Estimating Environmental Damages Due to Solid Wastes’ Open Burning Using Endpoint Approach in Life Cycle Assessment

Isam Alyaseri
Department of Civil Engineering, Al Muthanna University, 72001, Iraq.
ialyase@mu.edu.iq

Abstract. Open burning of solid waste represents one of the most important pollution problems in developing countries. In Iraq, the lack of an integrated solid waste management program had led to a situation where the practice of open burning of solid waste becomes the common disposal method. Solid waste’s open burning is associated with high pollution problems. Life cycle assessment (LCA) is an emerging methodology to test environmental burdens associated with processes. The Southern Governorate of AlMuthanna was taken as a case study and a life cycle inventory of inputs-outputs from technical publications related to open burning of solid waste in the Governorate was conducted. The endpoint approach in LCA was able to show that an annual loss of 901 (±607) DALY in human life and 2.31 (±1.60) species in ecosystems may occur due to the open burning of solid waste in the Governorate. Climate change affecting human health, human toxicity, and particulate matter formation are the major impact categories related to solid waste’s open burning. This relatively high level of damages requires an urgent strategy to stop or reduce these damages. Increasing the portion of recycled materials and energy can highly reduce the damages and alter the burdens. Information resulted from this study can be used by environmental activists to raise pressure towards sustainable solid waste management.

1. Introduction

1.1. Burning of Solid Waste

Solid waste result in high environmental problems such as dissemination of diseases, degradation of ecosystems, reduction in natural resources, and declination in real estate values. Random dumping of solid wastes creates air, soil, and water pollution [1]. It can also cause severe damage to human health if open burned in an urban area. Damages to the environment due to improper solid waste management in some developing countries (especially those who suffer crises such as Iraq) are not limited to these countries. Solid waste is well-known to be a significant contributor to several global environmental problems, such as climate change-related to greenhouse gases emissions from open burning or from landfills, human health damages that are related to exposure to particulates and chemicals during waste dissemination, damages to the ecosystem due to emissions such as heavy metals released to air, surface water and soil, and depletion in resources because of lack or incompetent certain key minerals’ recycling systems [2].

The process of burning combustible materials where emissions are released to the ambient air directly is called open burning. Recently, around 41% of global waste is burned openly which is an estimated 620 million tons of waste per year [3]. In the year 1979 in the U.S., the open burning of municipal solid waste (MSW) at landfills was banned by federal law; therefore, only private individuals now are practicing open burning. Although most municipalities around the world have laws that disallow open burning of MSW, it is still to be practiced as the easiest, cheapest, and most sanitary way to reduce volume and dispose of combustible solid waste in developing countries [4]. In these developing countries, inventories gathered to the Stockholm Convention showed that solid waste or biomass open burning is the largest source of unintentionally produced persistent organic pollutants [5, 6]. Solid waste open burning practice is popular in Iraq because it is a quick, efficient, and cheap method to diminish solid waste. This burning occurs in dumping sites where fires are either happened spontaneously or started intentionally to reduce the volume of solid waste.
Organic waste in trash is not burned totally during this open burning process. Thus, the released emissions from open burning are affected by many factors; examples of these factors are waste composition, moisture content, waste density, and climate conditions. The burning of solid waste regularly releases high concentrations of particulates, dioxins, heavy metals, carbon monoxide, acid gases, and other toxins, some of which are highly carcinogenic such as hexachlorobenzene (HCB), formaldehyde, hydrogen chloride gas, hydrochloric acid, etc. If these wastes were open burned, a high percentage of these pollutants will be transferred or deposited to air, soil, water, or crops and then inhaled or become part of the food chain.

Iraq now is facing major environmental problems. Solid wastes in Iraq represent one of these problems that threaten human life in the country. Inefficient management of solid waste in the country is related to a lack of implementing the basics of the integrated solid waste management practices [7, 8]. MSW may include food wastes, plastics, paper, metals, glass, wood, leather, rubber, textiles, etc. MSW in Iraq may also contain some hazardous refuse produced by households or industrial, commercial, and institutional sites.

AlMuthanna Governorate is one of the southern Governorates in Iraq. With a total area of 51740 sq. km, a population of 770476, and a poverty rate of 52.5% [9], the Governorate is suffering from the lack of essential solid waste management infrastructure. Tons of solid wastes in AlMuthanna are accumulated in streets, parking lots, and driveways. Every single day in the Governorate, tons of solid wastes are openly burned by citizens in streets and yards. Even the small portions of solid waste collected by the municipalities are usually taken away to dumping sites where some valuable materials and objects are picked up or recycled by scavengers then leaving the rest either accumulated or open burnt.

