Plastic waste management using a Life Cycle Assessment (LCA) approach: A step toward improving sustainability literacy
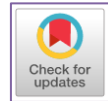
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Abstract: Plastic waste has become a serious issue for the environment and health. This study aims to analyze the management of plastic waste using the LCA approach and its influence on sustainability literacy in science learning. The research utilizes a mixed-methods exploratory sequential design. It begins with qualitative data collection through observation, interviews, and documentation, followed by quantitative data collection through experimental design. Sustainability literacy is assessed using a Sustainability Literacy questionnaire. Data analysis techniques include data condensation, data display, and data verification. Hypothesis testing is conducted using t-tests. The analysis results suggest that the LCA approach can be an alternative in managing plastic waste. LCA provides a systematic process consisting of goal formulation, data inventory, impact assessment, and interpretation. Knowledge and understanding of plastic waste management are efforts to promote sustainability literacy among university students. The sustainability literacy profile of students is categorized as very good. In terms of t-test analysis results, the SSIBL model proves to influence students' sustainability literacy with a significance value of 0.042.

Keywords: Management; Plastic waste; Life cycle asessment; Sustainability literacy

INTRODUCTION

Plastic waste has become one of the most severe environmental issues in the world (Aizudin et al., 2022; Wang et al., 2022). The primary cause of this issue is the increasing production of plastic, coupled with insufficient plastic waste management. Based on current trend data, approximately 343 million tons of plastic waste are generated annually (Geyer, 2020) and it is projected to generate 26 billion tons of plastic waste by 2050 (Lavoie et al., 2022). This data is corroborated by a World Bank Group report which determined that plastic contributes between 5-12% of the total global waste accumulation (20-30%) and approximately 60% of plastic ends up in the environment as plastic waste. The large amount of plastic waste ultimately impacts ecosystems through soil contamination caused by the accumulation of plastic waste, marine pollution resulting from the disposal of plastic waste into the ocean, and air pollution due to open dumping

and burning of plastic waste (Kibria et al., 2023; Mourshed et al., 2017; Paletta et al., 2019).

In Indonesia, plastic waste remains a very serious issue. Based on data from the Indonesia Solid Waste Association, it shows that plastic waste is the second largest waste, amounting to 5,4 million tons per year, or 14% of the total waste generation in Indonesia. (Widiyatmoko et al., 2016). The amount of plastic waste generation is always increasing in line with the population growth in Indonesia (Utami & Fitria Ningrum, 2020). The large amount of waste generation in Indonesia also has an impact on the sub-optimal plastic waste management system. In terms of plastic waste management systems, Indonesia ranks second among countries that have not managed plastic waste effectively (Jambeck et al., 2015).

Plastic waste originates not only from households but also from other sources such as industries, healthcare services, and agriculture. Most plastic waste can be recycled, but only 9% is recycled if the scraps are disposed of or burned (OECD, 2023). Plastic waste is estimated to be responsible for 4,5% of global greenhouse gas emissions (Cabernard et al., 2021). Excessive disposal of plastic accelerates environmental issues, causing significant environmental damage and posing health risks to humans (Ragaert et al., 2017). Furthermore, burning plastic waste directly releases sixteen types of polycyclic aromatic hydrocarbons into the environment, which negatively impact human health, including causing cancer, respiratory diseases, and obesity in children who inhale them (Praveenkumar et al., 2024). Because it produces pollution on a large scale, plastic waste has evolved into one of the world's largest waste issues (Dědek et al., 2023).

Considering the significant negative impacts on the environment and health, plastic waste needs to be managed properly. Based on the results of observations and interviews with the Head of the Regional Technical Implementation Unit (UPTD) for Wastewater and Waste Management in the Eastern Region of Department of Environment, Marine Affairs, and Fisheries (DLHKP) Kebumen in March 2024, it was explained that waste management in Kebumen has been carried out in accordance with established procedures. The established policies have made waste management performance more conducive. Optimizing waste into useful products is one of the focuses of the environmental service's work program as an effort to create zero waste in Kebumen. The existence of the benefits from the waste for the community provides an opportunity for the community to feel the benefits of waste management. This will foster public trust in the local government to continuously innovate in managing waste. Waste management in Kebumen, despite innovations such as making biogas from organic waste, is still a big problem, especially the management of plastic waste. The management of plastic waste in Kebumen is currently limited to using the 3Rs (*Reuse, Reduce, Recycle*) technique. In the future, there are plans to manage plastic waste in Kebumen by transforming it into more beneficial products such as briquettes, alternative energy sources, and so on. Waste management also poses a challenge for the government in fostering environmental awareness among the community.

Plastic waste causes various environmental problems that have garnered international attention. As a result, environmental programs have become integral to the sustainable development goals (SDGs). The SDGs are a new development agreement that promotes change towards sustainable development based on human rights and equality, advancing social, economic, and environmental sustainability (United Nations, 2015). The Paris Agreement stipulates that countries worldwide will collaborate to reduce greenhouse gas emissions, which are a major cause of climate change. Given the

global issues caused by plastic waste, cooperation across various sectors is necessary in order to raise awareness among the public about the importance of environmental conservation (Fatimah et al., 2024).

