Characteristics and forecasting of waste textile recycling in China

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ABSTRACT

China is the largest producer and consumer of textiles globally, generating more than 22 million tons of textile waste annually. Although the government has introduced a series of policies to promote the recycling of waste textiles, the recycling rate of waste textiles in China remains low, at only 20%. To further promote the recycling of waste textile, analyzed the characteristics and trends of textile waste recycling in China, providing a foundation for dynamically adjusting the refining supportive policies. Based on the waste textile recycling data from 2015 to 2023, the accuracy of forecasting results from three Grey models—namely, the Grey Verhulst model, GM (1,1) and discrete GM (1,1)—was compared. The results indicate that the Grey Verhulst model demonstrates superior modelling and generalization abilities for recycling data characterized by limited time and incomplete information, with an average relative error of only 5.92%. In contrast, the GM (1,1) and discrete GM (1,1) models showed errors of 23.93% and 23.66%, respectively. Furthermore, the Grey Verhulst model was used to predict waste textile recycling from 2025 to 2030, showing a gradual slowdown in growth, with an average annual increase of only 0.59%. To further promote textile recycling and generate economic benefits, several recommendations are proposed, including the introduction of supportive policies to encourage active recycling, the exploration of new models to enhance the economic returns from waste textile recycling, and the optimization of sorting technologies to improve efficient recycling. The forecast model and recommendations provided in this paper aim to contribute to the sustainable development of the textile industry in China.

Keywords: waste textile recycling; characteristic analysis; Grey Verhulst model; trend prediction; countermeasure

INTRODUCTION

China is the largest producer and consumer of textiles, with textile processing accounting for over 50% of global output, generating more than 22 million tons of textile waste annually. Studies have shown that if all of this waste were recycled, it could yield 12 million tons of chemical fibers and 6 million tons of natural fibres each year, potentially saving 24 million tons of crude oil [Teng Yue, 2023]. However, the recycling rate of waste textiles in China only 20% at present [Huang, 2015, Han, 2022]. This striking figure not only underscores the large resource wastage but also highlights the vast economic potential of textile recycling. In response, the government has implemented a series of regulations and policy initiatives aimed at promoting the recycling and utilization of waste textiles recent years. Despite significant governmental support and gradually increase in consumer awareness, the recycling rate of waste textiles in China remains critically low. This situation calls for a thorough examination of the current status and future trends in textile waste recycling, identification of the challenges that hinder progress, and the development of strategies to enhance recycling rates.

Accurate forecasting is essential for informed decision-making. Researchers have developed data-driven forecasting models based on large datasets across various fields, including export trade [Wang, 2011], population forecasting [Guo X, 2022, Tong M, 2020], and e-commerce [Zhang Y Z, 2019]. These models not only enable rapid and accurate predictions of developmental trends but also identify critical factors shaping development. However, in the context of textile recycling, the limited availability of statistical data on annual recycling volumes presents significant challenges in making reliable predictions, especially when working with small samples. Previous studies have shown that Grey forecasting models, which are particularly suited for small-sample data, offer a feasible solution to address the inherent uncertainty of such datasets [Julng D,1989, Yu X, 2014, Zhou Jie, 2014]. Meanwhile, as government policies and the social environment continue to evolve dynamically in real time, the impact of early information on future trends diminishes over time. Relying solely on traditional forecasting models, which assume relatively static conditions, can thus hinder accurate predictions of textile recycling volumes.

In this paper, a Grey forecasting model is applied to an empirical analysis of textile recycling data in China, taking advantage of the strengths of the Grey model in small-sample adaptability, low data distribution requirements, dynamic modelling capability, and high efficiency. The forecasting results were compared using the Grey Verhulst model, the GM (1,1) model and the discrete GM (1,1) model, demonstrating the effectiveness and accuracy of the proposed approach.

