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Promotion of Household Waste Utilization in China: Lessons Learnt from Three Case Studies

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Abstract: Household waste utilization has been regarded as an important pathway to promote the circular economy paradigm and sustainable development for a long time. However, relevant enterprises are facing dilemmas in terms of the backward disposal methods for food waste, inadequate recycling of low-value recyclable waste and the lack of leading enterprises, resulting in unsustainable expansion of the industry. To address these problems, we investigated governmental departments and 20 household waste utilization enterprises in China. From the investigation, three typical enterprises, representing the advanced technology for food waste, the recycling mode of recyclable waste and the cultivation mode of leading enterprises, were selected for case studies. The results indicate that applying the technology of bioconversion by maggots could improve the utilization of food waste and adopting the "online and offline" dual-channel mode could benefit the recycling of low-value recyclable waste. Additionally, leading enterprises can be cultivated by franchise mode, which can drive the utilization of household waste in China effectively. The findings enrich the theory of household waste utilization in terms of disposal methods, recycling modes and enterprise operation. Practically, this research should enlighten decision-makers to improve household waste utilization. Furthermore, the research results could be generalized in other countries, thereby advancing the household waste management worldwide.

Keywords: household waste utilization; bioconversion technology; online and offline recycling; franchise mode; case study

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1. Introduction

Driven by the growing populations and rapid urbanization in the past 20 years, the amount of global waste reached 2.01 billion tons in 2016 [1]. Meanwhile, in developing regions such as China [2], household waste generation jumped to 242.06 million tons in 2019 (Figure 1), and the figure increased by an average rate of 6.27% per year [3]. China has thus become the largest waste generator in the world [4].

Meanwhile, improper disposal of household waste has brought on several environmental problems, including soil pollution and groundwater pollution, which ultimately cause adverse implications on human health [5–7]. With the "garbage siege" becoming increasingly serious in cities, the management of household waste has been raised to an unprecedented level in China [8,9].

Various legislation and measures on household waste management have proved that the policies on household waste are given growing attention globally, especially the waste management policy proposed by the European Union. The priority principle, "prevention,

reuse, recycling, energy recovery and disposal", has been adopted by many other countries. China continuously improves the policies of household waste management to make them more in line with national conditions based on the experiences of other countries. In summary, the process of household waste management can be divided into three stages in China.

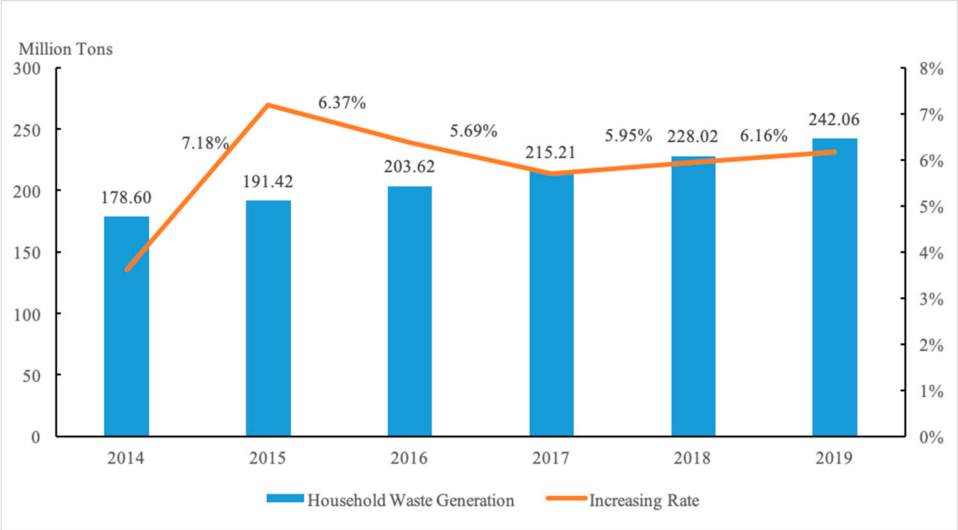

Figure 1. Household waste generation in China.