1.2. Life Cycle Assessment

Current solid waste practices in the country will need increasing collaborative efforts from all responsible parties and raising public concerns about the problem. Such efforts will need an inclusive evaluation of the environmental damages associated with these practices. Such evaluation can be achieved by the utilization of the life cycle assessment (LCA) methodology. A life cycle assessment is an evaluation of the environmental burdens related to any given activity from the preliminary assembly of raw materials from the earth until the stage at which all residuals are going back to the earth [10]. LCA is a method that uses a systems approach to identify the environmental consequences of various processes or alternatives by compiling a model of inputs-outputs of materials and energy and examining the associated environmental burdens throughout the life cycle [11]. LCA study can be conducted for various objectives. A survey performed by Breville et al [12] showed that there are many drivers for conducting LCAs. One of the most important drivers is to assess the environmental damages due to improper management.

Three components are included in the LCA method. The first component includes setting goals and the scope of the study, defining the system boundaries, and performing inventory analysis. The second is to assess the impacts resulting from the processes. Assessing impacts is performed through the use of a life cycle impact assessment (LCIA) method. LCIA can be defined as the examination of potential effects on humans and the environment associated with the use of resources and emissions releases to describe the impacts [13]. The impact assessment consists of three phases: classification, characterization, and evaluation. Hence, the results generated from inventory analysis are further examined under these phases. The third is to use the assessment to build a set of recommendations to improve the processes and to understand and reduce the environmental impacts [14].

The LCIA methods are based on two approaches; the mid-point approach utilizes the categories that position in the center of the cause-effect chain, while the end-point approach is altering the mid-point impacts to further specific categories of damage. For instance, one of the mid-point categories is the category of global warming impact that is measured as kg of CO2 eq., or the depletion in the ozone
layer that is measured in kg of CFC-11 eq. An example of end-point categories are the damages on human health measured as equivalent cancer cases or years spent in disability. Another example is the damages that occur on the ecosystems measured as the portion of species affected by the nutrients and toxins leached or introduced to these systems [15]. The end-point approach needs to use a more structured and informed normalization and weighing processes than the mid-point approach. In addition to the transparency complexity, data accessibility represents one of the major limitations that are restraining the end-point level approach utilization. However, with the growing interest in the LCA method and escalating in the amount of environmental and epidemiological researches [16], the gap between the data inventory and possible end damages becomes lesser [15]. Although the mid-point approach is easier to carry out, it has complications in understanding impacts. Most community members do not understand the impacts caused by one kg of CO emitted to ambient air in a highly-populated vicinity, or the impacts related to one kg of benzene emitted to a river or a lake. For public and decision makers, the utilization of the endpoint approach by LCA practitioners may offer a good chance for an easier understanding of final damages that may occur [17]. Also, environmental activists can utilize results from the end-point approach LCA studies to clarify their concerns to the public more effectively.

LCA was successfully used to evaluate the environmental profile of different products and processes. In solid waste management, LCA has been used as a tool to consider environmental impacts from collection and treatment processes, and to make decisions for environmental management [2, 18]. LCA also can be used to define the environmental burdens from any process in solid waste collection and treatment by evaluating the entire life cycle of the process’s inputs-outputs model from cradle to grave. It is a tool-box for analyzing masses and energy in solid waste management models to determine the possible improvements, for comparing alternatives, and for giving the decision-makers a quantitative analysis for benefits and burdens [19, 20]. Many studies used the LCA to analyze the environmental impacts associated with the solid waste management [21]. Laurent et al [18, 2] reviewed 222 LCA studies from various parts of the world to evaluate solid waste management practices. Among these 222 studies, a limited number of studies were conducted for the assessment of environmental impacts associated with the open burning of solid waste in developing countries, especially in Iraq.

The objective of this study is to raise the public concern about environmental damages related to the open burning of solid waste by estimating these damages using the end-point approach in LCA.

2. Methodology

Solid waste LCA studies have to be designed carefully and the methodology needs to describe goal and scope of the study, selection of reference unit, collection of data, LCIA application, and uncertainty analysis.