Awareness of environmental conservation is a crucial aspect in shaping environmental literacy towards sustainability literacy. Sustainability literacy is essential for achieving sustainable development goals (Ozdemir, 2023). The expansion of the meaning of environmental literacy to sustainability literacy is necessary due to the transition from environmental education to sustainable education (Leiva-Brondo et al., 2022). Sustainability literacy has become a primary outcome in sustainable education, serving as a transitional competency towards sustainable communities (Leiva-Brondo et al., 2022; Winter & Cotton, 2012). Individuals with sustainability literacy can understand the symbiotic relationship between environmental, social, and economic dimensions of sustainable development. They are capable of combine relevant knowledge with skills and further recognize and appreciate sustainable actions taken by others (Ozdemir, 2023). Mason stated that sustainability literacy is understood as the knowledge, skills, and mindset that enable individuals to be deeply committed to building a sustainable future and assist others in making informed and effective decisions towards sustainable societies (Mason & Sulitest, 2019).

There have been numerous studies examining plastic waste management as a way to raise individual awareness of the environment, especially in developing environmental consciousness among college students. Chow et al. provide an overview of plastic waste management, emphasizing the establishment of waste collection points designed to facilitate recycling and the sorting of plastic waste at the source. The issue of plastic waste can provide educators with insights into problem solving on environmental, thereby developing students' awareness of the environment (Chow et al., 2016). Barros et al. examine the importance of plastic waste management for students. As a form of developing environmental awareness, the university implements waste management practices by replacing disposable plastic cups with reusable plastic cups as a form of reducing plastic waste. These efforts provide recommendations for universities as an effort to shape a sustainable environment (Barros et al., 2020). Harman & Yenikalayci found that students are aware of recovery, reuse, recycling, and reducing plastic bag usage as efforts towards achieving zero waste. The existence of this good awareness has an impact on students' knowledge and understanding of the fundamentals of waste management, procedures for waste handling, and sorting waste based on its source and type, including proper disposal in designated waste bins (Harman & Yenikalayci, 2022). Lee et al. discovered a case of increased plastic usage during the COVID-19 pandemic. The issue of plastic waste can serve as a focal point for raising environmental awareness within the education sector. As an effort to make environmental education effective, it can be done by providing an understanding to live in harmony with the environment and collaborate towards sustainable societies. On the other hand, to build an environmentally friendly culture, it is necessary to change the paradigm by using plastic wisely or replacing plastic with alternative materials (Lee et al., 2022).

The literature review above still focuses on the importance of introducing plastic waste and how to manage it, such as reusing used plastic or recycling plastic waste, as efforts to create environmental awareness. However, there has been limited research on appropriate and environmentally friendly plastic waste management practices that provide significant benefits to society. The LCA approach provides a great opportunity for stakeholders to evaluate their performance in managing plastic waste. Furthermore,

the final stage of LCA involves providing recommendations that will enhance knowledge for all stakeholders involved in managing plastic waste. Compared to conventional approaches that focus solely on production stages, LCA provides a broader and more comprehensive view of the environmental impacts of a product. LCA also assists decision-makers in developing more efficient strategies to reduce environmental impacts (Sherry & Tivona, 2022). On the other hand, this plastic waste management provides an opportunity for the education sector to impart understanding to students, fostering environmental literacy towards sustainability literacy. Understanding the huge impact of plastic waste can motivate students to conduct inquiry activities through various ways.

Based on the above explanation, this study aims to analyze plastic waste management in Kebumen using the Life Cycle Assessment (LCA) approach and to use the results of this analysis as study material for students to introduce sustainability literacy and to analyze its impact on students' sustainability literacy. This research can serve as a recommendation for stakeholders in maintaining and preserving a waste-free environment as an effort to realize sustainable development.

METHOD

This study employs mixed methods with an exploratory sequential design, which involves collecting qualitative data first, followed by the collection of quantitative data (Creswell, 2014). The exploratory qualitative approach is employed to analyze plastic waste management in Kebumen using the LCA approach.

The LCA approach includes (1) Goal formulation: (a) Measuring the amount of plastic waste accumulation; (b) Assessing the performance and evaluation of plastic waste management in Kebumen; (c) analyzing environmentally friendly plastic waste management scenarios. (2) Data inventory: Measuring greenhouse gas emissions generated from plastic waste. (3) Impact assessment: Analyzing the impacts resulting from plastic waste accumulation. (4) Interpretation: Develop recommendations and strategies for reducing environmental impacts that are effective and environmentally friendly. The data used includes both primary and secondary data.

The location of this research is the Final Processing Site in Kebumen. The research subject is the Head of the Environmental Pollution and Damage Control Division (PPKL) of the Department of Environment, Marine Affairs, and Fisheries of Kebumen Regency, Head of the Technical Implementation Unit (UPTD) for Wastewater and Waste Management in the Eastern Region of Department of Environment, Marine Affairs, and Fisheries (DLHKP) Kebumen, Waste Management Field Workers, and Communities around Panjer Village. Data collection techniques include interviews, observations, documentary studies, questionnaires, and literature reviews.

