Life cycle assessment of plastic waste into furniture using open LCA software

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ABSTRACT Plastic waste management is one of the most severe environmental issues confronting municipalities worldwide, and it is the most serious environmental issue in Malaysia. Furniture gains attention in the life cycle assessment (LCA) of a net-zero energy building. It was responsible for 10% of the building's impact on global warming and non-renewable energy demand. Therefore, it shall be considered in the building's design. This study evaluates the environmental effects of recycled high-density polyethylene (HDPE) eco-furniture using the OpenLCA software. The scope of the study considered the cradle-to-gate boundary of recycling and manufacturing 1 kg of the eco-furniture functional unit. This paper assesses the LCA through OpenLCA in obtaining the environmental impact of waste-to-wealth product generation. Primary data (amount of plastic waste, electricity, emission, and water) were gathered in a local recycling centre, EZplast Plastic, data from the European Life Cycle Data database and data from a previous study for the electricity. In addition, the CML Baseline impact method, readily available in the EcoInvent LCIA database, is employed to determine plastic waste performance in their impact categories. Nine environmental impact categories were considered. The result shows that the consumption of electricity and HDPE during the manufacture of eco-furniture resulted in the most significant amount of environmental loading, up to 78% to 90% on all the impact categories.

KEYWORDS: Life Cycle Assessment; Plastic Waste; OpenLCA; Furniture; Environmental Effects
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INTRODUCTION

Plastics comprise synthetic organic polymers and are one of the most widely used materials because they are durable, lightweight, versatile, and relatively inexpensive to manufacture (Khoo, 2017). However, some of the factors that could impact the efficiency of plastic waste recycling are the lack of infrastructure for collecting and processing plastic waste, the requirement for new technology, a complicated recycling process, a poor economic return, lack of end users, as well as worries about quality and availability (Liang *et al*., 2019). Furthermore, the cost of virgin plastic production is lower than that of recycling since the price of crude oil from which the virgin plastics are made is low.

Thus, this is where the waste-to-resource agenda comes in line. It aims to identify, develop, and deploy technologies to treat waste to generate energy, recycle materials, and extract resources of value (Hossain *et al*., 2021). One of the waste-to-wealth agendas is recycling. Recycling can be broadly defined as a waste management practice that involves gathering waste materials and turning them into raw materials that may be used again to create other useful products (Evode *et al*., 2021).

Life Cycle Assessment (LCA) is a tool life cycle system proposed for this project to determine the environmental impact analysis (Amon *et al*., 2021). LCA assesses the environmental impacts of a product, process, or service throughout its life cycle (Asman, 2019). Many software packages, such as GaBi, Simapro, openLCA, and ATHENA Eco Calculator, can be utilised to analyse the data input.

Van der Harst *et al*. (2015) verified that the model choice to include recycling in LCA influences the environmental impacts considerably and can stimulate the recyclability of product materials.

This paper highlights using a well-known freeware package (open source) of OpenLCA. The package allows the user to compute all the steps connected with LCA (Iswara *et al*., 2020). It is a tool used to evaluate applications, alternative plastic materials, and destinations and, as a result, to identify opportunities for environmental improvement. As an outcome, it can and should be used to communicate sustainability data to public authorities, businesses, and consumers (Gileno & Turci, 2021). This study aims to determine the environmental impacts of plastic eco-furniture generation through life cycle assessment using openLCA.

METHODOLOGY

The life cycle assessment (LCA) approach is used in this study. According to ISO 14040 (2006), there are four phases of the LCA methodological framework, which include goal and scope definition, life cycle inventory analysis (LCI), impact assessment (LCIA) and interpretation. The goal and scope, such as the case study, functional unit, and system boundaries, were determined early before collecting the inventory data. The data was later used to analyze and calculate the LCA impact categories.

The goal and scope are typically used to determine the intention of LCA and the probable outcomes of the research (ISO 14040, 2006, as cited by Curran, 2017). An industry in Sabah, Malaysia, based in Papar, has actively collected waste plastic for recycling, including washing, shredding, drying, and classifying, all part of the mechanical recycling process. This process yields granules, pellets, or flakes used in various applications. They emphasized manufacturing waste plastic into furniture. Thus, this research aims to evaluate the environmental impact of plastic eco-furniture. The system boundary covers the cradle-to-gate with 1 kg of the functional unit. It includes sorting, cleaning, and grinding bottles into flakes and processing them into finished goods (plastic-wood), as shown in Figure 1.

