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Social Life Cycle Assessment (S-LCA) of formal and informal waste collectors in decentralized waste to compost facility

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ABSTRACT

The global generation of municipal solid waste (MSW) is expected to increase by 70 % by 2050, reaching 3.4 billion metric tons. Despite the need for proper waste management, less than 20 % of waste is recycled, and waste continues to end up in landfills. Waste management is a significant problem in Bangladesh and other rapidly urbanizing nations, exacerbated by densely populated housing coupled with inadequate infrastructure. The utilization of informal waste collectors arises from the government's frequent inability to offer sufficient waste collection and disposal services. A large number of Dhaka's informal sector workers depend on collecting waste for a living. In this study, the social life cycle assessment (S-LCA) is applied to analyze the social implications of formal and informal waste collectors on the waste management process in Uttara, Dhaka. Working conditions, human rights, health and safety, and socio-economic repercussions are the four primary areas of focus for the S-LCA. For the assessment, an indicator score ranging from 2 (best performance) to −2 (poor performance) was used. The data revealed that informal workers scored 0 for fair salaries, but formal workers received 1, showing that formal workers adhere to higher standards. Both groups obtained an average score of −2 in the social security subcategory, which is much lower than anticipated. Formal workers scored −2 on health and safety, while informal workers scored −1, indicating serious inadequacies in both categories. These findings highlight the need for stronger legislation and support systems to enhance waste collectors' working conditions in Dhaka and other similar cities throughout the world, as well as the considerable socioeconomic challenges they confront.

1. Introduction

Municipal solid waste (MSW) generation is expected to increase worldwide by roughly 70 percent to 3.4 billion metric tons by 2050 (Tiseo, 2022). Developing countries account for the highest percentage of solid waste, with 56 % produced globally (Alam and Qiao, 2020). One of the most pressing issues faced by developing countries like Bangladesh, which are undergoing rapid urbanization and population growth, is municipal solid waste management (MSWM) (Chowdhury et al., 2013). Elevated levels of waste generation are related to factors such as urbanization, industrialization, growth in population and increasing consumption due to a rise in the standard of living (Chowdhury et al., 2013).

According to the waste report by the Dhaka North City Corporation (DNCC) (Department), from 2019 to 2020, generated 3433 tons of waste per day (Department) and nearly 6000 tons from the greater Dhaka region (combined North and South Dhaka city corporations). Rising levels of solid waste imply that there is an obligation to conduct the appropriate collection, transportation, and safe disposal of the waste. To further encourage the proper disposal of waste, a thorough understanding of the types and separation of waste is required (Narayana, 2009). It is important to devise new waste treatment methods and ensure appropriate waste disposal services are available with the overwhelming amount of expected waste generation.

Although integrated solid waste management is important now more than ever, immense amounts of Dhaka's waste are still ending up in landfills, with less than 20 percent of waste recycled (Tiseo, 2022). As in other developing nations, waste is also often disposed of at hazardous open dump sites. Contaminants in waste can cause undesirable changes in the environment if disposal methods are not able to keep up with the

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rate of waste generation; that is, an unmanageable amount of waste is being produced without an appropriate system in place to handle and dispose of it (Hossain et al., 2018).

Dhaka North City Corporation has an area of 196.23 sq. km which makes up 54 different wards and 10 zones. The number of inhabitants in DNCC was recorded to be 6.1 million with an average population density of 31,488 per sq. km. Ultimately, this number induced 1,002,561 tons of waste to be generated in the financial year 2019–20 (Department). Several options like composting, recycling, and incineration have been considered to tackle the issue of waste disposal in Bangladesh. However, landfill is the option that has been selected and utilized due to its inexpensive and uncomplicated execution (Hossain et al., 2018).

Due to the lack of reserved funds, dense population, and insufficient organization, the DNCC government is unable to extend formal waste collection and disposal amenities to the entirety of the population (Abedin and Jahiruddin, 2015). As a result, informal waste collectors (or "Tokai" (Rifat et al., 2018);) play an important role in aiding waste collection and recycling in Dhaka. Informal waste collection or recycling is the act of collecting, separating (depending on the type of market to be sent at), sorting, and selling of solid wastes (SW) by an individual or a group to attain income to sustain their livelihood (Ahn et al., 2020). Though informal waste collectors are subjected to physical, chemical, biological, and psychological hazards during their waste collection and recycling activities, there are not many policies or legal frameworks in place to safeguard their lives or improve their working conditions (Ahn et al., 2020). The level of adherence to regulation varies between formal and informal waste collectors (Andrianisa and Brou, 2016), making their working conditions potentially hazardous.

It is reported that a large share of the population in Dhaka sustains their livelihoods as waste collectors in the informal sector (Wilson et al., 2012). In a study conducted in 2020, it was estimated that there are 21, 600 individual informal waste collectors in Dhaka. The investigation also indicated that these waste collectors' quality of life was below average in terms of income, housing, education, and social and cultural inclusion (Uddin et al., 2020). Though such a substantial number of informal waste collectors help to promote waste recycling and disposal services, they experience social stigma and their efforts are not recognized by the government (Matter et al., 2013; Dias, 2016). An arrangement where the formal waste collection sector, the government, residents, and the informal waste collection sector can work together to manage the waste in Dhaka would be optimal for the benefit of the state (Wilson et al., 2012) When assessing MSWM, it is vital to recognize its significant environmental and social costs on local populations. Landfills contribute to pollution, unsanitary conditions, and health hazards, disproportionately affecting poorer communities, particularly informal waste collectors. Standardizing waste management can unintentionally reduce income opportunities for these workers, though formalization could improve their conditions, compensation, and social security. The involvement of minors in waste collection is a key concern, as it hinders education and perpetuates poverty. To better understand the social impacts of different structures of waste management systems a social life cycle assessment (S-LCA) is conducted in this study. An S-LCA assesses the social and sociological elements of products, including their existing and potential positive and negative consequences throughout their life cycle (UNEP et al., 2020). Recent applications of S-LCA have been observed in studies related to waste (Yıldız-Geyhan et al., 2017; Azimi et al., 2020a), building and construction (Balasbaneh et al., 2018), textile industry (Muñoz-Torres et al., 2022), dairy farming (Chen and Holden, 2017) etc. S-LCA uses generic and site-specific data, can be quantitative, semi-quantitative, or qualitative, and serves as a supplement to environmental and life cycle assessments. The waste management systems considered here include combinations of formal and informal waste collectors combined with two waste management options that themselves include two configurations: centralized sanitary/unsanitary landfill operations and decentralized waste to composting facility using a solar panel-based machine or windrow composting method.

The paper is organized as follows: Section 1 provides an introduction and motivation for the S-LCA study being conducted in Dhaka, Section 2 provides the methodology used to conduct the study based on similar work done in the literature, Section 3 provides the study's results and discusses them, and Section 4 concludes the paper.

