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Life cycle assessment of industrial and urban wastewater treatment plant

Iwona SKOCZKO, Ewa SZATYŁOWICZ, Magdalena HORYSZ, Łukasz MALINOWSKI
Białystok University of Technology, Poland

Alican TUNC
Harran University, Turkey

Abstract: Life Cycle Assessment (LCA) is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave. With raising human population and the increasing industrialization, there has been very substantial increase in waste products too. Nowadays the importance of the wastewater treatment (domestic and industrial wastewater) need more attention in terms of the ecological balance. In this article a study was conducted and focused on the comprehension of the methods which are used for life cycle assessment and evaluation of environmental effects. In the proceeding sections of this study, Life Cycle Assessment method was used for evaluation the environmental advantages and expenses of other different wastewater treatment technologies and standards. An inventory of the input (chemical substances, electrical energy etc.) and output (emissions releases into the water, earth and the air, amount of sludge etc.) of the plants, where wastewater is treated, was documented. Potential environmental effects of the input and the output was assessed too. Finally, the obtained results were interpreted with regard to the objectives of LCA. With regard to these studies, attention was drawn to the importance of wastewater treatment plants which are regularly managed. Utilization of treatment systems resources and its effects on human health and ecology were assessed, finally the most suitable methods of wastewater treatment methods were tried to be explained with best examples.

Keywords: Life Cycle Assessment, Wastewater Treatment, Wastewater Treatment Methods and Environmental Effects
JEL codes: Q51, Q52

1. Introduction

Life Cycle Assessment (LCA) is the instrument used to assess the ecological burdens and human health impacts connected with the entire life cycle (creation, use, end-of-life) of products,

Correspondence Address: Iwona Skoczko, Ewa Szatyłowicz, Magdalena Horysz, Łukasz Malinowski, Department of Technology in Engineering and Environmental Protection, Faculty of Civil and Environmental Engineering, Białystok University of Technology, Poland. FULL ADDRESS. Tel.: +48857469563, Fax:+48857469015, E-mail:i.skoczko@pb.edu.pl Alican Tunc, Harran University, Institute of Natural and Applied Science, Turkey. FULL ADDRESS. Tel.: +904143183000, Fax:+904143128144, E-mail: alitunc1991@hotmail.com

processes and operations, allowing the assessor to model the entire system from which products are derived or in which processes and activities operate (Curan, 2005; Hauschild, Huijbregts 2015).

The International Organization for Standardization (ISO) defines LCA as a technique to identify the environmental aspects and potential impacts associated with the evaluation of the product. LCA according to ISO should contain the following four points:

- An identification purpose and scope of the audit
- Table of contribution and performance of the product system
- Potential environmental impacts related to contributions and outcome of the evaluation system
- Interpretation of results.

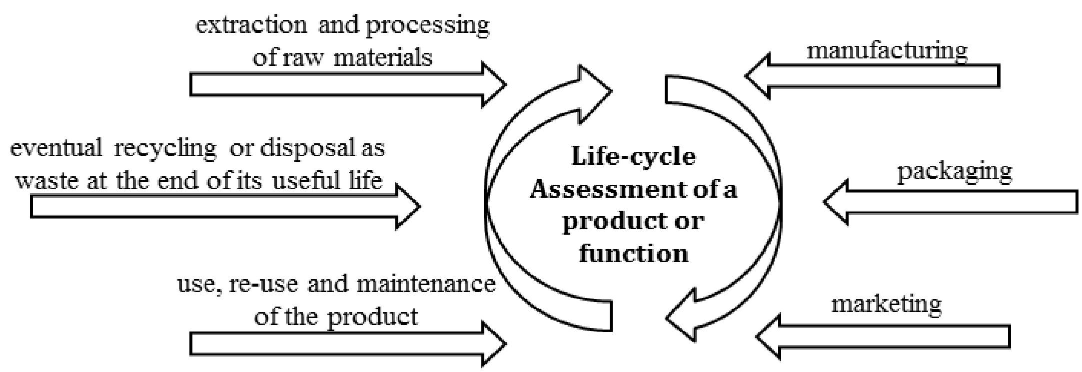
LCA related to complex interactions between the product and the environment. The main categories of environmental impacts requires taking into consideration human health, utilization of natural resources and the quality of the ecosystem. LCA provides to determine a methodology the effective management of raw materials in both environmental and economic aspect. For this reason, it is an important tool in shaping solutions to reduce consumption of natural resources and energy while remaining sufficiently provider of goods and services. In addition, LCA is used to evaluate environmental influences in modern and models technological processes and existing processes alternatives (EcoPaperLoop, 2014).

