Comprehensive Treatment and Disposal of Logistics Waste in China: Prospects of Biomass Resource Conversion

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GRAPHICAL ABSTRACT

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The exponential growth of China's economy, coupled with the surge in online commerce, has led to a significant expansion of the logistics industry. In 2022, China's express delivery industry generated approximately 9 million tons of waste paper and 1.8 million tons of plastic. This study analyzed the current composition and utilization of logistics waste in China, with suggestions for recycling. Logistics waste can be defined as the packaging waste generated in the logistics industry. Corrugated paper and plastic waste were chosen as the objects for utilization. Due to its high cellulose content, corrugated paper can be utilized along with other paper waste for biomass resourcing. Biodegradable plastics can also be converted into biomass resources through the action of specific microorganisms. These polymers can be enzymatically depolymerized by certain bacteria and fungi, yielding valuable organic products. In general, logistics wastes all have potential for biomass resource recovery. By adopting appropriate recovery and conversion technologies, these waste streams can be transformed into high-value bio-based products, such as biofuels, biochemicals, and biopolymers, thus contributing to the development of a circular and sustainable economy.

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Keywords: Logistics waste; Corrugated paper; Plastic; Resource recovery; Biomass conversion

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INTRODUCTION

The logistics industry is a multifaceted service sector that integrates transportation, storage, freight forwarding, information, and other industries (Liang *et al*. 2022). As a fundamental and strategic industry, it supports the development of the national economy by linking the primary, secondary, and tertiary industries and facilitating the connection between production and consumption (Sharma *et al*. 2023). The level of its development has become a vital indicator for measuring a country's modernization and comprehensive national strength (Deng *et al*. 2020). Since 2019, China's logistics industry business has seen a yearly increase of more than 10 billion pieces, and the number of logistics industry workers has reached 10 million (Su *et al*. 2020). The express delivery industry is a special manifestation of the logistics industry in China. Despite COVID-19's profound impact on logistics enterprises' warehousing, distribution, transportation management, and supply chain operations, the logistics industry continues to show an upward trend, as shown in Fig. 1. China's domestic demand has enormous potential, and in the long run, steady economic growth will continue to drive robust demand for logistics services (Wu *et al*. 2023).

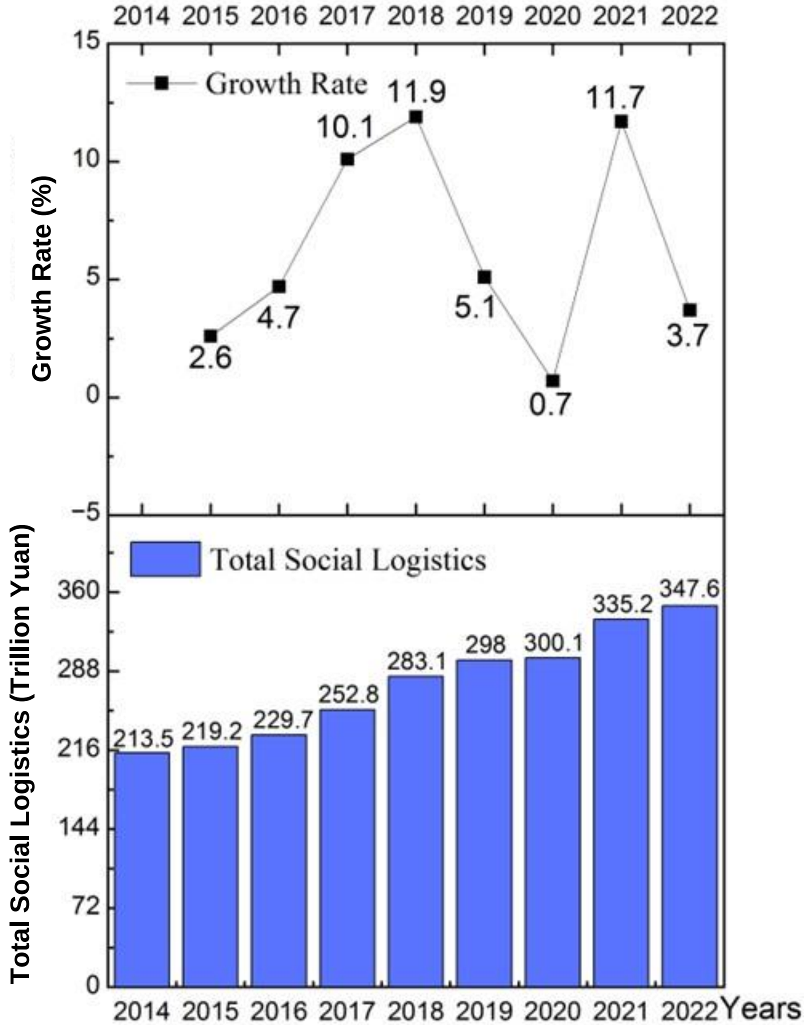

Fig. 1. Total amount of social logistics in China from 2014 to 2022

The continuous and robust growth of China's economy has led to a significant expansion of its logistics industry. As depicted in Fig. 2, the volume of express business has exhibited an upward trend since 2011 (Duan *et al*. 2019), and the annual total volume of express business surpassed 100 billion in 2022.