2. Methodology

This research uses the four phases/steps outlined in the revised UNEP/SETAC S-LCA Guidelines (UNEP, 2021) (Foolmaun and Ramjeeawon, 2013), corresponding to the ISO 14040 E-LCA standards (Benoît Norris et al., 2020), which include Objective and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation. These four steps form the framework for conducting Social Life Cycle Assessment (S-LCA),

The main goal of this research is to employ the most recent outcome assessment techniques while conducting and evaluating S-LCA analyses on the worker stakeholder group following UNEP's SLCA guidelines including fair wages, working hours, collective bargaining, health and safety, job security, non-discrimination, child and forced labor prevention, and access to training. These criteria ensure ethical labor practices and social sustainability across supply chains. The impact assessment process in this study involved a two-step approach to evaluate the social performance of formal and informal waste collectors. Initially, the collected data based on a questionnaire survey were quantified using a positive indicator scoring system. The positive indicator scoring system is a method used to quantify social sustainability performance by assigning numerical values to desirable or favorable conditions. This means that higher percentage scores reflect better social conditions. In the context of Social Life Cycle Assessment (S-LCA), this system helps evaluate social impacts by measuring positive attributes rather than just identifying risks or negative outcomes. To begin with, answers are converted from each selected indicator into percentages. Secondly, inventory scores are assigned based on the percentage using score scales. The scale was considered to grade the data that were collected from the questionnaire. Then questionnaire is scored using a positive indicator scale as shown in Fig. 1. This indicator goes from 0 to 100 % but has been segregated into sections to be able to spot the differences much more easily as it was focused on a smaller research capital. For the positive indicator, it was graded from highest to lowest meaning that the higher the percentage the better it is in the grading sense. A similar scoring system is applied to each indicator in subcategories with more than one indicator. In this case, a subcategory's total marks were determined by the average marks it received for each of the indicators it had. Lastly, a single score is then calculated by adding up the scores of all subcategories. This system facilitated the transformation of qualitative survey data into standardized, comparable metrics.

Following this, the impact assessment method employed a reference scale based on the latest UNEP guidelines ranging from +2 (best

Positive Indicator Score		Translated Scores
0-10%	0.9	-2
11-20%	0.8	-2
21-30%	0.7	-1
31-40%	0.6	-1
41-50%	0.5	0
51-60%	0.4	0
61-70%	0.3	+1
71-80%	0.2	+1
81-90%	0.1	+2
91-100%	0	+2

Fig. 1. Reference scale for quantification (positive indicator score) and impact assessment (equivalent translated scores).

performance) to −2 (worst performance). This scale provided a structured framework to contextualize and interpret the social impacts based on predefined benchmarks, ensuring a nuanced understanding of the severity and significance of the results. This approach enabled the study to assess social impacts systematically while capturing variations in performance across different indicators and stakeholder categories. Table 1 presents the translation of reference scale to the compliance levels for social performance indicators in waste management of SLCA.

The Positive indicator scale was utilized to identify and measure the number of instances in which waste collectors not only followed the law but also participated in activities that improved societal welfare. Formal waste collectors, for instance, may abide by labor rules about fair compensation; yet, those that offer extra perks, like health insurance or educational opportunities, are exhibiting noteworthy social progress. The degree of data gathered to depict the severity of the social impact is reflected in the scale. Better social performance is shown by higher percentages of "positive" indicators, which are results that are desired, such as fair salaries or safe working conditions.

2.1. Objective and scope

Uttara Model Town or simply Uttara (Zone No.01-Ward No.1, DNCC) was chosen as a study area, as shown in Fig. 2 (Department). The aim of this study is to assess and compare the social impacts of current and proposed waste management systems in Uttara city, landfill as well as a proposed decentralized waste-to-compost facility. Workers are a central stakeholder group in S-LCA in many LCA studies to date, as identified by Tokede, Kuhnen and Hahn (Kühnen and Hahn, 2017). A similar focus has been taken in this research study, with some further consideration of other stakeholder categories. S-LCA studies have focused the most attention on the stakeholder category of workers (Kühnen and Hahn, 2017). Although the core focus of this research is workers, other stakeholder groups are relevant and offer further insight into the wider socioeconomic implications of the waste disposal and treatment approach. In other S-LCA research on waste management, Chen and Holden (2017) found that involving the "local community" and "society" as stakeholders improves the scope of overall social performance of the system under observation, and is included here as well, however, due to limitation on in-depth data collection only literature review was conducted in this criterion.

The focus on workers, particularly informal waste collectors is important as they have been shown to influence the overall MSWM program's performance. For example, they have been shown to reduce litter, as well as save money for local governments through improved resource recovery leading to a reduction in the quantity of waste that has to be disposed of (Fergutz et al., 2011). Other people who work in the informal sector of the waste management system, including recyclers, are categorized as operating on the outside (Scheinberg et al., 2006).

For this S-LCA, the social impacts of managing Uttara's municipal solid waste over one year were considered as the functional unit to give an objective and quantifiable evaluation of social performance. Looking at Fig. 3, the system boundary covers processes related to stakeholder engagement, data collection, continuous learning, and the interpretation of social impacts within the functional unit of 1 ton, referring to waste management processes.

This study focuses on the S-LCA of formal and informal waste collectors within Dhaka's MSWM system. The primary goal is to assess the social impacts across the life cycle stages of waste collection, transportation, and disposal, specifically in the decentralized waste-to-compost facility or landfill operations. More details on the rationale for system boundary selection are provided in Supplementary Materials Section S1.1.

The diagram represents the three dimensions of sustainability—environmental, social, and economic—within a structured assessment framework. The environmental boundary is defined through data collection, hotspot analysis, and GIS-based monitoring to assess ecological impacts and ensure continuous learning. The social boundary focuses on stakeholder engagement, including workers, local communities, and society, using surveys to evaluate impact subcategories such as fair wages, working conditions, and collective bargaining. The economic boundary is interpreted as a combination of financial feasibility, cost-benefit analysis, and investment in sustainability. Financial feasibility ensures that sustainability initiatives remain economically viable, cost-benefit analysis helps balance expenses with long-term gains (e.g., improved productivity and reduced turnover), and investment in sustainability reflects financial commitments toward eco-friendly technologies, worker well-being, and community development.

2.2.1. Determination of impact categories and subcategories indicators

At every stage of the life cycle, stakeholder categories affect the choice of impact categories and subcategories and must be chosen in line with the study's objective and scope (Benoît Norris et al., 2020). In this

Table 1
Compliance levels for social performance indicators in waste management of SLCA.