2. Methodology

LCA have two main objectives. The first is to quantify and evaluate the environmental performance of a process from ‘cradle to grave’ it helps decision-makers to choose a more sustainable option among alternatives. Another objective is to provide a basis for assessing potential improvements in the environmental performance of a system. Two main problems are associated with these objectives of LCA. Life cycle assessment methodology shown in Fiugre 1 is used to evaluation of selected manufacturing processes, services, management systems in companies and to the economy assessment. LCA enables the assessment of environmental aspects and impacts arising from all phases of the lifecycle, including (EcoPaperLoop, 2014; Risch, 2014):

- acquisition and processing of natural resources,
- production,
- distribution,
- transportation,
- usage,
- reuse,
- recycling or other methods of recovery,
- waste management.

Figure 1. The phases of life cycle assessment



Source: own elaboration based on ISO 14040

In the study evaluated the different variants of urban wastewater treatment, in order to choose the most environmentally friendly option. This was achieved by assigning the validity of the impact of selected factors. Weights of individual factors assigned based on comparisons with comparisons indicated variations in mainstream literature.

Paper describes also the analysis for pretreatment methods of wastewater that comes from production of carton package. Two kinds of wastewater pretreatment systems were analyzed. The functional unit was the cubic meter of treated water. The raw materials and chemicals that were used in the production are reference parameters, which are well-thought-out to understand as the sources of the pollutants in the wastewater. In the analysis, it is assumed that both factories generate the same volume of wastewater. Both wastewater treatment systems have similar treatment efficiency. LCA was prepared with attend to treatment processes: the chemicals used for the treatment process, the amount of sludge, investment and operation costs. The first step in the Life Cycle Assessment methodology is to define range of the system. Knowledge of the production processes of carton package is important parameter for life cycle assessment. Other data are the sources of the pollutants. Wastewater results from washing the moulds and shaft of the machines during the operation. Determining wastewater quality such as pollutants parameters are established as: chemical oxygen demand (COD), suspended solids (SS), oil-grease, Sulfate, Sulphide, Zink and pH. Next, the most suitable treatment system were chosen according to the discharge criteria related to the geographical area where the factory is located. The functional unit was the cubic meter of treated water (Guinée, 2011).

3. Evaluation of LCA of treatment alternatives of industrial and urban wastewater

In this study, for control of water pollution due to domestic and industrial wastewater, the conventional wastewater treatment using activated sludge (separately or in combination with chemical coagulation) has been adopted. The treatment alternative selection in wastewater treatment plants is based on treatment requirement, land usability and capital costs. All the criteria should be considered in the LCA of the wastewater treatment plant including energy and chemical consumptions and overall environmental impacts. Conducted analysis were run for selection of the best wastewater treatment alternative for industrial wastewater and domestic wastewater which is produced by workers in the factories (Renou, 2008).

Different proven technologies for domestic and industrial wastewater treatment were considered for studied example. The treatment system includes primary treatment (with and without chemical addition), secondary treatment using aerobic and anaerobic process and tertiary treatment. Different possible treatment alternatives for wastewater treatment plant are shown below in table 1.

Table 1. Various wastewater treatment alternatives.

Alternative 1	Physio-Chemical Treatment (PCT) + Activated Sludge Process (ASP) + Chlorination
Alternative 2	Physio-Chemical Treatment (PCT) + Activated Sludge Process (ASP) + Waste Stabilization Pond (WSP)
Alternative 3	Pre-settler (PS) + Upflow Anaerobic Sludge Blanket (UASB) Reactor + Activated Sludge Process (ASP) + Chlorination
Alternative 4	Pre-settler (PS) + Upflow Anaerobic Sludge Blanket (UASB) Reactor + Activated Sludge Process (ASP) + Waste Stabilization Pond (WSP)
Alternative 5	Upflow Anaerobic Sludge Blanket (UASB) Reactor + Waste Stabilization Pond (WSP)
Alternative 6	Physio-Chemical Treatment (PCT) + Anaerobic lagoon (AL) + Activated sludge process + Waste Stabilization Pond (WSP)

Source: own elaboration based on Srinivasan et al. 2008.