1. "Centralized disposal" of household waste by landfills and incineration. The Chinese government strongly supported the construction of landfills and incineration facilities, accounting for 73.6% of financial investment for household waste management from 2011 to 2015 [4]. In 2017, household waste disposed in landfills reached 120 million tons [10]. However, landfills are gradually being replaced by incineration because of the long-term potential hazards. In 2020, the average rate of incineration reached 50%, and this rate has been in consistent growth [11].
2. "Improving the utilization rate" of household waste based on source separation. To utilize household waste efficiently, the regulations of household waste sorting are implemented strictly in this stage. In July 2019, Shanghai launched household waste management regulations [12], and many other cities in China such as Beijing, Nanjing, Hangzhou, Shenzhen, etc., have also issued relevant policies of household waste sorting management.
3. "Reducing the totality" of household waste by controlling the whole process. In this stage, the generation of household waste is reduced from the source and the resource utilization is improved at the end, thereby reducing the total amount of household waste and achieving the goal of "zero waste" [13].

At present, China is in the second stage and transferring to the third stage. With the widespread promotion of household waste sorting [14], the volume of recycling has increased a lot. Taking Shanghai as an example, after two months of implementing the regulation, the amount of recyclable materials and food waste surged to 5605 and 9009 tons per day in September 2019 [15], increasing by 409.55% and 109.99%, respectively, compared with the figures in December 2018. However, the development of household waste utilization in Shanghai, and also the whole of China, is still in the initial stage. There is a big gap between the large amount of classified household waste and the utilization ability. Therefore, exploring the promotion of household waste utilization based on the status quo in China is quite necessary and meaningful.

Utilization is proposed based on the principles of 3R, considering waste as a material to be reused rather than disposed of [16]. Additionally, utilization is the most fundamental way to save resources and reduce pollution. Therefore, in recent years, scholars have tried

to analyze waste utilization issues from different perspectives, especially for household waste. Fajfrlíková et al. explored the potential to produce briquettes based on the utilization of household waste [17]. Schmitt-Harsh and Wiseman emphasized the economic and environmental benefits of recycling and utilizing tree debris [18]. Pandey et al. explored the link between sustainable lifestyle and household waste generation as well as the prevailing green practices in utilization in the city of Bhopal, India [19]. Zacho et al. applied the case of a Danish household waste management company and provided more details of the potential value to be captured along with increased resource utilization [20]. Bovea et al. estimated the potential utilization value of small household e-waste. The research showed that about 67.7% of the waste could be refurbished and reused after a subsequent evaluation [21]. Andersson and Stage studied how waste management policies affect household behavior based on the case of Sweden [22]. Xiao et al. reported the results of a survey on public participation in household waste management conducted in Xiamen, China [23]. Ariffin and Zakili found that most respondents realized the adverse impact of household pharmaceutical waste, but proper disposal was seldom adopted in Malaysia [24]. Hamdan and Saidan estimated the generation of waste electrical and electronic equipment in Jordan [25]. Rogowska et al. conducted two case studies to explore the recycling and disposal of pharmaceuticals [26]. Ruzickova et al. evaluated the potential environmental risks in the course of household food waste utilization [27]. Luo et al. proposed a recovery system to promote the utilization of household appliances [28]. Stancin et al. analyzed the utilization possibilities of waste polyurethane based on an experimental analysis [29]. Wei et al. summarized the related research of agricultural waste utilization in China [30]. Furthermore, Ebin et al. proved the feasibility of extracting metal from waste batteries [31]. Ismail and Hanafiah emphasized the necessity of a proper e-waste management system to realize the utilization of waste electrical and electronic equipment [32]. Ascher et al. estimated the economic feasibility and environmental impacts of household waste reutilization based on township-based bioenergy systems [33]. Sharma et al. verified the biological methods that offer a sustainable way to transform food waste to resources [34]. Former studies have improved the utilization of household waste in different aspects; however, few studies clarified the household waste utilization from a comprehensive perspective by considering the infrastructure, technology and operation mode, especially with real-world case studies of utilization enterprises.

Considering the lack of studies on household waste utilization and the urgent situation of household waste management in China, we undertook a comprehensive study of utilization enterprises to address this need. The results of this study provide data and information that are conducive to the planning of strategies and decision-making regarding household waste utilization, thereby promoting household waste utilization in China.

