonesia, Depok, West Java 16424, Indonesia

*Corresponding author: e-mail: anggundjati@gmail.com

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Abstract

The health service industry involves activities that provide medical services (hospital), manufacture of medical equipment or drugs, and medical insurance services. Options of research methods to measure the impact of services on environmental aspects are available. One among which is life cycle analysis (LCA), the recently popular practice in Indonesia. This paper attempts to explore whether LCA could be fitted to the health service industry. A literature review would help in procuring related references from various publications accompanied by several research results and related studies. For describing the application of LCA in hospitals, several articles were collected, which were later arranged according to certain systematics from several sources. The LCA methodology used here consists of the following four stages: goal and scope definition, life cycle inventory analysis, impact assessment, and interpretation. The stages follow the International Organization for Standardization (ISO) 14040 and UNEP SETAC, 2011. Several studies using the LCA method in hospitals have reported specific profiles such as the management of biohazardous medical waste (BMW) and waste water. Several studies have also used LCA methods to assess specifically the environmental and health impacts of a specific component of the hospital or hospital activities. For example, studies have assessed the impact of equipment used in the form of containers, catheter, laryngeal mask, gowns and also infrastructures' facilities. The results of this study confirmed that the LCA method is suitable in health service industry, particularly in hospitals. Considering the merits and drawbacks involved in applying this method, one could further apply it to related health service issues.

Keywords: life cycle analysis; health service industry; hospital

1. Introduction

The increase in population growth exceeds the carrying capacity of the environment accompanied by various human activities that do not pay attention to ethics and environmental balance, leading to various environmental problems. These problems include energy crisis, global warming and climate change, extraction of natural resources, various forms of environmental pollution, increasing hazardous waste and hazardous substances in the environment, decreasing the quantity and quality of clean water, poor sanitation, and increasing diseases and epidemics (Hartono, 2018). Some pollutants found in the

environment come from human activities, which are known as anthropogenic pollutants (Adebowale, Agunbiade, & Olu-Owalabi, 2008; Rhind, 2009; Jhariya, 2014; Somma, 2014; Tyagi, Garg, & Paudel, 2014; Singh, 2015; Zhou, Huang, Yu, & Wang, 2015; Koff, Vandel, Marzecová, Avi, & Mikomägi, 2016). Human activities that significantly contribute to environmental pollution are the industries, which produce waste material that can pollute water.

The health service industry involves activities that provide medical services (hospital), manufacture of medical equipment or drugs, and medical insurance services. This sector with a wide range of services embraces the management of input, process or activity, output, and waste. Hospitals are a form of service industry in which management processes take place, and there are inputs, processes, and outputs, also producing waste. Various types of hospital waste produce dangerous pollutants, particularly to the water bodies, beach area, and sea as well (Al-Khatib, Eleyan, & Garfield, 2016; Laffite et al., 2016). The forms of hospital waste include hazardous materials, in the form of remnants of drugs, chemicals, disease-causing bacteria, and radioisotopes (Carraro et al., 2016). The activities in the healthcare industry, including hospitals, which can be a source of liquid waste include those occurring in the administration and patient care rooms, kitchens, laundry (washing cloth, clothing, bed sheets, etc.), surgical rooms, intensive care units or special care units managed to care for critically ill and critical patients, laboratory rooms, radiology rooms, dialysis rooms, dentistry, toilets, and technical and maintenance departments (WHO, 2018a). Various long-term effects caused due to hospital waste pollution not only occur in the environment, but they also eventually return to humans. One of them is the onset of disease and the occurrence of antibiotic resistance (Laffite et al., 2016), which can also increase the occurrence of disease, thus significantly reducing the degree of public health.

Efforts to control pollution include waste management and increased supervision of waste disposal from sources of pollution. Some forms of activities that can be done include “program kali bersih” or Prokasih (clean river program), water-saving movement, application of waste water disposal permits, improvement of drinking water services, and improvement of sanitation, especially in dense residential areas. These activities must be supported by increased participation of the community and government (Setiadi & Dewi, 2016). Healthcare industry waste management has been arranged in various modules published by the World Health Organization (WHO) (WHO, 2018b). Before processing, an important step that should be done first is to describe what ingredients can become pollutant waste. Knowledge and understanding of ingredients, management processes, material travel history, and the process of producing waste must be observed. The impacts that can be caused if the waste is discharged into the environment should also be evaluated carefully. Options of research methods to measure the impact of services on environment aspects are available. There are several tools, methods, and/or methods that can be used to analyze the impact assessment for the environment. Like several industries in general, one method of assessing the impact on the environment and health that can also be applied to the hospital industry is the life cycle analysis (LCA) method (Sofiyannurriyanti, 2017). This is also one of the methods that have recently become a popular practice in Indonesia. LCA is a method of assessing the environmental and health impact and has several advantages. Compared with

other impact assessment methods, such as the environment risk assessment, the LCA method has been found to be more comprehensive (Linkov et al., 2017).

This paper attempts to explore whether LCA could be fitted to the health service industry. Implicitly, this paper expands to determine the definition of LCA, its steps, and its use in an effort to assess environmental and health impacts on hospitals.

Not all researchers or public have known and understood about LCA, history, and types, moreover, its application to the hospital industry in Indonesia. The study of the application of LCA in the field of health, especially Indonesian hospitals, is very important to date. The increasing need for multidisciplinary knowledge to overcome the increasing environmental problems, especially human health, is the background of this article. This article, to some extent, could share knowledge of researchers and public towards LCA's perspectives.

2. Methods

A descriptive approach was used in this study, involving explanatory or deciphered information. In preliminary stage, it concerns with country wise. Then, since health issues in developing countries are alarming, Indonesia is finally selected as a based model. Indonesia is one of the developing countries with a large amount of varied resources.