The mentioned above alternatives were compared considering life cycle impact and other factors like:

- chemical and energy consumption,
- quantity of sludge generation,
- emission of greenhouse gases,
- capital cost (civil construction and mechanical installation),
- maintenance cost,
- land requirement (Curan, 2005).

For various treatment alternatives, the weight for each factor has been given four scales called: no, low, medium and high impact. They are shown in table 2. Total impact value is calculated by assigning values 0, 1, 2, 3 for no, low, medium and high impact factors respectively for choosing the best wastewater treatment alternative (Alfonsín C, 2014).

Table 2. Life Cycle considerations factors on various wastewater treatment alternatives.

Life cycle impact and other factors	Wastewater Treatment Alternatives (1 to 6)					
	PCT + ASP+ Chlorination 1	PCT + ASP+ WSP 2	PS+ UASB +ASP+ Chlorination 3	PS+ UASB+ ASP + WSP 4	UASB + WSP 5	PCT + AL+ASP+ WSP 6
Chemical requirement	High	Medium	Medium	No	No	Medium
Energy requirement	High	High	Medium	Medium	Low	High
Greenhouse gas emissions	Medium	Medium	Medium	Medium	Low	High
Sludge generation	High	High	Medium	Medium	Low	High
Capital cost	Medium	Medium	High	High	Medium	Medium
Land requirement	Low	Medium	Low	Medium	Medium	High
Chemical Hazard/ Risk	High	No	High	No	No	No

Source: own elaboration based on Srinivasan et al. 2008.

The alternatives 1, 2, and 5 will be able to meet environmental performance requirements for sewage treatment. For the four alternatives, total impact value is to calculate (Srinivasan et al. 2008; Project.. 2002).

- **For Alternative 1**, High - 4; Medium - 2; Low - 1 and No: 0

Total impact value = 4 x **3** + 2 x **2** + 1 x **1** + 1 x **0** = 17

- **For Alternative 2**, High - 2; Medium - 4; Low - 0 and No: 1

Total impact value = 2x**3** + 4x**2** + 0x**1** + 1x **0** = 14

- **For Alternative 5**, High - 0; Medium - 2; Low - 3 and No: 2

Total impact value = 0x**3** + 2x**2** + 3x**1** + 2x **0** = 7

Alternative 5 with lowest total impact value 7 is the best alternative considering the life cycle approach. The alternatives 1, 2, and 5 meet environmental requirements for sewage treatment. The alternatives 2, 4 and 6 meet environmental requirements for industrial wastewater. Chlorination or waste stabilization ponds cannot be used for industrial wastewater to reduce the pathogens. For the three alternatives (2,4,6), total impact value are calculated based on the life cycle factors given in the Table 3 (without impact) due to land requirement and chemical hazard (Srinivasan et al. 2008; Project.. 2002).

- **For Alternative 2**, High -2; Medium - 3; Low - 0 and No: 0

Total impact value = 2 x **3** + 3 x **2** + 0 x **1** + 0 x **0** = 12

- **For Alternative 4**, High -1; Medium - 3; Low - 0 and No:1

Total impact value = 1 x **3** + 3 x **2** + 0x **1** + 1 x **0** =9

- **For Alternative 6**, High - 3; Medium - 2; Low - 0 and No: 0

Total impact value = 3 x **3** + 2 x **2** + 0 x **1** + 0 x **0** = 13

Alternative 4 is the best alternative considering the life cycle approach for wastewater treatment plant.

4. Application of LCA to two kind of wastewater that come from two different carton package factories

The raw materials and chemicals that have used in the production are shown in the table 3.

Table 3. The raw materials and chemicals have used in the production.

