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Review on Life Cycle Analysis (LCA) Studies to Evaluate the Impact of Waste Managing Aluminium on The Environment

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Abstract: In this recent years, the increased amount of solid waste generation has become a threat to the environmental health which needs immediate attention. Moreover, many waste management methods have developed in order to overcome this problem. Hence, this research project is aimed to review the LCA studies done by researchers on waste management especially aluminium wastes to help decision-makers deciding which is the most suitable waste management methods for them to use. This research project is done by collecting data from literatures such as research papers and articles which are accounted as secondary data. Where this data is then reviewed and analysed to come up with a conclusion. The trend shows that the most preferable aluminium waste managing method was Conventional Recycling. While, some studies show that the new recycling methods which are Direct Recycling (DR) and Semi Direct Recycling (SDR) are more efficient and environmental friendly then the Conventional Recycling method.

Keywords: LCA, Conventional Recycling, Direct Recycling, Semi Direct Recycling

1. Introduction

The human population are getting bigger day by day which lead to a serious problem for the environmental health which is the rising of solid waste generation which are parallel to the size of human population. The environmental conditions in developing countries are seriously affected by solid waste damps which are often used to manage solid waste disposal. Harmful environmental impacts from improper solid waste management can easily be observed anywhere in this current developing world. Poorly managed waste will contribute to the global climate change through methane generation and also can promote urban violence.

In Pakistan, due to a lack of proper planning and funding, the solid waste management scenario is becoming worse day by day [1]. Hence, a proper study on solid waste managements could reduce the

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harm caused by improper solid waste disposal. Currently, there is two common waste management practice that is widely used globally which is landfills and incineration.

1.1 Landfill

A landfill, also known as sanitary landfill, is a land disposal site for waste, which is intended to protect from environmental pollution and health risks. It is not similar to open dump. Landfills are built to concentrate the waste in compacted layers to reduce the volume and monitored for the control of liquid and gaseous effluent in order to protect the environment and human health [2].

1.2 Incineration

Incineration is used as a treatment for a very wide variety of wastes. The purpose of waste incineration is to minimise the volume of waste and its dangerous characteristics while collecting or removing potentially harmful compounds that could be emitted during incineration. Incineration processes that generate hot flue gas may provide a means of energy recovery. Depending on the type of waste, it is also possible to recycle products such as minerals and/or chemicals [3]. Grate incinerators are commonly used for the incineration of mixed municipal waste. It can also be used in the handling of sewage sludge and some clinical waste.

1.3 Recycling

However, with the advanced technology and ideology, humans have come out with another waste management practice which is by recycling the solid waste into something that can be used again. Recycling is the process of collecting, and processing materials that are thrown or can no longer be used into something that is usable in form of new products [4]. By recycling, resources can be saved as less fuels will be used to burn this wastes in incinerators and less trash are sent to the landfills which also helps in reducing air and water pollution

2. Literature Review

2.1 Introduction to LCA

LCA is a holistic approach that considers the whole life cycle of a systems which is also known as ‘from cradle to grave’ approach that has been applied widely in industry to reduce the environmental burden from productions and disposal of products [5]. The purpose of applying LCA in waste management is to provide a new insight into environmental aspects of waste management. LCA focused on resource consumption and the impacts toward human health and the environment. In general, all impacts caused by a system or product are taken into account by the LCA. This also includes environmental impacts such as climate change because of greenhouse gasses emission, physical change of land because of landfills and also the impacts to human health because of the disposal of toxic substance. LCA is carried out in four main phases which are goal and scope definition, inventory analysis, impact assessment and interpretation.

2.2 Goal and Scope Definition

Defining the goal is the most important step in any studies. Therefore, it is the most crucial in LCA study to define a clear goal so that the purpose of this study can be achieved. In waste management and control, the goal of LCA studies is mainly on the environmental impacts of any waste management systems. Aside from that, the goal must also define the intended audience for the study and the problems that it needs to solve. This is crucial as the results of the study might vary because of a few factors such as the differences in geographic boundaries, legislation, technologic aspects, waste composition, etc. Hence, the results should not be generalised or wary outside the context of the study without detailed analysis [6].