A literature review would help in procuring related references from various publications accompanied by several research results and related studies. For describing the application of LCA in hospitals, several articles were collected, which were later arranged according to certain systematics from several sources. Systematic writing begins from understanding, history, development and types of LCA, the stages involved in the LCA, its strengths and weaknesses, and examples of research or studies in the field of hospital industry that apply LCA. Some keywords used in the literature search included “life cycle assessment,” “life cycle analysis,” “life cycle analysis health service industry”, “life cycle assessment health service industry”, “life cycle assessment hospital”, “life cycle analysis hospital” and “life cycle assessment hospital”. Because of limitation of Indonesian study publication about LCA in hospital, in order to retrieve studies in Indonesia, it also used keywords in Indonesian language included “life cycle analysis rumah sakit”, “life cycle assessment rumah sakit”, and “analisis siklus hidup rumah sakit”. Data collection carried out for approximately 10 months (February-December 2018). The search engine used to help collect data was Scopus, PubMed, Google Scholar (Google Cendekia) and Google. Consideration of the use of Google due to the limited publication of the results of similar studies in Indonesia. Although the year of publication of the articles or studies was not restricted, it was prioritized to selected were those published in the last 5 years (since 2013). It turned out that there were many articles that were very in line with the topics and themes but published in 2012, so the data collected was slightly expanded. As well as special publications in Indonesia. Because the amount of articles obtained was very limited, then the year was published an article which discussed the study in Indonesia almost unrestricted (since 2005). After the selection process that was not easy, finally there were retrieved 27 papers to be reviewed.

The articles that were collected were then screened by title and screened by abstract. Then records retrieved analyzed and grouped according to the sub-themes consisting of definition, history and development, strengths and weaknesses, research, and LCA studies in the

hospital. In the analysis and discussion, various analogies of the application of LCA in the industrial field in general in the hospital industry were described.

3. Results and Discussion

3.1 Definition and History of LCA

Life cycle assessment (LCA) is a tool or method used by several organizations to analyze and assess the environmental impacts caused due to or related to their products, services, or product systems. Impact assessment is linked or carried out at all stages or at each stage of the product or service life cycle (service). The more complete the assessment is done, the more it is in accordance with the assessment guide standards made by the International Organization for Standardization (ISO) (Knutsson, 2015).

Life cycle assessment can also be interpreted as a compilation and evaluation of inputs, outputs, and potential environmental impacts of a product system throughout its life cycle (Haselbach, 2015). In its development, LCA is commonly used in research, industry, and policy-making. From its origins in the analysis of energy around 1960 and 1970, LCA emerged as a tool that can be used more widely in exploring potential impacts on the environment and the decreasing resources (Mcmanus & Taylor, 2015). Life cycle assessment was created by the ISO in 1996. In 2006, the method was refined in the second edition. A more complete guide to LCA is published in ISO 14044, which contains requirements and implementation instructions. Further developments were carried out by separating a part of the LCA framework from the requirements, so that the issue of ISO 14040 contains a framework, while ISO 14044 contains the requirements (Haselbach, 2015).

In addition to the term LCA, there are also known terms of other similar methods such as life cycle costing analysis (LCCA), social life cycle analysis (Social-LCA), and life cycle sustainability analysis (LCSA). Life Cycle Costing Analysis is a method to calculate agency, user, and environmental damage costs throughout the entire lifetime of an infrastructure application. It takes into account three types of costs, namely, costs that must be incurred by the agency, costs that must be incurred by the user, and environmental costs (Kyriaki, Konstantinidou, Giama, & Papadopoulos, 2017). In some studies, LCA has been used or combined with LCCA, so that it can complement the analysis and provide an in-depth discussion of the research results (Norris, 2001; Gregory, 2013).

The Social-LCA is a method for analyzing the social impact of production, consumption and disposal of products, as well as processes and services, using a life cycle approach. In an effort to further develop thinking by the life cycle approach, Social-LCA can be a more useful tool for achieving sustainable development and consumption goals.

In the life cycle thinking approach, life cycle costing (LCC) has been developed to consider economic impacts, and S-LCA is currently being developed to include social dimensions. “Guidelines for Social Life Cycle Assessment of Products” or guidelines for implementing S-LCA were first published in 2009 by the United Nations Environmental Program (UNEP), the Society for Environmental Toxicology and Chemistry (SETAC), and the Life Cycle Initiative (Paragahawewa, Blankett, & Small, 2009). Furthermore, with the emergence of sustainable (sustainable) terms and principles that pay attention to the three major pillars, i.e., economic, social, and natural environment, LCA began to be developed into life cycle sustainability analysis (LCSA). LCSA was introduced more widely in “The

International Society for Industrial Ecology” in 2011. The emergence of LCSA originated from LCA, which is considered to have limitations in terms of economic and social aspects. The term LCSA was first used by Zhou et al. in 2007, but it is associated with only climate change issues and a decline in natural resources. At that time, LCA was combined with LCC. Furthermore, LCSA was developed again by Guinée et al. in 2011 by adding social aspects into the analysis (Guinée, 2016).

The process of impact assessment can be divided into a “life cycle stage” or a “life cycle stage” and a phase that is part of the LCA process. LCA phases or steps include the following (Haselbach, 2015).

- a. Determining the purpose and scope.
- b. Conducting a life cycle inventory (LCI), which involves mapping processes and learning systems and inventorying materials and energy inputs and outputs issued to the environment.
- c. Conducting a life cycle impact assessment that involves analyzing and evaluating the selected environmental impacts related to input and output.
- d. Interpreting the results to make the right decision.

There are several principles in using LCA that apply and need attention. The use of LCA is relatively adjusted to the functional unit. The functional unit is the number of functions calculated from a product or a process. In addition, in the LCA, the aspects that are discussed are only environmental aspects, while economic and social aspects are considered using other tools or methods. The last mentioned principle, in the history of the development of LCA, has changed to LCSA by considering economic and social aspects. The LCA method is comprehensive and includes all attributes or aspects of the natural environment, human health, and resources. In addition, the principle of using another LCA is iterative, the implementation of impact assessment in LCA is carried out at every phase, and the results of the assessment of the previous phase are the basis for the assessment of the next phase. In characterizing the impact using the LCA method, the scientific approach used is prioritized or prioritized on environmental impacts. Then, the impact can be considered in the aspects of social, economic, and/or international conventions, and the choice of the last approach can use the choice value in the form of opinions or preferences (Somma, 2014).

Although LCA prioritizes the natural environment aspects while conducting an impact assessment analysis, the LCA method is different from the environmental risk assessment (ERA). The primary difference between LCA and ERA lies in the starting point of the assessment. The starting point of the assessment of the impact in the ERA method lies in the substance being assessed, whereas it is the application or activity in the LCA method (Hallberg, 2005).