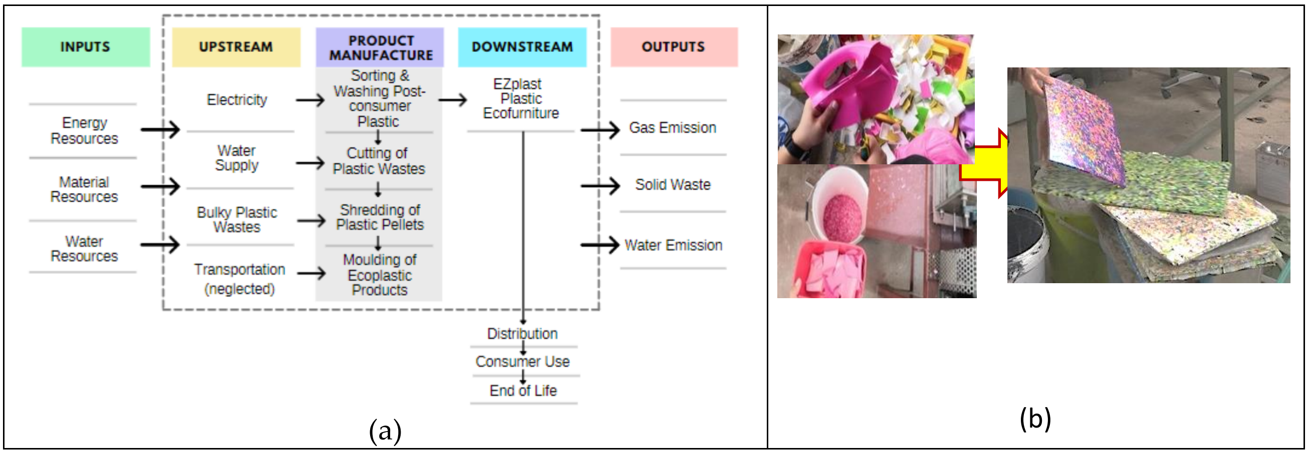

Figure 1. (a) Specific gate-to-gate boundary of plastic eco- furniture; (b) high-density polyethylene (HDPE) plastic waste-to-resource sample product.

Figure 1(a) shows the specific boundary for the plastic eco-furniture that shall be used as a guideline to adapt the LCA using OpenLCA. The manufacturing process starts after the collection and transportation of waste, with a gate-to-gate boundary.

Life Cycle Inventory (LCI) is the second stage of LCA that is concerned with gathering the necessary information to achieve the study's objectives. LCI analysis is a process of data collection and calculations intended to quantify the inputs and outputs of a product system (Babu, 2006). It also can be defined as a phase that involves the compilation and quantification of inputs and outputs for a given product system throughout its life cycle. For the LCI phase, data are collected from the EZplast company operations (fieldwork data). Other data are using the European reference Life Cycle Database (ELCD), as provided for free via the OpenLCA Nexus website. The electricity consumption uses the data from a previous study by Agarski *et al.* (2019). This work applies LCA (impact) methodologies in a cradle-to-gate approach to assessing the environmental impact and potential improvements of the plastic eco-furniture manufacturing procedure. The energy and emissions are quantified, and potential environmental impacts are considered. The primary energy inputs to the production system are electricity consumption from the manufacturing process. Table 1 summarises the input and output flows for a 1kg plastic eco-furniture functional unit.

Table 1. Production phase input and output flows of plastic eco-furniture.

Process		Flow	Amount	Source	Note
Shredding	Input	HDPE flakes (initial weight)	1.111 kg	This work	Colour granulate mass + waste plastic mass
		Consumption of electricity	2.64 kWh	Agarski *et al.* (2019)	Operation time: 1 hour; electricity consumption: 2 kW/h; Machine heating: 0.8 kW/h heated for 80% of the working hour.
		Machine operation	Electricity, low voltage, US	ELCD	US term is commonly for study and database
	Output	HDPE pellets (final weight)	1 kg		Colour pellets mass
		Material waste processed	0.111 kg	This work	Generated during shredding process
Moulding	Input	HDPE pellets (final weight)	1 kg	This work	Colour pellets mass
		Consumption of electricity	40.24 kWh	Agarski *et al.* (2019)	Operation time: 4 hours; electricity consumption: 18 kW/h at 55% efficiency; Machine heating: 0.8 kW/h heated for 80% of the working hour.
		Machine operation	Electricity, low voltage, US	ELCD	US term is commonly for study and database
	Output	Final Ecoplastic material	1 kg	This work	Plastic Eco-furniture
		Carbon Dioxide emission	6.13 kg	Agarski *et al.* (2019)	Emission release during plastic manufacture for each 1 kg functional unit