Question	Below Compliance	Slightly Below Compliance	In Compliance	Above Compliance	Ideal Performance (best in class)
Evidence of Child Labour?	Strong Evidence of Child Labour	Evidence of Child Labour	Absence of Child Labour	Proactive Measures to Discourage Child Labour	Funding of Children Education of Employees
How balanced is the gender representation in workforce?	Highly imbalanced gender in labour	Unbalanced Gender Presence in sector	Minimal Gender Discrimination	Approaching Gender Parity	Gender Parity
Are standardized working hours being adhered to, or are employees working beyond legal limits(48 h)?	Unscheduled overtime work	Uncertain working hours approaching 48 h	Mandated 48-h work	Flexible 48 h work	Employee defined work week
Are wages paid to workers at or above legally mandated minimum wage?	Well below (<20 %) minimum wage	Below minimum wage	Receiving minimum wage	Slightly above minimum wage	Well above (20 %) minimum wage
Are health issues in workplace being addressed?	Substantive evidence of working with health issues	Some evidence of working with health issues	Working with no health issues	Paid time off for health issues	Access to long-term health leave
Are necessary PPE provided to maintain safety standards?	No PPE available	Some PPE available/ provided	All PPE available	All PPE provided	Training and PPE provided
Which social benefits are provided beyond government requirement?	No social benefits provided	Limited social benefits provided	Social benefits provided by government employment	Above average benefits compensation	Well above average compensation
Are accessible or enhanced social security options provided?	No social security (saving schemes, loans and govt fund)	Minimal social security (saving schemes, loans and govt fund)	Accessible social security (saving schemes, loans and govt fund)	Readily available social security (saving schemes, loans and govt fund)	Granted security (saving schemes, loans and govt fund)

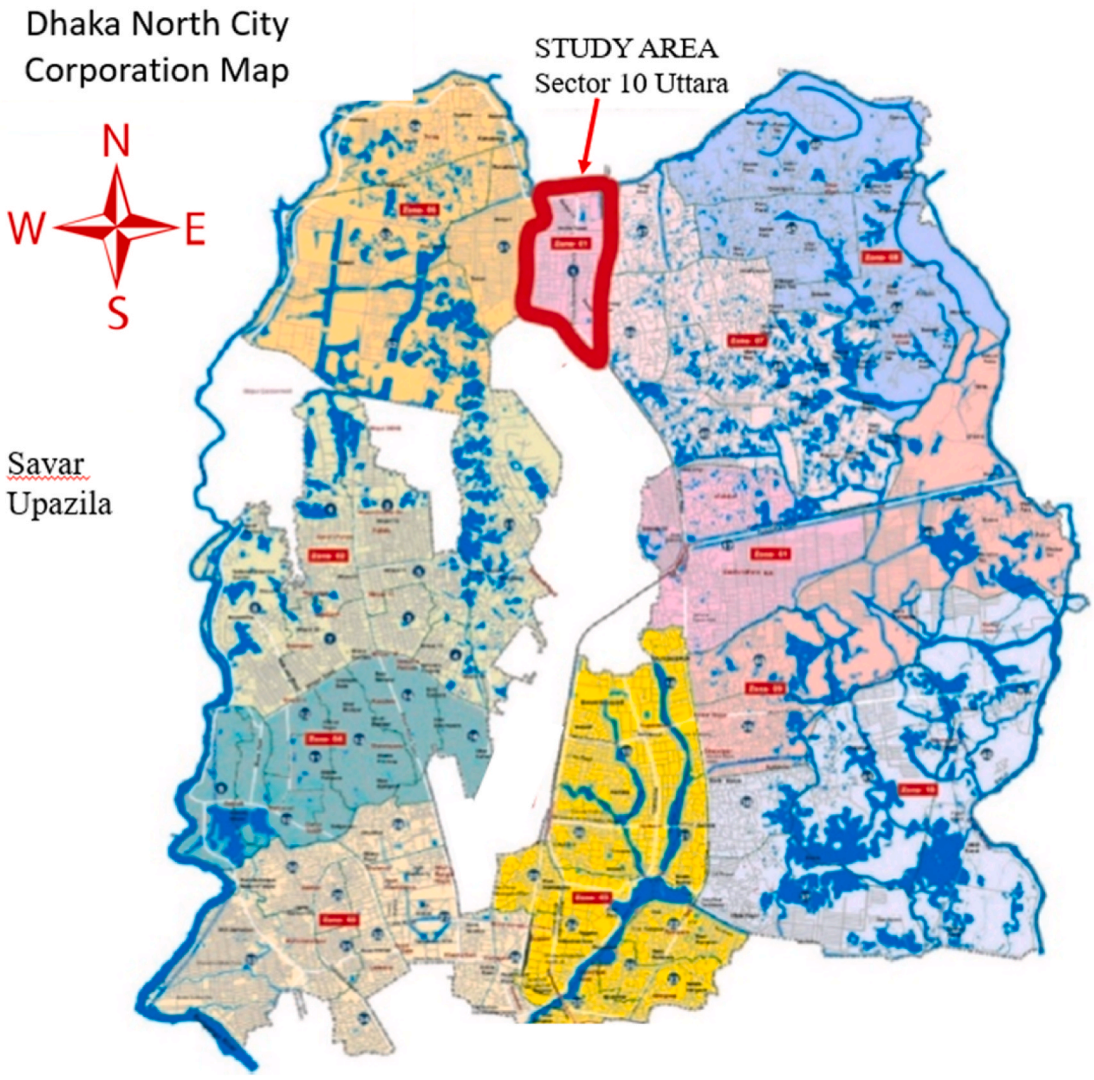

Fig. 2. Map of DNCC: Uttara model town - ward No.1.

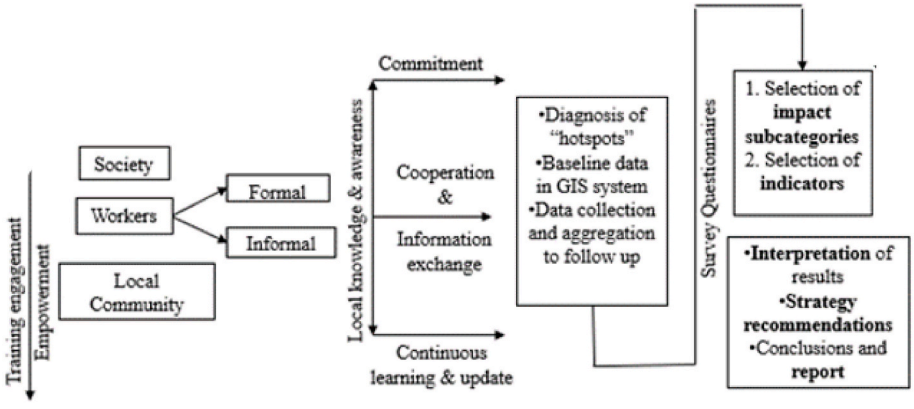

Fig. 3. System boundary of S-LCA adapted from literature (Azimi et al., 2020b).

study, "worker", "local community" and "society" were considered as key stakeholder categories. Four impact categories and eight sub-categories were relevant for the assessment under the "worker" category, concerning the established system boundaries. A further 17 indicators were also chosen to measure the status of the various sub-categories for workers.