3.2 Uses in Health Service Industry

LCA includes health aspects in its assessment elements. LCA has also been widely used in the health sector. One of the themes of health impacts discussed in the LCA method is human toxicity. Several studies on health impacts have measured the magnitude of the problem using the calculation of disability-adjusted life year, which is a unit that measures the burden of disease expressed in the form of years of life lost due to death and years of life with defects associated with the degree of disability suffered (Ferrão, 1998). Besides that, not all hospital

waste management systems always apply reduce, reuse, and recycle processes. Some hospital waste can be managed as municipal solid waste (MSW), but there is also other waste that is radioactive, toxic, or contagious. Proper waste separation in every part of the hospital is required (Inskeep, Pashouwer, Peige, & Watson, 2014). Using the LCA method or the life cycle approach, it is expected that the management of hospital waste can be more precise and efficient, so that it can minimize the impact on the environment and public health.

To the knowledge of the authors, there are only a few publications of hospital industries that have implemented LCAs in the assessment of the environmental impacts they have caused, especially in Indonesia. Regarding the field of hospital research, LCA has been used several times.

The application of LCA in the health service industry is most closely related to the environmental impact of waste produced. Several studies focused on this field. There are many types of waste produced from the hospital industry because this industry involves many processes of activities and equipments.

Management of biohazardous medical waste (BMW) in the United States is carried out using two primary methods, i.e., autoclave sterilization and incineration. The study of Inskeep et al. in 2014 aimed to quantify the environmental impacts of a hospital's daily BMW disposal in an area of Phoenix, Arizona. The only option to dispose of BMW in Arizona is to sterilize the waste by sending it through an autoclave and then dispose the sterilized waste in a landfill. The system boundary for the LCA includes BMW generated at the Phoenix area hospital as it travels to stericycle, where it is autoclaved and then transported to a landfill for disposal. The results showed that the greatest impact on the potential for global warming was caused by transportation, and the greatest fossil fuel depletion and the potential for inducing human toxicity occurred in the landfill. A 30% reduction in weight as a result of the autoclave process showed that the ideal case load on the landfill was larger, and there was more waste to move around and decomposed. This results in a higher potential for the depletion of fossil fuels and also potentially cause human toxicity. Therefore, it could be considered that the depletion of fossil fuels and the potential for causing human toxicity would be higher in the business-as-usual case, when more waste was autoclaved (Inskeep et al., 2014).

The study of Ali, Wang, & Chaudhry in 2016 in Gujranwala, Pakistan, conducted a case study of solid waste generated from the hospital industry. The authors discussed the prediction of greenhouse gas (GHG) emissions from various waste treatment activities. Waste segregation can help implement environmentally friendly waste disposal technology. By implementing the LCA, it is expected to help inform policymakers about minimizing hospital waste and the need for waste segregation and recycling. In that study, the objectives set out in the LCA method were to determine and compare the environmental burden of hospital waste through several different waste treatment scenarios. The limitations of the study were also discussed, which include the following, among others: the options of heat or electricity recovery were not involved in the model; several factors were not used such as the acidification potential, human toxicity, and photochemical oxidant creation; the study focused only on GHG emissions; the practical difficulty of the study was an effective segregation of waste items; and guidance and training were still required for the sanitary staff. One of the suggestions submitted by the authors was that LCC techniques can be used (Ali et al., 2016).

Fieschi & Pretato study in 2017 focused on another types of hospital waste. Based on the data mentioned in this study that estimated 88–100 million tons of food waste are generated every year in Europe, with a Global Warming Potential (GWP) of around 227 MT of CO₂ equivalents generated for their collection and disposal. A small part of this waste is estimated to arise from food service within the contract catering in hospitals. This study compared the environmental performance of two scenarios. The first was using biodegradable and compostable single use tableware with organic recycling of food waste through composting. The second scenario was a traditional scenario using fossil-based plastic tableware and disposal of the waste flows through incineration and landfill. The LCA study was carried out from “cradle to grave”. The results confirmed that the use of biodegradable and compostable tableware combined with organic recycling was the preferred option. It reduces significantly the carbon, water and resource footprint and is fully in line with the principles of a circular economy (Fieschi & Pretato, 2017).

Other researches discussed the type of liquid hospital waste known as waste water as done by Igos et al. (2012) and Köhler et al. (2012) in Luxembourg, and also Schwaickhardt, Machado, & Lutterbeck (2017) in Santa Cruz, Brazil. Igos et al. study compared wastewater treatment scenarios based on LCA, focused on the improvement of water reuse, including the assessment of pharmaceuticals in particular the antibiotic Ciprofloxacin as predominant. The first step was compared scenarios focuses on the full scale policy, i.e. the relevance of implementing a decentralized Waste Water Treatment Plants (WWTP) at the hospital. The second step was choice of post treatment to improve the elimination rates of pharmaceuticals. The results showed that an additional post treatment does not provide significant benefits because pharmaceuticals were found to have a comparatively minor environmental impact. In the comparison of post treatment technologies, ozonation and activated carbon performed better than ultraviolet radiation (UV). These results had high uncertainties due to the assessment models of the toxicity of pharmaceuticals in LCA (Igos et al., 2012).

Together with Igos in the same year, Köhler et al. conducted research related to hospital waste water of pharmaceuticals. This study used LCA to assess the feasibility of eliminating pharmaceuticals from wastewater hospitals in a cost-effective and environmentally way. For each treatment scenario, the environmental impact was generated by the infrastructure and resources used, such as electrical energy and H₂O₂, in terms of macro-and micro-pollutants. This study was reinforced by experiments to ultraviolet (UV) irradiation technology in the form membrane bioreactor (MBR) treatment of typical wastewater compounds and pharmaceuticals for five days both influent and effluent. Then, several batches of experiments were conducted to evaluate the UV treatment. The result showed that, in terms of the low organic carbon content and elimination of particulates, the MBR technology was adequate pretreatment before an energy intensive advanced technique was applied. To eliminate most persistent pharmaceuticals, UV advanced oxidation process (AOP) technology could be applied. The cost-benefit-analysis for UV technology has revealed 70% higher energy efficiency when using the low pressure UV lamp compared to the medium pressure (MP) UV lamp. In the end, the researcher concluded that the life cycle of the assessment and application of the complete and consensual methodology for a decision making process (Köhler et al., 2012).

As for research of Schwaickhardt et al. (2017) was more focused on the water waste

generated from the laundry process in hospital. This study aimed to develop a treatment system of hospital laundry wastewaters with greater efficiency and less environmental impacts. It tested seven different configurations combining the use of UVC and VUV photo-reactors. The researchers evaluated the performance of each configuration based on the removal of the load parameters, detoxification and life cycle assessment (LCA). One of the important results was the highest environmental burdens were associated with human toxicity, eco-toxicity and eutrophication of surface waters as well as to the use of non-renewable resources (Schwaickhardt et al., 2017).