Life Cycle Impact Assessment (LCIA) is the LCA phase that evaluates the importance of potential environmental effects with the aid of the inventory analysis results. The primary goal of LCIA is to assess the potential impacts after converting the LCI results into a quantitative report on the environment. This study was carried out with the openLCA software, which is open-source and free software for Sustainability and Life Cycle Assessment. This software is a fast and reliable calculation for LCA, is user-friendly, and provides detailed insights into calculation and analysis results. Nine impact categories were obtained in this study after the CML method was applied to the LCI data by using the openLCA software. The CML Baseline impact method, readily available in the EcoInvent LCIA database, determines plastic waste performance in their impact categories. The selected characterized LCA results for this study are global warming (GWP), acidification (AP), ozone layer depletion, depletion of abiotic resources and photochemical oxidation (POCP). According to the environmental product declaration for plastic products, the LCIA for these five impact categories is recommended (EPD International, 2018).

RESULT AND DISCUSSION

The model graph computed from the product system using OpenLCA is shown in Figure 2. The model graph represents the processes linked together in the product system with a functional unit of 1kg of HDPE/eco-furniture contributing to the software computation. Figure 3 shows the impact analysis (LCIA) results for all the assessed impact categories, namely global warming (GWP), acidification (AP), ozone layer depletion, depletion of abiotic resources and photochemical oxidation.

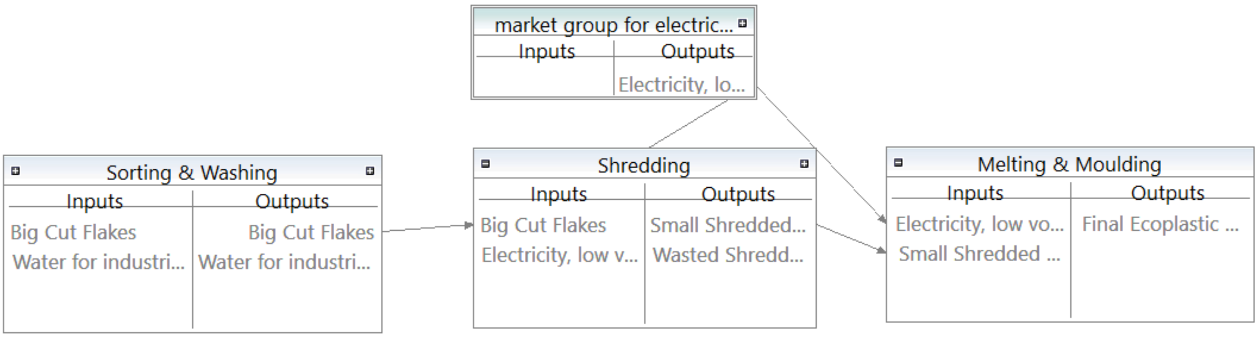

Figure 2. Model graph in product system.