Furthermore, Local employment, safe and healthy living conditions, contribution to economic development, and technology development were focused on under the local community and society category.

2.2.2. Selection rationale

These stakeholders and their corresponding subcategories were

chosen based on their direct link to the societal implications of waste management as well as their importance within the Dhaka context. Workers, the local community, and society as stakeholders are analyzed in this research to address the most pressing social concerns underlying waste collection and management. Table 2 and Fig. 4 represent the questions about stakeholders and sub-category relations during the survey. A description of these categories and subcategories is presented with further elaboration in Supplementary Materials Section S1.2.

2.2. Selection of indicators for subcategories

Social indicators were generated utilizing stakeholder feedback, which ensures in-depth perception for evaluating social performance. This organized process provides a transparent and trustworthy framework for assessing the socioeconomic implications of managing waste in Dhaka while minimizing subjectivity in indicator selection. The workers' stakeholder category received the primary focus, with further consideration of indicators within the local community Further details are provided in Supplementary Materials Section S1.3.

2.3. Inventory Analysis

In the second step, site-specific data is collected on the workers' stakeholder group. Surveys and questionnaires are used in this study to evaluate workers' conditions; however, these were not used to fully analyze "society" and "local community" as stakeholders. The assessment of the local community and stakeholders in this S-LCA study relies exclusively on secondary data. This data includes demographic information and social impact indicators, such as health, employment, and community engagement, sourced from existing reports, academic studies, and government statistics. This approach provides a comprehensive understanding of the social dynamics and impacts related to waste management in the community. Recycling, transportation, and composting facilities processes are not covered in this study (see Fig. 3).

Based on a literature review (Ciroth and Franze, 2011) recommendation, a quantitative and semi-quantitative questionnaire for DNCC was developed for formal and informal waste pickers in Uttara, and it was conducted during the period of July 2022 to August 2022. The questionnaire was divided into four sections: background details, work conditions, and benefits, health, and society to assess the social impacts in accordance with the UNEP methodological guidelines for the indicators of worker subcategory. According to the authors' (Prasara-A and Gheewala, 2018) recommendations, the questionnaire should be as simple as possible to capture as much information as possible, such as simple yes/no questions, which have proven to be more comfortable when conducting interviews with various stakeholders. In addition, multiple-choice tick boxes were used for most questions, but where appropriate, additional text boxes were used to allow respondents to provide further explanations or clarifications (Smith and Barling, 2014). The intended respondents received the questionnaires through a combination of community participation and direct approach. Further details are provided in Supplementary Materials S1.4.

Table 2
Stakeholder and subcategory relation within questionnaire questions.

Stakeholder category	Subcategory	Indicators
Worker[a]	Freedom of Association	Union engagement (Labor/cooperative society/others) Are you or any of the member in your group is associated with co-operative society?
	Child Labor	Age
	Fair salary	Salary/wage amount
	Working hours	Typical daily working hours
	Forced labor	Typical daily working hours and age
	equal opportunities/ discrimination	Gender, ethnicity, religion, marital status
	Health and safety	Training given, available PPE, awareness of toxic and hazardous material, routine medical checkup
	Social benefits/social security	Funds receive from government, fees taken from salary, savings scheme, ownership plan
	Employment relationship	Any other employment, medical insurance, holidays
Local Community	Local employment	% of local employment increases
	Safe & Healthy Living Conditions	Number of Workers Provided with PPE Number of Homeowners in the Community
Society	Contribution to Economic Development	Amount of financial investment made in waste management infrastructure (e.g., recycling plants, landfill upgrades) annually.
	Technology Development	Percentage of local GDP or business revenue spent on research and development (R&D).

[a] list of questions from the survey is included in Supplementary Materials Section S2.

2.4. Impact assessment method

As part of S-LCA, the social impact assessment (IA) method examines, calculates, and assesses the amount and relevance of a product system's possible social impacts for the entire product life cycle (Benoît Norris et al., 2020). According to Benoît and Mazijn in (Andrews, 2009), there are two types of impact assessment approaches: Performance Reference Points (PRP), also known as Type I or Reference Scale Assessments in the updated UNEP guidelines, and Impact Pathways Approach (Type II). In this research Type I was used as the focus is on social performance/risk, requiring the development of a reference scale for assessing social impact performance.

Reference Scale Assessments depend on data, information, or judgment, and provide results that focus primarily on the activities of companies in the product system and commonly consider their immediate evaluation (e.g. at inventory indicator), i.e., no further propagation of effects. As such, Reference Scale approaches do not commonly establish a link between the activity and longer-term impacts. Type 1 categories are more commonly applied in MSWM research; in 33 Studies analyzed by Costa et al. (2022), 25 case studies used Type I, 6 used Type II, and 2 used a combination of both types.

In our S-LCA, we chose Type 1 (Reference Scale Approach) over Type 2 (Impact Pathway Approach) due to several considerations that fit the objectives and limitations of our investigation. Type 1 offers a simple and direct way to measure social performance by determining whether or not particular social indicators are present using pre-established reference scales. Because of its simplicity, public officials and stakeholders alike can more easily comprehend and interact with the evaluation process.

Since the Reference Scale Approach is well-established and standardized, it improves the comparison of findings with those of other research efforts, lending greater validity and credibility to the conclusions. Furthermore, this study involves data collection through surveys and interviews with informal and formal waste collectors, so the Reference Scale Approach enables effective utilization of this primary data by assessing indicators based on their presence or absence as opposed to needing quantitative data that may be difficult to obtain.

Several methods to compute S-LCA exist, each tailored to specific research goals. Ciroth and Franze (2011) used a point system (1 being best, 5 worst) to quantify social impacts, allowing easy comparison of performance across waste collectors. This system helps assess the social performance of both formal and informal collectors objectively. Manik et al. (Foolmaun and Ramjeeawon, 2013) used a 1–7 ranking scale, weighted and categorized by impact, capturing the perspectives of waste collectors, making it relevant to this study. Martínez-Blanco et al.