There are two main components in goal and scope definition of a LCA studies which are functional unit that serves as a reference for the inventory analysis and system boundaries that applies limitations to the study so more accurate result could be produced. The aim of a functional unit is to quantify the function of a product or a service under LCA study. There are four main measures in a functional which are Unitary, Generation Based, Input-Based and Output-Based.

Whereas, system boundaries decide which unit processes are to be used in the LCA study. Defining system boundaries is partly based on a subjective choice that was made during the scope definition phase when the boundaries are initially set. The boundaries that are considered in LCA studies are geographical boundaries which is usually related to cities, regions or countries where the waste is treated [6]. Other than that, ecosystem sensitivity and time horizon are also considered in system boundaries.

2.3 Inventory Analysis (LCI)

Inventory analysis or also known as LCI gathers information regarding the physical flows in terms of input of resources, materials, by-products and products and the output of emissions, waste and valuable products for the product system [7]. Inventory analysis involves the creation of a flowchart according to the boundaries specified in the goal and scope definition, the compilation of data relating to tasks within the system boundaries and the measurement of inputs and outputs in relation to the functional unit. The amount of data necessary for the study can be huge because, for example, aluminium is necessary in manufacturing of vehicles, so aluminium production should also be included in the study

Data collection efforts involve a combination of research, site-visits and direct contact with experts, which results in producing huge data quantities. The emphasis during data collection is usually on the foreground data i.e. data that corresponds to a specific modelling process. In the context of LCA waste management, the foreground may be waste composition in the field of research, processing performance in a particular MRF, energy usage, type of vehicle used for storage, or emission from a specific plant.

Generally, most of the background data could be found in the literature and databases. The presence of environmental process data databases for the most common processes and materials is a requirement for the success and public review of LCAs. In these databases, the processes are presented as 'unit processes' and the environmental exchange information from the process is described by the practical production of the process e.g. per kWh of electricity generated for power plants, per kg for materials like aluminium, per kg–km or per m3–km for transport processes, etc.

A number of software tools are available to ease the modelling of the system, including both the inventory and impact assessment stages. These tools often provide access to the most important LCI databases. Some of the most used LCA software tools today are SimaPro (www.pre.nl), GaBi (www.gabi-software.de), Umberto (www.umberto.de) and TEAM (www.ecobilan.com/uk team.php) [5].

2.4 Impact Assessment (LCIA)

This phase focusing on assessing the significance of potential environmental impacts based on the life-cycle impact flow results. The LCIA procedure primarily consists of five elements which is *Selection*, *Classification*, *Characterisation*, *Normalisation*, and *Weighting* where the first three are mandatory according to the ISO 14040 standard

