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Classification and Resource Utilization of Rural Waste in China

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Abstract: In this study, we examined the problems inherent in the classification and utilization of rural waste in China. First, the generation of, hazards associated with, and the significance of recycling rural waste were described. Subsequently, we analyzed the issues that challenge the resource utilization of rural waste in detail, by evaluating the quantity generated, regional distribution characteristics, and the resource-utilization situation of rural waste in China. A reasonable design for the development path and phased targets was subsequently provided, based on the current goal of developing a beautiful countryside and the development trend in resource utilization of rural waste. Finally, we proposed supporting measures and policy suggestions for future resource development and utilization of rural waste.

Keywords: rural waste; classification; resource; development strategy; policy suggestion

1 Introduction

China produces the highest amount of solid waste in the world. Each year, nearly 1.2×10^{10} t of solid wastes from various economic activities and life processes are produced, among which the annual production of rural wastes exceeds 5.3×10^{9} t. The disorderly stacking of most rural household wastes, on-site burning of agricultural wastes and forestry residues, and the random discharge of livestock and poultry excrement cause serious atmospheric and agricultural pollution, leading to a significant waste of resources, with severe impacts on agricultural ecology and the urban environment. Wastes are valuable resources that have been misplaced. The amount of rural waste should be minimized, the generated waste should be significantly reutilized by converting it into a resource, the establishment of recycling agricultural systems should be accelerated, and the efficiency of resource consumption should be improved. This would not only solve the energy and environmental problems in rural areas, but also create new industries to increase employment, improve farmers' economic circumstances, and result in significant environmental, economic, and social benefits.

2 Hazards of rural wastes and significance of resourcelized utilization

2.1 Origins and hazards of rural wastes

Rural wastes mainly refer to rural domestic wastes, agricultural wastes, forestry residues, and livestock and poultry excrement. Rural domestic wastes mainly include kitchen waste, waste plastics, waste paper, and ash. Agricultural wastes mainly contain crop straws and agricultural product processing residues. Forestry residues incorporate forest harvesting residues, wood processing residues, and afforestation and pruning residues.

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Livestock and poultry excrement refers to the feces and urine discharged by livestock (such as cows, sheep, and pigs) and poultry, as well as their mixture with litter.

The hazards and environmental influence of rural wastes originate mainly from straw burning, livestock and poultry excrement, and misplacement of rural domestic wastes. Straw burning is especially prominent during the transition period from winter to fall in China and has become a cause for haze. It continues despite repeated prohibition. Livestock and poultry excrement lead to water quality deterioration, the eutrophication of lakes and reservoirs, severe heavy metal pollution in soil, land hardening and salinization, and the emergence of pathogenic microorganisms and parasitic diseases in livestock and poultry. The greenhouse gases released by large ruminants are significant contributors to the greenhouse effect [1]. Owing to the lack of efficient waste disposal facilities and operational management mechanisms, most rural domestic wastes are randomly piled up and burned on site. These problems are yet to be solved effectively. With the improvement of living standards in rural China, nonbiodegradable materials such as food bags, plastic bags, agricultural films, and fertilizer bags have begun to gradually accumulate, posing a threat to the ecological environment in rural areas.

2.2 Significance of resourcelized utilization of rural wastes

2.2.1 Enhances the ecological environment in rural areas and strongly supports the development of beautiful and livable rural areas

A beautiful and livable countryside is characterized by its beauty and greenery, including beautiful rural scenes and villages. It remains a necessary requirement for the advancement of a new type of urbanization and the construction of a new socialist countryside and ecological civilization. The resourcelized utilization of rural wastes helps prevent and control pollution at its source, enables comprehensive utilization of straws, increases the intensity of the prevention and control of environmental pollution caused by the breeding industry, and improves the agricultural production environment and rural ecological environment. This provides a strong support for the construction of a beautiful and livable countryside and an ecological civilization.