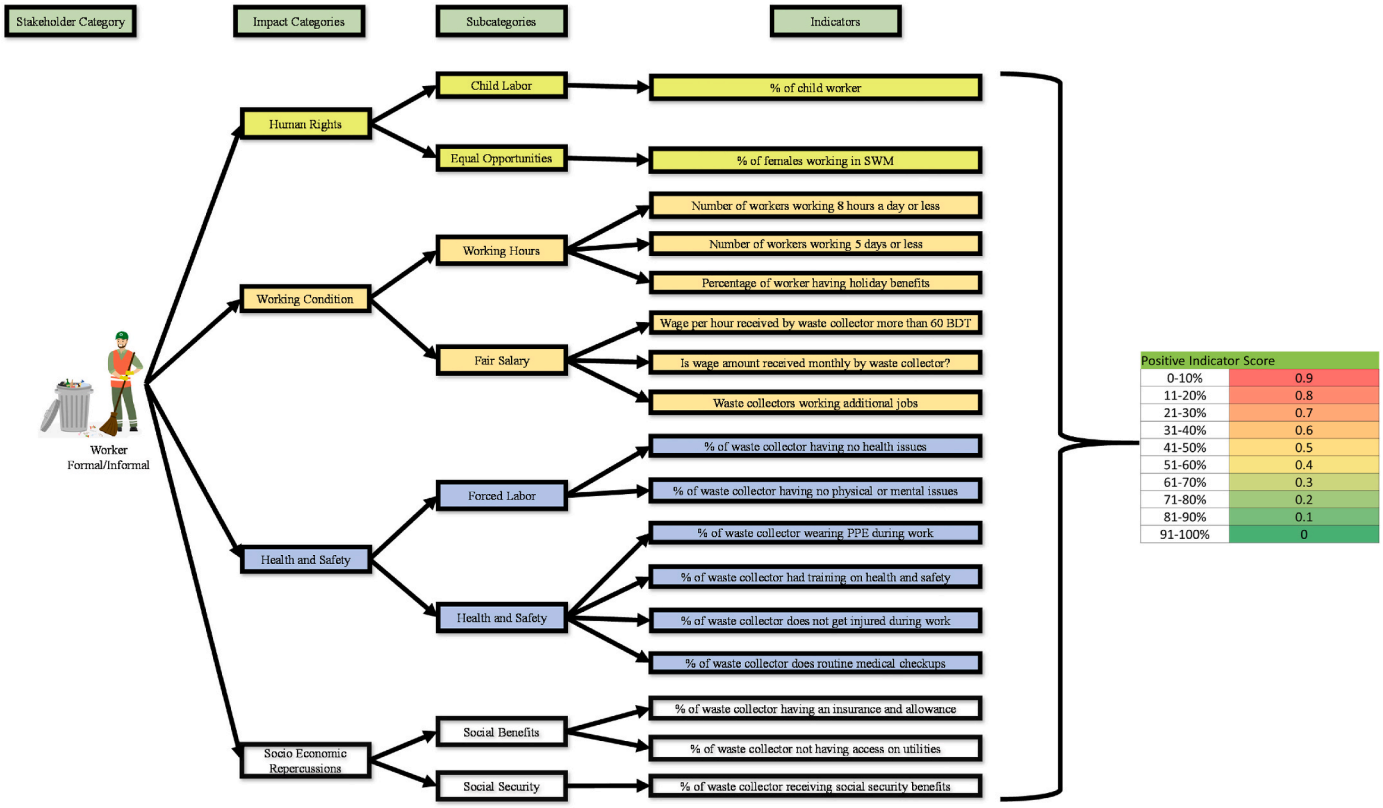

Fig. 4. Methodology adopted in the quantification for the workers' stakeholder category of S-LCA study.

(Manik et al., 2013) created a rating system from '1′ to 'n' to rank impacts by importance, helping highlight severe social issues. By combining these methods, this study offers a comprehensive analysis of the social impacts of waste disposal in Dhaka. During the initial phases, the study was concentrated on choosing important metrics that represent important societal concerns including child labor, health and safety, and fair wages. To guarantee that the indicators remained both inclusive and accurate, this selection was made after a careful examination of relevant research and discussions with stakeholders. We collected both quantitative and qualitative information about the identified indicators during the data collection phase. Qualitative data from the survey was translated into quantifiable data (Table 3). Metrics such as the percentage of child labor and the percentage of employees with health problems were measured as part of this. The severity and importance of the social repercussions under consideration are determined by the data gathered during this phase. To evaluate the social impact of each indicator, data collection from the inventory stage were analyzed during the Impact Assessment Phase. This analysis identified important hazards and problems by interpreting the frequency data into larger implications for society. For example, a large proportion of child labor or inadequate safety and health precautions may indicate serious social dangers. This stage is essential for connecting the existence of indicators to possible negative consequences and identifying areas that require intervention.

Inventory indicators, such as wages, working hours, and health conditions, were transformed into social impacts by linking them to predefined impact categories (e.g., fair salary, health and safety) using benchmarks established in the UNEP et al., 2020 guidelines. These benchmarks serve as performance reference points rather than direct comparisons between systems.

To make the results comparable, the raw data were normalized in Table 4 to a scale from −2 to +2, with −2 representing the worst performance and +2 the best.

Along with following the most recent S-LCA methodological guidelines, this research work presents a structured impact assessment approach designed specifically for waste collectors, both formal and informal. While similar techniques have been employed in the existing literature, the unique component of this study is the use of local participant-driven data, which enables a more region-specific and contextually relevant study, providing more insight into the social implications of both formal and informal waste collectors in Dhaka specifically.

2.4.1. *The assessment of the community and society stakeholders*

Assessment of the local community and society stakeholders' group is done in a separate segment. This is because questionnaire surveys have limits in both the local community and larger society (i.e., difficulty in achieving representative data on perceptions of impacts). The existing sources of literature were utilized to evaluate the effects of both formal and informal waste collectors and summarize the findings on the local community and society.

3. Result and discussion

The questionnaire survey reflects the quantifiable results of this study (Table 3).

3.1. *Human rights*

Human rights impact category consists of 2 subcategories – child labor and equal opportunities/discrimination. The indicator for the child labor subcategory is percent of child workers and the indicator for the equal opportunities/discrimination subcategory is percent of female workers working in solid waste management. From the samples surveyed in Uttara, it is inferred that while there are no child workers in the formal sector, a small percent of workers in the informal sector are below the legal age for labor. Informal and formal workers highlighted a score of 10 % and 0 % for percent of child workers which is under the positive scale indicator. Assessing the score according to Table 3, it is

Table 3
Quantification of *Social Impact on Formal and Informal Waste Collectors in Dhaka.*