Furthermore, the Grey Verhulst model is used to predict textile recycling volumes in China for the next six years, with accompanying recommendations to expand recycling efforts and create economic benefits at scale.

STATUS AND TREND OF WASTE TEXTILE

Trends in market and policy for waste textile recycling

The generation of waste textiles is increasing at a rapid rate of over 10% annually, while the efficiency of recycling and reuse remains relatively low[4]. In response to this challenge, government reports since 2020 have emphasized the need for a comprehensive green transformation of the economy and society. Key objectives include accelerating the development of green, low-carbon industries and fostering a circular economy. In this context, a series of policy measures have been introduced across various regions to promote the recycling of waste textiles.

Concurrently, the development of standards has played a crucial role in improving the efficiency and quality of textile recycling [Guo Yan, 2022]. Table 1 summarizes the national and industry standards for waste textile recycling. Under the guidance of the "14th Five-Year Plan" (initiated in 2021), the establishment of China's waste textile standard system has entered a phase of rapid development. These standards serve as a key driver for the industry, providing important guidance for the sector's growth and establishing a strong foundation for the standardization and sustainable development of waste textile recycling. Industry standards are increasingly tailored to address the specific sources of waste textiles and further refine management practices across the entire recycling process.

Table 1. Standards for Waste Textile Recycling

Implementation year	Title of standards	Level
2020	GB/T 38418-2019 General technical requirements for donated textiles	National Standard
2021	GB/T 38923-2020 Classification and code of textile waste	National Standard
2021	GB/T 38926-2020 Technical specification for collection of textile waste	National Standard
2022	GB/T 39781-2021Technical specification for recycling of textile waste	National Standard
2018	T/CNTAC 6-2018 General technical requirements for donated textile	Industry standard
2019	T/CACE 012-2019Specification for the textile waste collection and recycling	Industry standard
2019	T/SACE 003-2019The construction of domestic garbage sorting the specification of the recycle and use of residential waste textiles	Industry standard
2021	T/CRGTA 009-2021Technical specification for second-hand textile clothing circulation	Industry standard

In addition to policy support, consumer behaviour is also shifting. According to the 2022 China Consumer Insight Report, more than 70% of Chinese consumers now consider sustainability in their purchasing decisions, with 43% willing to pay a premium for environmentally friendly products, such as second-hand clothing [Teng Yue, 2023]. The fashion industry has also responded, with numerous reports and media outlets highlighting the issue of waste textiles and retailers actively promoting in-store recycling programs for unwanted garments [Wagner M M, 2020]. Driven by both policy initiatives and growing consumer awareness of environmental problems, the waste textile recycling industry is positioned for rapid growth, with substantial potential for expansion.

Current status of waste textile recycling

The recycling volume of waste textiles in China from 2015 to 2023 has generally exhibited a fluctuating upward trend, as shown in Figure 1. This trend has been significantly influenced by both government policies and the market economic turbulence caused by the COVID-19 pandemic. From 2015 to 2016, textile recycling in China remained at a relatively low level, with the recycling rate at only about 12% of total waste. In 2017, a pivotal policy shift occurred when China implemented a ban on the import of solid waste, which effectively curtailed the import of waste textiles, particularly reducing the import of waste cotton and waste fabric by 50% [Report, 2020]. This policy change triggered a notable increase in domestic textile recycling, resulting in a significant growth rate of 29.63% in 2017.

Following this, the recycling volume of waste textiles steadily increased from 2019 onward, driven by the revision of the Solid Waste Law and the promotion of waste sorting initiatives in various cities [Report, 2022]. By 2021, the recycling volume reached 4.75 million tons. This surge can be attributed to a series of regulations and policy documents introduced that year, which played a pivotal role in guiding the development of China's waste textile recycling sector. However, in 2022, the recycling volume experienced negative growth, primarily due to the economic impact of the COVID-19 pandemic. Textile production declined during this period, with yarn production falling by 1.546 million tons compared to 2021, fabric production dropping by 6.6%, and synthetic fibre production decreasing by 1.0% year-on-year [Report, 2023]. Despite these setbacks, the recycling volume rebounded in 2023, reaching 4.8 million tons—an increase of 15.7%—thanks to the continued implementation of favourable policies [Report, 2024]. Although there has been a positive trend in recycling volumes spurred by policy support and advocacy, the overall growth remains sluggish. This highlights the need for a more detailed analysis of the factors influencing this development trend, which is crucial for formulating more effective strategies to enhance textile recycling in the future.