2.2.2 Solves rural energy shortage and promotes rural energy revolution

Rural areas represent a weak link in China's energy revolution. The energy sources in these areas are fairly primitive, with most people residing in these areas using energy in a relatively primitive way. In particular, it involves a significant amount of carbon, with biomass energy sources such as straw and fuel wood still being the major energy sources for farmers, accounting for more than half of their domestic energy supply. As a kind of low-carbon, clean, and renewable energy that can be used as a substitute for fossil energy, the use of biomass energy in rural areas can not only mitigate the shortage of rural energy, but also contribute to the alleviation of national energy and power shortage.

2.2.3 Promotes development of a green agricultural industry and creates new economic growth points

Development of a green agricultural industry can be further promoted by maximizing the resourcelized utilization of rural wastes, making full use of waste resources, and promoting the modernization of the agricultural industry. In 2015, the Ministry of Environmental Protection of the People's Republic of China implemented eight major projects regarding green industries, such as green clean energy, solid waste resourcelization, and comprehensive improvement of rural environments. This further enhances the importance of resourcelized utilization of rural wastes, driving the vigorous development of industries, and creating new economic growth points with large green inputs.

3 Output of rural wastes in China and the status of its resourcelized utilization

3.1 Output of rural wastes in China and its distribution characteristics

Due to the lack of statistical data, the output of rural wastes can only be estimated in accordance with the discharge characteristics of the various types of waste. The physical quantity of waste can be obtained by calculating the amounts of rural domestic waste, agricultural waste, forestry residues, and livestock and poultry excrement based on: the rural population and per capita waste generation [2]; agricultural product output and the ratio of the output of the main product to the by-products of crops [3,4]; cutting limits approved by the government [5]; and livestock and poultry counts with daily feces discharges [6,7]. The results show that the annual amount of rural domestic wastes in China decreased from 1.35×10^8 t in 1995 to 0.95×10^8 t in 2015, with an estimated caloric value of 4000 kJ·kg^{-1}. The resource amount in 2015 reached approximately 1.3×10^7 ton of coal equivalent (tce), with continuous improvement in the agricultural production level in China. The total output of crop straws also presented an upward trend overall. The output of agricultural wastes in China in 2015 reached 9.94×10^8 t, among which commodity crop straws (such as maize, rice, and wheat) accounted for 73.2%, with the remainder being accounted for by the main crop straws in China. On converting the caloric values of various crop straws into standard coal, it was found that their total amount in 2015 reached 4.74×10^8 tce. In the past 15 years, forestry processing residues totaled 0.72×10^8 t to 0.86×10^8 t, while the annual output of fuel wood was approximately 0.5×10^8 t [5]. In 2015, the annual output was 1.38×10^8 t, which is equivalent to 7.875×10^7 tce. The amount of livestock and poultry excrement

reached 4.1×10^9 t in 2015, which is equivalent to 4.21×10^8 tce, among which pigs, cows, sheep, and poultry accounted for 43.6%, 41.0%, 6.6%, and 6.8%, respectively. To summarize, in terms of the total amount, the waste generated in rural China in 2015 reached 5.327×10^9 t, which is equivalent to 9.87×10^8 tce.

From the perspective of regions, the Henan Province and the Sichuan Province produced the most rural waste in 2015, at 4.51×10^8 t and 4.38×10^8 t, respectively. Guangdong Province produced the most rural domestic wastes, up to 7.27×10^6 t, in 2015. Henan Province and Heilongjiang Province generated the most agricultural waste, at 8.607×10^7 t and 8.546×10^7 t, respectively, in 2015. Yunnan Province and Guangxi Province generated the highest forestry residues, with 1.557×10^7 t and 1.366×10^7 t, respectively, in 2015. Sichuan Province and Henan Province produced the most livestock and poultry excrement, totaling 3.76×10^8 t and 3.56×10^8 t, respectively, in 2015 (Fig. 1).

