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EVALUATION OF GREEN LOGISTICS SYSTEM OF SOLID WASTE AT PORTS BASED ON ANALYTIC HIERARCHY PROCESS

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Abstract

This paper attempts to realize the green logistics of solid waste at ports, enabling the harmless treatment, reduction and recycling of such waste through the entire life cycle. For this purpose, the life cycle assessment and the analytic hierarchy process (AHP) were applied to evaluate the green logistics of solid waste at ports. Firstly, the solid waste logistics system was examined from the perspective of logistics system. Drawing on life cycle evaluation, the author analyzed how the solid waste logistics system affects the society, economy and environment. Meanwhile, an AHP-based evaluation system was established to quantify the overall impacts of solid waste. On this basis, the solid waste logistics system of a port was optimized, and subjected to life cycle assessment. The evaluation results show that the optimized system has much lower social, economic and environmental impacts than the original system. The research findings shed important new light on solid waste logistics at ports.

Key words: Analytic Hierarchy Process (AHP), life cycle, logistics system, solid waste at ports

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1. Introduction

In recent years, many modern urban problems have arisen due to the rapid economic growth and urban sprawl. One of the most serious problems is the huge amount of solid waste, which severely damages the ecology and deteriorates the living environment. Solid waste has already become a bottleneck of the sustainable development of environment and economy in China (Cheng and Hu, 2010; Straka et al., 2018; Zhang et al., 2010).

For solid waste at ports, the disposal must highlight harmless treatment, reduction and recycling, without causing any harm to health and environment (Burinskiene et al., 2018; Dabbagh et al. 2016; Garciagil et al., 2000; Hargreaves et al., 2008; Hossain et al. 2016). Particularly, rational recycling techniques should be adopted to extract reusable substances, cutting down the discharge amount of solid waste (Alkhatib et al., 2010; Martinez-Sanchez, 2017; Schiopu and Gavrilescu, 2010).

At the end of the last century, the disposal cost of solid waste gradually increased with the amount of solid waste (Li and Zhang, 2015; Pérez et al., 2017). To solve the problem, many scholars have set out new principles for solid waste disposal: reducing the discharge amount at the source, classifying the waste during collection and recycling the useful substances (Chen et al., 2017; Parekh et al., 2015; Suthar, 2009, Tang et al., 2017; Zhao et al., 2019a; Zhao et al., 2019b). Some foreign researchers have investigated the evaluation and selection of solid waste disposal plans (Bjelic et al., 2017; Kaviraj and Sharma, 2003; Namasivayam and Sangeetha, 2006; Zabeo et al., 2017). For instance, Kaviraj and Sharma (2003) suggested evaluating solid waste disposal plans against environmental impact, energy utilization and disposal cost. Namasivayam and Sangeetha (2006)

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argued that solid waste should be analyzed, assessed and selected from multiple perspectives.

The research on solid waste disposal started late in China, and has not yielded fruitful results. This calls for in-depth analysis in the light of the actual situation in China. Zhang et al. (2008) advised to evaluate the economic, resource and environmental benefits of the technical plan for solid waste disposal, using fuzzy comprehensive evaluation (FCE). Zhao et al. (2009) proposed to evaluate the overall impacts of solid waste on environment through life cycle assessment, considering the -wastewater, waste gas and energy consumption in the disposal process.

This paper establishes a comprehensive evaluation system for solid waste at ports, after analyzing the logistics system, life cycle assessment and the AHP theory. The evaluation system consists of various indices about the economic, social and environmental impacts. Taking an actual port for instance, the author conducted life cycle assessment of the solid waste logistics system at the port, and optimized the solid waste classification for the system. The optimization was proved to promote the sustainable development of environment, society and economy (Liu et al., 2006).

2. Basic theories

2.1. Logistics system

The goal of logistics is to deliver items to the destination at the right time in the correct order. Therefore, a logistics system should be able to move elements like items, machines and persons by the required distance within the required time. Like any other system, the logistics system is pertinent, purposeful and complete. It also has a complex structure and a large scale.