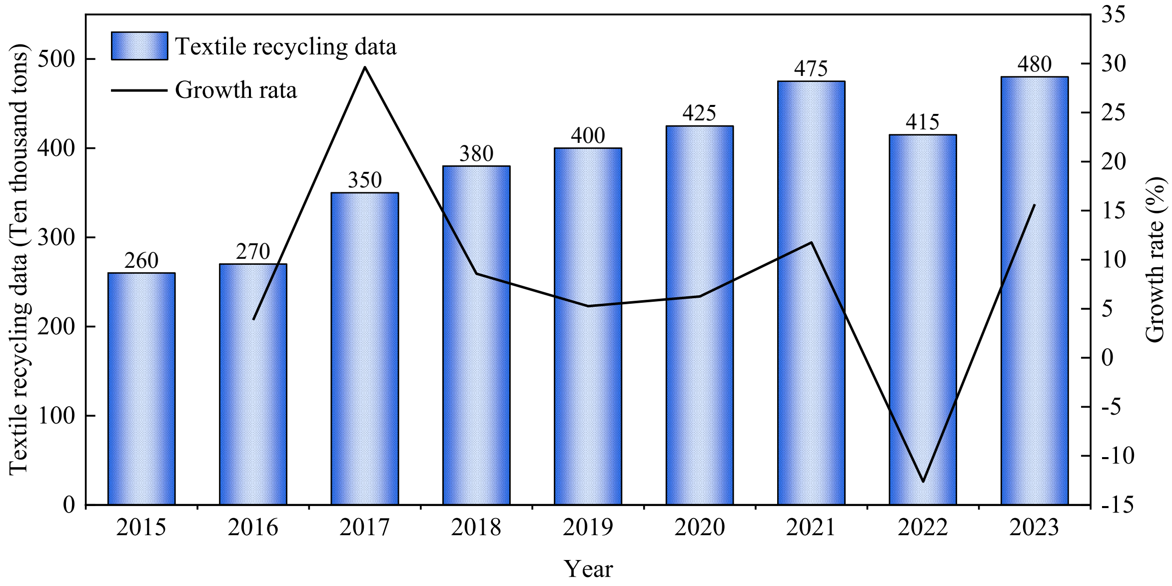

Fig. 1 Textile recycling data and growth rate in China from 2015 to 2023

FORECASTING OF WASTE TEXTILE RECYCLING

Methodology

The Grey forecasting model is known for its ability to model small sample data with high computational accuracy. Among the various Grey models, the Grey Verhulst model stands out as a nonlinear growth model, with its core formula being the Verhulst Logistic equation. This model is particularly effective at capturing the saturation and constrained growth processes of a data system [Huang C, 2023]. As shown in Figure 1, the growth trend of waste textile recycling data from 2015 to 2023 aligns well with the characteristics of this model.

The classic GM (1,1) model is one of the fundamental models in Grey system theory, widely used for forecasting univariate time series data [Xie N, 2022, Shen X, 2019]. However, while the GM (1,1) model provides relatively accurate predictions for early data points, its predictive accuracy tends to decline for subsequent time points, which limits its effectiveness in long-term forecasting [Naiming Xie, 2005]. To address this limitation, the discrete GM (1,1) model was introduced. This model is essentially a discrete adaptation of the GM (1,1) model and uses interpolation or approximation techniques to generate predictions at discrete time points, improving both accuracy and computational stability [Li K, 2024].