Several studies also use LCAs to assess specifically the environmental and health impacts of the hospital industry. There are also studies that specifically assess only certain activities in the hospital industry, e.g., activities in the operating room.

The study of Thiel, Eckelman, Sherman, & Shrake in 2015 conducted in Magee-Women Hospital (Magee) of the University of Pittsburgh Medical Center used LCA to perform a robust analysis of the life cycle impacts of a single surgical procedure, specifically hysterectomy, i.e., the removal of a woman's uterus, using four different surgical methods. A hysterectomy was the second most common major surgery among women in the U.S. The four different surgical methods were vaginal, abdominal, laparoscopic, and robotic. This study used a hybrid LCA framework by entering process LCA data and economic input output LCA (EIO-LCA) data. The hybrid LCA is a combination of process LCA and EIO-LCA, which is used to address issues that may be encountered using each method alone (Thiel et al., 2015).

Furthermore, the authors conducted an assessment of waste. Variability and uncertainty in emissions for each hysterectomy component were measured using a Monte Carlo simulation. Monte Carlo analysis, or random number sampling, was used to account for the uncertainty inherent in the LCI data and the variability of material and energy consumption for each type of hysterectomy performed at this hospital. The results of the study included the average material composition of MSW generated by the four types of surgeries and also the average environmental footprint over hysterectomy types in every impact category analyzed (Thiel et al., 2015). The total life cycle environmental impacts of an average hysterectomy according to the surgery type (normalized to the highest hysterectomy type in impact category) are presented in Figure 1.

As shown in Figure 1, robotic hysterectomies had the largest contribution to all impact categories. In all four surgeries, spunbound-meltblown-spunbound polypropylene (SMS PP) material or gowns, bluewraps, and drapes comprised the majority of MSW based on weight. Gloves contributed to about 5% by weight to each surgery's waste stream. Based on the results of that study, it can be observed that although advanced medical technologies often imply better outcomes, current laparoscopic and robotic hysterectomies also cost more and utilize more resources, especially packaging and plastics, and produce more waste, namely, disposable electronic devices. As recommendations, the researchers suggested a number of opportunities to improve the environmental sustainability of current surgical procedures. On the other hand, the researchers also stated that the results of their study should not be used to dictate clinical care. The limitations of the study were that the study did not consider postoperative length of stay and also did not account for factors such as length of stay and postsurgical resource use, which may result in different emission profiles (Thiel et al., 2015).

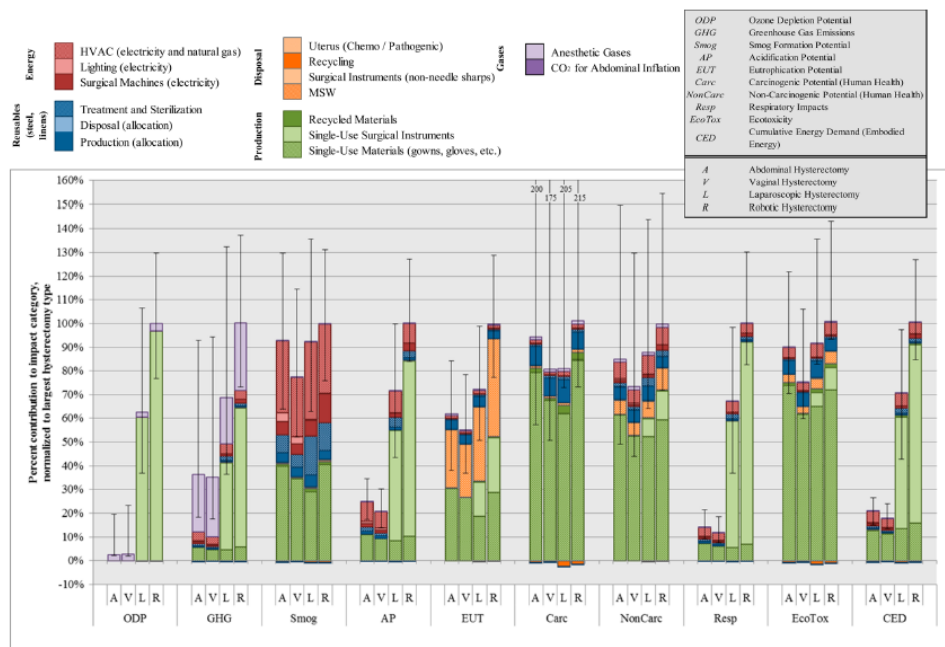


Figure 1. Total life cycle environmental impacts of an average hysterectomy according to surgery type
(Source: Thiel et al., 2015)

In another research publication in 2018, Thiel, Woods, & Bilec reviewed the impact analysis of laparoscopic hysterectomy using LCA hybrid. The difference was that in this study 17 procedures were performed at Magee-Women Hospital of UPMC between July and September 2011 based on 3 categories that produced the largest proportion of GHG emissions, as determined anesthesia; surgical materials and equipment; and energy for heating, ventilation, and air conditioning. One of the result was the largest carbon footprint savings came from selecting specific anesthetic gases and minimizing the materials used in surgery. The researcher concluded that to reduce the environmental emissions of surgeries, especially carbon footprint, health care providers need to be used combination efforts, including minimizing materials, moving away from certain heat-trapping anesthetic gases, maximizing instrument reuse or single-use device reprocessing, and reducing off-hour energy use in the operating room (Thiel et al., 2018).

In 2015, Esmaeili et al. study in radiology departments of two general hospitals in Wichita, Kansas aimed to provide quantitative information specifically to radiologists in making energy improvements while maintaining quality patient care. The process assessed with LCA was focused on the use of CT scanners. The result's study concluded that although the apparent electrical requirement for obtaining a CT image is the direct electrical energy from inside the hospital during a short imaging period (seconds), the full energy needs expand beyond this energy to a much larger in-hospital electrical energy consumption. Further, the CT footprint goes substantially beyond the in-hospital electrical energy from a life cycle perspective to the use of fuel for generation and transmission of electricity and manufacturing of all the consumables for a CT scan. This larger life cycle footprint is outside-the-hospital and represents a direct impact on the health of populations through emissions to air, water and land (Esmaeili et al., 2015).