Primary data to measure the performance and evaluation of plastic waste management is derived from interviews, observations, and questionnaires. Meanwhile, secondary data includes the amount of plastic waste accumulation in Kebumen sourced from the National Waste Management Information System (SIPSN) and greenhouse gas emissions from plastic waste sourced from documentary studies, specifically from the greenhouse gas inventory report in Kebumen published by the Department of Environment, Marine Affairs, and Fisheries (DLHKP) of Kebumen Regency in 2023. Data on estimated impacts and recommendations or scenarios for plastic waste management are obtained from literature reviews. Literature data retrieval is conducted using the Scopus database. Scopus is one of the quality data sources, making it a consideration in document selection (Wei et al., 2023).

The data analysis technique utilizes the Miles, Huberman, & Saldana model (Miles et al., 2014) which consists of three stages: data condensation, data display, and conclusion drawing. Data condensation involves collecting the data and then sorting it based on the research needs. If any data is deemed irrelevant, it is disregarded. The next stage is presenting the data in various forms, including descriptions, tables, and figures, so that readers can understand the meaning of the research data. The final stage is verification/conclusion drawing, where the data is summarized based on the research objectives, and an overall conclusion is drawn from the conclusions of each research objective.

Furthermore, quantitative research is carried out which aims to produce data on the measurement of sustainability literacy profiles and the influence of science learning with content on plastic waste management through the Socio-Scientific Inquiry-Based Learning (SSIBL) model conducted using a quasi-experimental design. The population in this study consists of all Primary School Teacher Education (PGSD) totaling 3 classes. The sample technique was carried out using simple random sampling, with two classes assigned as the experimental group and one class as the control group. Data collection for measuring sustainability literacy profiles uses the Sustainability Literacy questionnaire adopted from (Ozdemir, 2023). Furthermore, the data analysis technique was carried out using the t-test with the assistance of SPSS.

RESULT AND DISCUSSION

Result

LCA approach as a method for plastic waste management in Kebumen

Profile of Plastic Waste Generation in Kebumen

Waste generation in Kebumen Regency always increases every year. The waste generation in Kebumen, based on data from the SISPSN (National Waste Management Information System), can be seen in Table 1.

Table 1. Total Waste Generation in Kebumen in 2018-2022

No.	Year	Annual Waste Generation (m^3)
1.	2018	601,00
2.	2019	610,84
3.	2020	633,42
4.	2021	671,65
5.	2022	763,47
Average		**656,076**

Source: (Satu Data Kabupaten Kebumen Portal, DLHKP Kebumen Regency, 2023)

Table 1 shows that waste generation in Kebumen Regency has been increasing over the past five years. The interview results show that one of the factors contributing to the increase in waste generation in Kebumen Regency is the increasing population in Kebumen Regency. Table 2 shows the total population of Kebumen Regency.

Tabel 2. Total Urban Population in Kebumen Regency

No.	Year	Total Population
1.	2018	278.880
2.	2019	299.629
3.	2020	320.378
4.	2021	350.050
5.	2022	361.949

Source: (Satu Data Kabupaten Kebumen Portal, DLHKP Kebumen Regency, 2023)

Meanwhile, in terms of plastic waste generation in Kebumen, plastic waste ranks as the third largest contributor.
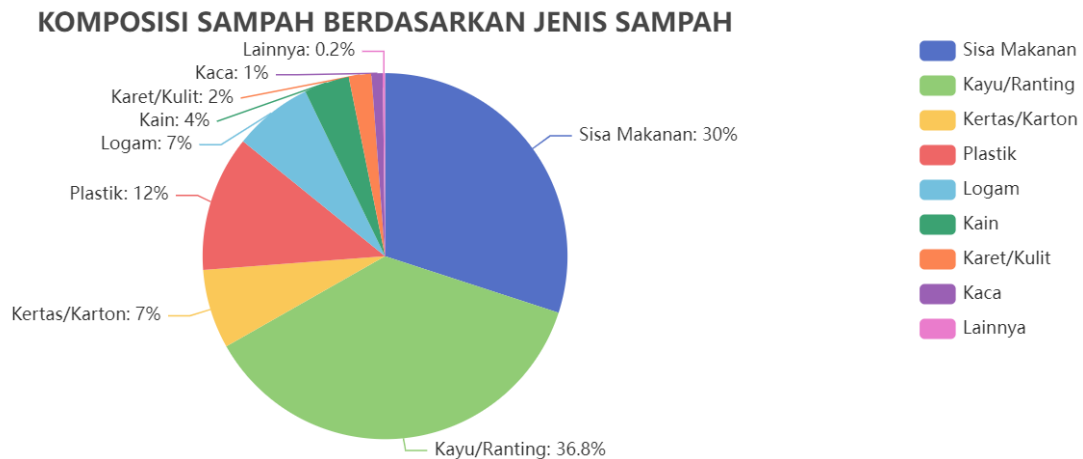

Figure 1. The composition of waste types in Kebumen Regency in 2022 (SIPSN, 2023)

Figure 1 shows that plastic waste ranks third as the largest type of waste in Kebumen District, accounting for 12%, following wood/branches waste (36,8%) and food waste (30%), which rank first and second, respectively, as the largest types of waste in Kebumen. Based on the interview with the Head of the Technical Implementation Unit (UPTD) for Wastewater and Waste Management in the Eastern Region of the Department of Environment, Marine Affairs, and Fisheries (DLHKP Kebumen), it was explained that plastic waste management in Kebumen still focuses on managing organic waste, which is processed into biogas and compost. Currently, 40 households are utilizing biogas produced from organic waste management. However, plastic waste management is still limited to using the 2Rs technique (*Reuse, Reduce*). Meanwhile, unsorted plastic waste continues to accumulate at the Final Processing Site in Kebumen.