In this study, the Grey Verhulst model, the GM (1,1) and discrete GM (1,1) models were applied to predict the trends of waste textile recycling in China. The accuracy of results were compared. This comparison holds both theoretical and practical implications, as it provides insights into the effectiveness and reliability of different Grey forecasting models for predicting waste textile recycling volumes.

Dimension determination

The original sequence for the Grey forecasting model is constructed using data on China's waste textile recycling volumes from 2015 to 2023. In Grey forecasting, selecting an appropriate data sequence length, denoted as n, is critical. If n is less than 4, the modeling conditions are not satisfied. On the other hand, if n is too large, increasing system uncertainties may reduce the accuracy of the prediction results. In this study, we explore the method for determining the optimal data sequence length using the Grey Verhulst model as an example based on the characteristics of the data depicted in Figure 1.

To identify the optimal data sequence length, we constructed several Grey Verhulst models using different time series data subsets: from 2015 to 2023, from 2015 to 2022, from 2015 to 2021, from 2015 to 2020, from 2015 to 2019, and from 2015 to 2018. These subsets correspond to dimensions ranging from 9 to 4, respectively. The model performance was evaluated using two key indicators: the mean simulation error (E_{MSE}) and the mean prediction error (E_{MPE}). A smaller value for both indicators indicates higher accuracy in both simulation and prediction.

The simulation results and relative errors for the Grey Verhulst model at different dimensions are presented in Table 2. As shown, the model's fitting performance varies across different dimensionalities. The mean prediction errors (E_{MPE}) for the Grey Verhulst model at dimensions 8 through 4 are 7.2%, 24.74%, 6%, 5.92%, and 36.30%, respectively. Notably, the 5-dimensional Grey Verhulst model exhibits the lowest mean simulation error (E_{MSE}) and mean prediction error (E_{MPE}), both falling below 6%. This demonstrates its superior performance and establishes it as the optimal model for forecasting.

Table 2. Simulation results and relative error of raw data

Year	Raw data	9 dimensions		8 dimensions		7 dimensions		6 dimensions		5 dimensions		4 dimensions	
		Results	Error /%	Results	Error /%	Results	Error /%	Results	Error /%	Results	Error /%	Results	Error /%
2015	260	260	0.00	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00	260.00	0.00
2016	270	298.52	10.56	303.38	12.36	293.94	8.87	299.89	11.07	299.82	11.04	296.98	9.99
2017	350	335.44	4.16	341.25	2.50	29.46	91.58	337.71	3.51	337.65	3.53	337.85	3.47
2018	380	369.40	2.79	372.17	2.06	366.00	3.68	371.93	2.12	371.98	2.11	382.60	0.68
2019	400	399.44	0.14	396.04	0.99	402.91	0.73	401.62	0.41	401.87	0.47	483.34	20.83
2020	425	425.14	0.03	413.69	2.66	439.52	3.42	426.47	0.35	447.39	5.27	538.76	26.77
2021	475	446.48	6.00	426.34	10.24	475.19	0.04	462.60	2.61	463.62	2.40	596.95	25.67
2022	415	463.78	11.75	435.19	4.87	541.48	30.48	474.98	14.45	476.26	14.76	657.32	58.39
2023	480	477.53	0.51	445.43	7.20	571.26	19.01	484.45	0.93	485.95	1.24	719.16	49.83
E_{MSE} / %		4.00		4.46		15.47		2.91		3.43		3.54	
E_{MPE} / %		/		7.20		24.74		6.00		5.92		36.30	

Model comparison and forecasting

To select the optimal Grey forecasting model, the Grey Verhulst model, GM (1,1) model, and discrete GM (1,1) model were used to predict the waste textile recycling volume in China from 2015 to 2023. The simulation results and relative errors for the raw data are shown in Table 3, while Figure 2 presents the calculation results for the mean prediction error and the total average error. The mean prediction error is consistently below 24%, and the total average error remains below 15%, underscoring the advantages of Grey theory in forecasting.