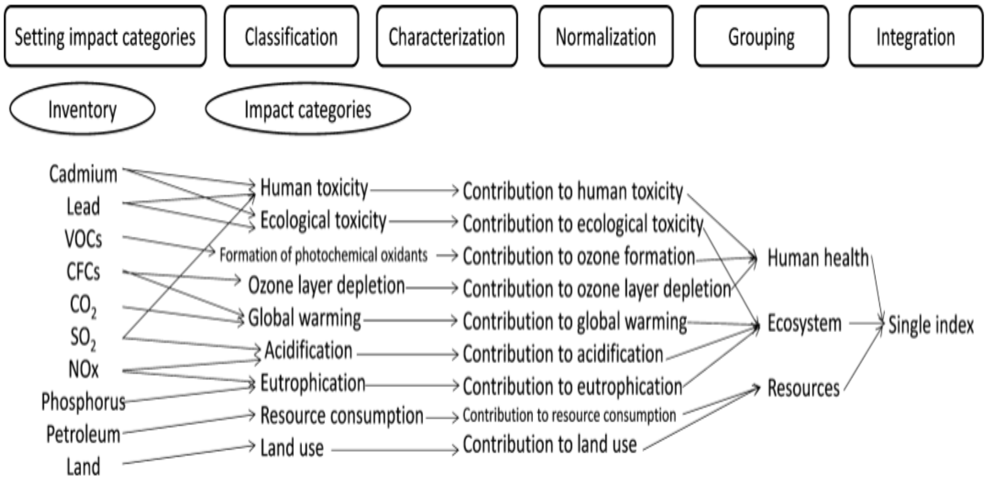

Figure 2.1: Procedures for Conducting Lifecycle Impact Assessment [8]

Figure 2.1 describes the procedures for conducting lifecycle impact assessment. When doing the LCIA, one must perform all mandatory duties up to and including characterisation. Either to carry out normalisation and integration depends on the final goal, since the challenges of a systematic evaluation of the value from various impact categories and the formulation of a single index are known.

2.5 Interpretation

Life cycle interpretation is a structured technique used to define, measure, track and analyse information from the LCI and LCIA outcomes and to convey it effectively. The understanding of the life cycle interpretation is the last step of the LCA mechanism. The first step in the life-cycle interpretation phase includes the examination of information from the first three phases of the LCA process in order to determine the data elements that contribute most to the outcomes of both the LCI and LCIA for each product, process or service, otherwise known as "significant issues" [9].

In addition, many of the data used in LCI, including those for calculating and estimating errors, and determining how these errors affect outcomes, are also significant. One must conduct sensitivity analyses" and "uncertainty analyses" in order to take errors into consideration.

3. Methodology

3.1 Type of Data Collection

The process of collecting data that is required for this study is by using secondary data. Hence, this study is a review and the data collected will be accounted as secondary data collection. Plus, the data obtained on the study are based on the form of methodology used by the previous researcher and also the feedback earned from those research.

3.2 Data Collection Method

The findings and data obtained for this research paper will be from newspapers, articles, studies, reviews and research on aluminium LCA studies. All citations will be produced in appreciation and respect of the original and sole owner of those papers and studies, as their analysis findings and discussions will be used as the main source and in addition, these study and review of those figures will address and appeal to other viewpoints.

4. Result and Discussion

For the main discussion, Figure 4.1 illustrates the statistical analysis of the number of studies that is classified into three different waste option comparisons. (LvsCR) and (IvsCR) is a common comparison in waste management option. Whereas, only a few studies comprise the new recycling technique. Therefore, both techniques were combined into one scenario which is (CRvsSDR).