2.1. System Boundaries

The system boundary of this study started at the point of solid waste generation. The reference unit for assessment was set as one ton of mixed solid waste openly burned in the Governorate. The model included the emissions from burning, leaching to surface and groundwater, and contamination to soil including the heavy metals. The system boundary will also include the burdens from operations of collection. Municipalities are collecting only a portion of the solid waste generated in the governorate’s cities. The remaining portion is either burned in the yards around homes, accumulated in soil, or leached to surface or groundwater. Only burned wastes will be included in the analysis. To normalize the reference flow, all inputs/outputs were divided by one ton of solid waste. Labor during collection was not included in the system boundaries. It also does not include the tires open burned in the streets and yards.
2.2. Life-Cycle Inventory

After defining the system boundary, a life cycle inventory (LCI) was conducted. Inputs and outputs to one ton of solid wastes in the Governorate of AlMuthanna were arranged in a model. Solid wastes’ allocations and fates into different compartments were proposed based on the observations in the field.

A survey was conducted by a group of volunteers from The College of Engineering at AlMuthanna University to estimate the fate of solid wastes and the level of collection in the Governorate. Volunteers managed to have 267 persons to participate in the survey. The survey shows that the percentage of solid waste that is collected and taken to the dumping site by the municipality is 31.6±24.1%. Workers at the dumping site estimated that 50±10% of this collected portion is openly burned while the rest stayed and absorbed by the soil. Also, the survey shows that the percentage of solid waste burns in streets and around homes and turned into ash and air pollutants is 26.7±19%. Based on these percentages, 42.5±22.7% of solid wastes generated in the Governorate was estimated to be open burned. Also, volunteers asked participants to estimate the recycled materials from the streamlined solid waste. The percentages recycled were 3.1±2.2% food waste, 1.23±1.4% cardboards, 0.52±0.16% plastics, 0.39±0.17 leather, and 0.86±0.13 aluminum. Transportation of solid waste to the dumping site was estimated based on the number of packers working in the whole Governorate. The average distance packers take to reach the dumping sites in the cities of the Governorate is 20±10 km/hr. In addition to the environmental damages from the open burning process; a transportation of 15.8±12% of solid waste generated in the Governorate will be added to these burdens.

Emission factors for solid waste open burning were collected from various technical sources. Those emissions that are not found for open burning were compensated from the ecoinvent published data related to the combustion of municipal solid wastes at Waste-to-Energy (WTE) incinerators. SimaPro-8 software was used to implement an analysis of the inventory model. Every collected data were assigned with proper uncertainty estimation using the pedigree matrix as described in [22-23].

2.3. The Selection of LCIA Methodology

Multiple methods are now using the end-point approach such as; ReCiPe 2008 and IMPACT 2002+ [15]. ReCiPe 2008 converts the LCI into 17 impact categories represents the most environmental concerns. These categories can be described as the disability adjusted life years (DALY) in humans, the percentage reduction in biodiversity in an ecosystem over an area during a certain period in the environment (species. yr), or the extra $ expenses required by future generations to get resources (minerals or fossil fuel) they need. The method also can describe the overall impacts as a single score (measured in point or milli-point). The ReCiPe 2008 method was used in this study. The characterization sets and the normalization/weighting factors were based on the “World/Average” in ReCipe 2008 considering the “Hierarchiest” perspective.

3. Results and Discussions

Table 1 shows the environmental burdens on 17 impact categories related to open burning of one kg of solid waste in the Governorate. As can be seen in the Table, the emissions released due to burning and the transportation of solid waste represents an environmental burden while the recycled materials are gains. Table 1 showed that the highest damage to human health was associated with toxicity (6.3E-06 DALY/kg), and particular matter formation (2.6E-06 DALY/kg), while the lowest was associated with photochemical oxidant formation (3.0E-10 DALY/kg). Most losses on human health due to human toxicity came from emissions to air, soil, and water.

Table 1 also shows that the highest damage to the ecosystem was associated with terrestrial eco-toxicity (2.0E-08 species.yr/kg), and climate change ecosystem (4.8E- species.yr/kg), while the lowest was associated with marine eco-toxicity (1.8E-13 species.yr/kg), and the most losses on damages to the ecosystem is due to emissions to air, soil, and water as well. Table 1 showed that the process may have depletion on resources of $1.8E-02/kg fossil fuel, while the recycled materials may introduce savings to metals resources at a rate of $1.4E-05.
In all categories, the materials recycled reduced the environmental burdens in spite of the fact that this percentage was relatively low. The highest reduction came from plastic recycling although a small percentage of plastic is recycled more likely due to the high level of toxins released when plastics are burned.