Figure 2. The condition of waste at the Kaligending Final Processing Site in Kebumen (Personal document, March 2024)

Figure 2 illustrates that there is still a significant amount of waste at the Kaligending Final Processing Site that has not been managed. Especially plastic waste that is not properly managed and only dumped in the Final Processing Site. One of the reasons for the inadequate management of plastic waste in Kebumen is the lack of facilities/equipment that can be used to process plastic waste into alternative energy sources, briquettes, and so on.

Measurement of Performance and Evaluation of Plastic Waste Management in Kebumen

Based on the results from the Satu Data Kabupaten Kebumen Portal, Department of Environment, Marine Affairs, and Fisheries (DLHKP) Kebumen Regency data from 2018-2022 indicates the performance of waste management as shown in Table 3.

Table 3. The performance of waste management in Kebumen Regency in 2018-2022

No.	Description	2018	2019	2020	2021	2022
1.	Percentage of waste collected (%)	51,93	51,51	58,73	59,14	60,51
2.	Total number of TPSS (unit)	190	195	196	196	221
3.	TPS capacity (tons)	431,30	536,25	539,00	539,00	607,75
4.	Total volume of waste collected (m^3)	312,09	314,64	372,00	397,20	462,00

Source: (Satu Data Kabupaten Kebumen Portal, DLHKP Kebumen Regency, 2023)

Table 3 explains the performance of waste management in general has shown to be good. It is known that each year there is an increase in the amount of waste collected. Based on the assessment of plastic waste management in Kebumen according to the community's responses gathered through questionnaire distribution, it shows good criteria. Performance measurement uses five aspects: productivity, service quality, responsiveness, responsibility, and accountability adopted from Dwiyanto (Dwiyanto, 2021). Figure 3 is the result of the questionnaire on the performance measurement of plastic waste management in Kebumen.
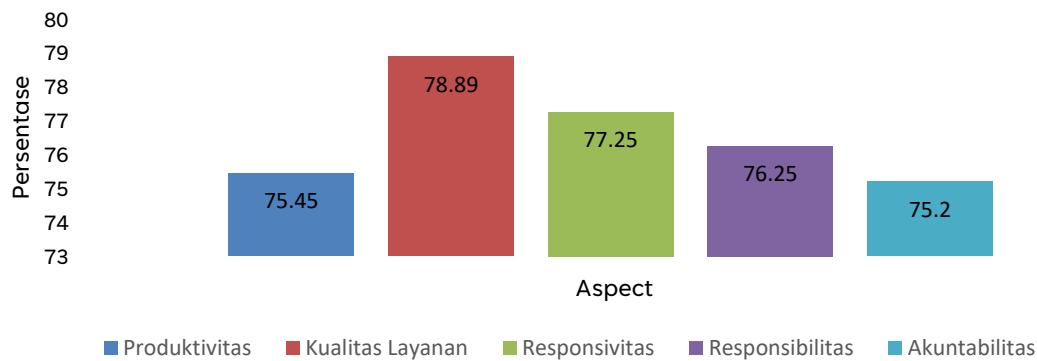

Figure 3. Performance of plastic waste management in Kebumen according to the community

Figure 3 shows that the performance of plastic waste management in Kebumen has been categorized as good, with an average percentage of 76,60%. Based on the observation results at TPS3R Kebumen, plastic waste management is carried out continuously every day. The plastic waste entering TPS3R Kebumen undergoes selection and sorting. Meanwhile, the evaluation results of plastic waste management in Kebumen measure six aspects, including effectiveness, efficiency, adequacy, equity, responsiveness, and accuracy, adopting Dunn's evaluation measurement (Dunn, 1994).

Based on the questionnaire results, the community is sufficiently capable of sorting and separating different types of waste. The existing plastic waste is collected and sold to TPS3R. Although not many community members practice the 3Rs independently, the activities of sorting waste types and avoiding littering have become one of the community's efforts to care for the environment. Based on the results of observations and interviews, the community in Panjer village collects plastic waste and sells it to the TPS3R manager which will then be processed by TPS3R for selection and sorting. This has become an effective program in reducing plastic waste disposed into the environment.

Figure 4. TPS3R facilitates the sale of community plastic waste (Personal document, March 2024)

Figure 4 illustrates that the local community is very enthusiastic in implementing programs issued by TPS3R. Based on interviews with the local community, buying and selling plastic waste is a very good program and makes residents more enthusiastic in selecting types of waste. This plastic waste weighing activity is carried out once a month. After weighing the plastic waste, the collected plastic waste is directly sent to TPS3R for sorting and selection (see Figure 5).