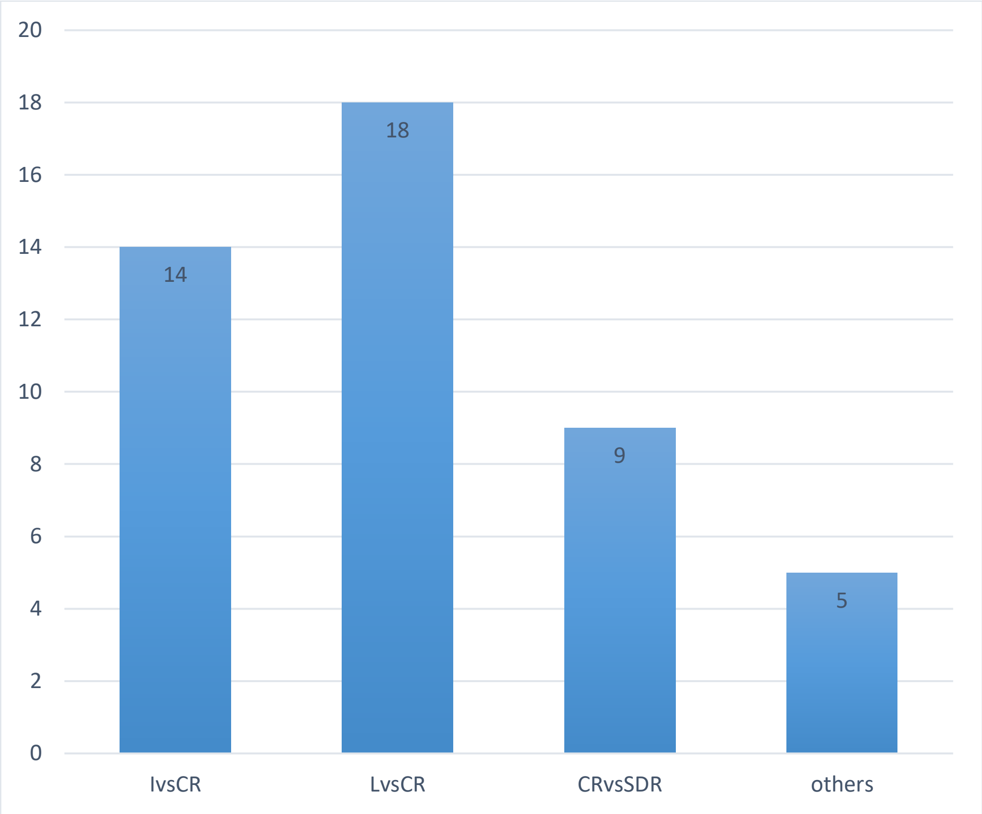

Figure 4.1: Waste Handling Scenario

4.1 Landfill versus Conventional Recycling (LvsCR)

Recycling was clearly preferable than landfill in all conditions and natural impact groups studied. This conclusion was based on six scenarios from diverse assessments that covered the complete life cycle. Smith et al. (2001), recycling, as opposed to landfill, yields an overall net greenhouse gas flux savings of 95kg CO2 eq/tonne waste. However, the advantages of landfill regulations and carbon sequestration are virtually unbiased [10]. Morris (2005), determined that in terms of decreasing global greenhouse gas emissions, recycling is 194 times more effective per ton of waste handled than landfilling in both countries, USA and Argentina even with energy generation from landfill gas [11].

C.C. Faircloth et al (2019) concluded that aside from metal depletion, landfilling solar panels does not cause a significant environmental burden [12]. However, the burdens averted by recovering materials from panels are larger than the costs imposed by the energy and fuel required to collect, disassemble, and recover them. When one of the recycling procedures is employed instead of landfilling, environmental loads are reduced across all categories, regardless of the allocation technique employed [12].

The LCA findings from P. Dias et al (2021) reveals that using the improved approach (Optimised Recycling) has a lower environmental effect than landfilling the entire waste [13]. The research also reveals that if done on a large scale with high-throughput assumptions, the suggested recycling technique is more useful than landfilling the waste. Recycling proved to minimize the quantity of solid waste disposed into landfills, extending the lives of each landfill for longer terms.

4.2 Incineration versus Conventional Recycling (IvsCR)

Incineration are a good waste management option when it comes to reducing the amount or the volume of the waste while also provide energy generation. However, incineration generates a series of harmful gaseous which can cause a significant environmental burden and also cause harm to human wellbeing. Manfredi et al. (2011) decided that because no energy recovery can be obtained for this proportion, incineration has the potential to have an influence on GWP, primarily in terms of nutrient enrichment and acidification.

In terms of toxicity-related categories, possible consequences were evaluated for all management approaches, particularly Eco-Toxicity in Water Chronic and Human-Toxicity through Water (up to 29 and 12 mPE/tonne for incineration, respectively) [14]. Whereas, Merrild et al. (2012) concluded that the studies demonstrating an unmistakable pattern of recycling is preferable to incineration for the material parts metals; at the close of the day, the material parts that spare truly substantial amounts of vitality and assets when reused as contrasted to being delivered from virgin crude material and don't add to any vitality creation at the cremation plant [15].