There are three types of nodes in each logistics system, namely, nodes, transport means and routes. Among them, the nodes refer to distribution centres, garbage transfer stations and ports; the transport means include ships, cars, trains, planes and pipelines; the routes stand for sea lanes, highways, railways and air routes. The structure of a typical solid waste logistics system is shown in Fig.1.

In terms of life cycle assessment, the solid waste has the following differences from general products:

(1) The life cycle of general products includes raw material exploitation, production, distribution, utilization and recycling, while that of solid waste begins when a product loses its value and becomes waste and ends when the waste is discharged out of the logistics system.

(2) For general products, the life cycle assessment evaluates the environmental impacts of the products. For solid waste, the life cycle assessment evaluates the environmental impacts of the solid waste logistics system.

Once discarded by the original user, the solid waste enters our solid waste logistics system. The inputs and outputs of the system are illustrated in Fig.3 below.

2.2. Life cycle assessment

The life cycle of a product starts from the exploitation of raw materials. The materials are processed, fabricated and packaged into the product. Then, the product is transported, stored and sold to the consumer. After that, the product is utilized, repaired and recycled, ending up as waste.

The entire process from processing to recycling is the target of life cycle assessment. The assessment mainly measures the efficiency of material utilization in processing and fabrication, and discloses the environmental impact of the recycling waste. The goal is to strike a balance between the functionality and greenness of the product. As shown in Fig. 2, the framework of the life cycle assessment contains four modules.