Figure 5. Plastic Waste Selection and Sorting at TPS3R (Personal document, March 2024)

Figure 5 shows the process of selecting and sorting plastic waste at TPS3R Kebumen. This TPS3R is the final place for plastic waste management in Kebumen. Based on interviews with the manager, the sorted plastic waste is collected together and will be picked up by collectors. The interview results with the manager explained that additional facilities and adequate infrastructure are still needed at the TPS3R. The future program from Department of Environment, Marine Affairs, and Fisheries (DLHKP) regarding the management of plastic waste into useful and economically valuable goods is warmly welcomed by the field managers.

Greenhouse Gas Emission Data from Plastic Waste in Kebumen

The measurement of greenhouse gas emissions conducted by the Department of Environment, Marine Affairs, and Fisheries of Kebumen Regency is measured using the SIGN-SMART application. Emission testing using this application involves inputting data into the SIGN-SMART application, where calculations are performed directly by the application through computation, and emission graphs are subsequently generated. The SIGN-MART application is developed based on methods set forth by the Intergovernmental Panel on Climate Change (IPCC) Guidelines, specifically following the IPCC Guidelines 2006 (DLHKP, 2023). In trend, greenhouse gas emissions generated by waste have shown an increasing trend.
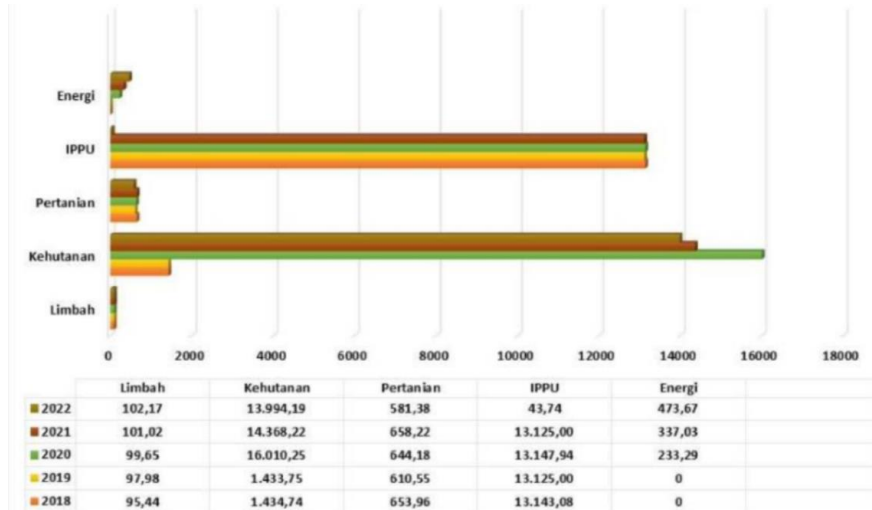
	Limbah	Kehutanan	Pertanian	IPPU	Energi
■ 2022	102,17	13.994,19	581,38	43,74	473,67
■ 2021	101,02	14.368,22	658,22	13.125,00	337,03
■ 2020	99,65	16.010,25	644,18	13.147,94	233,29
■ 2019	97,98	1.433,75	610,55	13.125,00	0
■ 2018	95,44	1.434,74	653,96	13.143,08	0

Figure 6. Greenhouse Gas Emission Trends in Kebumen (DLHKP, 2023)

Based on the trend graph of greenhouse gas emissions in Kebumen from 2018 to 2022, there is an increase in greenhouse gases from waste. In terms of plastic waste greenhouse gas emissions from the SIGN-SMART application data can be seen in Table 4.

Table 4. Calculation of Waste Sector Emissions in Kebumen Regency in 2022

Emission Type			
CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)	CO_2 Eq (Gg)
-	0,16	-	3,44

Source: (SIGN-MART Application, 2023)

Based on SIGN-MART calculations, waste emissions in Kebumen contain 0,16 Gg of CH4 and 3,44 Gg CO_2 Eq. Measurements of greenhouse gas emissions from burning waste produce CO_2 (3,67), CH_4 (6,5), and N_2O (0,15) when conducted in an open environment. Meanwhile, when conducted in a closed environment (incineration), waste burning is not affected by environmental conditions and occurs at high temperatures, primarily producing CO_2 gas. Plastic waste contains the highest carbon (C) content compared to other types of waste. When plastic waste is burned directly/in an open environment, it produces higher carbon content compared to other types of waste.

Impact of Plastic Waste

Plastic waste has serious impacts on the environment and health. Based on the results of the literature analysis, the impact of plastic waste is responsible for global warming. In addition, plastic waste that is not easily decomposed causes damage and pollution to soil, water and air. Meanwhile, the impact of plastic waste on human health includes direct burning of plastic waste releasing sixteen polycyclic aromatic hydrocarbons into the environment, which negatively impacts human health, including cancer, respiratory diseases, and obesity in children who inhale it. Plastic waste that transforms into microplastics and nanoplastics within the human body can trigger cancer, digestive disorders, stunted growth, shortened lifespan, and reproductive system disorders.