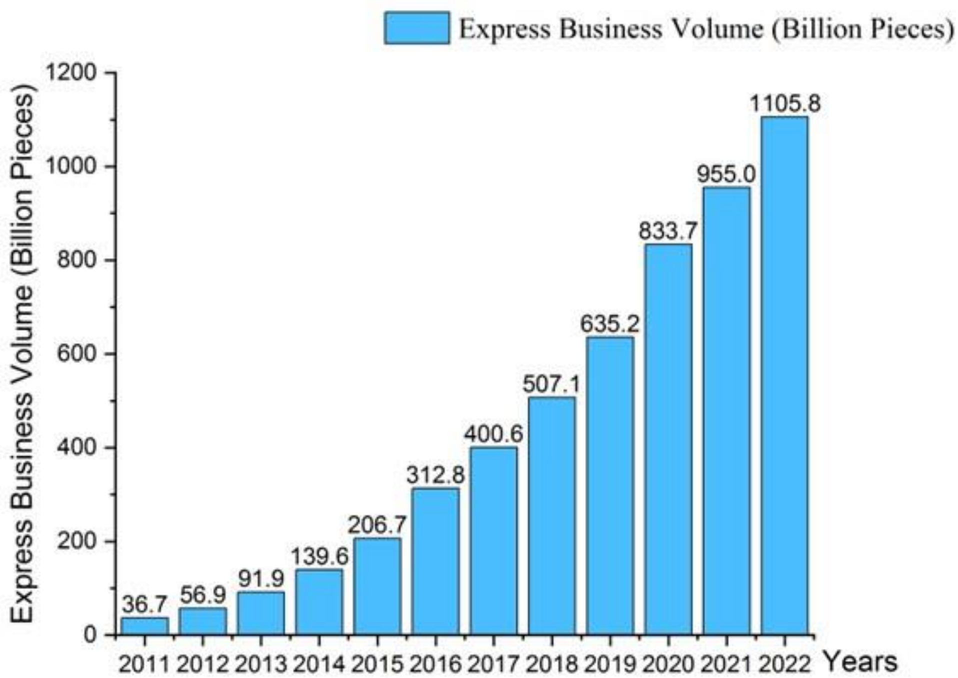

Fig. 2. China's express delivery volume from 2011 to 2022

Based on projections by logistics experts, China is expected to emerge as a global trade powerhouse by 2030, with enhanced trade ties with major economies, emerging economies, and developing countries. As a result, the international logistics scale of China is predicted to exceed 200 million units per day by the end of 2030.

The swift expansion of the logistics sector has resulted in the emergence of huge volumes of logistics waste. The volume of express delivery has consistently topped global rankings for seven consecutive years. Also over 9 million tons of paper waste and around 1.8 million tons of plastic waste were produced each year. Managing these logistics wastes has become a problem.

Current Status of Logistics Waste Generation

According to statistics from the China Paper Association, the amount of express packaging materials used or discarded in 2022 was more than 11 million tons. Among them, more than 8 million tons were in the corrugated box category, accounting for about 90% of the total packaging materials, while nearly 800,000 tons were in the plastic category, accounting for 8% (Lim and Thian 2022). In 2022, the nationwide production of paper and paperboard was 1.211 billion tons, which was 7.50% higher than the previous year (Wu *et al*. 2023).

Figure 3 illustrates the various types of packaging materials used in the logistics industry, including express waybills, woven bags, plastic bags, envelopes, corrugated boxes, tape, and more. Additionally, logistics packaging often includes a significant amount of filler materials such as bubble bags, bubble film, foam plastic, and other cushioning materials.

Fig. 3. Categories of logistics waste

China's express packaging industry is mainly dominated by two materials: corrugated cartons and plastic bags. According to Fig. 4 (data from China Logistics Yearbook 2022), corrugated cartons account for 44.03% of express packaging (by number of pieces), with a majority of medium and small-sized cartons (Xiao and Zhou 2020). Plastic bags account for about 33.5% of the packaging, making it the second most widely used material after corrugated boxes. Plastic bags used in express packaging are often directly recycled from waste and appear gray or black, accounting for about 73% of the total number of pieces (Tan *et al*. 2023). Additionally, 25.6% of plastic bags are produced by mixing waste with a small amount of virgin material, resulting in yellow-green bags. Pure white express packaging plastic bags made entirely from raw material (such as PP or PE) only account for 1.5% of the total (Fan *et al*. 2017).

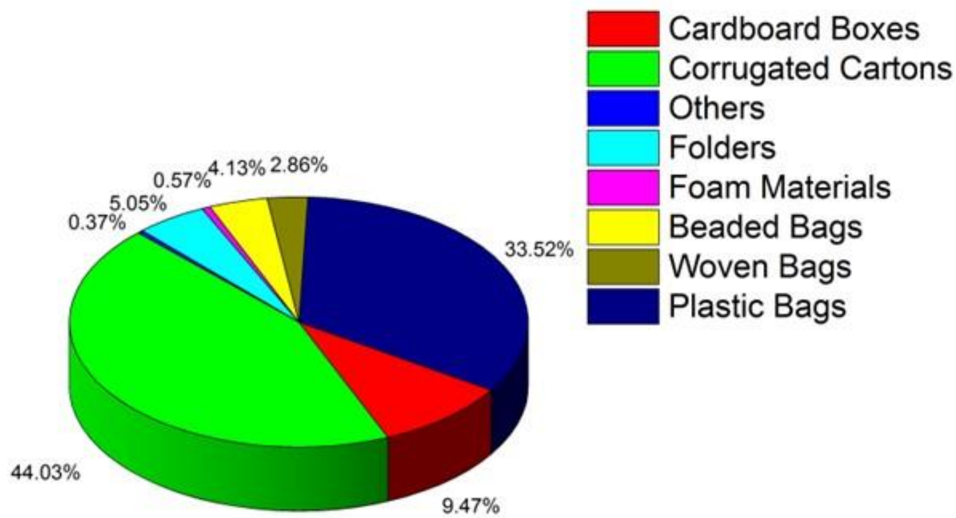

Fig. 4. Composition proportion of logistics waste

Paper-based packaging materials are primarily composed of corrugated paper, accounting for 96.18% of the total, while other paper-based materials include waybills, document bag envelopes, and indirect packaging materials such as tape cores, accounting for a total of 3.82% (Duan *et al*. 2019). In some cases, corrugated boards that have lower quality demands may use 100% recycled fiber for repapering (Mao and Li 2012).