Both the GM (1,1) and discrete GM (1,1) models exhibit relatively high fitting accuracy in the early stages of prediction. However, as time progresses, their predictive accuracy declines significantly, indicating that these models are more suitable for short-term forecasting. In contrast, as shown in Figure 2, the predictive accuracy of the Grey Verhulst model is substantially higher, with an average prediction accuracy of 94.08%. This demonstrates that the Grey Verhulst model offers superior predictive stability, making it well-suited for both short-term and long-term forecasting.

It is also worth noting that, despite being a more precise form of the GM (1,1) model, the discrete GM (1,1) model does not outperform the GM (1,1) model in practical applications. In this study, the predictive accuracy of both models is similar. Additionally, the posterior error ratio is a key indicator for evaluating the performance of Grey models. This ratio assesses the model's prediction accuracy and reliability by comparing the errors between predicted and actual values. The calculation method is provided in Formula 1[Liu S,2017]. For the Grey Verhulst model, the posterior error ratio was calculated as 0.059, indicating that the model exhibits high predictive accuracy and is capable of making precise predictions.

$$\varepsilon_p = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_i^{(p)} - y_i}{y_i}\right| \quad (1)$$

Where $y_i^{(p)}$ is ith predicted value of model; y_i is raw value; n is total number of data; ε_p is poster error ratio.

Based on the superior predictive performance of the Grey Verhulst model, it was selected to forecast the future development trend of waste textile recycling in China. Figure 3 illustrates both the projected recycling volume and its growth rate over the next six years. As shown, while the recycling volume demonstrates a year-on-year increase, the growth rate is relatively modest, with expansion remaining slow. This indicates that the waste textile recycling industry in China will encounter significant challenges in the coming years. Given these findings, it is imperative to implement more targeted policies and measures to address the existing barriers in the recycling system. These efforts are crucial to ensuring the sustainable and healthy development of waste textile recycling in the country.

Table 3. Simulation results and relative error of raw data

Year	Raw data	Grey Verhulst model		GM (1,1) model		Discrete GM (1,1) model	
		Simulation results	**Relative error/%**	**Simulation results**	**Relative error/%**	**Simulation results**	**Relative error/%**
2015	260	260.00	0.00	260.00	0.00	260.00	0.00
2016	270	299.82	11.04	291.64	8.01	292.56	8.36
2017	350	337.65	3.53	327.40	6.46	328.12	6.25
2018	380	371.98	2.11	367.56	3.27	368.01	3.16
2019	400	401.87	0.47	412.64	3.16	412.75	3.19
2020	425	447.39	5.27	463.25	9.00	462.93	8.92
2021	475	463.62	2.40	520.06	9.49	519.21	9.31
2022	415	476.26	14.76	583.85	40.69	582.34	40.32
2023	480	485.95	1.24	655.45	36.55	653.13	36.07