Name	Unit	Amount
Carton	kg/year	5007,487
Paper	kg/year	3004,089
Ink	kg/year	15,959
Glue	kg/year	300,151

Source: own elaboration

The average production in the factory is about 8100 kg carton package per year. It forms about 0.5 m^3 of wastewater per day. Value of the pollutants in raw wastewater and the effluent wastewater value are shown in the Table 4.

Between both analyzed treatment systems important differences were found. They are:

- chemicals that have used,
- equipment and devices of treatment,
- amount of growing sludge,
- investment and management costs.

Mentioned parameters have differences shown in the Life Cycle Assessment methodology.

Table 4. Influent and effluent wastewater characteristics.

Influent Wastewater Characteristic		Effluent Wastewater Characteristic	
Parameter	**Value**	**Parameter**	**Value**
COD	2000	COD	1800
SS	1000	SS	400
Oil-Grease	350	Oil-Grease	140
Sulphate	100	Sulphate	100
Sulfide	<2	Sulfide	2
Zink	1	Zink	0,5
pH	4	pH	7

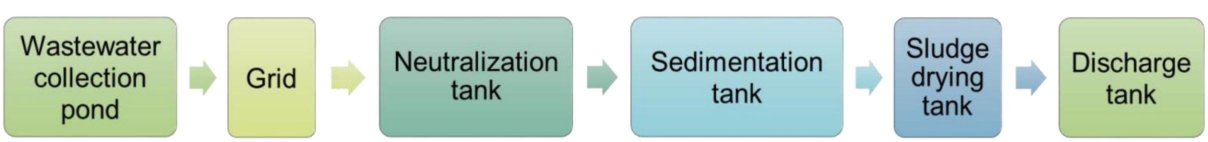
Source: own elaboration

**All parameters' units are mg/l except pH.

Selected units to remove COD, SS, oil-grease, sulfate, sulphide and zink shows in the figure 2.

Figure 2. Various wastewater treatment alternatives

Alternative 1



Alternative 2

Source: own elaboration

4.1. Life cycle consideration factors

The alternative 1 and alternative 2 (figure 3) were compared in terms of life cycle assessment, chemical and energy usage, amount of sludge produced, investment and management costs. For the above treatment alternatives, the weightage for each factor has been given four scales: no, low, medium and high impact and the same are shown in table 5.

Table 5. Life Cycle considerations factors on various wastewater treatment alternatives.

Life cycle impact and other factors	Wastewater Treatment	
	Alternative 1	**Alternative 2**
Chemical Usage	Low	Medium
Energy Usage	Medium	High
Sludge Production	Medium	High
Land Requirement	Medium	Low
Investment Cost	Low	Medium
Management Cost	Medium	Medium
Chemical Hazard/Risk	Low	No

Source: own elaboration based on Curan, 2005

Calculations for alternative wastewater pretreatment.

For alternative 1 = 0 high, 4 medium, 2 law, 1 no;

Total impact value = 0 x **3** + 4 x **2** + 2 x **1** + 1 x **0** = 10

For alternative 2 = 2 high, 3 medium, 1 law, 1 no;

Total impact value = 2 x **3** + 3 x **2** + 1 x **1** + 1 x **0** = 13

4.2. Selection of the best wastewater pretreatment alternative

For selection of the best wastewater treatment alternative, the alternatives are based on the characteristics of the influent wastewater and requirement of quality of the treated wastewater. The effective alternative is the one with lowest total impact value. According to life cycle approach the alternative 1 is better than alternative 2 to wastewater treatment of the carton package production. In this example, a simple methodology has been developed for selection of wastewater treatment alternative incorporating life cycle impact and other factors.

5. Summary

The Life Cycle Assessment which is discussed in the early sections of this paper is a still developing technique. The success of this technique is dependent on its flexibility, feasibility, financial convenience and technique reliability. These values come into prominence depending on the capacity of the factory.

Fundamentally, Life Cycle Assessment which is comprised of two stages, which are inventory and impact assessment studies respectively; is one of the environmental management techniques such as risk analysis, evaluation of the success of the environmental management techniques, environment control and environmental impact assessment.