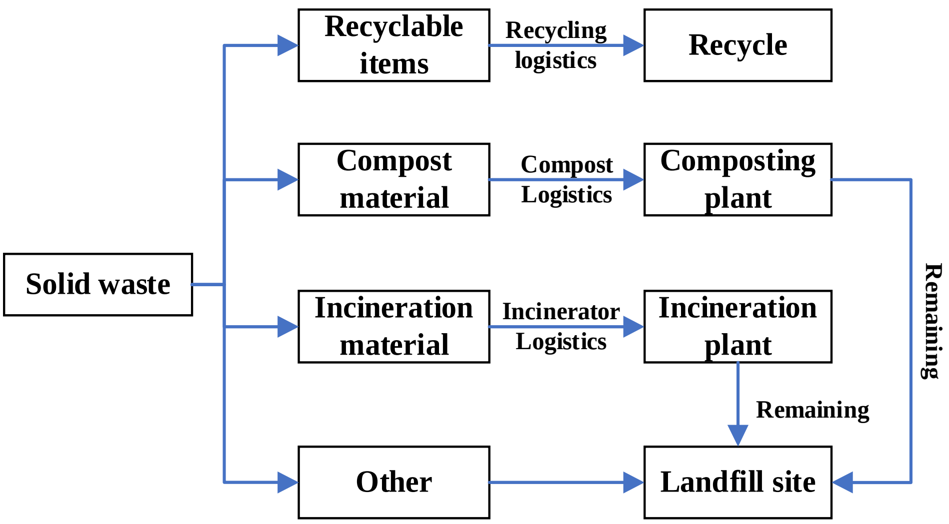

Fig. 1. Logistics management system of solid waste

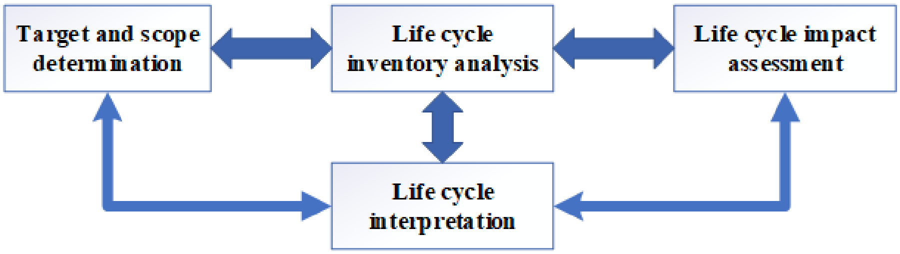

Fig. 2. Framework of life cycle assessment

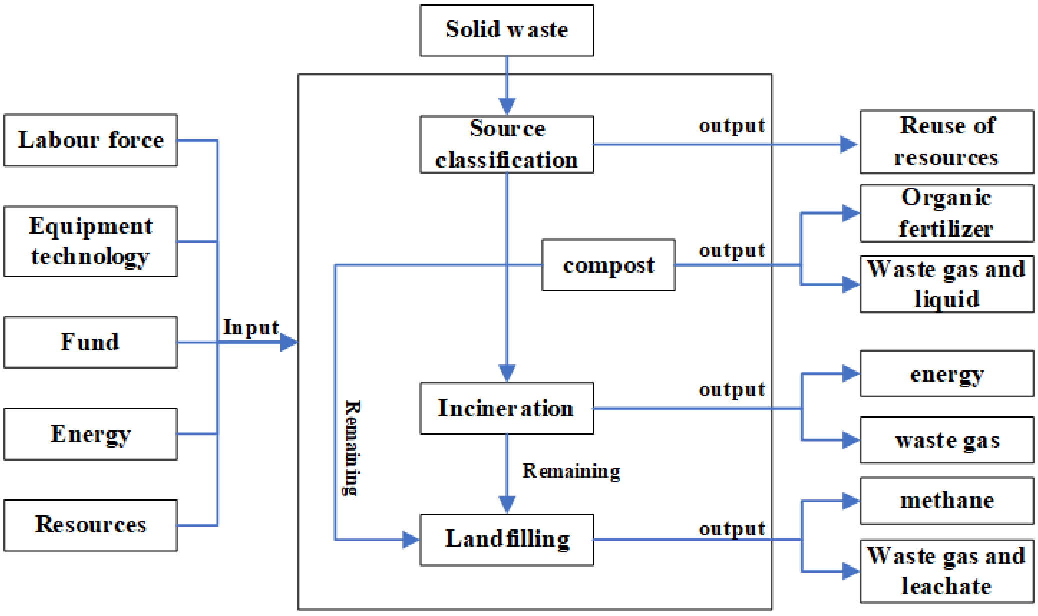

Fig. 3. Inputs and outputs of solid waste logistics system

2.3. AHP

Since its proposal by Saaty in the 1970s, the systematic analysis approach of the AHP has been widely adopted to determine product structure, evaluate scientific results and appraise personal achievement. The AHP breaks down a complex problem into multiple elements, and then group them into a hierarchical structure, as shown in Fig.4.

The AHP generally has four steps:
(1) Establish a hierarchical structure model (Fig.4);
(2) Construct an importance judgment matrix of the elements on the level of criteria against the scale in Table 1, and perform the consistency test;
(3) Calculate the relative weight of each sub-criterion relative to its superior criterion according to the judgement matrix;
(4) Calculate the synthetic weight of the elements on each level.

3. AHP-based evaluation of solid waste logistics system

To dispose the solid waste at ports, it is necessary to establish a solid waste logistics system that supports harmless treatment, reduction and recycling of solid waste, without causing excessive burden to the society, economy and environment. The following objectives should be satisfied by the system:

(1) *Completeness*: All solid waste at the port should be disposed of;
(2) *Greenness*: The environmental impact of solid waste must be minimized;
(3) *Economics*: The logistics costs like energy, resource and money should be reduced;
(4) *Harmony*: The system should win support from the general public;
(5) *Recyclability*: Renewable energy and resources should be obtained as much as possible.

Table 1. Importance scale

Scale of a_{ij}	*Definition*	
1	i factor vs. j factor	Equally important
3		Slightly more important
5		Obviously more important
7		Strongly more important
9		Extremely more important

Hence, an evaluation system was set up to assess the environmental, economic and social impacts of solid waste logistics at ports (Fig. 5).