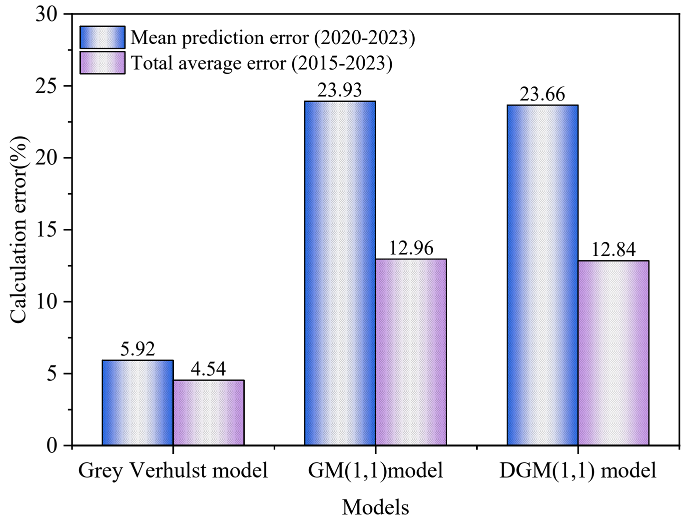

Fig. 2 Calculation error of three different prediction models

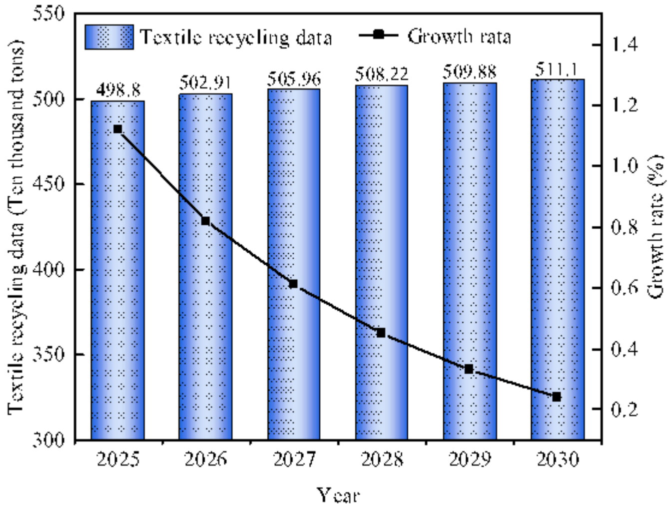

Fig. 3 Textile recycling data and growth rate in China from 2025 to 2030

SUGGESTIONS

This study analyzes the characteristics of waste textile recycling in China and forecasts its future development. It is found that there is considerable potential for improvement in both the recycling capacity and the overall level of waste textile recycling in China in the future. Some suggestions are proposed in this section. Incorporating the Grey Verhulst model, auxiliary measures are dynamically adjusted and optimized to better align with development needs, thereby promoting the rapid and sustainable growth of waste textile recycling.

Introducing supporting policies for active textile recycling

The development of policies and standards for waste textile recycling in China has progressed from an initial phase to one of continuous development and refinement. To further enhance the standardization system, government authorities can draw on the experiences of other countries, adapting their best practices while considering China's unique characteristics, such as the large volume and diverse categories of waste textiles. Many developed countries have established relatively mature recycling systems, offering valuable insights that could inform the development of appropriate standards for waste textile recycling in China.

In addition, the government should actively formulate, pilot, and refine mechanisms for waste textile recycling while exploring effective policy measures to support these efforts. It is also essential to encourage enterprises, particularly industry leaders, to leverage information technology to optimize the textile recycling and reuse process. Strengthening market regulatory functions will be crucial in ensuring the effectiveness of recycling efforts. Moreover, the government should focus on promoting successful case studies to raise public awareness of recycled products, thus encouraging individuals to donate waste textiles, such as used clothing, and facilitating the broader circulation of waste textiles.

Exploration new models for enhancing economic returns from recycling

Waste textile recycling holds substantial economic potential. To fully realize this potential, it is crucial for recycling enterprises to undergo transformation and upgrading. This involves shifting from traditional, extensive operational models to more innovative approaches that emphasize independent innovation capabilities. Key strategies include increasing investment in research and development, fostering technological innovation, and strengthening patent applications to enhance core competitiveness and improve market adaptability. Additionally, enterprises should invest in advanced machinery and equipment to boost recycling efficiency and automation, thereby reducing costs and increasing output.

Furthermore, exploring new models of waste textile recycling based on internet technology is vital. For example, the development of mobile applications (apps) that offer online booking and free doorstep collection services, in conjunction with offline recycling stations, could create an integrated online-offline recycling network. This model would significantly enhance the convenience of recycling services and encourage greater public participation in textile recycling.