However, M. Haupt et al. (2018) concluded that in the case of a worldwide aluminium market, the environmental benefits of aluminium recycling can be as high as 17.5 t CO2-eq/t or 177 GJ-eq/t of recycled aluminium [16]. Moreover, G. Faraca et al. (2019) determined that recycling (plastic, WEEE, and textiles) is more beneficial when it avoids incineration, minimizing climate change impacts, implying that these fractions should be derived predominantly from small combustible waste (SCW) and redirected to recycling [17].

It is obvious that prioritizing recycling over incineration can improve air and water quality thus reducing the environmental burdens by reducing the release of pollute substances to the air and water source. However, in some cases incinerating waste will also produce some sort of benefit by reducing fossil fuel depletion as the waste can provide energy recovery from the incineration process.

4.3 Direct/Semi-Direct Recycling versus Conventional Recycling (SDRvsCR)

Three studies from Paraskevas et al. (2012), Duflou et al. (2015) and Ingarao et. al. (2016) included five scenarios of conventional recycling (CR) and semi-direct recycling (SDR) that included hot extrusion, screw extrusion, and spark plasma sintering (SPS), and indicated that SDR delivers considerable environmental advantages, primarily by avoiding metal losses during secondary aluminium production.

Paraskevas et al. (2012) concluded that metal lost during secondary ingot production has the greatest impact on total impact in conventional recycling since it is substituted by primary aluminium [18]. This impact share was almost 70% for the 10% aluminium lost during secondary production. Each 5% loss of aluminium leads in a 72 mPt impact, which is 4.6 times the overall impact of the alternate recycling approach. The inclusion of Mg as an alloying element during recycling affects the overall environmental effect by 10%. The remaining portion is accounted for by the energy (thermal and electrical) consumption of the secondary re-melting and casting stage [18].

Duflou et al. (2015) concluded that SDR have a smaller impact than incineration since aluminium consumes energy and produces discharges and slag deposits when burnt [19]. When contemplating regular current material misfortune divisions for the proposed reuse forms, a reduction factor of 2–4 was found for the expulsion forms. While with the spark plasma sintering (SPS) method, depending on the severity of the oxidation losses, turnings can be reduced by up to a factor of 2.5. (material losses of

16 percent or higher). This is especially true for scrap kinds with a high surface-to-volume ratio, due to the significant material losses averted by extensive oxidation in the conventional remelting procedure. As a result, SDR is the recommended waste management method for tiny volume waste (chip) [19].

This proves that the new recycling method consists of direct and semi-direct recycling which requires hot forging processes or spark plasma sintering (SPS) clearly have some significance environmental advantages over the conventional recycling method with requires the remelting approach. Where in this approach, possible losses can occur thus requires more energy.

5. Conclusion

This LCA review research project provides insights of various waste handling methods which are landfilling, incineration, and recycling for helping decision-makers to come out with an appropriate decision on how to handle the aluminium wastes by using these methods. Whereas for recycling, this review focuses on reviewing three major recycling techniques which includes, Conventional Recycling (CR), Direct Recycling (DR), and Semi-Direct Recycling (SDR). Where the most used scenario in all of the LCA studies reviewed is Landfill Vs Conventional Recycling (LvsCR).

The most preferable waste managing method is Conventional Recycling which comprises the usage of melting techniques, where the temperature exceeds the melting point. However, comparing to SDR/DR, this technique lacks in some ways as the SDR/DR result in higher environmental advantages as mentioned by N.K. Yusuf et al. and lower metal losses as mentioned in the studies by Paraskevas et al., Duflou et al., and Ingarao et al.

Hence, this review shows that the usage of recycling that includes the three major recycling techniques in aluminium waste handling gives a noteworthy benefit to the environment. LCA study on SDR and DR should be further conducted as it is proven that these techniques are the future of metal recycling especially for aluminium.

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