The 17 impact categories are summed into three damage categories as shown in Table 1: human health, quality of the ecosystems, and the depletion of resources. The total number of disability years due to open burning of one kg of solid waste was 9.7E-06 DALY/kg. The total number of species lost per year is 2.5E-08 per kg of solid waste burned, while the total depletion in resources is $1.8E-02/kg.

Table 1. Environmental damages related to open burning of one kg of solid waste in the AlMuthanna Governorate using LCIA method: ReCiPe 2008 Endpoint (Hierarchies) V1.05 / World (H/A).

| Impact category                     | Unit  | Total Emissions | Transport waste | Food waste recycled | Paper recycled | Plastics recycled | Leather recycled | Aluminum recycled |
|-------------------------------------|-------|-----------------|-----------------|---------------------|----------------|------------------|------------------|-------------------|
| Climate change Human Health         | DALY  | 8.6E-07         | 8.5E-07         | 3.7E-08             | -5.8E-10       | -1.4E-08         | -5.1E-09         | -4.1E-10          |
| Ozone depletion                     | DALY  | -3.2E-11        | 3.3E-12         | 1.0E-11             | -1.7E-13       | -3.4E-12         | -1.9E-11         | -2.3E-11          |
| Human toxicity                      | DALY  | 6.3E-06         | 6.3E-06         | 7.8E-10             | -1.5E-11       | -7.6E-10         | -7.9E-10         | -1.5E-10          |
| Photochemical oxidant formation     | DALY  | 3.0E-10         | 2.9E-10         | 1.0E-11             | -1.6E-13       | -7.9E-13         | -1.3E-12         | -4.8E-13          |
| Particulate matter formation        | DALY  | 2.6E-06         | 2.6E-06         | 1.5E-08             | -2.5E-10       | -1.7E-09         | -4.7E-09         | -4.0E-09          |
| Ionising radiation                 | DALY  | -1.3E-10        | 3.4E-11         | 1.7E-11             | -3.2E-13       | -9.9E-12         | -1.7E-10         | 0.0E+00           |
| Climate change Ecosystems           | species. | 4.8E-09           | 4.8E-09    | 2.1E-10             | -3.3E-12       | -8.1E-11         | -7.9E-11         | -2.9E-11          |
| Terrestrial acidification           | yr species. | 1.5E-11           | 1.5E-11    | 7.0E-13             | -1.2E-14       | -1.0E-13         | -3.9E-13         | -2.0E-13          |
| Freshwater eutrophication           | yr species. | 3.9E-11           | 3.9E-11    | 3.8E-14             | -7.4E-16       | -4.9E-14         | -2.5E-15         | -5.2E-14          |
| Terrestrial ecotoxicity             | yr species. | 2.0E-08           | 2.0E-08    | 2.8E-13             | -4.7E-15       | -1.6E-13         | -1.0E-13         | -2.4E-12          |
| Freshwater ecotoxicity              | yr species. | 2.3E-12           | 2.4E-12    | 7.0E-15             | -1.3E-16       | -1.1E-14         | -1.9E-15         | -3.4E-14          |
| Marine ecotoxicity                  | yr species. | 1.8E-13           | 1.8E-13    | 2.5E-17             | -4.6E-19       | -2.5E-17         | -1.1E-17         | -7.5E-18          |
| Agricultural land occupation        | yr species. | -1.4E-10          | -3.1E-13    | -6.7E-15            | -9.2E-12       | -1.3E-10         | -1.3E-10         | -1.3E-10          |
| Urban land occupation               | yr species. | -4.1E-13          | -2.8E-12    | -5.0E-14            | -6.8E-13       | -2.5E-12         | -2.5E-12         | -2.5E-12          |
| Natural land transformation         | yr species. | 1.1E-11           | 1.4E-11    | -2.2E-13            | -2.5E-12       | 0.0E+00          | -                | -                 |
| Metal depletion                     | $      | -1.4E-05         | 1.6E-05      | -4.2E-07            | -2.3E-05       | -7.0E-06         | -                | -                 |
| Fossil depletion                    | $      | 1.8E-02          | 1.4E-01      | -2.3E-03            | -5.9E-02       | -4.4E-02         | -1.8E-02         | -1.5E-03          |
| Human Health                        | DALY  | 9.7E-06         | 9.7E-06      | 5.3E-08             | -8.4E-10       | -1.7E-08         | -2.0E-08         | -9.3E-09          |
| Ecosystems                          | species. | 2.5E-08           | 2.5E-08    | 2.3E-10             | -3.6E-12       | -9.3E-11         | -7.9E-11         | -1.7E-10          |
| Resources                           | $      | 1.8E-02          | 1.4E-01      | -2.3E-03            | -5.9E-02       | -4.4E-02         | -1.8E-02         | -1.5E-03          |