Plastic packaging materials are a major component of China's express packaging waste. Among these, ordinary plastic bag film is used most commonly, accounting for 62.90%. Around 80% of the bag is obtained through recycling of waste materials (Lim and Thian 2022). Other plastic packaging materials used in express packaging include woven bags, foam boxes, pearl bags, tape, and filled plastic. The environmental impact of packaging waste is primarily characterized by two aspects. Firstly, some packaging waste is difficult to degrade and accumulates in the environment, leading to soil and water pollution, which can have detrimental effects on ecosystems and human health. Secondly, the production, disposal, and transportation of packaging waste results in significant emissions of greenhouse gases, exacerbating global climate change (Pan *et al*. 2022).

China's logistics waste is mainly divided into corrugated paper and plastic, and the total amount is still growing rapidly. Logistics waste can be characterized as having a large amount, complex composition, and difficult comprehensive utilization. Efficient recycling needs to be based on a complete garbage classification system, and it is necessary to invest a lot of manpower, material and financial resources. The economic and environmental costs brought by express packaging cannot be ignored, and how to achieve sustainable development of the logistics industry needs to be further studied.

Current Status of Logistics Waste Utilization

According to statistics, less than 5% of express carton packaging waste is reused, with about 80% of cartons recycled and approximately 15% mixed into household waste (Chia *et al*. 2020). As illustrated in Fig. 5 (data from China Logistics Yearbook 2022), in 2022, the Chinese express delivery industry consumed a total of 8,373,300 tons of paper packaging materials, including 119,300 tons of paper, and 8,254,000 tons of corrugated paper, paper briefs, and tape cores. Only approximately 340,800 tons of this corrugated cardboard were reused, and around 6,888,900 tons of express packaging waste paper (6,794,300 tons of corrugated paper and 94,600 tons of document pouches) were recycled through mobile recyclers. There were 1,143,600 tons of packaging waste that are not being effectively reused (Fan *et al*. 2017). These neglected logistics wastes need effective resource utilization.

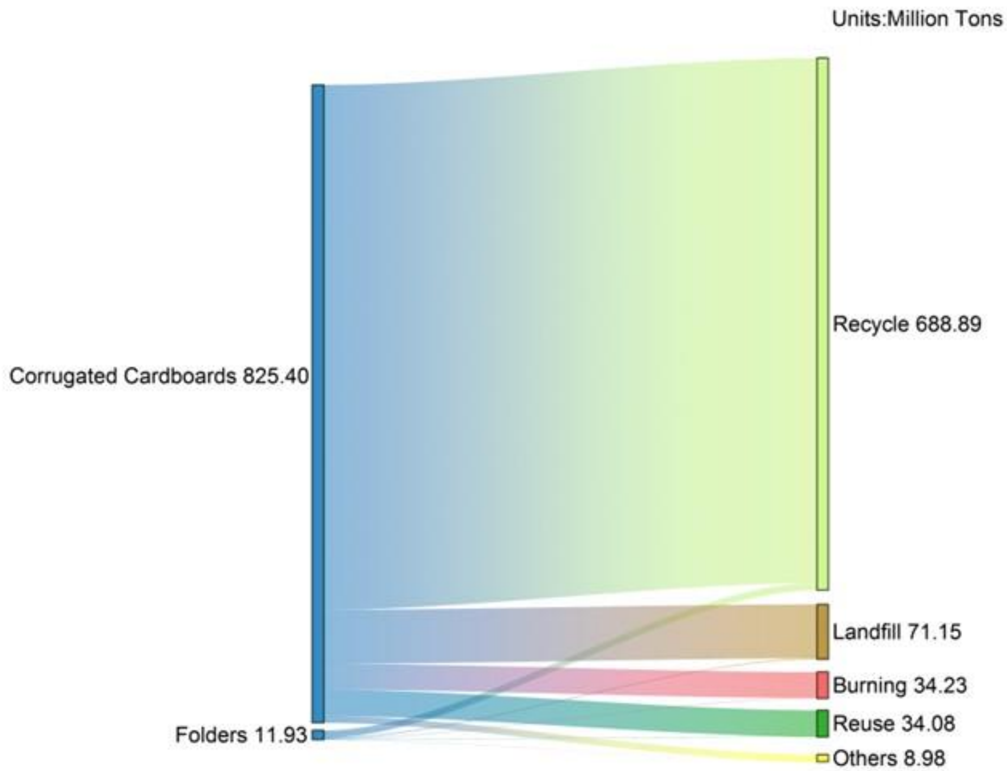

Fig. 5. Paper logistics waste utilization sangeet map

Most of the plastic packaging materials are mixed into the household waste. The vast majority of express plastic packaging bags, representing approximately 95% of the total mass, are not effectively recycled due to low recycling prices and the presence of plastic tape and waybills, which cannot be processed through existing recycling channels (Xiao and Zhou 2020). Consequently, these materials are typically incinerated or landfilled along with domestic waste. As illustrated in Fig. 6 (data from China Logistics Yearbook 2022), in 2022, China's express delivery industry consumed a total of 851,800 tons of plastic-based packaging materials, including 694,300 tons of plastic film bags (including filled film), 54,700 tons of woven bags, 11,100 tons of pearl bags, 10,000 tons of foam boxes, and 80,700 tons of tape (Tan *et al.* 2023). Despite the significant amount of plastic express packaging waste generated, recycling rates remained low due to the high cost and limited profitability of recycling. Traditional methods of landfilling or incinerating plastic waste can lead to significant pollution (Oberoi *et al*. 2021). Treating such pollutants requires expensive equipment and cannot be implemented on a large scale for environmental control of incineration (Chen *et al*. 2021). As a result, plastics in logistics waste needed further research on utilized as a resource.