Plastic Waste Management Scenario

The management of plastic waste in Kebumen currently uses the 2Rs scenario (Reuse, Reduce). Any action that can reduce and prevent waste disposal is referred to as the first principle, Reduce. The second principle is reuse (Reuse), which involves utilizing

waste again for the same purpose. This technique is an effective solution in plastic management considering how long it takes for plastic to decompose.

Based on literature analysis, many countries have conducted research on plastic waste management, particularly converting it into renewable energy sources. Table 5 is plastic waste management based on the literature analysis review.

Table 5. Plastic waste management as an energy source

No.	Plastic Waste Management	Publication Year	Energy Outcome
1.	a. Plastic waste can be utilized as electrode and supercapacitor materials through activated carbon (Dědek et al., 2023; Tashima et al., 2023) b. Pyrolysis/gasification (Charusiri et al., 2023) c. Polihidroksialkanoat (PHA) (Ali et al., 2023) d. Plastic management using biomass raw materials (Bio-CCS) (Aracil et al., 2023; Stegmann et al., 2023) e. Plastic management through advanced thermochemical treatment (ATT) (Arena et al., 2023) f. Plastic management via monolithic multilayer stainless steel mesh catalysts (Liu et al., 2023; Mirjalili et al., 2023) g. Plastic waste management through physicochemical and thermal analysis (Dodo & Ashigwuike, 2023)	2023	a. electrode and supercapacitor materials b. diesel fuel as microbatch reactor c. electricity and biodiesel energy sources d. transformed into bioenergy/biomass e. transformed into energy such as converted into oil, hydrogen, methane, etc. f. transformed into a lithium-ion battery g. transformed into power generation energy
2.	a. Management of plastic waste (masks) through pyrolysis reactors (Skrzyniarz et al., 2022) b. Management of plastic waste through synthesis of graphene nanosheets (GNs) (Karakoti et al., 2022) c. Plastic waste management through thermal process (Kijo-Kleczkowska & Gnatowski, 2022)	2022	a. Transformed into an energy source b. transformed into a supercapacitor c. transformed into fuel and energy sources
3.	a. Plastic waste management through pyrolysis reactor (Lameh et al., 2021) b. Plastic waste management through pyrolysis and gasification methods (Antelava et al., 2021)	2021	a. transformed into a solar energy source b. transformed into an energy source in the form of oil

Promoting Sustainability Literacy through plastic waste management as an effort to achieve sustainable education.

Promoting sustainability literacy for students is achieved through the implementation of the Socio-Scientific Inquiry-Based Learning (SSIBL) model (Amos & Levinson, 2019). There are three stages in SSIBL learning (see Figure 7): (1) Ask, asking authentic questions based on research on socio-scientific issues; (2) Find out, research-based inquiry into questions for effecting change (such as conducting experiments, analyzing data, collaborating with others); (3) Act, finding solutions (communicating findings based on research evidence, convincing others of the need for change, and taking action towards change) (Levinson et al., 2017).

Figure 7 is a diagram of the SSIBL learning stages. The stages can be explained in more detail as shown in figure 7.
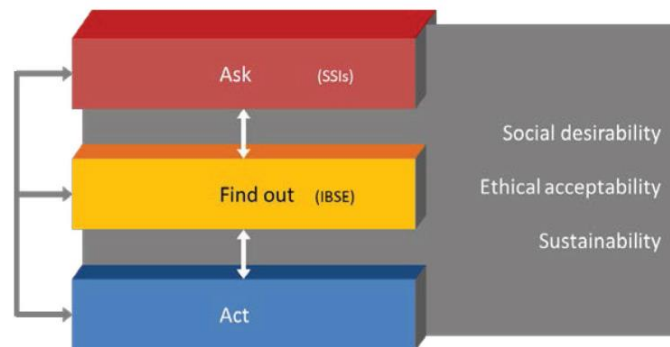
Figure 7. SSIBL learning stages (Amos & Levinson, 2019)

Raising authentic questions – Ask

At this stage, the lecturer starts the learning by asking authentic questions that are related to everyday life issues closely related to students. The questions posed by the lecturer are about environmental pollution issues caused by waste. These issues are presented using various types of images and videos depicting the impacts of poorly managed plastic waste. The presentation of photos, videos, and other engaging media will capture students' attention regarding the socio-environmental issues being presented.

An inquiry-based approach – Find out

At this stage, after students know and understand the issues or authentic questions given, they engage in group discussions to analyze the issues presented by the lecturer. Through discussions, students are guided by the lecturer to conduct investigations to gather data/facts in order to find solutions to the issues presented. At this stage, students conduct interviews directly in their respective environments to analyze problems about waste. For example, the results of environmental issue analysis based on interviews with the local community. Students can analyze the results of these interviews as a reference for conducting further in-depth investigations to find the right solution.