Impact Categories	Subcategories	Indicators	Formal Worker	Informal Worker
			Score	Score
1.Human rights	1.1 Child Labor	1.1 % of workers under the age of 14 (Q1)	0	0.1
	1.2 Equal Opportunities/ Discrimination	1.2 % of females working in in SWM (Q2)	0.4	0.5
Total Score			0.4	0.6
Average Score			0.2	0.3
2. Working condition	2.1 Working Hours	2.1.a Number of workers working 8 h a day or less (Q13)	0.1	0
		2.1.b Number of workers working 5 days or less (Q9)	0.9	0.9
		2.1.c % of Worker having holiday benefits (Q18.1.a)	0.9	0.8
	Total Score - working hours		1.9	1.7
	Average Score - working hours		0.6	0.6
	2.2 Fair Salary	2.2.a Wage/hr received by waste collector more than 60BDT (Q15)	0.5	0.1
		2.2.b is Wage amount received monthly by waste collector (Q14)	0	0
		2.2.c Waste collectors working additional jobs (Q16)	0.9	0.9
	Total Score - Fair Salary		1.4	1
	Average Score - Fair Salary		0.5	0.3
Total Score			3.3	2.7
Average Score			0.6	0.5
3. Health and Safety	3.1 Forced Labor	3.1.a % of waste collector having no health issues (Q23)	0.2	0.3
		3.1.b % of waste collector having no physical and mental problems		
		no vision problems (Q7a)	0.2	0.2
		no Hearing problems (Q7b)	0.1	0.2
		no Walking problems (Q7c)	0.1	0.3
		no Concentrating problems (Q7d)	0	0.1
		no Self-care problems (Q7e)	0	0
		no Communicating/Understanding problems (Q7f)	0	0.1
		Total Score Worker no health issues	0.4	0.9
		Average Score Worker no health issues	0.1	0.2
	Total Score - Forced Labor		0.6	1.2
	Average Score - Forced Labor		0.3	0.6
	3.2 Health and Safety	3.2.a % of waste collector wearing PPE during work (Q19.a)	0.7	0.9
		3.2.b % of waste collector had Training on health and Safety (Q20)	0.9	0.9
		3.2.c % of waste collector does not get injured during your work (Q24)	0.3	0.4
		3.2.d % of waste collector does routine medical check-ups (Q26)	0.9	0.9
	Total Score - Health and Safety		2.8	3.1
	Average Score - Health and Safety		0.7	0.8
Total Score			3.4	4.3
Average Score			1.7	2.1
4.Socio-economic repercussions	4.1 Social Benefits	4.1.a % of waste collector having insurance and allowance		
		Medical Insurance (Q18.2.a)	0.9	0.9
		Medical Allowance (Q18.2.b)	0.9	0.9
		Transportation Allowance (Q18.3.a)	0.9	0.9
		Formal Education Allowance (Q18.3.b)	0.9	0.9
		Training Allowance (Q18.3.c)	0.9	0.9
		Total Score Worker insurance and allowance	4.5	4.5
		Average Score Worker insurance and allowance	0.9	0.9
		4.1.b % of waste collector having access on utilities		
		Water availability (Q33.a)	0	0
		Electricity availability? (Q33.b)	0	0
		Gas availability? (Q33.c)	0.3	0.1
		Total Score Worker access on utilities	0.3	0.1
		Average Score Worker access on utilities	0.1	0.0
	Total Score - Social Benefits		1.0	0.9
	Average Score - Social Benefits		0.5	0.5
	4.2 Social Security	% of waste collectors receiving social security benefits		
		Fund received from the Government (Q27.a)	0.9	0.9
		Association with any co-operative society (Q27.b)	0.9	0.9
		Savings scheme (Q27.c)	0.9	0.9
		Loan/credit from the borrower (Q27.d)	0.9	0.9
		Fees given to authorities/externals (Q27.e)	0.9	0.9
		Other fees taken out from salary (Q27.f)	0.9	0.9
		Total Score Worker social security	5.4	5.4
		Average Score Worker social benefits	0.9	0.9
Total Score			6.4	6.3
Average Score			0.7	0.7

regarded as an excellent result because a score of 0 which implies that there are no child laborers actively employed in the solid waste management sector in Uttara, Dhaka. According to Table 3, the percentage of female working in solid waste management, suggests 51–60 % for informal and 41–50 % formal workers respectively. The results indicate that the percent of female workers in the solid waste management sector for both worker categories is satisfactory.

3.2. Working condition

The working condition impact category also consists of 2 subcategories – working hours and fair salary. The first indicator under the working hours subcategory is a number of workers working 8 h a day or less. All indicators under the working condition impact category are scored on a positive indicator scale. For working hours we interpret these scores as 81–90 % for the formal workers and 91–100 % for the informal workers. Both results are excellent and essentially mean that most workers in the SWM sector in Uttara work an appropriate number of hours. The second indicator under working hours is the number of workers working 5 days or less. Both formal workers and informal workers revealed that only 0–10 % of workers work 5 days or less. This is a very poor score and may indicate that both classifications of workers are possibly overworked or exploited. The last indicator for the working hours subcategory is the percentage of workers having holiday benefits. As evident from the previous indicator, these scores are inadequate. Both scores translate to 0–10 % and 11–20 % respectively. This means that collectively less than 20 % of workers from both formal and informal sectors have holiday benefits. The next subcategory is fair salary. The wage per hour received by the waste collector is more than 60 BDT is the first indicator of this subcategory. For this indicator, referring back to Table 3, we see that the score for formal workers indicates that 41–50 % of workers have a wage per hour more than 60 BDT and the score for informal workers indicates that 81–90 % of workers have their wage per hour more than 60 BDT. While the informal workers display a good score, the formal workers display a lower, but moderate score. The second indicator of fair salary subcategory is whether wage is received monthly by the waste collector. Both workers unanimously exhibited their score as 91–100 %. This suggests that both informal and formal workers in Uttara get their wages monthly without postponements. The final indicator for fair salary subcategory was if workers were working additional jobs. Both workers consistently provided evidence that 0–10 % of workers work additional jobs besides solid waste management.

3.3. Health and safety

The mix of dangerous wastes from industries, healthcare (clinics and hospitals), and municipal wastes poses several public health risks because the wastes are not properly collected and disposed of (Hai and Ali, 2005). Workers who manage waste help society and the environment while risking their overall health and wellness. They are likely to be exposed to dangerous chemicals on a regular basis, such as home detergents and chemical wastes, especially the informal waste collectors who collect and sort waste. A large portion of the informal waste collectors that gather and sort waste does so without the simplest personal protective equipment (PPE) such as masks, gloves, and safety shoes which expose them to the risk of infections and the possibility of acquiring illnesses. According to the findings in Table 3, formal workers had a percentage of 25 % wearing PPE and informal workers had a percentage of 4 % wearing PPE. Thus, informal waste pickers are less likely to wear the PPE required to do their jobs safely than formal waste pickers as there may be numerous limitations to formal PPE usage that must be investigated, including availability, cost, and easy usage. Solid waste management problems affect residents at many levels. Including eyesores, bad odor, environmental pollution, and enticing rats and insects (Matter et al., 2013). Aside from generating aesthetic problems and nuisances due to nauseating strong smells, open-air disposals of solid wastes encourage the spread of diseases via disease vectors such as flies, insects, and rodents (Hai and Ali, 2005). Looking at the forced labor subcategory, we see that the scores are relatively lower for both formal and informal workers.

Based on these research findings, both formal and informal were unfamiliar with the simplest preventative steps for staying healthy and cleanliness as well as getting 0 % had training on health and safety. Moreover, both formal and informal showed an inadequate medical check-up percentage on the positive indicator scale. By comparing the overall social impact between formal and informal waste collectors' health and safety as shown in Table 3 the informal sector has more negative social impact than the formal sector. The result of this study shows that informal waste collectors pose greater health concerns. As a result, understanding the health hazards to this sector and alerting policymakers is a critical step toward recognizing this portion of the informal sector as well as the formal sector and their support to healthier and more sanitary societies. Receiving more knowledge and performing future studies may enhance workplace risk perception, which in turn may promote protective measures such as increasing the PPE use, providing training on health and safety and do regular medical checkup at low cost.