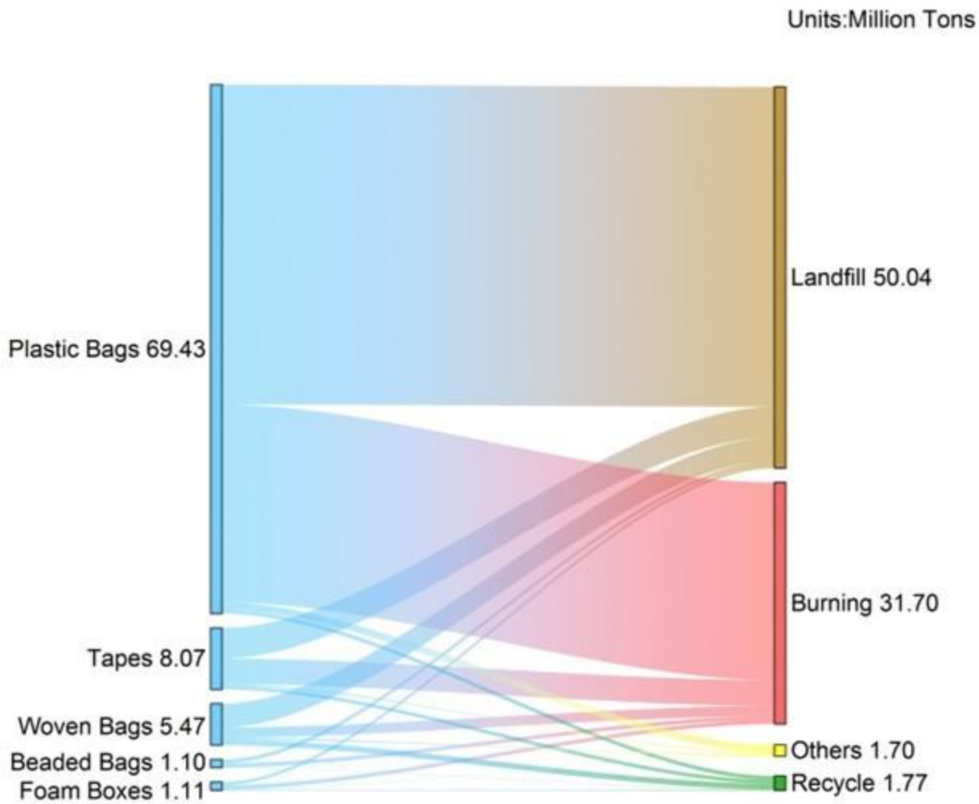

Fig. 6. Plastic logistics waste utilization sangeet

Based on data analysis, although logistics waste has been paid attention to with respect to recycling, there are still some that are not included in the recycling system, and others are ignored because of serious damage or pollution. Although paper logistics waste has been effectively recycled, some of it is still mixed with domestic waste for incineration and landfill, while most of plastic logistics waste is incinerated and landfill, resulting in a great waste of resources and environmental pollution. In general, logistics waste still has the potential of resource utilization.

Resourceful Utilization of Logistics Waste

Waste collection is the first step in the process of logistics waste reuse. In many Chinese cities, waste separation has been piloted with great success, the core of which is the transformation of waste collection points originally set up in residential areas into integrated separation and collection stations, which have special categories for logistics waste and other recyclable waste, and then are unified by the various stations. The waste is then transported by each site. In addition, logistics companies also act as collectors in the recycling process. By setting up recycling stations in logistics companies and various logistics pick-up points, users can collect and pre-select logistics waste at the first time after obtaining parcels, which reduces the burden on users and also helps the recycling of logistics waste. Currently, the main treatment method of logistics waste is recycling. For sustainable development in the logistics industry, it is inappropriate to rely only on recycling. As an emerging mode of sustainable development, resource utilization has a good prospect in the logistics industry. Paper logistics waste needs to pay special attention to the effect of ink in the process of biomass reuse, through the addition of bio-enzymatic deinking composite is a good choice, the method not only has a better deinking effect, while the deinking sludge produced can be carried out back-end resource treatment, such as deinking sludge utilised to the production process of low-end paper products (Xu 2021). The resource value of carton waste is expected to remain high in the future, the analysis of the resource utilization of carton logistics waste, along with recommendations for plastic logistics waste, will be conducted in this part.

Resourceful utilization of waste corrugated paper

The main composition of waste corrugated paper in logistics waste is cellulose, a widely available renewable resource. The benefits of cellulosic feedstocks are gaining attention due to their great availability and enormous potential. Various utilization methods for waste corrugated paper are shown in Table 1.

Recycling of waste corrugated paper

The resource utilization technology for traditional carton-based logistics is currently at a low level. The most common approach is to collect discarded cartons for reuse through express recycling systems and garbage sorting systems. Some discarded cardboard boxes are also collected and shipped to the paper industry, where they are made into pulp to enter a new cycle through a special process (Wang 2019). Additionally, they have established the feasibility of furniture design using courier cartons and combined theoretical conditions as well as relevant technical process conditions to design a series of cost-controllable corrugated furniture items. Direct recycling enables the maximization of resource utilization while reducing reliance on primary materials, thereby promoting resourcefulness.

Although the above-mentioned recycling methods are effective in reusing carton logistics waste, they rely on a complete recycling system and the carton waste being in good condition. Furthermore, there is significant energy loss during the recycling process. There still existed many discarded cartons that are damaged or heavily polluted, which cannot be recycled. And these corrugated sheets can be used for resource utilization in the future.

Modified reuse of waste corrugated paper

The modification and processing of waste corrugated paper can yield materials that offer improved performance and additional functionalities. Li (2020) utilized $NaClO_2$ to generate ClO_2 in an acidic environment, to modify waste corrugated paper. Such materials were used for the packaging and transportation of fresh fruits and vegetables. Jiang *et al*. (2018) applied the modified corrugated cartons to the transportation of preserved fruits. The authors employed the laccase/aspartic acid system to modify the fibers of old corrugated paper, which resulted in a significant enhancement of its tensile index, tear index, and breakage resistance index.