Finding a solution – Act

In this stage, the activity involves instructors guiding students to create project as a form of solution to the existence of plastic waste in the surrounding environment. For example, utilizing plastic waste to create works of art such as ecobricks, hydroponic planting media, etc. The results of the activities carried out by students are then presented and documented in reports as a form of developing students' communication skills. The use of SSIBL can enhance students' sustainability literacy. In this case, the lecturer helps students to stimulate their interest in the issue by using images, videos, newspaper clippings, or social media that are related to students' lives and concerns. For example, the lecturer uses a video about the adverse effects of unmanaged plastic waste. The existence of appropriate solutions for plastic waste management will encourage students to develop sustainability literacy.

Students have excellent sustainability literacy after engaging in learning activities using the SSIBL model. The influence of the SSIBL model was assessed using a t-test through the help of SPSS. Table 9 presents the output results of the regression test conducted using SPSS.

Table 8. T-test results from SPSS output

	Coefficients^a					
Model	Unstandardized Coefficients		Standardized Coefficients		t	Sig.
	B	Std. Error	Beta			
1 (Constant)	2.349	.399			5.881	.000
Literasikeberlanjutan	-.011	.005	-.254		-2.072	.042
a. Dependent Variable: Class						

Table 9 demonstrates that the SSIBL model has a significant impact on students' sustainability literacy, with a significance value of 0,042 < 0,05. The significance value proves that the SSIBL model has a positive impact on students' sustainability literacy.

Discussion

Plastic waste management using the LCA approach is carried out using systematic stages, starting from analyzing the profile, measuring performance, analyzing greenhouse gas emissions, impact assesment, and providing recommendations for environmentally friendly plastic waste management. Based on the analysis of waste profiles in Kebumen, it was found that the amount of waste generated and the population are increasing every year. The increase in population in Kebumen Regency as shown in Table 2 has a big impact on the increase of waste in Kebumen. Wikurendra et al. mentioned that the increase in waste volume is closely related to the rapid increase in population from rural to urban areas (Wikurendra et al., 2024). Other studies examine the same issue regarding the impact of population growth on the increasing volume of waste generation (Atmanti et al., 2023; Elyasa, 2020; Saitullah, 2022). The increasing human population, which impacts the distribution of plastic waste, leads to environmental pollution and subsequently decreases the quality of the natural environment (Gabuya, 2021).

The evaluation results show that plastic waste management needs to be improved. In terms of effectiveness, with the increasing use of plastic, there is a need for serious plastic waste management. One of them is the even distribution of TPS3R facilities in every district and even at the village level. On the other hand, concern and awareness that is proven by concrete actions from the surrounding community are needed as a form of effort to maintain a healthy environment. Plastic waste management using the 2Rs technique has been widely adopted. This is because of the non-biodegradable nature of plastic, reusing plastic waste and then recycling is an effective technique (Uvarajan et al., 2022).

The measurement results of plastic waste emissions using the SIGN-SMART application indicate that plastic waste has the highest carbon (C) content compared to other types of waste. When plastic waste is burned directly or in open environments, it produces higher carbon content compared to other types of waste. Plastic waste is estimated to account for 4,5% of global greenhouse gas emissions (Cabernard et al., 2021). This is because plastic waste emits gases such as methane and carbon dioxide, thus contributing to greenhouse gas emissions (Okunola A et al., 2019; Shen et al., 2020; Vishwakarma, 2020; Yadav et al., 2020).

Apart from being responsible for global warming, plastic waste causes environmental damage and pollution, including soil, water, and air pollution, due to the slow decomposition process of plastic (Adeniran & Shakantu, 2022). The presence of plastic waste causes changes in water pH, and rainfall facilitates plastic pollutants entering the soil,

thereby contaminating the soil and groundwater, which eventually bioaccumulates in the food chain (Asuquo, 2018; Rajmohan et al., 2019; Wanner, 2021).

The large amount of plastic waste also clogs waterways, which results in the breeding of mosquitoes and other disease-causing organisms a as well as causing unpleasant odors (Alda-Vidal et al., 2020) and reduces aeration, thereby decreasing productivity in agricultural land (De-la-Torre, 2020; Patrício Silva et al., 2021). The accumulation of plastic waste ending up in final processing site and not managed properly results in soil and water contamination. Microplastics and nanoplastics, which are fragments of plastic waste, are a predominant concern in marine ecosystems (Lehner et al., 2019; Zhang et al., 2020). Plastic waste disposed into the sea will settle in coastal ecosystems such as mangrove forests and coral reefs. Plastic waste is responsible for the deaths of 100,000 marine mammals, 2 million seabirds, and other marine organisms (Pasaribu et al., 2023). Plastic waste ingested by marine organisms can lead to intestinal blockages and potential poisoning from chemical contaminants (Erawati, 2024) and adversely affect the fitness of the organism such as metabolism, reproductive abnormalities, immune system, and even death (Lei et al., 2018).

Excessive plastic disposal accelerates environmental issues, leading to significant environmental damage and posing risks to human health (Ragaert et al., 2017). In addition, directly burning plastic waste releases sixteen polycyclic aromatic hydrocarbons into the environment, which have negative impacts on human health, including cancer, respiratory diseases, and obesity in children who inhale them (Praveenkumar et al., 2024). Plastic waste that turns into microplastics and nanoplastics ithin the human body can trigger cancer, digestive disorders, inhibited growth, shortened lifespan, and reproductive system disorders (Erawati, 2024).