The structure of this paper is organized as follows. The methodology and data collection adopted in this paper are introduced in Section 2. In Section 3, based on the status quo of household waste utilization in China, the main tasks and dilemmas are concluded. Then, three representative enterprises are proposed as case studies in Section 4. In Section 5, the research results are discussed along with strategies for household waste utilization. Finally, the concluding remarks are mentioned in Section 6.

2. Materials and Methods

2.1. Methodology

Case study is one of the prime methods adopted in social sciences [35]. A case study not only produces a detailed and integral description of the situation but also provides focused solutions to the problems. In this study, the case study research method is employed to analyze and explore solutions for the dilemmas of household waste utilization in China.

As seen in Figure 2, the main tasks and problems of household waste utilization in China were proposed based on the status quo. Then, following the investigation of governmental departments and 20 household waste utilization enterprises, we selected 3

representative enterprises as cases to study. At this stage, using the bottom-up analysis approach, we concluded the key points to solve the dilemmas related to household waste utilization in China. Finally, the strategies were generalized and discussed and the main findings were displayed.

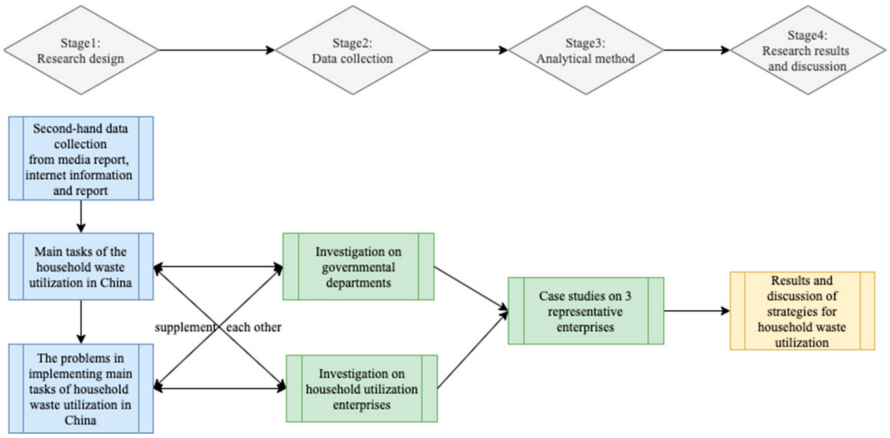

Figure 2. Flow chart of case study.

2.2. Data Collection

The data for this paper were collected from enterprises in Shanghai and Hangzhou. Shanghai is located in the east of China, covering an area of 6340 km^2. It is one of the most developed cities, with a GDP of RMB 3.87 trillion and a population of 24.24 million in 2020 [36]. Hangzhou is the capital of Zhejiang Province, located in southeastern China. It is an important commerce center with a GDP of RMB 1.54 trillion [37] and a population of 11.94 million. Both cities began to pilot the program of household waste sorting in China in 2000. After nearly 20 years of development, the comprehensive utilization capacity of household waste is at the leading level in China, and many promising household waste utilization enterprises have been established in the two cities which are worthy of study. Additionally, the experience can be generalized in other countries, especially in developing regions.

Furthermore, we surveyed government departments to ensure the objectivity of the primary data and discussed the feasibility of development strategies we proposed by face-to-face interviews.

3. Main Tasks and Problems of Household Waste Utilization in China

3.1. Main Tasks of Household Waste Utilization in China

Household waste in China is sorted into four categories: food waste, recyclable waste, hazardous waste and other waste (different names in different cities; other waste is also called residual waste in Shanghai) [38]. Hazardous waste needs to be disposed of in a designated site according to the regulations [39], and 100% of other waste is disposed of in landfills or by incineration. Thus, these two kinds of waste are not considered in this article.

Based on former study [40], we can recognize that food waste is the largest component of household waste, accounting for 64.48% (Figure 3). However, it is not disposed of properly because of the characteristics of high moisture content (generally more than 80%) and rich nutrients [41–43]. If adopting the landfill or incineration method, negative impacts would appear. Therefore, advanced ways of utilizing food waste should be considered.