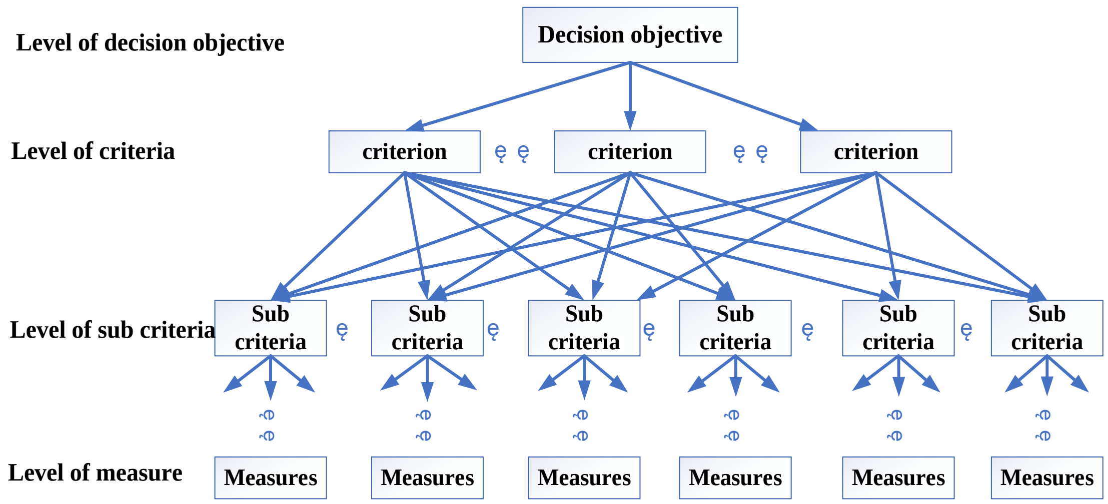

Fig. 4. The hierarchical structure of the AHP

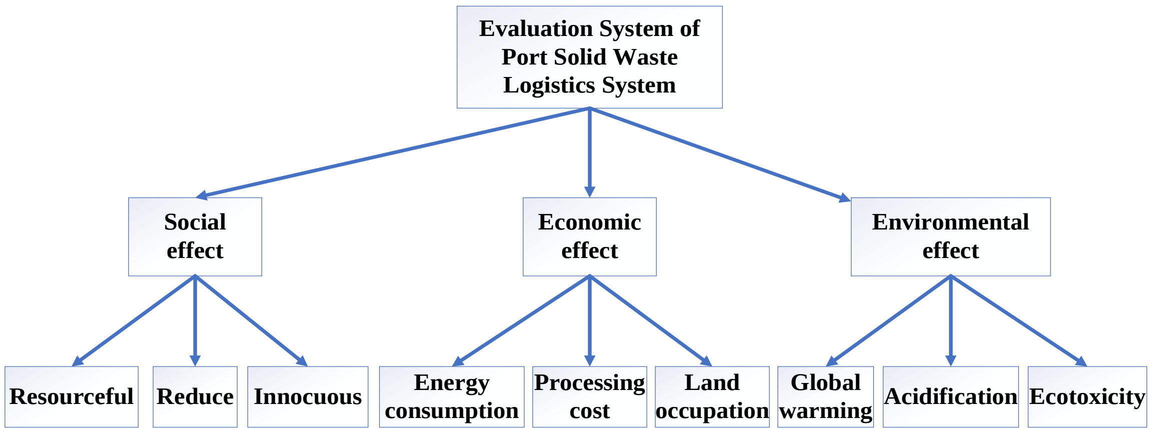

Fig. 5. Evaluation system for the logistics management system of solid wastes at ports

3.1. Environmental impact evaluation

The weights of environmental factors are listed in Table 2.