Humans who consume marine animals that have been exposed to microplastics poses significant health risks and even endanger the human food system. (Li et al., 2021; Wong et al., 2020). Microplastics have even been found in human feces from 90% of the particles excreted (Yong et al., 2020). Some particles are likely to travel from the stomach to the lymphatic system and bloodstream, passing through brain cell tissue and the placenta (Barboza et al., 2020). This can trigger reactions in the body such as immunosuppression, immunologic activation, and aberrant inflammatory responses (Imran et al., 2019). There is a correlation between exposure to airborne microplastics and chronic respiratory diseases (pulmonary fibronis), Furthermore, their accumulation can potentially trigger cancer development (Li et al., 2021). Research findings from 114 respondents indicate that 87% of human lungs contain plastic fibers. This is due to the inhalation of nanoplastics in the atmosphere that settle into the lungs of adults and children (Bhat et al., 2023; Prata, 2018).

Considering the recommendations for plastic waste management scenarios in Kebumen, due to limited facilities, the implementation of the 2Rs techniques by Kebumen Regency proves to be effective. The Minister of Environment Regulation No. 13/2012 on the guidelines for implementing the 3Rs serves as a strong regulation in plastic waste management through the 3Rs technique. Plastic waste management using the 3Rs technique has been widely adopted. Due to the non-biodegradable nature of plastic, reusing plastic waste and then recycling is an effective technique (Uvarajan et al., 2022). The recycling program was first started in 1993 by MHLG which encouraged the habit of implementing the 3Rs. Based on the literature analysis, besides employing the 3Rs techniques, plastic waste management can also be achieved by converting it into alternative energy sources.

The analysis of the issues and management of plastic waste in Kebumen serves as a subject of study in science education for students. Based on the data analysis, science learning through the SSIBL model has been proven to influence the sustainability literacy of Preservice elementary teacher. The use of SSIBL can strengthen students' sustainability literacy. These findings are consistent with Sari & Wiyarsi's research, proving that SSIBL model helps students in developing scientific literacy skills, especially in chemistry literacy. In this case, educators provide issues about energy use and its impact on life. This issue will provide students with an understanding of how their attitudes toward energy use as a form of protecting the environment (Sari & Wiyarsi, 2020). The SSIBL model focuses on problem solving with investigation activities so that it can develop students' reasoning skills in solving problems. SSI has the following characteristics: (1) has aspects of controversy, (2) involves reasoning, (3) uncertainty and risk (Levinson, 2011).

The SSIBL model focuses on questions that are related to everyday life around issues that are close to students, such as questions about how to use the cooling and heating system at school, electronic cigarettes, or various types of pollution in their surroundings. These questions are presented using various media such as photos, videos, newspaper/magazine clippings, and so on to capture students' attention regarding the given issues (Amos & Levinson, 2019). In-depth investigation will provide a lot of experience for students so that they can find the right solution (Amos & Levinson, 2019). The solutions provided are indeed suitable for addressing the existing questions, namely evidence/data/fact-based research that can be presented in the form of videos, brochures/posters, and class presentations. At this stage, students are directed to identify existing problems, analyze what they know and what needs to be learned, propose creative ideas for investigation, and decide together the right solution to the problem and explain what kind of action is taken as concrete evidence (Amos & Levinson, 2019).

CONCLUSION

Based on the analysis results, it can be concluded that the LCA approach can be one of the alternatives in managing plastic waste. The LCA approach provides a systematic process consisting of goal formulation, data inventory, impact assessment, and interpretation. It is known that the average accumulation of plastic waste in Kebumen reaches 656,076 m^3/year. This has an impact on gas emission produced by green house, specifically CH_4 and CO_2 Eq. Meanwhile, when combustion is carried out directly, it produces a carbon content of 75% if from dry plastic material and 100% if it comes from plastic waste that has fossilized. The abundance of plastic waste in Kebumen has environmental and health impacts, such as contributing to global warming, air, soil, and water pollution, as well as causing cancer, respiratory diseases, and obesity to children who inhale it. Several scenarios for managing plastic waste are implemented with strategies such as using the 3Rs or 2Rs techniques and processing plastic waste into alternative energy sources.

The presence of knowledge and understanding of plastic waste management is one of the efforts in promoting sustainability literacy among college students. The profile of sustainability literacy among students is categorized as excellent. Based on the results of the t-test analysis, the SSIBL learning model has been proven to significantly influence students' sustainability literacy, with a significance value of 0.042. Thus, it can serve as a model for the education sector, particularly in universities, to introduce sustainability

literacy through strengthening environmental literacy as an effort to achieve sustainable development goals (SDGs).

The recommendation in this study is that the LCA approach can be used to evaluate waste management practices in general. To optimize plastic waste management, collaboration with various experts in the field of environmental science can be undertaken. Understanding of plastic waste management can be the initial step in promoting sustainability literacy, which is only obtained when students have good environmental literacy. Therefore, educators must employ innovative strategies to introduce sustainability literacy to students.

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