All the material and energy supply chain is taken into consideration in the life cycle assessment of the wastewater. Products which, are formed by matter's and energy's penetrating into the system, staying there and leaving it, are the emissions released into the air, water and soil. Those emissions simply burden on the environment and are refined during the process of wastewater treatment. The dismissal of the contaminants which, are released during the formation, transmission and treatment of the wastewater, is one of the causes of the environmental pollution. The environmental effects of those contaminants triggered global threats such as: global warming, acid rains, holes in the ozone layer and eutrophication.

In the last part of this paper is emphasized how LCA is used in the treatment process of domestic and environmental wastewaters. With the result of those studies, the importance of building a wastewater treatment plants have arisen. In some studies analyzed in this part, the comparisons about systems' environmental suitability with the Life Cycle Assessment method during the process of wastewater treatment have been made with different effect evaluation methods. While these researches are made, primarily it is useful for identifying the limits of the system to know the wastewater sources emerging during production. At this point, utilizing the facilities, planned according to wastewater characterization, in terms of environment gains importance.

For some examples, a simple methodology has been developed for selection of wastewater treatment alternative incorporating life cycle impact and other factors; chemical and energy consumption, quantity of sludge generation, emission of greenhouse gases, capital cost (civil construction and mechanical installation), maintenance cost, land requirement. This approach for selection of wastewater alternative can be further improved by giving weightage for each factor and also by adding secondary parameters depending upon the site specific requirements.

In this study it is recommended that it will be better to choose the most environmentally suitable method. One of this methods like Life Cycle Assessment, is not enough to plan only waste water treatment facilities to protect ecological balance. It is necessary to take account in each case of all environmental protection measures. In order to have the practice of Life Cycle Assessment and to lower the cost of the method, it is necessary for researchers and executors to meet for sharing thoughts and information. This will bring a permanent partnership between the government, the university and industry and its being national and international will be important (Hauschild, 2015).

6. Conclusions

1. It is recommended to choose the most environmentally suitable methods like Life Cycle Assessment methods for selection of the best alternative of wastewater treatment plant. It is not enough to plan only wastewater treatment facilities to protect ecological balance.
2. This is necessary for researchers and executors to connect thoughts and information in order to the low cost practice maintenance of Life Cycle Assessment. LCA conception may bring a permanent partnership between the government, the universities and industry.
3. Application of LCA to choose the best variant of industrial waste treatment indicated alternative 5, which has lowest total impact value equal to 7.
4. Application of LCA to choose the best variant of urban waste treatment indicated alternative 4, which has lowest total impact value equal to 9.
5. The best alternative wastewater treatment for carton factory is alternative 1, because it has lowest total impact value equal to 10.

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Ocena cyklu życia w oczyszczalni ścieków komunalnych i przemysłowych

Streszczenie

Ocena cyklu życia (LCA) jest techniką mającą na celu identyfikację potencjalnych zagrożeń środowiska związanych ze wszystkimi etapami życia produktu „od kołyski do grobu". Wraz z rozwojem cywilizacji nastąpił znaczny wzrost ilości powstających ścieków i odpadów. Obecnie oczyszczanie ścieków zarówno bytowych jak i przemysłowych wymaga uwzględnienia zasad równowagi ekologicznej i zrównoważonego rozwoju. W niniejszym artykule przeprowadzono badania dotyczące zastosowania oceny cyklu życia produktu w odniesieniu do technologii oczyszczania ścieków. Z interpretacją LCA wiąże się także ocena oddziaływania na środowisko danego układu bądź obiektu oczyszczania ścieków. W początkowej części opracowania zaprezentowano metodę oceny cyklu życia, która została wykorzystana do analizy korzyści i kosztów różnych technologii oczyszczania ścieków. Uzyskane wyniki zinterpretowano w odniesieniu do celów polityki LCA. Szczególną uwagę zwrócono na znaczenie oczyszczalni ścieków oraz ich wpływ na środowisko naturalne i zdrowie ludzi. Celem pracy było także przedstawienie w użyciu narzędzia LCA poprzez dokonanie analizy dwóch wariantów oczyszczania ścieków pochodzących z różnych fabryk produkujących opakowania kartonowe.

Słowa kluczowe: ocena cyklu życia, LCA, oczyszczalnie ścieków, równowaga ekologiczna