3.2 Status of the resourcelized utilization of rural wastes in China and major issues identified

Backfilling is the main method of disposal of domestic wastes in rural China, followed by incineration, carting away, no-treatment disposal, etc. The rate of recovery of resources has been appreciably lower, especially in relatively impoverished and backward areas, where most of the wastes are randomly piled. The main ways to utilize the crop stalks, an agricultural waste, include straw turnover, transformation into fodder, and utilization as energy. In 2013, the rate of multipurpose utilization of agricultural wastes was merely 77%, with more than 3×10^8 t of agricultural wastes not being utilized effectively. The recovery of energy from forestry wastes has made relatively greater progress, as a diversified pattern dominated by briquette fuel, liquid fuel, cogeneration, and gas fuel has been formed. Currently, the rate of multipurpose utilization is over 95%. Bio-aerobic high-temperature fermentation fertilizer production and anaerobic fermentation biogas production continue to be the topmost choices for the recovery of resource from the excrement of livestock in foreign countries. However, the rate of multipurpose utilization of livestock excrement is merely 40%.

Multiple reasons have led to a low rate of recovery of resources from agricultural wastes in China. Some of the prominent issues responsible for this are as follows: ① the absence of overall planning for the collection, transportation, and disposal of agricultural wastes at the district (county), village (town), or local scale; ② the lack of relevant laws and regulations as some of the laws regarding the protection of the rural environment