Table 4
Final Scores after impact assessment.

Indicators	Informal	Formal
Human Rights	*1*	*1*
Working Hours	*−1*	*−1*
Fair Salary	*0*	*1*
Forced Labour	*2*	*2*
Health and Safety	*−1*	*−2*
Social Benefits	*−2*	*−2*
Social Security	*−2*	*−2*

3.4. Socio-economic repercussions

A study conducted by the two authors Marello and Helwege (2018) investigate the possibilities and difficulties in SWM and their social impact. They reported firstly that due to the status of informal waste collectors, they may not be able to access social benefits such as medical insurance, retirement savings, and unemployment insurance. Moreover, waste workers are unable to protect and secure themselves due to physical limitations, poor education, mental health conditions, and monetary imperatives. In addition, waste collectors are considered informal labor by municipal workers since they escape laws, not paying taxes, and other fees and this prevents them from obtaining social services. In this paper, results indicate the study's social benefits analysis outcomes clearly show that both sectors perform the worst social scores in terms of the indicator of waste workers having insurance and allowance as it shows lower percentages on the positive scale. On the other hand, the indicator of waste workers having access to utilities, informal worker achieves lower score than formal worker. However, both sectors have a low score on the positive scale. The overall social benefits subcategories on both formal and informal waste collectors are in the middle of the positive scale indicating improvement is needed in the overall social safety net.

According to the report published by the International Labor Organization ILO (2021) (Ippei Tsuruga et al., 2021), over 60 % of the global workforce is in informal jobs, vast majority of these workers are uninsured or have inadequate social security coverage. Indeed, numerous employees in the informal sector are among the 55 % of the worldwide population without any type of social security, whereas several others are just partially covered. Survey results show that the subcategory "social security" for both formal and informal workers scored poorly on the positive scale which means that both workers extremely lack social security and no difference showed between the two sectors. In conclusion, the average score of "socio-economic repercussions" impact categories for both sectors scored low on the positive scale which indicates a negative social impact. All waste collectors, including contract workers and self-employed workers, should be eligible for social security benefits (Lakshmi et al.).

Many recommendations must be made by the policy makers. Firstly, it is imperative that formal and informal waste sectors be integrated with wider social policies to genuinely satisfy the requirements of waste

collectors. Secondly, increasing awareness of social security and benefits as well as improving waste collectors' associations. Finally, companies and government cand help waste collectors to overcome their personal disappointments by offering better social security stability and a proper social benefit.

3.5. Analysis of formal and informal waste collectors' contribution toward local community and society

As shown in Table 5, two other stakeholders have been considered for this study: 'the local community' and 'society'. This analysis is considered to be preliminary as it is literature-based only and further research can be done in-depth in the future. For the local community stakeholder group, several categories are depicted by Benoit-Norris et al. (Benoît-Norris et al., 2011) For the reasons presented in the methods section and supplementary materials section 1, the study looks into the following subcategories: safe and healthy living conditions and local employment. Exploring the subcategory of safe and healthy living conditions, it is evident that waste build-up not only poses an aesthetic problem but also a significant health hazard to communities. A study conducted in Afghanistan (Azimi et al., 2020b) highlighted the absence of awareness campaigns or effective health and safety strategies in waste management, leading to the spread of diseases like cholera and dengue fever. Similarly, in Dhaka, informal waste collectors play a crucial role in filling the gap left by the lack of formal waste collection services. Though informal collection is not without challenges, it helps reduce the accumulation of waste, which in turn improves sanitation and mitigates health risks in the medium term. Research has shown that improper waste management contributes to water contamination, exacerbating the spread of waterborne diseases like cholera, particularly in areas where access to formal services is limited (Alam and Ahmade, 2013). By improving waste removal, informal waste collectors indirectly contribute to better public health outcomes and safer living conditions, demonstrating the significant role of informal systems in sanitation in Dhaka.

Another subcategory in the local community stakeholder worth studying is local employment. If a number of informal workers can be given ownership to small waste collection or sorting stations, will the standard of living be improved for the said informal workers? A predictive outcome would be the local employment of workers in the waste management sector leading to a rise in the social status of these workers (Rothenberger et al., 2006). This may also lead to increased entrepreneurial spirit among lower social class members of the community, creation of a social safety net, and more employment opportunities in total (Tong et al., 2021). claims that the living conditions of the informal workers involved in the waste management sector could be uplifted if the government can establish regulations in favor of sustainable and controlled growth of the informal sector of waste management.

Examining the Society stakeholder category, technology development and economic development were the subcategories selected for this stakeholder group. In a study, the selected stakeholders were 'academic researchers', who can be a contributors to technology development, as a participant type under the society stakeholder category (Nubi et al., 2021). This selection was based on a literature review. This reveals that academic researchers can delve into other advanced forms of waste management technology like Waste-to-Energy, automated composting, incineration, etc. can improve society as a whole. For example, work conducted by the authors [Ashraf et al., 2025, 'Environmental life cycle assessments of decentralized municipal solid waste management: A novel waste-to-compost approach', manuscript under review] has explored novel technologies in this application with results currently being disseminated amongst governmental and academic stakeholders in Dhaka. By incorporating novel treatment methods into a society with a rudimentary waste management system, many sectors can benefit and the potential for leapfrogging conventional approaches may become possible (Binz et al., 2011). This point can be established further by a study based in Africa (Dunmade, 2019) where bioenergy production technology within the waste management system provides advantageous results to the social impacts of the workers and the society itself.

Overall, it is evident that there is a scope for future studies to explore further into these themes to analyze whether a social safety net can be created for the society and the community within by conducting more S-LCA studies with society and community as stakeholders investigated primarily.

3.6. Comparative insights

This research provides important new understandings of the societal effects of Dhaka's formal and informal waste collection methods. Our findings highlight certain distinctions from previous research and theoretical predictions, even as they offer insightful information about the condition of waste management today.

The reported discrepancy in working conditions between formal and

Table 5
The table shows the stakeholders group with the impact categories along with their data revealed from the literature review.