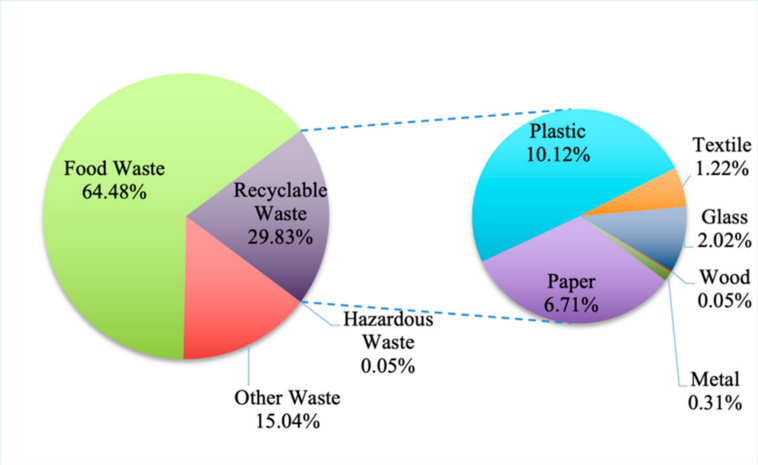

Figure 3. The composition of household waste in China.

Recyclable waste, mainly including paper, plastic, glass, metal and textile waste, has high potential resource value. For instance, in the USA, about 20 million tons of glass waste are produced each year, with a shipping value of USD 29 billion [44]. All of the glass waste can be utilized, and the quality would not change [45,46]. However, in China, recyclable waste is not utilized sufficiently, leading to a large amount of wasted resources [47].

Therefore, the crucial task for China's household waste utilization is the effective utilization of food waste and recyclable waste. To achieve this, it is necessary to identify the problems with food waste and recyclable waste utilization in China, which are discussed in Section 3.2.

3.2. The Dilemmas of Food Waste and Recyclable Waste Utilization in China

3.2.1. The Backward Disposal Methods for Food Waste

Food waste is mainly disposed of in China by the traditional way of anaerobic and aerobic fermentation, with disadvantages such as huge investment, unstable operation and high disposal cost (Table 1). Furthermore, due to eating habits, the components of food waste in China are different from those in other countries. Therefore, imported technologies are not suitable to dispose of China's food waste.

Table 1. Traditional disposal methods for food waste in China.

Component	High-Temperature Aerobic Fermentation Technology						Wet Anaerobic Fermentation Technology				
	Solid Organic Matter	Liquid Matter				Others					
		Biogas Residue	Grease	Organic Matter	Biogas Liquid	Plastic	Impurity	Biogas Residue	Grease	Organic Matter	Biogas Liquid
Proportion	40%	50%				10%	32%	8%	4%	8%	48%
Method	Producing biological humic acid and soil conditioner	Incineration	Outward transport	Biogas power generation	Leachate treatment system	Incineration	Incineration		Outward transport	Biogas power generation	Leachate treatment system
Price	700 RMB/ton					-	110 RMB/ton				
Square	161 m^2/ton						121 m^2/ton				
Process cycle	12–24 h	20–40 days					20–40 days				
Cost	1000 RMB/ton						380 RMB/ton				
Profit	−300 RMB/ton						−270 RMB/ton				

Specifically, many enterprises operate with negative profits. For example, the disposal cost of high-temperature aerobic fermentation is 1000 RMB/ton, but the price of the product

is only 700 RMB/ton. The government has to assist these enterprises with massive subsidies. In Shanghai, the daily output of food waste is about 7800 tons, and the annual subsidy from the government is nearly 1.7 billion RMB/year with a subsidy of 600 RMB/ton. As a result, the government faces a heavy financial burden, and it adversely affects the sustainable development of the household waste utilization industry.

3.2.2. Inadequate Recycling of Low-Value Recyclable Waste

Utilization enterprises are eager to recycle high-value recyclable waste, such as steels, metals, etc. Paper, glass, plastic and textile wastes are ignored due to the low profit levels. Eventually, low-value recyclable waste has to be mixed into other waste and disposed of by incineration and landfills, resulting in incomplete recycling and resource waste.