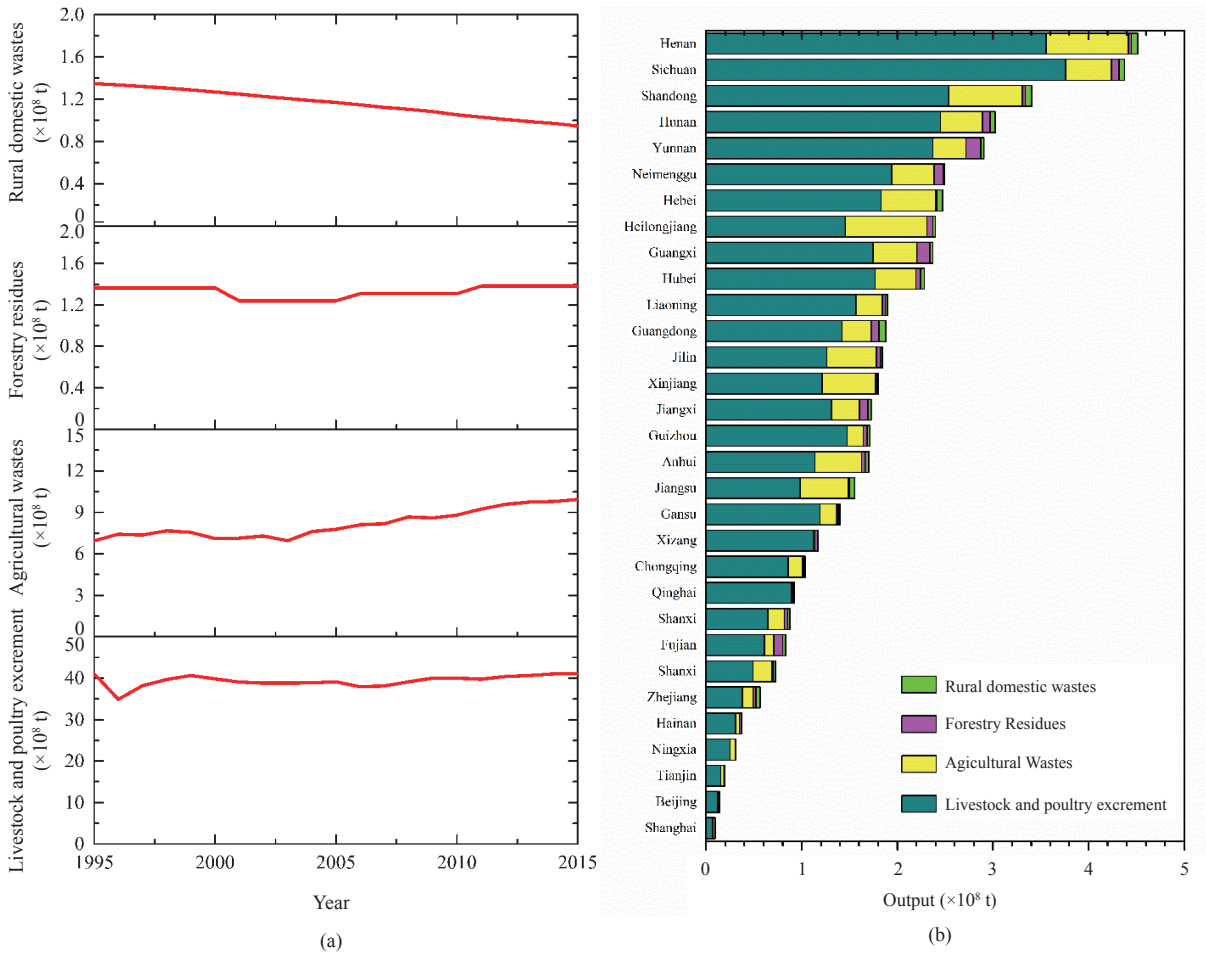

Fig. 1. Output and distribution of rural wastes in China.

are merely principles or policies, which are neither practical nor implementable in rural areas; ③ the imperfection of technological systems due to the absence of regional laws and technical standards regarding the recovery of resources from agricultural wastes; ④ the absence of environmental monitoring in rural areas due to the poor environmental infrastructure in rural areas; and ⑤ the incredibly low marketization level due to a lack of interest and low levels of participation among the village residents.

4 Development trends for the recovery of resources from rural wastes in China

4.1 Prediction of the amount of rural wastes in China

The quantity of rural wastes potentially generated in the future is mainly subject to two factors: rural population variation and the quantity generated per capita. On the one hand, the rural population will decrease by 168 million by 2030. On the other hand, the quantity generated per capita may increase as the living standards in rural areas improve. The agricultural wastes can be predicted according to the ratio between the grain output and millet straw, or the linear relationship between the grain output and agricultural residues. The quantity of forestry wastes generated may remain at the same level because the logging quantity may be further restricted in the future. The prediction of the quantity of livestock excrement generated may refer to the ratio between the actual output of meat, eggs, and milk, and the quantity of excrement produced during the same year in the past [8]. According to the prediction methods mentioned above, it is estimated that the total generated quantities of agricultural wastes may range from 5.447 $\times 10^9$ t to 5.625 $\times 10^9$ t in 2020–2030, which is approximately equivalent to 1.05×10^9 tce and 1.08 $\times 10^9$ tce, respectively (Fig. 2).

4.2 Analysis of comprehensive benefits of recovery of resources from rural wastes

The recovery of resources from rural wastes not only provides energy, but also promotes investment, increases tax revenues, facilitates employment, improves the income of local farmers, and saves national land resources via the collection, storage, and transportation of wastes according to their varying potentials as resources, which leads to significant economic, environmental, and social benefits. According to the development goals regarding the recovery rate of domestic wastes, the rate of multipurpose utilization of agricultural wastes, and the resource recovery rate for the excrement of livestock determined by the Agriculture Sustainable Development Program, the total quantity available for the recovery of resources from rural wastes from 2020 to 2030 were estimated to be equivalent to 8.43×10^8 tce and 9.93×10^8 tce, respectively (Table 1). Therefore, based on the analysis of how the recovery of resources from rural wastes uses industrial investment to promote its benefits, the reduction in the emissions of carbon dioxide and sulfur dioxide, and how it facilitates employment and improves the income of farmers [9], we can predict the comprehensive benefits of the recovery of resources from rural wastes from 2020 to 2030 (Table 2).