Figure 1 shows where the damages are mostly concentrated. The Figure shows that most damages related to human health categories (climate change human health, human toxicity, and particulate matter formation) and ecosystems (terrestrial ecotoxicity) are mainly related to emissions. Figure 1 also shows that -on the weighting level- human toxicity represents the major issue related to open
burning indicating the necessity to make changes on current open burning and disposal of solid waste in the country.

![Figure 1](image_url)

**Figure 1.** Environmental damages on weighting level due to burning of one kg of solid waste using LCIA method: ReCiPe 2008 Endpoint (Hierarchiest) V1.05 / World (H/A).

To show the total annual damages that occurred, the data in Table 1 were multiplied by the generation rate and the population. Data related to the Governorate showed that 0.78 ±0.23 kg capita⁻¹ day⁻¹ is the average generation rate at the Governorate [24]. Table 2 shows the total estimated damages in terms of disability-adjusted life years, species losses per year, and resources cost in $.

While LCA studies related to incineration in WTE facilities show savings and gains to human health, ecosystems, and resources [25, 26], open burning shows high damages especially in the category of human health. 901 (±607) years can be spent in disability or lost by the governorate residents. If an average of 70.4 years as a life expectancy at birth was considered as indicated by the World Bank for the year 2018 in the country [27], the calculated risk level is 1.7x10⁻⁵, which is close to the 10⁻⁴ the upper-end risk level of the Environmental Protection Agency’s generally acceptable risk range between 10⁻⁶ and 10⁻⁴ as described by the National Contingency Plan in the U.S. [28].
Table 2. Estimated total annual damages occur due to openly burnt solid waste in AlMuthanna Governorate.

| Damage Category | Unit     | Mean     | Total damage/yr* |
|-----------------|----------|----------|------------------|
| Human Health    | DALY     | 9.66E-06 (±2.73E-06) | 901 (±607)       |
| Ecosystems      | species.yr | 2.48E-08 (±8.15E-09) | 2.31 (±1.60)     |
| Resources       | $        | 3.00E-02 (±3.85E-02)  | 2.80E+06 (±3.98E+06) |

*damage=mean x average generation rate x population x %solid waste burnt x365

The reliability of results in Table 2 may be highly dependent on the quality of the data obtained from the surveys conducted by the volunteers and the data obtained from the Municipality. For example, the estimated percentage of solid waste burnt was based on the public’s observations and Municipality packers’ drivers, and in both cases, they may not have an accurate observation. Also, data related to the Governorate population, average generation rate of solid waste, the composition of solid waste, all resulted from an old census (in 1997) and a single study on waste’s characteristics analysis [24]. Therefore, all data are suffered from high inaccuracy due to the general lack of information updating efforts in the Governorate.

Values in Tables 1 and 2 were compared to data resulted from the analysis of input-output model of solid waste incineration in average WTE facility in Europe that is available in the ecoinvent database stored in SimaPro 8.5.0.0 software. Figure 2 shows the comparison between open burning of MSW in Iraq and incineration of MSW inside WTE facility in Europe. It shows high altering of damages to human health and ecosystem and big savings in resources.

![Figure 2](image_url)

Figure 2. Comparing one kg of MSW openly burnt in AlMuthanna, Iraq with one kg of average MSW incinerated in Europe on the damage assessment level using LCIA method: ReCiPe 2008 Endpoint (Hierarchy) V1.05 / World (H/A).

As can be seen in Figure 2, there were savings in all categories when applying WTE as an alternative of open burning. Instead of losing 9.7E-06 DALY, 2.5E-08 species.yr, and $1.8E-02 per every kg of
solid waste openly burnt in the governorate, it is possible to save 2.9E-07 year, 8.2E-10 species.yr, and $1.83, respectively if adopt another technique such as incineration in a WTE facility.