Other studies that used LCA as a tool for assessing hospital activities are those carried out by [Campion et al. \(2012\)](#). This study aimed to analyze the birth of a baby in Magee-Womens Hospital as one aspect of sustainability in healthcare by LCA. It evaluated two common procedures in a hospital, a cesarean section and a vaginal birth. The results showed that a large percentage of the environmental impacts generated from heating, ventilation, and air conditioning, waste disposal, and the production of the disposable custom packs ([Campion et al., 2012](#)).

If previously one of the results of a study on waste water was produced from pharmaceuticals or drugs, so further it was reviewed a little about GHG emissions from anesthetic drugs. [Sherman, Le, & Eckelman](#) study in 2012 found that for all of the inhalation anesthetics, GHGs were dominated by uncontrolled emissions of waste anesthetic gases. Furthermore, researchers recommended other than inhalation techniques for anesthetics, such as total intravenous (IV) anesthesia, neuraxial, or peripheral nerve blocks. According to researchers, they have been least harmful to the environment compared to inhalation anesthetics ([Sherman et al., 2012](#)).

Several studies using the LCA method in hospitals have demonstrated specific profiles on medical equipments. Other studies have used LCA to assess the impact of equipment used in the form of containers, catheter, laryngeal mask, and gowns. Although they had same object of assessment were that medical equipment but the fields that judged were different. From the data collected, the most assessment area was the comparison of types of equipment usage (single-use or reusable). These were [Berghe & Zimmer](#) study in 2011, [Grimmond & Reiner](#) study in large US hospital in 2012, [Unger, Campion, Bilec, & Landis](#) study in 2016 in the form of review and in 2017 in the form of research, and [Sherman et al.](#) study in at Yale-New Haven Hospital (YNHH) 2018.

The study of [Berghe & Zimmer](#) in 2011 described the results of an impact study comparing multiple-use polyethylene terephthalate (PET) surgical gowns with disposable polypropylene (PP) gowns used in a healthcare setting. Specifically, the analysis compared the solid waste generated at the point of disposal and the relative environmental impact factors for gowns required for 50 surgical procedures as follows: one multiple-use gown with 50 wash cycles compared with 50 disposable gowns ([Berghe & Zimmer, 2011](#)). The results are shown in Figure 2.

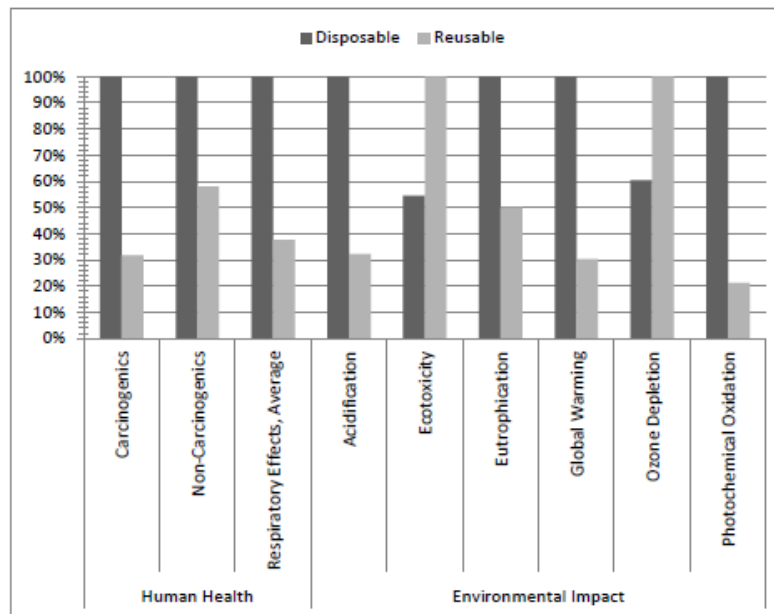


Figure 2. Comparison of environmental profile of disposable and reusable gowns in human health and environmental impact categories

(Source: [Berghe & Zimmer, 2011](#))

Figure 2 compares the normalized environmental impacts of the two cases, i.e., 50 single-use disposable PP gowns and one multiple-use PET gown laundered 50 times. The authors concluded that reusable gowns have an improved environmental profile compared with single-use gowns in all human health and most environmental impact categories. This suggests that, in this case, the multiple-use surgical gown option is a more environmentally preferred option ([Berghe & Zimmer, 2011](#)). The results of the study were consistent with the statement of Nancy Jenkins, Executive Director, American Reusable Textile Association, Mission, Kansas, which mentions that several life cycle analyses have confirmed that reusable surgical gowns and drapes are environmentally preferable over single-use disposable products. The 2009 life cycle assessment study conducted by the University of Minnesota Technical Assistance Program (MnTAP), the 2008 study conducted by the Textile Rental Association of Australia, and the 2000 study conducted by the European Textile Services Association have confirmed similar findings. The 2009 life cycle assessment of MnTAP examined the following three areas: cost, environmental impact, and infection prevention. In summary, the research conducted at the University of Minnesota Medical Center (2000 beds and 20,000 surgical procedures a year) found that reusable medical textiles (chemo, isolation, and surgical gowns) provided cost savings of \$360,000 per year, reduced waste by 254,000 pounds per year, reduced CO₂ emissions by three times less than disposables, and reduced carcinogenic emissions by 16 times less than disposables (i.e., arsenic, chromium, lead). Both the studies showed no difference in infection prevention attributes ([Jenkins, 2011](#)). Discussion regarding the assessment of the impact of using gowns was also strengthened by the 2015 study of Lucas in seven hospitals in Portugal that did not use LCA. The study analyzed disposable hospital gowns primarily made of polypropylene (PP). There was

annually about 688 t of nonwoven material in Portugal, 70% of which was nonsurgical. After their use, these gowns are discarded as hospital waste (HW) belonging to Group II or III. Group II wastes are classified as nonhazardous HW and are equivalent to urban waste. Groups III wastes are considered as hazardous and have to be incinerated or, alternatively, can undergo a decontamination treatment such as autoclaving, microwave treatment, or chemical disinfection before disposal (Sofia & Lucas, 2015).

Another study related to the assessment of gowns was conducted by [Vozzola, Overcash, & Griffing](#) in 2018. These researchers compared the environmental impacts of market-representative reusable and disposable isolation gown systems using standard life cycle assessment procedures. The basis of the comparison was 1000 isolation gown uses in a healthcare setting. The scope included the manufacture, use, and end-of-life stages of the gown systems. The result of the study showed that at the healthcare facility, the reusable gown system had a 28% reduction in energy consumption, a 30% reduction in GHG emissions, a 41% reduction in blue water consumption, and a 93% reduction in solid waste generation compared with the disposable gown system. The study concluded that by selecting reusable isolation gowns, healthcare facilities can add these quantitative benefits directly to their sustainability scorecards ([Vozzola et al., 2018](#)).