Table 2. The weights of environmental factors

Global warming	***Material***	CO_2	***CO***	CH_4	N_2O	***CH1.CH***
	kg CO_2/Kg	1	2	25	320	3300
Acidification	Material	SO_2	SO_3	HC1	HF	H_2S
	kg SO_2/Kg	1	0.8	0.88	1.60	1.88
Eutrophication	Material	NO_3	NO_x	NO	NH_3	COD
	kg NO_3/Kg	1	1.35	2.07	3.64	0.23

The comprehensive environmental impact of solid waste, denoted as CEP, can be computed by (Eq. 1):

$$CEP = \sum [CEP(j)_i * P_i] + CEP(LF)_j * P_j \qquad (1)$$

where $CEP(j)_i$ is the environmental impact of the *i*-th type of solid waste treated by the *j*-th method; P_i is the content of the *i*-th type of solid waste; $CEP(LF)_i$ is the environmental impact of resident treatment by the *j*-th method; P_j is the amount of residue of the *j*-th method.

3.2. Economic impact evaluation

The economic impacts were computed based on disposal costs. Inspired by the research by Cruz et al. (2017) the costs of different disposal methods for solid waste were summed up (Table 3). As shown in Table 3, mixed disposal consumes more energy than classified disposal. This is because the solid waste collected in mixed mode needs to go through repeated screening, drying and compression until meeting the disposal requirements.

3.3. Social impact evaluation

The disposal of solid waste should turn the waste into harmless substances and reduce the amount of waste. Considering public satisfaction, the social impact evaluation system was set up as shown in Fig. 6.

Table 3. The costs of different disposal methods for solid waste

	Collection and transport costs (year/person)	*Processing costs (year/person)*	*Energy consumption (MJ/ year/person)*
Mixed incineration	21.3	19.3	253
Mixed landfill	23.8	8.2	91.4
Classified composting	19.2	12.5	82.9
Classified landfill		26.2	32.5
Classified incineration		15.4	73.5

4. Case study

This chapter mainly optimizes the solid waste logistics system of a port, and performs life cycle assessment of the optimized system.

4.1. The current system

The current solid waste logistics at the port is shown in Fig.7. The weights of various evaluation factors were obtained by the AHP and listed in Table 4. As shown in Table 4, the environmental impact has the greatest weight for the elements on the level of criteria, followed in descending order of social impact and economic impact. This ranking is in line with the current principles for solid waste disposal: the control of environmental pollution is the top priority; the next goal is to dispose of the waste in a way acceptable to the public; the economic cost needs to be minimized after fulfilling the previous two goals.

Judging by Fig.7 and Table 4, the current solid waste logistics at the port is still cumbersome. There are many redundant steps and potential pollution hazards within the system.

4.2. System optimization

To dispose of the solid waste in classified mode, the current logistics system at the port was optimized in this subsection. Firstly, the solid waste was sorted by the following principles during collection:

(1) The items likely to affect and contaminate each other should not be placed together;

(2)The items that will be disposed of by different methods (e.g. landfill and incineration) should not be placed together).

In the light of the two principles, the collection methods of different items were optimized as shown in Table 5. Table 6 provides the percentage of each component in the solid waste at the port, Table 7 shows how much each component is disposed of by each method, and Fig. 8 presents the optimized system. Based on the data of the above tables, it was computed that 24.95% of the solid waste was recycled, 50.40% was composted, 11.15% was incinerated and 13.5% was landfilled.

Further, the solid waste logistics system at the port was optimized, considering the components of items from different sources. In the optimized system, the different items do not interfere in each other from collection to transport. The mixing and classification operations were minimized, greatly improving the recovery efficiency. Different types of items can be sent to suitable places for disposal.

The key measures of the optimized system are as follows:

(1) Fabrics and metals were added to the system scope. The recovery prices for the two items were increased, so as to collect more beverage bottles and waste packaging paper from residential areas and office areas.