- Glass waste

Glass waste has the typical characteristics of large volume, high weight and high recycling costs, leading to low enthusiasm for recycling and utilization enterprises. Few enterprises can operate normally without subsidies as the profits are meager. For example, recyclers can only earn about 1 cent/kg of glass waste in Shanghai. Therefore, most of the glass waste is mixed into other waste and recycled by the environmental sanitation department.

- Paper waste

Paper waste is the main raw material for papermaking in China, and more than 50% of paper waste comes from household waste. In 2018, the total production output of paper in China reached 10.435 tons, and 62% of it used paper waste as the raw material. However, the sorting of paper waste is not currently meticulous enough. It is mainly divided into 3 categories, namely old newspapers, magazines and cartons, which cannot meet the requirements of paper waste utilization enterprises. The value of paper waste is not fully utilized.

- Plastic waste

There are about 3000 plastic waste utilization enterprises in China. The industrial chain, including community recycling sites and sorting centers, has been formed preliminarily [48]. However, since China imposed a ban on the import of plastic waste [49], plastic waste has sharply decreased. The enterprises have to focus on the utilization of domestic plastic waste. How to recycle domestic plastic waste effectively has become a problem [50].

In addition, with the booming development of China's express delivery industry, packaging waste has become an important part of plastic waste. In 2018, China's express delivery business volume reached 50.7 billion, and the total consumption of express packaging materials was 9.412 million tons, increasing by 447.19% compared with the figure in 2000. Additionally, 4.5 million tons of plastic waste was produced, but almost all of it was not recycled [51].

- Textile waste

China is a large textile-manufacturing country with an annual output of 20 million tons of textile waste. However, 80% of textile waste is not recycled. In Shanghai, the annual production of textile waste is about 40,000 tons, but less than 3000 tons can be recycled, and most of it is not utilized [52].

3.2.3. Lacking Leading Enterprises

In 2017, there were about 90,000 utilization enterprises in China [53], most of which were self-employed and small-sized. Only about 1500 enterprises are in a designated scale and mainly engage in recycling work. However, they only can recycle 10–20% of the waste, while other waste is recycled by hawkers and small enterprises. Meanwhile, most enterprises still adopt backward, traditional treatments, resulting in insufficient value-added products and low profitability of the enterprises [54].

In addition, the household waste management policies are different in different cities in China, causing barriers to the large-scale operation of non-local utilization enterprises. It is hard for them to grow into leading enterprises due to the poor growth environment.

4. Case Study

4.1. Shanghai "Yuanshi": Maggot Bioconversion Technology for Food Waste

Yuanshi Environmental Technology Development Company is dedicated to developing food waste utilization technology. It has successfully applied maggot bioconversion technology for food waste to realize its harmless disposal and profitable utilization (Figure 4).

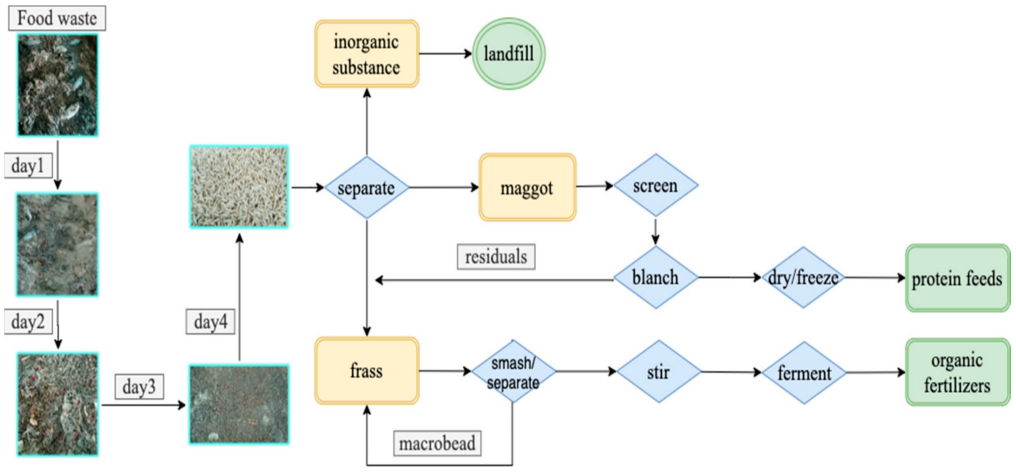

Figure 4. The process of food waste utilization by maggot bioconversion technology.