Table 1. Uses for Waste Corrugated Paper

Methods	Utilization Method and Principle	Advantages and Disadvantages	References
Direct recycling	Pulping of waste corrugated paper using a new process	It is possible to recycle corrugated paper that is in good condition, while corrugated paper that is badly damaged or contaminated is a waste of resources	Wang (2019)
	Secondary use of courier cartons for direct paper furniture design		Liu and Zhang (2021)
Modified reuse	Corrugated cardboard boxes modified with coating to prepare ClO_2 controlled release cartons for fruit preservation application	The modified material has better mechanical and barrier properties as well as other special properties. However, during the recycling and modification process, the fibers in the corrugated paper are structurally damaged and therefore need to be compensated for by additional processing	Li (2020)
	Fiber modification of old corrugated paper using laccase/aspartic acid system to improve the physical properties of recycled paper		Jiang *et al*. (2018)
	Accelerated carbonation-cured corrugated cement board has higher performance, mainly in terms of permeability, dimensional stability, and physical and mechanical properties		Alexandre *et al*. (2020)
	Paper reinforcement using chitosan, CMC and kraft cellulose fibers to improve the mechanical properties of recycled paper		Ballinas-Casarrubias *et al*. (2017)
	Designed indirect evaporative cooler in which PET/cellulose corrugated sheets are used as wet channels to significantly improve wet bulb efficiency		Kim (2021)
	Paperboard made from waste corrugated mixed with other raw materials has high strength resistance, improved barrier properties, and better printability and biocompatibility		Ozcan *et al*. (2021)
	Recovered fibers from corrugated waste can be used to produce high value-added paper due to their improved barrier and mechanical properties		Tarrés *et al*. (2018)
Reuse of biomass resources	After carbonization and activation, waste corrugated paper is used in water treatment and as electrode material for supercapacitors	The prepared biomass resources are regenerative, environmentally friendly, clean, low-carbon, multi-dimensional conversion and have a low content of harmful substances, making them clean resources. The utilization of biomass from corrugated waste paper will improve the competitiveness of biorefineries and promote the development of bioeconomy	Wang (2020)
	Activated carbonization of waste corrugated paper fibers as biomass feedstock to produce porous carbon materials with different properties		Zeng (2020)
	Preparation of lactic acid from waste corrugated cardboard catalyzed by lanthanum trifluoride salt with significant economic benefits		Kim *et al*. (2022)
	In the presence of zeolite catalysts, the rapid pyrolysis of waste corrugated paper can produce a fairly high level of liquid bio-oil		Sotoudehnia *et al*. (2021)
	Alkali-treated graded HZSM-5 zeolite catalyzed waste corrugated cardboard can be quickly pyrolyzed to produce aromatics		Ding *et al*. (2017)
	Preparation of bio-oil and biochar by pyrolysis of waste corrugated cardboard at different temperatures, and further processing of the products into fuel		Sotoudehnia *et al*. (2020)
	Preparation of biochar fibers from corrugated cardboard by pyrolysis at different temperatures		Wang *et al*. (2019)
	Production of hemicellulose and glucose from corrugated board residues		Yáñez *et al*. (2004)
	Recovery of wax from wax coating on corrugated board and production of carbon		Sotoudehnia *et al*. (2021)

Alexandre *et al*. (2020) modified waste corrugated paper using accelerated carbonization curing. The resulting hybrid board exhibited superior performance in terms of air permeability, dimensional stability, and physical and mechanical properties.

In Ballinas-Casarrubias *et al*. (2017), chitosan and kraft cellulose fibers were employed to reinforce waste corrugated paper. The authors utilized phenoxy radicals in the paper and bio-grafting to produce covalent bonds between the fibers, thereby polymerizing and enhancing the mechanical properties of the waste corrugated paper. Kim (2021) investigated the waste corrugated paper as a filling material in the wetting medium of an indirect evaporative cooler (IEC), using PET/cellulose corrugated board as a wet channel. The researchers compared the performance of the modified waste corrugated board with that of the existing PET/IEC and found that the former led to a 44% improvement in wet bulb efficiency. In another study, Ozcan *et al*. (2021) incorporated CNF/CNF-OX into waste corrugated board, resulting in a modified material with high strength, improved barrier properties, better printability, and biocompatible polymers. Tarrés *et al*. (2018) recycled waste corrugated paper for the production of high-value-added paper with enhanced barrier and mechanical properties.

Overall, the recycling of waste corrugated paper has been modified to yield new reinforced materials with improved mechanical and barrier properties, as well as other specific functionalities. These modified secondary fibers hold significant value and present promising prospects in the high-value-added market, while also supporting the advancement of a green circular economy.

Conversion of waste corrugated paper into biomass resources

Corrugated cardboard, composed of plant cellulose, has great potential for biomass conversion. Despite the current practice of recycling most corrugated cardboard for reuse, its packaging performance gradually declines with each reuse. Such corrugated cardboard waste that has reached the end of its usable life cycle will eventually enter the household waste system. The development of an appropriate method for recycling waste corrugated cardboard resources that have lost their reuse value is essential.

The utilization of biomass carbon as a raw material for preparing porous carbon offers several advantages, such as non-toxicity, good stability, high specific surface area, and superior electrical, and chemical resistance. Biomass carbon material is considered a high-quality precursor for porous carbon preparation. In a recent study by Wang (2020), waste corrugated cardboard was utilized as a biomass carbon precursor, and the resulting corrugated cardboard porous carbon showed significant potential for use in water treatment and as an electrode material for supercapacitors. Zeng (2020) utilized waste corrugated paper fibers to prepare porous carbon materials via an activation carbonization method. By adjusting the activator type, dosage, and carbonization temperature, they determined the optimal process parameters for achieving the best adsorption performance of the carbon materials, which varied based on the activator utilized.