[Grimmond dan Reiner](#) study in large US hospital in 2012 showed that at Northwestern Memorial Hospital (NMH), reusable sharps containers (RSC) significantly reduced the global warming potential (GWP) over disposable sharps containers (DSC). The major contributors to the GWP was manufacturing and transport of DSC. Figure 3 showed annual GHG emissions by life stage of disposables and reusable sharps containers normalized to occupied beds ([Grimmond & Reiner, 2012](#)).

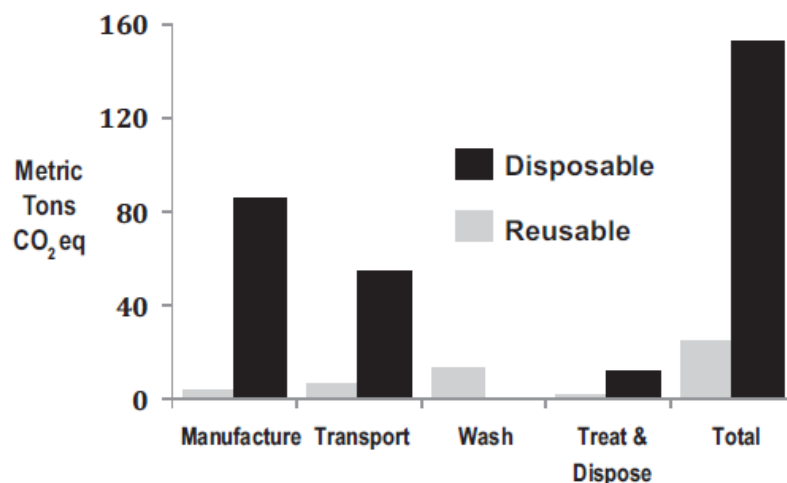


Figure 3. Annual GHG emissions by life stage of disposables and reusable sharps containers normalized to occupied beds
(Source: [Grimmond & Reiner, 2012](#))

Figure 3 showed that DSC treatment disposal emissions were 6.5 times that of RSC owing to the mass of DSC autoclaved versus zero RSC autoclaving (CDSC included in both systems; end-of-life' transport to landfill included in RSC). It also mentioned in the conclusion of this study that larger containers have little GWP impact. However, transport

distances and electricity cleanliness were important factors that need to be considered (Grimmond & Reiner, 2012).

Unger et al. (2016) reviewed several research applied LCA in hospital. It focused on the use of reusable medical products, comparable disposable medical products, and a series of medical services. The disposable and/or reusable medical products included a: bedpan, central venous catheter insertion kit, dental bur, gown, laparoscopic cholecystectomy instruments, laryngeal mask airway, scissors, trocar, and veress cannula. The assessed medical services included: custom packs used in vaginal deliveries, medical waste treatments, infant delivery, reprocessed products, and products with increased biopolymer content. One of result of review study showed that when several medical products (e.g., scissors, laryngeal mask airways, and dental burs) used as a reusable, they had a lower lifecycle GHGs as opposed to be used as single-use disposables. However, not all reusable medical products have a lower environmental impact compared to those used once (Unger et al., 2016).

Another Unger et al. study in 2017 compared the environmental impacts of single-use disposable devices with increased biopolymer content versus typically manufactured devices in hysterectomy. This study also conducted a comparison of assessments using LCA for single-use disposable medical products containing plastic versus the same single-use medical devices with biopolymers substituted for plastic at Magee-Women's Hospital (Magee) in Pittsburgh, PA. In addition, this study also compared the assessment of the products used in four types of contained plastic hysterectomies, potentially suitable for biopolymer substitution (Unger et al., 2017). This research seemed to be part of a study conducted by Thiel, 2015 in the same place.

Sherman & Eckelman. studies in 2018 aimed to describe cradle-to-grave life cycle assessment (LCA) and life cycle costing (LCC) methods and apply these to reusable and single-use disposable (SUD) metal and plastic laryngoscope handles and tongue blade alternatives. Costs may vary between facilities. However, the reusable options offering a better option environmentally and also presented a considerable cost advantage. LCC methodology demonstrates the importance of time-motion labor analysis when comparing reusable and disposable medical equipments. LCA and LCC are feasible methods to ease interpretation of environmental impacts and facility costs when weighing device procurement options (Sherman & Eckelman, 2018).

The application of LCA to assess the impact on other equipment, namely as examined by Eckelman, Mosher, Gonzalez, & Herman, 2012 (laryngeal mask airways) and McGain et al., 2012 (central venous catheter kits). A summary of results studies as follows. The reusable laryngeal mask airways (LMA) was found to have a more favorable environmental profile than the disposable LMA as used at Yale New Haven Hospital. The most important sources of impacts for the disposable LMA were the production of polymers, packaging, and waste management, whereas for the reusable LMA, washing and sterilization dominated for most impact categories (Eckelman et al., 2012). For the reusable central venous catheter kits, sterilization had the greatest environmental cost, and for the single-use kit, the manufacture of plastic and metal components had the largest environmental costs. the reusable central venous catheter insertion kits were less expensive than were the single-use kits (McGain et al., 2012).

In the construction sector or a hospital building, the study of [Eisazadeh & Allacker \(2018\)](#) used LCA of several advanced window systems for patient rooms in Belgium using the MMG+_KULeuven tool. As background of the study, it was essential to analyze the role of patient rooms, and specifically the role of windows, in environmental performance. Patient rooms occupy the largest space of hospital buildings and windows play a major role in both energy loads and quality of the indoor environment. The aim of that study was to determine the window systems that have the highest potential to improve the environmental footprint of hospitals. The study discussed the influence of several components, including glazing, coatings, window frame material, and window-to-wall ratio. It also presented an example of how an integrated energy and environmental analysis can inform architects in the early design stage. For the patient room, five scenarios were considered with the glazing unit as the variable element. The scenarios were analyzed along with their varying parameters. For each scenario, the operational energy and the life cycle environmental impact were assessed. The study concluded that the role of advanced coated glazing in energy efficiency was more dominant than the environmental performance, as the environmental impacts of window systems are primarily influenced by the amount of glazing used in construction and the frame type; however, it should be noted that the effect of coated glazing on the operational energy use influences the environmental impacts of buildings, i.e. primarily the CO₂ emissions. The operational energy refers to the energy consumed for the purpose of space heating, cooling, and lighting ([Eisazadeh & Allacker, 2018](#)).