4. Conclusions

Solid waste pollution is severe in Iraq mainly due to the lack of implementing the basics of integrated solid waste management. One of the main elements in overcoming this problem is to raise decision-makers and public concerns towards the damages related to the open burning of solid waste. The LCA methodology can be utilized as an effective tool for evaluating damages due to improper environmental management. An input-output model for solid waste open burning in AlMuthanna Governorate was built and analyzed using the endpoint approach in LCA methodology. The analysis showed that open burning of solid waste in the governorate may cause an annual loss of 901 (±607) DALY in human life, 2.31 (±1.60) species.yr in ecosystems, and $2.80x10^6±3.98x10^6 depletion in natural resources. Analysis also showed that human toxicity is the main impact category affected by open burning. Continuation of the current state of burning and disposal will continue the current high level of damages. The municipalities in developing countries need to encourage and increase recycling programs or WTE facilities to stop these damages.

Data Availability Statement
Life cycle inventory is available from the corresponding author upon reasonable request.

Acknowledgments
The Municipality of AlMuthanna administration and the faculty at the Department of Civil Engineering at AlMuthanna University had provided high support to this study. Mustafa Kadhem, Umm-AlBaneen AKeel, and Israa Sabah (students at the fourth level in the Department of Civil Engineering at AlMuthanna University in the academic year 2018/2019) had participated in conducting surveys and collecting data.

References

[1] Aziz, S. Q., Aziz, H. A., Bashir, M. J., & Yusoff, M. S. 2011. Appraisal of Domestic Solid Waste Generation, Components, and the Feasibility of Recycling in Erbil, Iraq. Waste Management & Research, 29(8), 880-887.

[2] Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., Hauschild, M. Z., & Christensen, T. H. 2014a. Review of LCA studies of solid waste management systems – Part I: Lessons learned and perspectives. Waste Management 34 (2014) 573–588. [http://dx.doi.org/10.1016/j.wasman.2013.10.045](http://dx.doi.org/10.1016/j.wasman.2013.10.045)

[3] Alexander, C. 2016. Open burning of waste: A global health disaster. R20 regions of climate action. October 2016. [https://regions20.org/wp-content/uploads/2016/08/OPEN-BURNING-OF-WASTE-A-GLOBAL-HEALTH-DISASTER_R20-Research-Paper_Final_29.05.2017.pdf](https://regions20.org/wp-content/uploads/2016/08/OPEN-BURNING-OF-WASTE-A-GLOBAL-HEALTH-DISASTER_R20-Research-Paper_Final_29.05.2017.pdf) (3/26/2019).

[4] UNIDO, 2008. Capacity Building and Public Awareness Raising Program on Unintentionally Produced POPs from the Open Burning of Waste at Dumpsites in the Kingdom of Cambodia. Project Code: XP/CMB/08/002.
[5] Zhang, T., Fiedler, H., Yu, G., Ochoa, G. S., Carroll Jr, W. F., Gullett, B. K., Marklund, S., & Touati, A. 2011. Emissions of unintentional persistent organic pollutants from open burning of municipal solid waste from developing countries. *Chemosphere, 84*(7), 994-1001.

[6] Fiedler, H. 2007. National PCDD/PCDF release inventories under the Stockholm Convention on persistent organic pollutants. *Chemosphere 67*, S96–S108.

[7] Knowles, J. A. 2009. “National Solid Waste Management Plan for Iraq.” *Waste Management & Research*. 2009: 27: 322–327. DOI: 10.1177/0734242X09104129.

[8] Yasir, R. A., Hussein, T. E., Khalaf, H. A., Selman, M. D., Hadi, F. K., and Semir, A. H. 2012. Survey on Solid Waste Management in the Southern Governorates of Iraq. *Marshland Research Centre, Marsh Bulletin 7*(1), (2012) 69-101.

[9] Statistics Directorate in Al-Muthanna Province. 2014. Statistical Data for Al-Muthanna Province. Census 2014, Statistics Directorate, Al-Muthanna, Al-Samawah, Iraq.

[10] Vigon, B., Tolle, D., Cornaby, B., Latham, H., Harrison, C., Boguski, T., Hunt, R., and Sellers, J. 1993. Life Cycle Assessment: Inventory Guidelines and Principles. EPA/600/R-20/245, Cincinnati, OH.