Pyrolysis is a highly efficient method for waste recovery that involves the thermal decomposition of biomass under oxygen-free conditions to produce carbon-rich solids, such as biochar (which can have properties similar to that of coal coke), as well as volatile substances including bio-oil and gas. Waste corrugated paper can be converted into biochar via pyrolysis, resulting in a product with low nitrogen and ash content, as well as desirable hydrophobicity and thermal stability.

Kim *et al*. (2022) demonstrated the effective use of lanthanum trifluorosilicate catalyst in the hydrothermal conversion of waste corrugated cardboard to produce lactic acid, along with the production of various phenolic compounds in the liquid stream. This provides a promising avenue for the sustainable utilization of waste corrugated cardboard for value-added chemical production. Similarly, Sotoudehnia *et al*. (2021) reported the successful production of liquid bio-oil via the rapid pyrolysis of waste corrugated board using zeolite catalysts. This approach provides a renewable and sustainable source of liquid fuel, while simultaneously reducing the amount of waste sent to landfills. The use of alkali-treated graded HZSM-5 zeolite as a catalyst for pyrolysis of waste paperboard has been reported to produce aromatic hydrocarbons (Ding *et al*. 2017). Sotoudehnia *et al*. (2020) demonstrated that pyrolysis of recycled waste corrugated paperboard could yield bio-oil and biochar, which can be further processed into fuels. In addition, Wang *et al*. (2019) prepared biochar fibers by pyrolysis of waste corrugated cardboard and used them to produce wood-plastic composites. The composites exhibited improved mechanical properties, dimensional stability, light stability, and resistance to fungal decay. Sotoudehnia *et al*. (2021) reported the pyrolysis of the wax coating on corrugated board to produce wax oil and coal coke. Higher pyrolysis temperatures led to increased cracking and a higher proportion of smaller hydrocarbon fractions in the wax oil product, which contains long-chain hydrocarbons, such as alkanes and olefins, in the C9 to C36 range. The recovered wax is upgraded *via* catalytic cracking to produce transportation fuels, and the recovered carbon fiber has potential for use in high-value composite products.

In the current circular and sustainable bioeconomy paradigm, the utilization of waste corrugated cardboard can enhance the competitiveness of biorefineries and enhance social acceptance by converting waste corrugated cardboard into valuable biomass resources. Waste corrugated cardboard possesses the potential to serve as a significant contributor to sustainable biorefining. Given the goal of carbon neutrality by 2060, the advancement of modern biomass energy will have a crucial role in addressing carbon reduction, climate change, and ecological protection.

Currently, waste corrugated paper can be reused in three ways, namely, direct recycling, modified reuse, and reuse as biomass resources. However, both direct recycling and modified reuse require a well-established waste separation and recycling system. However, logistics waste is still mixed with domestic waste in many cities. No matter how many times it is reused, used corrugated paper eventually loses its use value and is landfilled and burned. The current terminus of the waste corrugated paper recycling chain continues to exhibit significant deficiencies. A separate recycling category can be established for these cellulose-rich biomass resources to achieve more efficient resource utilization in the context of a circular and sustainable bioeconomy.

Resourceful Utilization of Waste Plastics

Plastics have a high recycling rate and offer significant energy savings compared to recycled paper. Currently, plastic packaging waste can be treated using three main methods: landfill, incineration, and recycling. Although landfill treatment is simple and cheap, it does not promote resource utilization and occupy large areas. Incineration, on the other hand, can significantly reduce the volume of waste plastics and make use of combustion heat, but the process generates harmful gases. Thus, recycling has become a feasible and effective solution for managing plastic waste. Corresponding recycling efforts are on polyolefins, polystyrene, polyvinyl chloride, and polyester. Table 2 shows various methods of utilizing waste plastics.

Waste Plastic Modification and Reuse

The dominant component in plastic waste streams is the resin, which comprises approximately more than 40%. Resin serves as the fundamental raw material for synthetic fibers, coatings, adhesives, and insulation materials. Recycling of waste plastics can also serve as a potential avenue for modified materials. Khan *et al*. (2016) improved the elastic behavior of bonding material by compounding waste plastics with rubber powder, thereby extending pavement service life and reducing susceptibility to rutting and cracking. Fuentes-Audén *et al*. (2008) used recycled polyethylene as a modifier to enhance the mechanical properties of asphalt and improve its resistance to permanent deformation or rutting, as well as resistance to thermal and fatigue cracking. Fan and Wang (2021) investigated the reaction between waste polyvinyl chloride and coal tar using a catalyst, which resulted in the production of asphalt and plastic oleum. The PVC molecules bonded with small molecules in coal tar during the reaction, leading to the formation of a two-dimensional mesh structure that improved the softening point of the modified tar pitch. The modified tar pitch exhibited advantages such as good flexibility and low-temperature resistance (Fan and Wang 2021). Similarly, Qiu *et al*. (2021) found that both single and mixed plastics or polymers positively affect the modification of asphalt, improving its high-temperature stability, rheological properties, and resistance to rutting and fatigue cracking. Additionally, the modification improved the indirect tensile strength of asphalt mixes in terms of strength. Waste polystyrene exhibits great potential for reuse in various applications. For instance, it can be used as a lightweight aggregate in concrete with thermal insulation properties that are similar to expanded perlite, but with lower thermal conductivity. Moreover, waste polystyrene foam can be employed as a raw material for producing light building materials, such as lightweight cement composites, by adding appropriate fillers and binders, leading to materials with low density, good thermal insulation, and mechanical properties suitable for construction applications. Additionally, due to its high transparency and excellent refractive index, waste polystyrene can also serve as a primer for vacuum coating on other plastics.

Recycling waste plastics for modified reinforcement materials can be a crucial strategy in reducing non-renewable resource consumption, constructing sustainable pavements, and mitigating the environmental impacts of landfill waste disposal in accordance with the principles of sustainable development, while avoiding secondary pollution. The key technical point of waste plastic modification is to achieve the balance and stability of multiple properties.