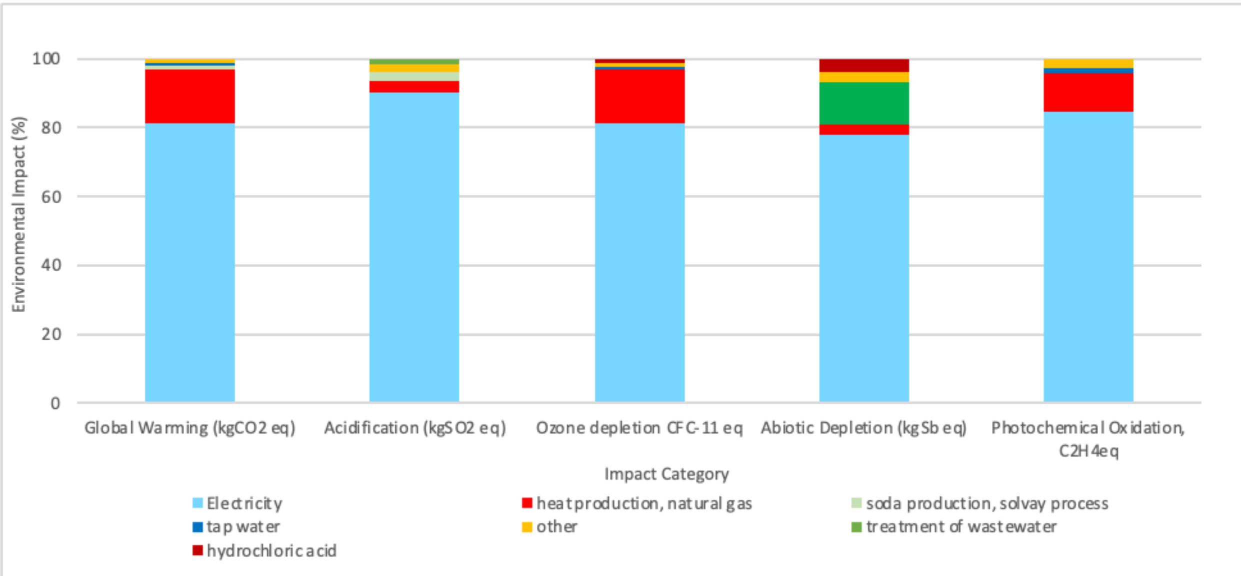

Figure 3. Life cycle impact assessment of the eco-furniture.

The findings show that the consumption of electricity during the manufacture of eco-furniture resulted in the most significant amount of environmental loading. Electricity consumed by the machines during shredding and molding in the workshop provided the most extensive set of significant clusters of the environmental impacts assessed. It was observed that among the impact categories, electricity contributed 81% to global warming potential (GWP), 90% to acidification, 81%

to ozone depletion, 78% to abiotic depletion and 85% to photochemical oxidation. The electricity group peaked in each impact category (78% to 90%), surpassing the heat and water group.

This finding broadly supports the work of other studies in this area, linking Agarski *et al.* (2019) and Dassisti *et al.* (2016). Similarly, research done by Agarski *et al.* (2019) on LCA characterization found that the environmental impact of injection moulding tools and plastic cap manufacturing is determined mainly by the amount of electricity consumption and demonstrates the need for developing countries to increase the use of cleaner sources of electricity.

One major drawback of Eco-furniture's manufacturing process is the significant electricity consumption. The difficulties associated with waste recycling are tied to using electricity generated by fossil fuels (European energy mix) (Horodytska *et al.,* 2020). This can be supported by Sabah's main electricity supply is mainly from a non-renewable gas plant (SESB, 2019). Sabah's energy is generated by gas (86%), hydropower (7%), diesel (4%), biomass and biogas (2%), and solar energy (< 1%). While the less populated East Coast primarily uses diesel for power generation, the West Coast region heavily depends on gas (SESB, 2019). Thus, due to the source being non-renewable, it heavily affects the impacts caused by electricity consumption. In their influential study regarding LCA of single-cap manufacture, Agarski *et al.* (2019) concluded that the quantity of energy consumed influences the environmental impact of the manufacture of plastic waste products. Even though production has a negative environmental impact, this impact can be overlooked when looking at the manufacture singlehandedly, which also applies to this study research. Based on previous research, electricity has been the significant consumption for plastic products such as HDPE agricultural nets by Dassisti (2016), recyclates by Storm (2017) and bottle caps by Agarski (2019).

CONCLUSION

The involvement of the OpenLCA software package, of which the manufacture of the EZplast’s plastic eco-furniture has been evaluated and measured for its impacts on the environment. Five impact categories, namely climate change, acidification, ozone layer depletion, abiotic depletion, and photochemical oxidation, were analysed using the CML Baseline impact method. In conclusion, electricity had the most significant impact, about 78% to 90%, compared to others impact categories.

Some recommendations are provided where more modelling work are needed to assess the LCA of plastic waste-to-wealth products in different scenarios. Future study recommendations could include conducting and comparing the LCA data on different types of plastic waste, to critically analyse either differences or similarities of the sustainability attribute of the materials investigated. Then, utilizing other software package for the LCA of the manufacture of plastic waste-to-wealth product, such as Gabi and Simapro. However, results need to discuss more as different software has different conversion factors and quality standards in computing the LCA. Finally, using other database for the Life Cycle Inventory input of the manufacture of plastic waste-to-wealth product, to reap the benefits of more relevant data for the particular local application, resulting in the distinction of vast and real-life scenarios.

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