(2) More dustbins were arranged in public places to collect solid waste. Each dustbin has two clearly labelled chambers, one for recyclables (e.g. beverage bottles, plastic bottles and paper) and the other for non-recyclables.

(3) Separate solid waste bins were provided in residential areas.

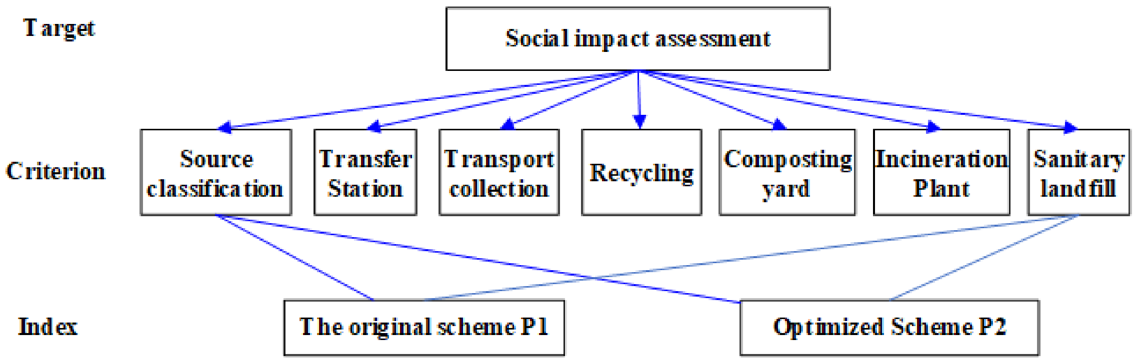

Fig. 6. Social impact evaluation system

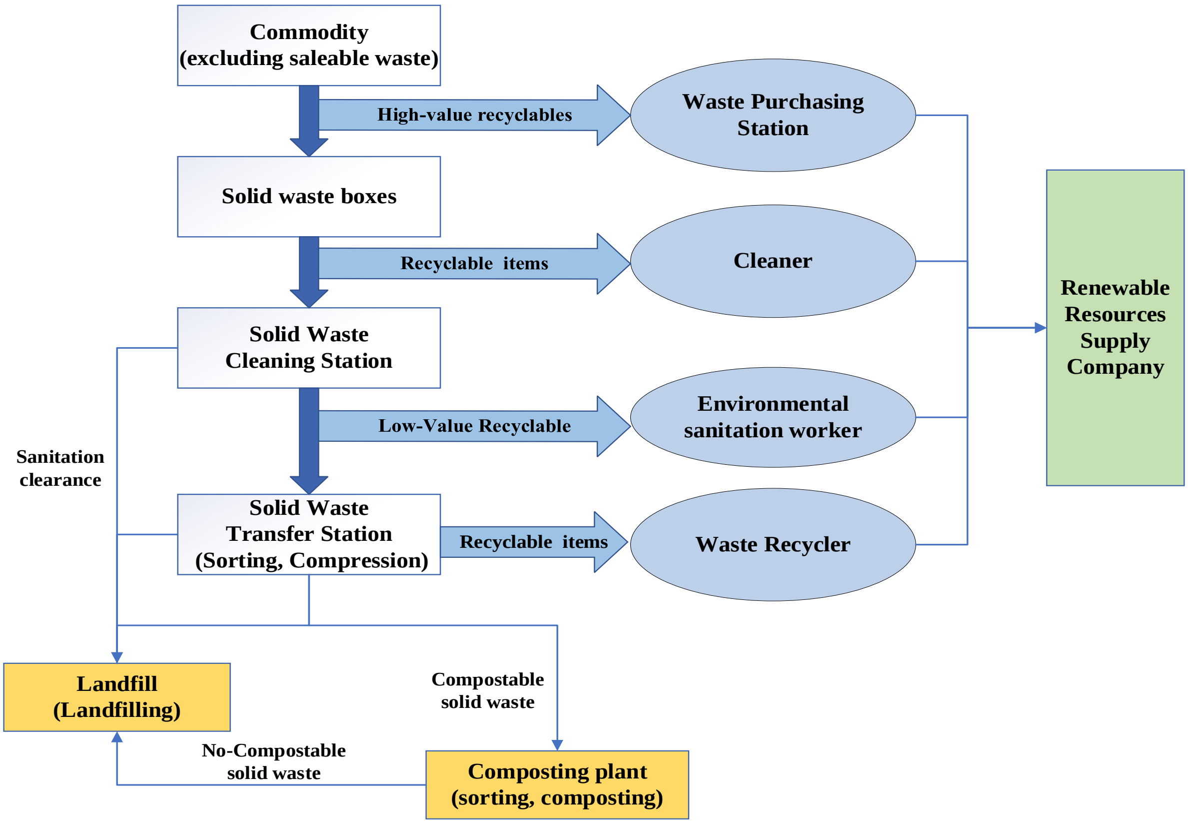

Fig. 7. The solid waste logistics system at the port

Table 4. Weights of evaluation factors

Level of criteria	*Social impact*	*Economic impact*	*Environmental impact*	*Weight relative to the total objective*	*Ranking*
Recycling	0.15			0.05	8
Reduction	0.56			0.16	2
Harmless treatment	0.29			0.09	5
Energy consumption		0.32		0.06	7
Disposal cost		0.12		0.04	9
Land occupation		0.56		0.11	4
Global warming			0.53	0.26	1
Acidification			0.32	0.15	3
Eco-toxicity			0.15	0.08	6

Table 5. Optimized collection methods for different items

Name	*Final disposal*	*Features*	*Current methods*	*Optimized methods*
Food waste	Composting	Produced in large amount, wet, perishable, likely to contaminate other items	Mixed collection, plus separate collection in certain areas	If conditions permit, compost it onsite; otherwise, transfer it to composting plants
Glass	Landfill	Requiring redissolution, resource-consuming	Recycle beverage bottles through special channels	Recycle beverage bottles only, and landfill the rest
Plastic	Landfill	Having high recovery value; not suitable for incineration	Collect beverage bottles in residential areas and schools.	Collect waste plastics door-to-door, classify the collected waste, and send the non-recyclable parts to composting plants or landfills