Specifically, maggots absorb the organic components from eggs to larvae. In this process, the nutrients, including nitrogen, sulfur, phosphorus and protein, are decomposed by the maggots without environmental pollution. Thus, compared to other treatments, the output of pollutants such as hydrogen sulfide and hydrazine is reduced a lot.

Additionally, the maggots cultivated by food waste can be processed as high-quality protein feeds and organic fertilizers with high economic value. This is also more efficient compared with other treatments and other insects, such as *Hermetia illucens*, cockroach and earthworm (Table 2).

Table 2. Comparison between different bioconversion technologies.

Insects	*Hermetia illucens*	Earthworm	Cockroach	Maggot
Growth cycle (day)	15	30	90	5
Cultivation area (m^2/ton)	50	80	60	35
Degree of process automation	Medium	Low	Low	High
Economic value (RMB/ton)	500	100	200	750

4.2. Shanghai "Chengsheng": "Online and Offline" Dual Channel to Recycle Recyclable Waste

Chengsheng Environmental Protection Technology Company has been engaged in the recycling of recyclable waste for 7 years, and the advantage is a combination of online and offline recycling (Figure 5).

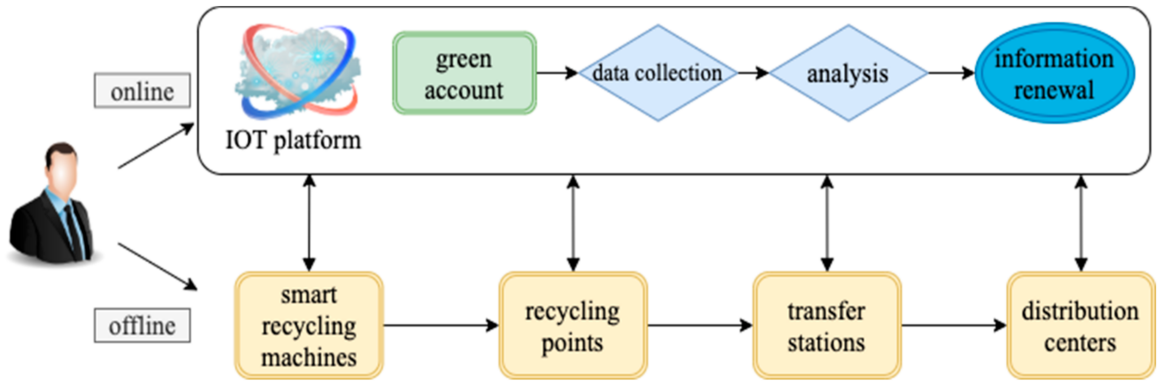

Figure 5. The combination of online and offline recycling.

1. For online recycling, the IOT platform, GIS and other technologies are adopted to realize the interaction and renewal of information in every procedure, and customers' dropping behavior can be recorded by a unique green account. Thus, supervision of the whole process of recyclable waste is realized, which benefits waste management for relevant departments.
2. For offline recycling, an integrated recycling system including recycling points, transfer stations and distribution centers has been built. To facilitate the recycling work, intelligent recycling machines are provided in every recycling point.

In this way, the rate of citizen participation and the accuracy of sorting have reached 95.51% and 92%, respectively. Thus far, Chengsheng's service has covered most areas in Shanghai, including Huangpu District, Putuo District, Jing'an District, etc. Furthermore, it was awarded the title of the new recycling model enterprise in China by the China National Resources Recycling Association.

4.3. Hangzhou "Huge Recycling": Leading Enterprise Cultivated by Franchise Mode

The Huge Recycling Company has become the leading enterprise of household waste recycling in Hangzhou by the franchise mode (Figure 6), which is supported by the government. The franchise mode means that all household waste, including high-value waste and low-value waste, must be provided to this company as raw material in the stipulated area. Meanwhile, the enterprise guarantees the recycling work in this area, thereby realizing a win–win situation between the enterprise's profitability and waste recycling work. With Huge Recycling's development, many utilization enterprises and remanufacturers are gathered, which ameliorates the industry chain's structure and drives the development of the industry.