Pyrolysis of Waste Logistics Plastics

Plastics are predominantly composed of polymers, with resin being the primary organic material (Kärkkäinen and Sillanpää 2021). By means of decomposition and other techniques, the original resin polymers in waste plastic products can be extensively broken down, resulting in a low molecular weight state. Thereafter, it can be transformed into various highly valuable products based on specific requirements. Liu (2018) utilized low-temperature microwave dechlorination as a pretreatment for chlorinated plastic packaging waste to obtain dechlorinated semi-coke, which can be further mixed with other combustible packaging waste to prepare solid-derived fuel. Similarly, Zhang (2019) found that waste plastic packaging was decomposed into char, fuel gas, and tar through pyrolysis in a relatively short period of time.

Table 2. Analysis of Utilization Methods of Waste Plastics

Methods	Utilization Method and Principle	Advantages and Disadvantages	References
Modified reuse	Compounding of waste plastics with rubber powder to improve the elastic behavior of bonding materials	As a modified reinforced material, it can play an important role in reducing the use of non-renewable resources, building sustainable pavements, and reducing the environmental impact of landfill waste disposal, but it is difficult to balance multiple properties with stability	Khan *et al*. (2016)
	Recycle polyethylene as a modifier to modify asphalt to enhance its mechanical properties		Fuentes-Audén *et al*. (2008)
Pyrolysis reuse	The reaction of waste PVC with coal tar under the action of catalyst can make asphalt and plastic oleum, and the softening point of the modified tar pitch is increased	Pyrolysis can transform plastics into high-value products, bringing better economic benefits while having less impact on the environment, but there are still difficulties in the large-scale application of pyrolysis technology	Fan and Wang (2021)
	Single or mixed plastics have a positive effect on the modification of asphalt		Qiu *et al*. (2021)
	Pretreatment of plastic packaging waste by microwave method to prepare solid derived fuel		Liu (2018)
	Pyrolysis of waste plastic packaging can be broken down into charcoal, fuel gas and tar in a relatively short period of time		Zhang (2019)
	Co-pyrolysis of biomass and plastics for syngas production		Mensah *et al*. (2022)
	Co-pyrolysis of plastic waste with biomass		Berthold *et al*. (2022)
	Co-pyrolysis of plastic waste and date seeds for bio-oil production as a sustainable biofuel in the UAE		Abrar *et al*. (2022)
Reuse of biomass resources	Preparation of molded biomass charcoal by pyrolysis of waste plastics and pine wood chips in a hot press furnace	It makes full use of the organic substances in waste plastics, reduces the energy loss in the treatment and disposal of plastics significantly, and no secondary pollutants are produced, so the reduction is complete and the waste treatment problem can be solved	Liu *et al*. (2020)
	Co-synthesis of aromatic hydrocarbons from mixed waste plastics and rice husk under different conditions		Kang *et al*. (2022)
	Biodegradation of plastic waste using low-density polyethylene degrading yeast produced by wood-feeding termites.		Elsamahy *et al*. (2023)
	Two PETases capable of hydrolyzing PET were isolated from a novel bacterium.		Kosiorowska *et al*. (2022)
	A PE-degrading strain of the fungus *Penicillium simplicissimum* YK was isolated.		Yamada-Onodera *et al*. (2001)
	Streptomyces scabies isolated from potatoes shown to degrade PET, and other polymers.		Jabloune *et al*. (2020)
	Laccase from *Actinomyces erythropolis* exhibits significant degradation of polyethylene.		Santo *et al*. (2013)
	Aspergillus flavus showed significant degradation of polyethylene.		Zhang *et al*. (2020)
	The algae secrete enzymes to break down the plastic, using the plastic polymer as a carbon source for their energy and growth.		Chia *et al*. (2020)

In another study, Mensah *et al*. (2022) employed co-pyrolysis of biomass and plastics for the production of syngas. Berthold *et al*. (2022) conducted a study on the co-pyrolysis process of plastic waste and biomass, investigating the effects of various parameters such as plastic type, biomass type, mixing ratio, reactor type, heating rate, reaction temperature, and catalyst. Abrar *et al*. (2022) explored the potential of co-pyrolysis of plastic waste and date seeds for bio-oil production as a sustainable biofuel in the United Arab Emirates. Liu *et al*. (2020) used a combination of thermal compression and pyrolysis to prepare formed biomass char from waste plastics and pine chips. Kang *et al*. (2022) investigated the co-pyrolysis of mixed waste plastics and rice husk under various conditions and found that the resulting liquid phase products contained high levels of aromatic hydrocarbons and oxygenated compounds. Another study conducted by Japanese researchers used a new solvent to dissolve polystyrene to produce a finished product with properties comparable to the new resin.

Compared with landfill and combustion, the application of waste logistics plastics in pyrolysis has a lower carbon footprint, and the impact on the environment is also greatly reduced. The pyrolysis product market is broad, which can bring higher economic benefits. However, the plastic pyrolysis technology is also faced challenge of the complexity in large-scale application and operation, and the pyrolysis reactor needs regular maintenance.

Conversion of waste plastics into biomass resources

Some bio-based plastics have also been put into use (Bustamante *et al*. 2019). Bio-based plastics can be converted to biomass, methane, hydrocarbons, carbon dioxide and heat under anaerobic conditions (Tabatabaei *et al*. 2021). The degradation and utilization of plastics do not always occur simultaneously. Many plastics do not degrade naturally and need to be degraded by man-made means (Yan *et al*. 2022). The degradation of plastics can provide raw materials for the use of plastics, and the degraded small molecules can be used to produce new plastic products or converted into energy (Bianchi *et al*. 2021).