5 Strategic objectives of and policy suggestions for recovery of resources from rural wastes in China

5.1 Strategic objectives for the development of recovery of resources from rural wastes in China

The strategic positioning for the classification and utilization of rural wastes should be determined by 2020. Modern industrial approaches, as well as operational and management

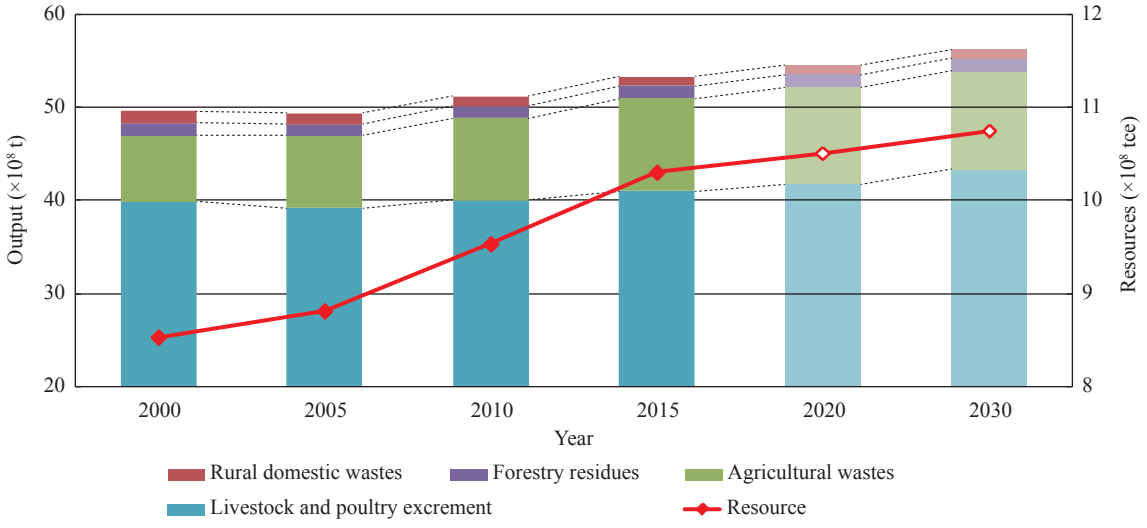

Fig. 2. Prediction of agricultural wastes in China through 2020 and 2030.

Table 1. Future rural waste resources in China.

Classification	Amount of resources	2020	2030
Domestic wastes	Theoretical reserve ($\times 10^8$ tce)	0.13	0.13
	Resource utilization target (%)	30	60
Agricultural and forestry wastes	Theoretical reserve ($\times 10^8$ tce)	6.18	6.26
	Resource utilization target (%)	85	95
Livestock manure	Theoretical reserve ($\times 10^8$ tce)	4.18	4.34
	Resource utilization target (%)	75	90
Total	Total utilization of resources ($\times 10^8$ tce)	8.43	9.93

Table 2. Comprehensive benefits of the recovery of resources from rural wastes in China.

Classification	Amount of resources	2020	2030
Economic benefits	Promoting investment (100 million yuan)	33 720	39 720
Environmental benefits	Emission reduction of CO_2 ($\times 10^8$ t)	22.51	26.51
	Emission reduction of SO_2 ($\times 10^8$ t)	0.17	0.20
Social benefits	Employed population (ten thousand people)	1475	1142
	Increase in total income for farmers (100 million yuan)	3 794	4 469

patterns, should be preliminarily realized in combination with the development of new and beautiful rural areas, rural poverty alleviation, as well as rural environment, energy, and resources. Random piling of agricultural wastes, open incineration of biomass wastes of rural forests, and arbitrary disposal of the wastewater from livestock breeding should be eliminated, while the recycling of agricultural resources should be realized within the agricultural production areas. A classification and collection system for rural wastes should be developed to establish a distributed and small collection and disposal system for agricultural domestic wastes that covers major cities and towns. An ecological agricultural production mode should be promoted to improve the local recovery of resources from biomass wastes such as crop stalks and livestock residues. This will enable the multipurpose utilization rate of crop stalks to reach 85% and that of the livestock residues to reach over 75%.