The Huge Recycling Company has served more than 200,000 customers in Yuhang District, and the weight of all kinds of household waste was more than 7800 tons in 2017. The rate of reduction and harmless disposal of household waste reached 23% and 100%, respectively.

The experiences based on the case studies, including highlights, types and results, are shown in Table 3.

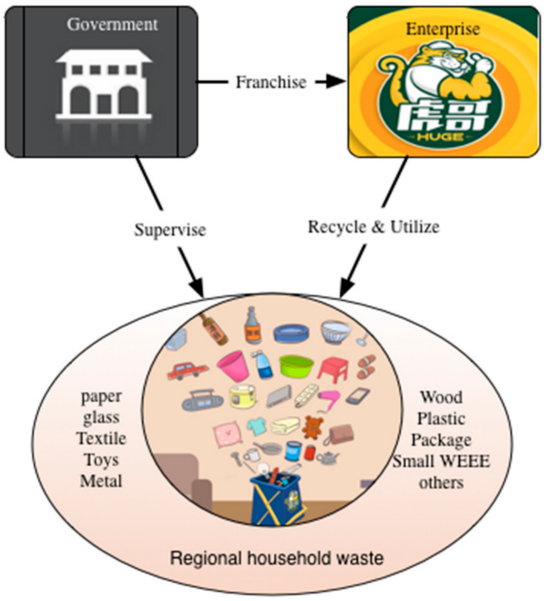

Figure 6. Franchise mode between enterprises and government.

Table 3. Experiences from three case studies.

Cases	Highlights	Types	Results
Case 1: "Yuanshi"	Adopting bioconversion technology (maggots) to degrade food waste and taking the maggots' larvae as protein feeds to make profits.	Food waste	• No pollution generated • Lower costs • Higher profits • Shorter processing cycle
Case 2: "Chengsheng"	Building a dual online and offline recycling channel using the IOT platform, smart recycling machines, etc.	All kinds	• Whole process management • Integrated recycling system • The rate of citizens' participation is 95.51% • The accuracy of classification is 92%
Case 3: "Huge"	Cooperating with the government by franchise mode and becoming a leading enterprise.	All kinds	• Overcoming the dilemma of "insufficient sources" • Solving the problem of low-value recyclable waste • The reduction rate of household waste is 23% • The harmless disposal rate is 100%

5. Results and Discussion

5.1. Bioconversion Technology by Maggots for Food Waste

In terms of value-added household food waste, a new strategy is to use food waste as the basis to cultivate edible insects [55]. Maggots can be cultivated in a high-density environment and are easy to manage procedurally. However, due to the production of a large number of leachate, the maggot bioconversion technology would not be profitable

when the amount of food waste is over 200 tons/day according to the investigation. Therefore, maggots are proposed as a means to utilize food waste in regions with an output of less than 200 tons/day.

For regions with a daily output of more than 200 tons, the technology of maggot bioconversion could be combined with anaerobic fermentation to utilize food waste. Some enterprises, such as Shanghai Laogang Waste Utilization Company, which adopt anaerobic technology should also set up maggot bioconversion facilities. After the food waste is sorted into solid substance and liquid substance, maggot bioconversion technology can be used to convert the solid substance into protein feeds and organic fertilizers, while the liquid substance can be disposed of by anaerobic fermentation. In this way, the profit from household food utilization would be RMB 285 per ton, thus improving the economic efficiency and reducing the government's subsidy burden (Table 4).

Table 4. Relevant parameters of household food waste utilization.