The study of [Stevanovic, Allacker, & Vermeulen \(2017\)](#) used the life cycle approach in the sustainability of a hospital building. The subjectivity of several certification tools to facilitate the sustainability evaluation of healthcare facilities from the early design phase was the background of the selection of life cycle approach in the study. This study did not fully use the LCA method, but only in the form of an approach. The purpose of the study specifically was to compare the two existing certification schemes used in Flanders, namely, BREEAM New construction and DuurzaamheidsmeterZorg, in terms of weighting criteria and phase coverage of the building's life cycle. The first step taken in that study was analyzing the building's professional experiences in using sustainability assessment tools in hospital facilities in Flanders. Furthermore, a strengths, weaknesses, opportunities, threats (SWOT) analysis was conducted to identify the professionals' expectations. The study concluded that a correct method was required to help evaluate the sustainability of the hospital project from the initial design phase. It is important to carry out a rough LCA and LCC analysis on one or several hospitals in the Flemish region, which will enable the identification of hotspots and methodological challenges for the quantitative life cycle approach.

In the context of sustainability construction in particular, LCC receives considerable attention. On the other hand, the application of LCC in the construction sector is still limited and faces practical problems. This was partly due to the lack of understanding of the methodology. The study of [Dwaikat & Ali \(2018\)](#) aimed to demonstrate the application of life cycle cost analysis to green buildings and identify life cycle cost variables, so that a life cycle budget could be developed for the entire life cycle of green buildings extending for 60 years. Figure 4 presents the total life cycle budget summary for the case study.

Figure 4. Total life cycle budget summary for the case study

No	Description	Total life cycle cost (\$)	Weight
1	Design and construction cost	3,666,518	22%
2	Building energy cost	8,076,352	48%
3	Building water and sewerage cost	337,911	2%
4	Building maintenance cost	4,631,839	27%
5	End of life cost	173,014	1%
6	Total life cycle cost	16,885,634	100%

(Source: [Dwaikat & Ali, 2018](#))

It was found in that study that the future costs of green building under study were about 3.6 times higher than the initial design and construction costs. This energy cost is a weight of 48% of the total life cycle budget for buildings, and this ratio is >60% when weighted against the operational costs of the building alone. It was also found that reducing energy consumption in green building is the most influential factor to reduce total life cycle costs ([Dwaikat & Ali, 2018](#)).

Related to the use of LCA approach in hospital infrastructure assessment, [Dang, Han, & Le](#) study (2015) aimed to propose an indicator of seismic performance based on life-cycle cost of a building. The indicator was expressed as a ratio of lifetime damage loss to life-cycle cost. The calculation based on an actual seven-story, isolated hospital building during an earthquake at Gulang, Gansu, China. The results showed that building of hospital in this study was built by meeting the requirements of Chinese seismic design provisions. This could reduce the expected loss because the earthquake was only 37% and life-cycle costs were nearly 1% compared to other buildings not built on these requirements. The researchers concluded that the indicator based on lifecycle cost assisted owners and engineers in making investment decisions. It is also to hospital infrastructure.

Based on the results of data collection conducted, it was known that there are several focuses and areas of research that are often discussed. These topics included hospital waste, especially waste water, process activities, equipment, and infrastructures. A summary of the results of the research based on research's focus or fields was presented in the Table 1.

[McGain](#) review (2012) showed that LCAs are relatively novel to healthcare. [McGain](#) review (2012) compiled and reviewed the research results that relevant to environmental sustainability within hospitals included novel approaches/trends to the study such as life cycle assessment (LCA). The result of 49 references review showed that several themes such as general/several themes (10), hospital design (10), energy (6), water (3), travel (4), procurement (8), waste (4), and staff behavior (4). This is slightly different from the results of the review in this paper that specifically used LCA as criteria selection of references. There were hospital equipments and activities theme had discussed as many as waste theme. As for the results of a review by [McGain \(2012\)](#) which more specifically discusses LCA in hospital, there are some similarities in the results with this paper. The similarity is stated among others that it is often easier to perform LCAs of medical equipment rather than medications because there is usually open access to the manufacturing methods for the former. In addition, operating theatre LCAs have primarily been comparisons between reusable and single use variants of medical devices.

Table 2. A summary of the results of the research based on research's focus or fields

No.	Research themes	Year	Authors	Focus of study	Type of LCA method
1.	Hospital waste	2014	Inskip et al.	Biohazardous medical waste	LCA
		2016	Ali et al.	Solid waste	LCA
		2017	Fieschi & Pretato	Food waste	LCA
		2012	Igos et al.	Waste water (pharmaceutical)	LCA
		2017	Schwaickhardt et al.	Waste water (laundry)	LCA
		2012	Köhler et al.	Waste water (pharmaceutical)	LCA
2.	Hospital activities	2015	Thiel et al.	hysterectomy	Hybrid LCA (LCA and EIO-LCA)
		2015	Esmaeili et al.	radiology (CT scan)	LCA
		2018	Thiel et al.	laparoscopic hysterectomy	Hybrid LCA (LCA and EIO-LCA)
		2012	Sherman et al.	anesthetics (drug)	LCA
		2016	Unger et al.	custom packs used in vaginal deliveries, medical waste treatments, infant delivery, reprocessed products, and products with increased biopolymer content	LCA
		2012	Campion et al.	the birth of baby	LCA
3.	Hospital equipments	2011	Berghe & Zimmer	Surgical gowns (single-use and reusable)	LCA
		2018	Vozzola et al.	Isolation gowns (single-use and reusable)	LCA
		2012	Grimmond & Reiner	Sharps container (single-use and reusable)	LCA
		2016	Unger et al.	bedpan, central venous catheter insertion kit, dental bur, gown, laparoscopic cholecystectomy instruments, laryngeal mask airway, scissors, trocar, and veress cannula (single-use and reusable)	LCA
		2017	Unger et al.	manufactured devices in hysterectomy (single-use and reusable)	
		2018	Sherman et al.	laryngoscope handles and tongue blade	LCA and LCC
		2012	Eckelman et al.	laryngeal mask airways	LCA
2012	McGain et al.	central venous catheter kits	LCA		
4.	Hospital infrastructures	2018	Eisazadeh & Allacker	window systems for patient rooms	LCA
		2017	Stevanovic et al.	Hospital building	LCA approach
		2018	Dwaikat & Ali	Hospital building	LCC
		2015	Dang et al.	Hospital building	LCC

3.3 Uses in Health Service Industry in Indonesia

There are also some publications of some studies about the assessment of hospital industry using the LCA method in Indonesia. Unfortunately, based on this research, there were very little publication.