Stakeholder Category	Impact Category	Subcategory	Indicators	Reference
Local Community	Social Impact Social and environmental impact	Local employment Safe and healthy living condition	% of local employment increases due to informal waste collections. Based on DNCC plan from JICA 2015 report waste collection and transport section have a staffing rate of 45 % (out of 139 waste collection post only 59 were filled) which can be filled with informal waste collectors through decentralized waste to compost facility. This shows the evidence of there is a gap difficulty employing staff in this sector, therefore, informal waste collectors can give opportunity to get engaged in this segment. A decentralized facility will employ more people than centralized mechanized version of waste processing. Increase demand for unskilled labor, improve waste recycling to guarantee their quality, increasing cleanliness.	Source: JICA Project Team based on "Provision Survey Report of Solid Waste Management Equipment (2015)"
Society	Economic impact Technological Impact	Contribution to economic development Technology development	Access to knowledge and information, education, and skill development. Using PV solar-based automated machines and training informal and formal waste collectors in decentralized waste to compost can add skill development focusing on renewable energy within the waste management employees. High-quality value-added product in the waste materials with composting technology	

informal waste collectors is one important distinction. Our results indicate that informal workers typically encounter better circumstances regarding fair wages in comparison to formal workers, which stands in contrast with findings from similar research in different contexts where formal workers usually enjoy more favorable conditions (Ferronato et al., 2020). This disparity may result from Dhaka's distinct socioeconomic dynamics, where informal waste collection is important to the city's economy and social structure.

The safety and health outcomes are particularly noteworthy. Although informal workers scored somewhat higher than formal workers, both groups reported working in subpar conditions. This result defies theoretical predictions that better health and safety standards would be provided by formal waste management systems with their regulatory frameworks (Nawaz et al., 2021). It implies that the actual application of safety measures and the enforcement of rules may be less successful than expected, necessitating more research to determine the causes of these findings.

3.7. Limitations

As stated above, three stakeholder categories were examined. The examination was limited based on the environmental, political, and governmental restrictions within Dhaka, North city corporation. Furthermore, the remaining categories (Children, Value Chain Actors, and Consumers) were not assessed. However, there is some evidence of the impact of waste collection methods on children; for example, informal waste collectors observed a higher incidence of child labor, meaning that children were not engaged in education (an impact category under this stakeholder group), they collect waste from households and scavenge in garbage dumps (Chandan, 2019), According to the Bangladesh Labor Foundation (BLF), an estimated 100,000 waste pickers work in Dhaka alone—most of whom are women and children. Another limitation that may be considered in this study is the modest sample size. To further validate and expand these findings, future research could take into account bigger sample numbers or more studies in varied circumstances. Furthermore, an in-depth analysis is required, as indicated by the preliminary evaluation of the "Local community" and "Society" stakeholder groups. Although helpful in establishing the context, these categories need more investigation to completely grasp their social implications. Additionally, Stakeholder participation and multi-criteria analysis were not used in this study, however, the indicators were selected using accepted practices to reduce bias. Future studies might profit from using direct stakeholder involvement or structured decision-making techniques to improve the transparency and dependability of the indicator selection. Moreover, even though our technique was thorough, it may be improved by adding more quantitative measures or supplementary data to better represent changes over time. Another point to consider is that the sections on weighting are still in the initial stages and require a more thorough investigation. Although weighted scores improve the evaluation, the study recognizes that a binary approach still restricts the breadth of analysis. To better capture the complexity of social impacts in waste management, future work should strive to include a wider range of qualitative and quantitative measures and engage a more diverse array of stakeholders, especially marginalized groups. To overcome the constraints of the present investigation, subsequent studies should aim to integrate a comprehensive life cycle viewpoint. This involves assessing the effects of waste management process-related goods and byproducts, which will offer a more thorough grasp of the societal consequences.

4. Conclusion

This research study illustrates the Social Life Cycle Assessment of formal and informal waste collectors in Uttara, Dhaka City using guidelines established by UNEP. In this study, workers were classified as the stakeholder group for the assessment of four impact categories, specifically, working conditions, human rights, health and safety, and socio-economic repercussions. The S-LCA of Dhaka's formal and informal waste collectors provides important new information as well as areas that still need development. The report outlines important areas where the socioeconomic circumstances of Dhaka's waste collectors require improvement. It is imperative to implement targeted measures and legislative changes within Dhaka to tackle the identified concerns to promote environmentally friendly and socially conscious waste management methods, assuring the well-being of all those involved in waste management.

The results show that there have been few instances of both gender-based discrimination and child labor, indicating that neither of these issues is frequent. Nevertheless, there's potential for development in the field of gender equality. Subsequent efforts should be directed towards consolidating these positive outcomes by enacting regulations that enhance safeguards against offenses of human rights and promote equality between genders in the waste management sector.

It was determined that the working hours for both formal and informal employees were acceptable. On the other hand, there is a discrepancy in fair salary norms, suggesting that formal workers have worse working circumstances. This shows that to guarantee equitable compensation, especially for formal workers, stronger policies regarding wages and regulation are required. Raising wages and upgrading working conditions are likely to increase productivity and worker satisfaction, two things that sustainable waste management strategies rely on.

Significant health and safety concerns were expressed by both formal and informal workers, demonstrating the urgent need to implement these standards in waste management operations. To protect workers from occupational dangers, it is imperative to implement safety protocols that are improved, provide appropriate health and safety training, and guarantee that workers have access to protective equipment. The socioeconomic circumstances were insufficient for both formal and informal workers, especially concerning social security. This emphasizes the need for improved social security programs, including retirement pensions, health insurance, and other social protections, for waste collectors. Resolving these problems can greatly enhance waste collectors' quality of life and promote societal stability.

To reach relevant conclusions, the outcomes are incorporated with the objectives and parameters of the research. The research starts by looking at broad impact categories such as health and safety and child labor. For instance, the rate of child labor suggests a serious problem for the waste management sector, while data on PPE use reveals information about safety standard compliance. This synopsis aids in pinpointing important areas that need attention. Additional insights can be gained by analyzing impact subcategories in greater detail. Metrics like frequent medical checkups and work-related injuries are evaluated under the health and safety category to identify particular areas that require improvement. This systematic methodology pinpoints specific areas where focused interventions can improve worker safety and health protocols. The viewpoints of several stakeholders involved, such as waste handlers and administration, are also taken into account. Gaining a practical knowledge of the outcomes involves examining how various indicators impact these groups. For example, analyzing fair wages for similar jobs reveals information about equality and security in the economy. A thorough understanding of the social repercussions is provided, along with practical suggestions, by combining these evaluations. The results highlight the importance of addressing child labor, enhancing health and safety protocols, guaranteeing fair wages, etc. They also provide direction for successful interventions and improved societal sustainability.

For a more thorough analysis, future studies should broaden the scope of S-LCA to include more stakeholder types and subcategories. Greater sample sizes and a range of geographic locations can be included to offer a more thorough knowledge of the social effects of waste management. Furthermore, incorporating cutting-edge procedures and data-

gathering strategies can improve the assessment's flexibility.

CRediT authorship contribution statement

Azad Ibn Ashraf: Writing – review & editing, Writing – original draft. **Eugene Mohareb:** Supervision. **Maria Vahdati:** Supervision. **Amith Khandakar:** Writing – review & editing, Writing – original draft.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2025.100284.

Data availability

Data will be made available on request.

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