[11] Tarantini, M., Buttol, P., Maiorino, L. 2007. An Environmental LCA of Alternative Scenarios of Urban Sewage Sludge Treatment and Disposal. *Thermal Science, 11*(3), 153-164.

[12] Breville, B., Gloria, T., O’Connell, M., and Saad, T. 1994. Life Cycle Assessment: Trends, Methodologies and Current Implementation. Department of Civil and Environmental Engineering, Tufts University, Medford, MA, 145-35.

[13] Bishop, P. 2000. Pollution Prevention: Fundamentals and Practice. McGraw-Hill Series in Water Resources and Environmental Engineering, University of Cincinnati, Cincinnati. ISBN: 0-07-366147-3.

[14] Scientific Applications International Corporation (SAIC), & Curran, M. A. 2006. Life-cycle assessment: principles and practice. EPA/600/R-06/060.

[15] Goedkoop, M.J., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., Van Zelm, R. 2013. “ReCiPe 2008: A Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level.” 1st ed, Report I: Characterisation; 6 January 2009, http://www.lcia-recipe.net

[16] Zamagni, A., Masoni, P., Buttol, P., Raggi, A., Buonamici, R. (2012). “Finding Life Cycle Assessment Research Direction with the Aid of Meta-Analysis.” *J. of Ind. Ecol*. 16, S39–S52. doi: 10.1111/j.1530-9290.2012.00467.x

[17] Bare, J.C., Hofstetter, P., Pennington, D.W., Udo de Haes, H.A. 2000. Midpoints versus Endpoints: The Sacrifices and Benefits. Inter J of LCA 5(6): 319-326.

[18] Laurent, A., Clavreul, J., Bernstad, A., Bakas, I., Niero, M., Gentil, E., Hauschild, M. Z., Christensen, T. H. 2014b. Review of LCA studies of solid waste management systems – Part II: Methodological Guidance for a Better Practice. *Waste Management* 34 (2014b) 589–606. http://dx.doi.org/10.1016/j.wasman.2013.12.004
[19] Arena, U., & Di Gregorio, F. 2014. A waste management planning based on substance flow analysis. *Resources, Conservation and Recycling, 85*, 54-66.

[20] Yadav, P., & Samadder, S. R. 2014. Life cycle assessment of solid waste management options: A Review. *Recent research in Science and Technology*.

[21] Liikanen, M., Havukainen, J., Viana, E., & Horttanainen, M. 2018. Steps towards more environmentally sustainable municipal solid waste management–A life cycle assessment study of São Paulo, Brazil. *Journal of Cleaner Production, 196*, 150-162.

[22] Alyaseri, I. 2014. Qualitative and quantitative procedure for uncertainty analysis in life cycle assessment of wastewater solids treatment processes. Southern Illinois University at Carbondale.

[23] Alyaseri, I. and Zhou, J. 2019. Handling Uncertainties Inherited in Life Cycle Inventory and Life Cycle Impact Assessment Method for Improved Life Cycle Assessment of Wastewater Sludge Treatment. *Heliyon* 5 (2019) e02793.

[24] Alyaseri, I. Kuba, Z, and Hinoosh, A. 2018. Solid Waste Management Improvement in Al-Muthanna Governorate, Iraq. Technical report submitted to Al-Muthanna Governorate. Al-Muthanna, Iraq.

[25] Arena, U., Ardolino, F., & Di Gregorio, F. 2015. A life cycle assessment of environmental performances of two combustion-and gasification-based waste-to-energy technologies. *Waste Management, 41*, 60-74.

[26] Fernández-Gonzalez, J. M., Grindlay, A. L., Serrano-Bernardo, F., Rodríguez-Rojas, M. I., & Zamorano, M. 2017. Economic and environmental review of Waste-to-Energy systems for municipal solid waste management in medium and small municipalities. *Waste Management, 67*, 360-374.

[27] World Bank. 2020. Life expectancy at birth, total (years). Available online at: https://data.worldbank.org/indicator/SP.DYN.LE00.IN (November 2nd, 2020).

[28] Environmental Protection Agency. 2020. Risk Assessment: Regional Removal Management Levels (RMLs) User's Guide. https://www.epa.gov/risk/regional-removal-management-levels-rmls-users-guide#:~:text=A%202010%20D4%20risk%20level%20range%20for%20non%20carcinogenic%20risks. (November 2nd, 2020).