In the study of Puspitasari in Indonesia in 2005, LCA was used for analyzing the impact of hospital activities in PT Rumah Sakit Pelabuhan Surabaya (Hospital of Surabaya Port). The process observed and compared in this study is the process of health services for patients with typhoid disease treated by injections and tablets. The service process in accordance with the fixed procedure can contribute to the impact on the environment and requires a corrective action. In addition, this study also recommended the need for control over health service activities to achieve the green and environmentally friendly concept (Puspitasari, 2005).

The research conducted by Iswanta, Hardiyatmo, & Triwiyono in 2006 by taking the case of an inpatient building at Cendrawasih Hospital in Yogyakarta, Indonesia, showed that the construction of the building was carried out in stages from 1997 to 2000. The results of the economic life cycle cost analysis revealed that the hospital building provided enough profit and a break-even point was estimated that will occur in 2006 or 6 years from use and up to the planned age of 2050. The index of space conditions after being used for 5 years showed that the treatment room index using 24 h a day (93.73%) is smaller than the index of non-space conditions treatment that did not use 24 h a day (98.53%) (Iswanta et al., 2006).

The study of Sofiyanurriyanti in 2017 sought to implement business process efforts in implementing green hospital concept in the hospital environment and help the hospital to design strategies for environmental improvement. The background of this research included the concept of a green hospital as an effort to support healthy, clean, and environmentally friendly management. The life cycle assessment method was used to assess the environmental impact on waste in this study based on characterization, damage assessment, normalization, weighting, and single score. The results of observations of the existing conditions in the hospital indicated that the hospital under study had never implemented a business process and had not applied the green hospital concept. The largest increase in environmental impact was the single score, which consists of a total of 0.691031 Pt covering water use, electricity use, use of medical waste, non-sharp medical waste, and sharp medical waste. Based on the results of the calculations, the environmental impacts produced in the hospital had the greatest influence on resources, followed by the quality of ecosystems and human health (Sofiyanurriyanti, 2017).

3.4 Merits and Drawbacks

Some of the merits of LCA are that the environmental impact assessments are holistic and encompass global and regional levels. Using LCA, impact assessments can be conducted more objectively. In addition, LCA is a method that continues to grow, as has been briefly stated in the development of the history of the use of LCA. Another advantage of LCA is that it can be used to compare environmental impacts between different products but have the same function, compare the environmental impact of a product with its standards, can identify the most dominant phases of impact on the environment, and can be used as a basis for information for improvement, communication, strategy, lobbying, and so on (Ferrão, 1998; Haselbach, 2015).

The drawbacks of the LCA method are that it is a modeling tool. Modeling is a simplification of reality or reality. The characterization carried out in the LCA phase is not perfect, because not all environmental problems can be included in the assessment, depending on the purpose and scope that have been determined in the initial phase of the LCA. In addition, the data used in the second phase of the LCA, LCI, are often limited and contain uncertainty. Sensitivity and other uncertainty analyses are not fully developed (Koff et al., 2016; Hartono, 2018).

Another limitation, as stated in the history of LCA development and the LCA principle, is that conventional LCA does not include economic and social aspects. This has now been developed so that the LCSA method appears and the analysis carried out is more profound by involving the participation of stakeholders, policy makers, and researchers (Ekvall, Ljungkvist, Sandvall, & Ahlgren, 2016).

Indonesia is one of the developing countries that has a variety of resources and varied environmental characteristics. In addition to the positive benefits obtained, on the other hand, many environmental problems can arise. One of them is in the hospital industry. The types of hospitals in Indonesia are quite diverse and widespread in almost all regions in Indonesia. Each has a different level of development. This includes management of activities that can have an indirect impact on the environment and public health. The application of LCA to the assessment of the impact of the hospital industry in Indonesia in particular, and the assessment of service processes and products in general, will have many advantages. Not only for the environment and public, but also for the development of the hospital industry itself. However, the development of LCA itself, which is still in its early stages in Indonesia, has become one of the challenges especially for researchers and observers of public health issues, especially in the field of hospital industry in Indonesia. Several aspects that can enrich the understanding and development of the application of LCA in hospitals in Indonesia, including social culture, geography and the physical environment.

The application of LCA in the health services industry is apparently important and needs to be developed. Often new LCAs are only applied in industries that produce certain physical goods products. Even though in the industrial sector that produces services, LCA can be applied. Various types and processes of activities in the hospital services industry have a detrimental impact on both the environment and health itself, both short and long term. The environmental impact assessment that has been applied so far has not been comprehensive and the analysis or proof of the results requires a long time. On the other hand, the need for prevention and control of environmental and health impacts is increasing and urgent. With LCA, the impact assessment process is more in line with today's needs.

This paper has several limitations. One of the main weaknesses was the lack of publications regarding researches or studies using LCA in the health service industry, especially in Indonesia. This caused the data collected and analyzed to be limited. There are several studies that have used LCA in assessing environmental and health impacts in the hospital industry, but are not published internationally, especially within the scope of Scopus. Another limitation was the method of collecting data that was still general in nature and did not specifically select the topic of similar activities in the field of hospital. However, it was expected that this study could be one of pioneers in improving research and international

publications regarding the application of LCA in the hospital industry, especially in Indonesia.

4. Conclusions

The LCA method is needed for assessing the implementation of industrial service activities, including those related to the health service industry. This is of significant importance, especially in improving the implementation and development of occupational health in the natural environment. LCSA is a method of developing LCA that can be used more widely and for the needs of a more in-depth analysis.

The results of this study confirm that the LCA method can be suitably applied in the health service industry, particularly in hospitals. Life cycle assessments have been used to assess the environmental and health impacts of all processes and equipment used in hospitals, some of which are surgical process, as medical gowns, and infrastructures. Based on the search results of the data in this paper, the application of LCA was mostly done on the use of medical equipment. In addition to assessments easier and faster to do, the types of medical equipment are quite numerous and the impact can be in direct contact with the environment. Considering the merits and drawbacks involved in applying this method, one could further apply it to related health service issues.

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