LCA&MFA for E-Waste Management

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The complexity in WEEE management has prompted the need for suitable tools to understand the generation of e-waste as well as to assess the associated environmental impacts. Two such tools that are frequently used in waste management in general and also associated with WEEE are material flow analysis (MFA) and life cycle assessment (LCA). Both of these tools are frequently referred to in literature as useful in assisting decision-making in WEEE management.

Keywords: electronic waste ; literature review ; keyword co-occurrence network ; material flow analysis ; life cycle assessment

1. Introduction

Regardless of the differences in economic values, material composition, lifetime profiles, and waste quantities, all EEE is capable of generating severe environmental and human health impacts if recycled inappropriately [1].

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Material flow analysis (MFA) is popular among many researchers around the world as a valuable tool to study and manage complex waste systems [3]. Specifically in resource management and waste management, MFA is considered to be an attractive decision support tool [4], since it is capable of studying the route of materials flowing into recycling sites and stocks of materials in space and time [3][5]. This tool can be applied to understand issues and gaps in the value chain and develop appropriate management strategies. It is especially beneficial for complex and distinct waste streams, such as e-waste, where the waste is comprised of both valuable and toxic materials [3][4][6].

LCA is an effective and popular environmental management tool that is capable of evaluating environmental impacts of a product or a service and can help to identify hotspots and potential for improvement [7][8]. Several researchers have recommended LCA as a suitable tool to assess environmental impacts of waste management and also to compare the environmental performance of various waste management strategies including WEEE management [7][9][10][11]. Previous studies have also found that there is an increasing trend of LCA application in waste management research [8]. Two recent reviews by Xue & Xu (2017) and Ismail & Hamafiah (2019) focused on the application of LCA in e-waste literature published before 2018 [7][8].

2. Discussion

The current literature review identified 31 studies that have used LCA as a tool to understand the life cycle environmental impacts associated with WEEE. Being the largest producer, consumer, and recycler of electronics, China appears to be the country with the highest number of studies (eight studies) followed by Italy (four studies). However, it is worthwhile to note that nearly half of LCA studies related to WEEE are from the European region (15 studies), whereas only three developing countries (except for China) have at least a single study among the selected literature.

Although it is not claiming to be an exhaustive content analysis, the present study demonstrates how MFA and LCA concepts have been applied to study numerous scopes related to different stages of the WEEE life cycle using a holistic approach. In relation to MFA studies, it was observed that the existing knowledge on the stocks and flows of e-waste in developing countries is extremely limited, especially in countries such as Nigeria, India, Indonesia, and Ghana which have become prominent e-waste importers. In order to discover the real efficiency of existing formal and informal e-waste recycling systems and to identify the potential for improvement, further research on e-waste stocks and flows in these developing countries is essential.

Moreover, when considering the element-level MFAs, there are still significant research opportunities to study the flow of precious elements such as gold across national/regional levels. Since precious metals can contribute significantly towards economic recovery potential, further research in this area could induce more attention and motivation towards a recycling economy.

Overall, most of the LCA studies were focused on assessing the recycling or resource recovery strategies relating only to pre-processing and processing stages. This reveals that, although there is an ample amount of knowledge regarding the impacts associated with numerous recycling and recovery technologies, there are also significant knowledge gaps on comparing these strategies with other management options, such as reuse and incineration for energy. Only a limited number of studies have attempted a holistic approach to evaluating WEEE management from collection to disposal or to the reuse of the second product. None of the studies took into consideration the 'prevention' aspect into their system boundary, which is the top priority in the waste management hierarchy.

3. Conclusions

This systematic literature review provides a panoramic overview of the last decade of e-waste literature with an in-depth analysis of research that used MFA and LCA as a tool to analyze and assess generation, flows and stocks, and the environmental impacts regarding the handling and treatment of e-waste. E-waste is a growing area of research with significant potential in both developing and developed countries. At present, the majority of the e-waste research is focused on associated environmental and human health impacts and recycling/resource recovery technologies. Although there is a larger fraction of studies that have attempted to estimate the generation of e-waste using MFA, there are still major data gaps in relation to national-level estimates for both developed and developing nations. In addition, the MFA studies aimed at understanding the processing of e-waste at pre-processing and recycling facilities are limited. Moreover, MFA has already gained significant attention in e-waste research since it is capable of assisting in decision-making in relation to the management of complex waste streams such as e-waste. However, more research is required to deal with the assumptions being made while conducting e-waste MFAs due to data limitations. Similarly, LCA research regarding e-waste generation and handling is also sparse. This review emphasizes the need for more cradle-to-grave and cradle-to-cradle LCAs to obtain a more holistic understanding of the e-waste life cycle in order to improve the current management practices and regulatory frameworks. Only a handful of studies have integrated MFA with LCA to quantify the associated environmental impacts. There is significant potential for future research for a combined MFA–LCA approach which would be inherently valuable in decision-making with respect to efficient management of finite raw materials. In addition, given that the circular economy is a fairly new field of research that is still on continuous development, regardless of the many studies that were identified through our review, there is potential for further research on the application of the circular economy principles in e-waste management. Nevertheless, this review could be a starting point for any researcher interested in e-waste to gain a preliminary understanding of the major research themes and gaps, and also to apprehend the application of MFA and LCA in relation to numerous contexts related to e-waste.

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