Several studies have been carried out to depolymerize high molecular weight plastic waste into low molecular weight monomers using microorganisms or enzymes, which are subsequently mineralized into carbon dioxide, water, and new biomass. These microorganisms comprise actinomycetes, algae, bacteria, fungi, and their corresponding enzymes (Amobonye *et al*. 2021). Elsamahy and colleagues developed a novel tri-culture yeast community, named LDPE-DYC, utilizing LDPE-degrading yeast derived from wood-feeding termites for plastic waste biodegradation. The community was constructed based on the symbiotic relationship between termites and microorganisms present in their gut (Elsamahy *et al*. 2023). Amobonye *et al*. (2021) utilized molecular cloning or pure culture techniques to manipulate microorganisms, modifying enzyme properties and metabolic pathways with the goal of accelerating plastic degradation. Through these efforts, several degrading microorganisms and enzymes have been successfully patented. Kosiorowska *et al*. (2022) isolated two PETases from a newly discovered bacterium, *Ideonella sakaiensis*, which exhibits the ability to hydrolyze PET. The two enzymes work in tandem to break down PET into non-toxic monomers, namely terephthalic acid and ethylene glycol. Yamada Onodera *et al*. (2001) isolated a strain of the fungus *Penicillium simplicissimum* YK that is capable of degrading polyethylene. Jabloune *et al*. (2020) isolated *Streptomyces scabies* from potatoes, which was demonstrated to possess the capability to degrade PET as well as other polymers such as p-nitrophenyl esters, keratin, and corkin. Laccase derived from the actinomycete *Rhodococcus erythropolis* (Santo *et al*. 2013) and *Aspergillus flavus* (Zhang *et al*. 2020) exhibited notable ability to degrade polyethylene. Chia *et al*. (2020) discovered that algae colonize the surface of plastic and secrete enzymes that break down the plastic polymer, utilizing it as a carbon source for their growth and energy. Skariyachan *et al*. (2016) identified a novel microbial community using 16S rDNA sequencing, which included new strains of *Enterobacter* spp. and *Panobacter* spp. that demonstrated a higher efficiency in degrading LDPE compared to the previously known community. The emergence of genetic engineering has facilitated the sequencing and modification of microorganisms and enzymes involved in catalyzing polymer hydrolysis, leading to the identification of microorganisms capable of polymer degradation. Nonetheless, the efficient degradation of synthetic polymers (such as plastic polymers) and biopolymers (such as lignocellulosic biomass) still poses a significant challenge for biorefinery applications (Elsamahy *et al*. 2023). The inherent properties of plastics render it impossible for a single enzyme or microorganism to decompose them. Research at this stage shows that a single microorganism or enzyme cannot undertake the entire process of degrading and utilizing plastics. By building a community of multiple microorganisms, it seems to be more advantageous in dealing with the complex situation of plastic, a non-recyclable waste, and plastic mixed with other wastes, such as plastic mixed with corrugated paper, which exists in the logistics industry.

The conversion of waste plastics into biomass resources enables the utilization of organic materials and reduces the energy loss associated with plastic processing. Moreover, it avoids the generation of secondary pollutants and provides alternative resources for energy and chemical raw materials, thus addressing the issue of waste disposal and supporting the implementation of sustainable development principles. In China, there is a vast amount of waste plastics that have not been effectively recycled, indicating a broad prospect for the application of this approach. Currently, the utilization of waste plastics mainly includes modified reinforcement and biomass conversion. Due to the complex composition of logistics plastics, it is challenging to recycle them directly, even with advanced waste separation technologies in pilot cities. Similar to the recycling of waste corrugated paper, all waste plastics will ultimately enter waste treatment plants, which requires effective and environmentally friendly solutions for waste management.

At present, only a small part of the waste plastics in the logistics industry is recycled. Most of the waste plastics are not properly disposed of, and recycled plastics lose their use value after multiple uses. The degradation and reuse of logistics waste plastics and biomass reuse seems to be a more reasonable disposal method. To overcome the challenge of separating and recycling logistics plastics, innovative approaches can be developed to achieve their resourceful reuse. One potential strategy is to cultivate bacteria that are capable of using logistics waste as a mixed substrate for biomass resource utilization. This would enable a unified approach to the processing of logistics waste, which is often mixed with other packaging waste, such as corrugated cardboard.

CONCLUSIONS

1. This study summarizes the current status of logistics waste generation and utilization in China. It also examines the technologies for the reuse of waste corrugated paper and waste plastic. Converting logistics waste into biomass resources for reuse can help reduce environmental pollution and promote the principles of green recycling development.

2. China's logistics industry currently generates about 11 million tons of logistics waste each year, with corrugated paper and plastic being the main types of waste. In view of the successful experience of the pilot waste separation programme in China, government departments can refine the categories of waste separation through the introduction of relevant policies to target the recycling and disposal of logistics waste.
3. Corrugated logistics waste currently has three main routes: recycling, improved reuse, and biomass utilisation. Through analysis, it is concluded that one of the ways in line with sustainable development is biomass resource utilisation. For subsequent modes of resource utilisation, government departments can set up separate recycling categories for lignocellulose-rich recyclables such as corrugated paper, waste paper, food waste, straw, *etc*., while promoting research support for flora capable of utilising mixed substrates for biomass utilisation.
4. Plastic logistics waste can be treated by three main methods: modified reuse, pyrolysis, and biomass utilisation. For the special types of waste generated by the logistics industry, the unified disposal and biomass resource utilisation of plastic logistics waste and corrugated paper logistics waste will have great prospects for development. By developing functional bacterial communities, mixed substrates can be efficiently converted into biomass resources. This method not only reduces the pressure of urban waste separation, but also achieves precise and efficient resource utilisation of logistics waste.

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Author Contributions

Conceptualization, H.M. and P.L.; methodology, J.Z.; software, P.L.; validation, J.Z. and C.W.; formal analysis, H.M. and P.L.; investigation, H.M. and P.L.; resources, J.Z. and H.M.; writing—original draft preparation, P.L.; writing—review and editing, H.M., P.L. and C.W., visualization, H.M.; supervision, H.M. and J.Z.; project administration, H.M.; funding acquisition, J.Z. and H.M. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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