Paper	Incineration	Mostly recyclable and easily contaminated	Collect waste paper from residential areas and schools door-to-door, and collect the rest in mixed mode	Collect waste paper onsite and from dust bins on the street, and send the rest to incineration
Metal	Landfill	Produced in small amount, easily sortable	Collect metals in mixed mode	Collect metals together with plastics and glass

Fabrics	Incineration	Produced in large amount, having high recovery value	Collect fabrics in mixed mode	Recycle fabrics through separate channels
Limestone	Landfill	Highly stable, likely to contaminate other items and the environment	Collect limestone in ordinary channels	Collect limestone separately from recyclables and composts
Vegetable	Composting	Produced in large amount, conductive to soil quality if disposed of onsite	Collect vegetable in special channels	Collect and transport vegetable separately from the other items

Table 6. The percentage of each component in the solid waste

Component	*Food waste*	*Metal*	*Plastic*	*Paper*	*Glass*	*Vegetable*	*Limestone*	*Fabrics*	*Bricks*
Proportion	35.9%	20.3%	16.5%	9.1%	6.9%	5.7%	2%	2.3%	1.3%

Table 7. The proportion of each component being disposed by each method

Component	*Recycling*	*Composting*	*Incineration*	*Direct landfill*	*Residual landfill*
Food waste		35.90%			
Metal	9.10%		10.30%		0.90%
Plastic	8.90%	8%			
Paper	4.50%			4.60%	
Glass		6.90%			
Vegetable				5.70%	
Limestone	1.15%		0.85%		
Fabrics				2.30%	
Bricks	1.30%				