Technology		Maggot Bioconversion	Maggot Bioconversion + Anaerobic Fermentation
Cost (RMB/ton)		315	385
Time (day)		1	1 (solid substance)
Production (%)	**Protein**	20	10
	Fertilizer	40	20
	Oil	4	4
The output of sewage (%)		0	0
Area covered (square meter/ton)		50	50
Subsidies (RMB/ton)		0	0
Profits (RMB/ton)		435	285

5.2. Recycling Low-Value Recyclable Waste Based on an Online and Offline Dual Channel

Case 2 proves that the online and offline dual channel has a positive effect on citizens' participation and the sorting accuracy of recycling work. The single recycling mode could be transformed to the dual-channel recycling mode in the following ways.

1. For the offline enterprises recycling low-value recyclable waste, smart recycling machines that can be placed in public areas for offline recycling work could be developed. Meanwhile, these enterprises can build an online platform to expand their O2O (online-to-offline) service based on smart recycling machines.
2. Traditional utilization enterprises can cooperate with online recycling enterprises. Apps or smart recycling machines should be developed, thereby constructing an "online and offline" dual channel.
3. For online recycling enterprises, it would also be beneficial to work with traditional enterprises to share their logistic service by collaborating with mature e-commerce platforms [56].

5.3. Cultivating Leading Enterprises by Franchise Mode

Leading enterprises can drive the utilization of household waste. They can not only attract the inflow of talent, capital and technologies but also provide references for other enterprises. The cultivating procedures of leading enterprises are as follows:

(1) Selecting the key enterprises to be cultivated. The enterprises with the potential to achieve development goals are selected through a comprehensive assessment of the market scale, core technology, recycling network, and other aspects of existing enterprises.
(2) Granting the franchise mode to key enterprises. Within the prescribed scope and operating period, key enterprises have the right to operate this project and make

profits. The government supervises key enterprises and intervenes in market prices to ensure the coordinated development of enterprises and industries.

(3) Constructing a full-featured industry park. The park should be constructed by taking key enterprises as the core and the industry chain should be integrated into the park. Also, building high-tech facilities and comprehensive service platforms is necessary to form the scale effects of key enterprises.

(4) Strengthening governmental support. The government should support key enterprises by reducing taxes, such as VAT (value-added tax) reduction, or increasing financial subsidies.

6. Conclusions

Currently in China, household waste classification policies are being widely implemented to build a circular economy. To dispose of the sorted waste scientifically, utilization is obviously a more suitable way than "centralized disposal". In this article, based on the current situation and main problems of China's household waste utilization, we launched an investigation between governmental departments and enterprises, and representative enterprises were selected as cases to study. Subsequently, effective solutions to existing problems have been proposed to promote the utilization of household waste. The main findings are as follows:

1. The main task in China regarding household waste utilization is the effective and efficient utilization of household food waste and recyclable waste. Food waste and recyclable waste are not only large in proportion and complex in composition but also have a high potential value. Therefore, the utilization of food waste and recyclable waste should be considered first.
2. Bioconversion technology by maggots improves the utilization of food waste. Due to the high organic content in Chinese food, finding a suitable technology is the main bottleneck in the utilization of food waste. Bioconversion by maggots is the best way, which can make high profits and be combined with anaerobic fermentation. In addition, enterprises can be independent of government subsidies in this way.
3. An online and offline dual channel assists the recycling of low-value recyclable waste. By developing an online and offline dual channel, the information flow, logistics flow and capital flow can be integrated. All categories of recyclable waste can be recycled. Additionally, based on the dual channel, supervision and management of the whole process can be realized.
4. Franchise mode supports the cultivation of leading enterprises. Through cooperation between the franchise mode and the government, household waste in the stipulated area is allocated to specific enterprises. Meanwhile, enterprises can obtain enough raw materials to make profits, which provides a suitable environment to develop leading enterprises. Furthermore, with the establishment of facilities and the improvement of relevant supporting policies, the agglomeration effect would form and leading enterprises would become the "locomotives" of industrial development.

This study clarifies the status quo of household waste utilization and proposes strategies for household waste utilization in China based on representative case studies. It enriches the theory of household waste management and provides a research basis for China to develop a circular economy. There are some issues that can be resolved in the future research: firstly, not all types of household waste are included in this research; secondly, food waste bioconversion by maggots and recyclable waste recycling by a dual channel could be developed through further economic and environmental analyses; and thirdly, the impact of cultivating leading enterprises could be provided with more relevant information.

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