The promotion of an ecological agricultural production mode will be crucial for the improvement of agricultural production and living environment in 2025. A distributed and small collection and disposal system of agricultural and domestic wastes that covers all administrative villages should be constructed. Biomass resources such as crop stalks, livestock residues, and forestry wastes should be locally recovered as resources or energy. All rural domestic wastes should be disposed of according to the biosafety protocols. The recycling of agricultural resources should be realized within the national modern agricultural demonstration areas and major grain-producing counties. The multipurpose utilization rate of crop stalks could reach 90%, while the multipurpose utilization rate of livestock wastes could reach over 80%.

In 2030, the realization of beautiful rural areas and the establishment of a new pattern of sustainable agricultural development should be determined as the objective, creating an ecological agricultural pattern that incorporates recycling to completely utilize biomass waste. Rural wastes could be recovered as resources at the nearest location. The use of rural wastes for the recovery of resources can be highly effective, as the environment of the production area remains good and the ecosystem remains stable. The resource recovery rate of rural wastes across China would greatly improve, with the multipurpose utilization rate of crop stalks reaching over 95%, and the multipurpose utilization rate of livestock residues reaching over 90%.

5.2 Suggestions for the development of classification and resourcelization of rural wastes in China

(1) Conduct top-level design and planning. First, it is recommended that the implementation of top-level design and planning should take into account the major needs of ecological cultivation development, integrated urban and rural development, urbanization, beautiful countryside development, new rural construction, and industry transformation and upgrading. Development strategies and roadmaps for the classification and resourcelization of rural wastes should be formulated and established, along with scientific and normalized compensation mechanisms and pricing standards. Additionally, a new planting and raising mode and a rural way of life that promotes the development of "urban and rural mines" should be gradually developed. Lastly, the strategy of "waste-based production" should be implemented for forestry residues and livestock and poultry excrement. This means, the breeding scale is tailored in accordance with the amount of rural wastes, while prioritizing the resourcelization and reutilization of wastes.

(2) Improve the awareness of local governments and expedite

the development of laws and regulations concerning the management and control of rural wastes. It is recommended that the local governments at all levels have a complete understanding of the significance of and urgent requirement for managing and controlling rural wastes. Based on this understanding, a series of laws and regulations for the protection of the rural environment, based on the local characteristics, should be developed. In the meantime, the local governments should actively pass special laws and implement them as soon as possible, providing practical guidance for the management and control of rural wastes to achieve compliance with the laws.

(3) Promote diverse classification and resourcelization technologies in accordance with local conditions and establish a systematic and efficient management mode to guarantee the processing of rural wastes. A dedicated waste processing company should be established to systemize the collection, recovery, processing, and sales of wastes, which should be operated based on an efficient commercialization mode. Additionally, for urban and rural wastes, diverse disposal methods should be adopted to enhance the resourcelized utilization rate of rural wastes. These methods include the energy and chemical industry system for agricultural and forestry wastes, comprehensive utilization system for solid domestic wastes, resourcelization system for characteristic agricultural and forestry wastes, energy and chemical system for livestock and poultry excrements, co-processing system for multiple wastes, and polygeneration system.

(4) Strengthen the investments and inputs and perfect the processing facilities of rural wastes. The problem of managing and controlling wastes can be solved via governmental investments, funds raised within the society, and money and labor from farmers. The financial inputs into the processing of rural wastes should be increased to ensure sufficient budget for carrying out tasks like establishing appropriate infrastructure, such as waste transfer stations and points, and providing waste transportation vehicles and classified dustbins that meet the operational requirements. It is recommended to solicit investments from multiple parties for the construction of rural sanitation infrastructure.

(5) Set up a mechanism for the public to participate in the management and control of wastes. The villages should establish propaganda and guidance mechanisms, effectively using the media to widely propagate the significance of waste resource utilization, thus deeply rooting the waste recycling and utilization concept in the minds of the masses, allowing them to obtain the real benefit and encouraging them to consciously shoulder the responsibility of environmental protection. The local governments should play an autonomous role in the management and construction of environmental sanitation facilities, thus achieving decentralized management and scientific decision-making.

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