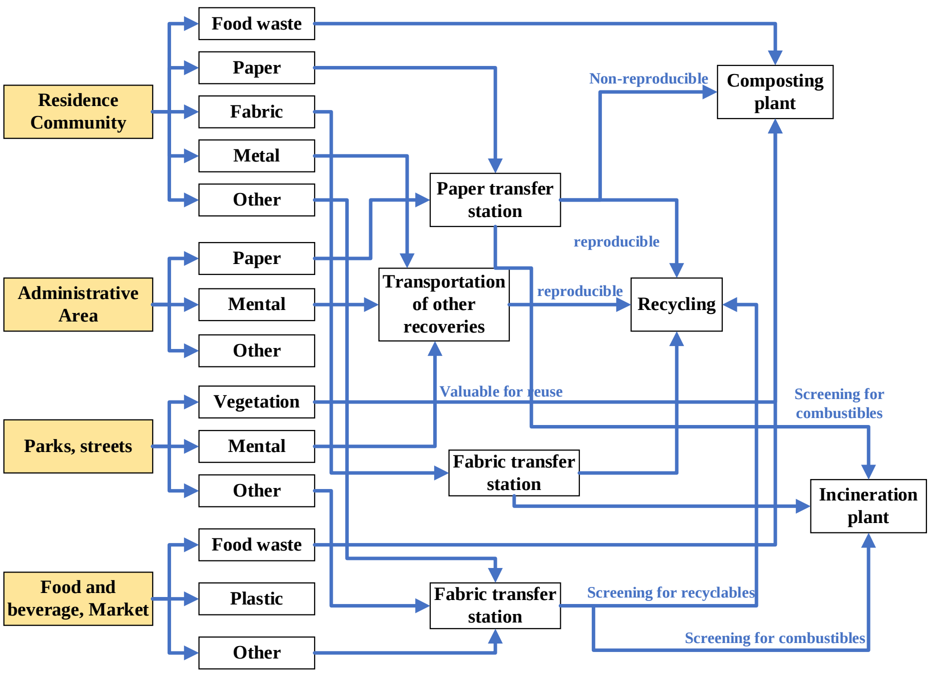

Fig. 8. The optimized solid waste logistics system

The optimized logistics system was subjected to AHP-based lifecycle evaluation. The scores of the original and optimized systems are compared in Table 8. As shown in Table 8, the overall impact of the original system was 0.55, while that of the optimized system was 0.32. The lower score demonstrates the high feasibility of the optimized logistics system for solid waste at the port. Therefore, three suggestions were put forward for optimizing the green logistics system of solid waste at ports:

(1) To protect the environment, landfill should be replaced with incineration and composting.

(2) The solid waste collection process should be optimized, such that recyclables can be disposed of differently from solid waste.

(3) The items should be classified based on the disposal method.

Table 8. The scores of the original and optimized systems

Factor	*Weight*	*Score of the original system*	*Score of the optimized system*
Environmental effect	0.54	0.40	0.24
Economic impact	0.16	0.45	0.11
Social influence	0.30	0.88	0.62
Total weighted score	1	0.55	0.32

4. Conclusions

This paper attempts to realize the green logistics of solid waste at ports, enabling the harmless treatment, reduction and recycling of such waste through the entire life cycle. To this end, the life cycle assessment and the AHP were applied to evaluate the green logistics of solid waste at ports. The main conclusions are as follows:

(1) The solid waste logistics system at ports was examined from the perspective of logistics system. The waste was divided into recyclables and non-recyclables, and disposed of by recycling, incineration, landfill and composting. In this way, the mixing and classification operations were minimized, greatly improving the recovery efficiency.

(2) The author set up an evaluation system for green logistics of solid waste at ports, after analysing how solid waste logistics affect the environment, economy and society.

(3) The solid waste logistics system of a port was optimized, and subjected to life cycle assessment. The evaluation results show that the optimized system has a much lower environmental impact than the original system, thanks to the classified collection methods of different items.

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