Another promising approach is the establishment of a comprehensive platform for waste textile recycling and reuse, providing one-stop services that encompass dedicated collection channels, sorting, disinfection, secondary sales, and after-sales support. This would facilitate the creation of a fully integrated industrial value chain, optimizing industrial processes and maximizing the economic recovery value of waste textiles. By doing so, recycling revenues could be increased, contributing to the healthy and sustainable development of the entire textile recycling industry.

Optimizing sorting technologies for efficient recycling

Recycling sorting is a critical component of the waste textile recycling process [Shen Ya, 2023]. Rapid and accurate sorting not only improves the overall efficiency of the recycling process but also ensures the quality of the recycled materials, providing a strong foundation for their subsequent reuse. An effective sorting system facilitates better resource utilization while minimizing unnecessary waste. However, current sorting methods in the industry are insufficient to meet these demands.

To support the sustainable development of the recycling industry, it is essential to encourage enterprises and researchers to optimize sorting technologies and processes. This will help reduce labour costs, improve production efficiency, and enhance the overall effectiveness of the recycling process. For instance, automated sorting systems based on intelligent technologies have significant potential to improve both the efficiency and accuracy of waste textile recycling. Therefore, fostering innovation in sorting technologies and promoting their application will play a crucial role in improving the recycling and re-utilization of waste textiles.

CONCLUSION

This paper analyzes the characteristics of waste textile recycling in China and utilizes the Grey Verhulst model to forecast the sector's development trends over the next six years. Based on the findings, several recommendations are proposed to expand waste textile recycling, establish a scalable economic benefit framework, and accelerate the advancement of the circular economy. The key conclusions are summarized as follows:

1. Under conditions of small data samples, the Grey Verhulst model demonstrates higher predictive accuracy compared to the GM (1,1) and discrete GM (1,1) models. It aligns more closely with the actual development trends of waste textile recycling in China, offering both superior predictive accuracy and scientific validity.
2. From 2025 to 2030, while the recycling volume of waste textiles in China is expected to show a year-on-year increase, the growth will be relatively modest, with the annual average growth rate remaining below 1.2%. This projection provides valuable insight for formulating policies and strategies to promote waste textile recycling.
3. Waste textile recycling in China is still in its early stages, with considerable room for development and improvement. To promote further growth in this sector, it is recommended that the government introduce supportive policies for active recycling, explore innovative economic models for textile recycling, and enhance the recycling sorting technology system.

REFERENCES

China Renewable Resources Recycling industry development Report:2020. China National Resources Recycling Association.https://ltfzs.mofcom.gov.cn/cms_files/oldfile//ltfzs/202106/20210630093358717.pdf.

China Renewable Resources Recycling industry development Report:2022. China National Resources Recycling Association. https://www.lvziku.cn /article/ 35045.

China Renewable Resources Recycling industry development Report:2023. China National Resources Recycling Association. https://www.hbzhan.com/news /detail/16351.html.

China Renewable Resources Recycling industry development Report:2024. China National Resources RecyclingAssociation. https://www.chinaisa.org.cn/gxportalFile/attach/2024/07/10/1720599598339032383.pdf.

Guo X, Zhang R, Shen H, et al. An optimized damping grey population prediction model and its application on China's population structure analysis[J].International Journal of Environmental Research and Public Health, 2022,19(20),pp.13478.

Guo Yan. Analysis on the current situation of waste textile recycling standard system in China[J]. Recyclable resources and circular economy,2022,15(11),pp.14, 18+28.

Han fei, Lang Chenhong, Qiu Yiping. Research progress of waste textiles recycling system[J].Cotton textile technology,2022,50(04),pp.42-48.

Huang C, Zhou L, Liu F, et al. Deformation prediction of dam based on optimized grey verhulst model[J]. Mathematics,2023,11(7),pp.1729.

Huang Meilin,Chen Yongsheng,Liang Yueji. An investigation on reclamation of waste textiles in China[J]. China Textile Leader, 2015(1),pp.26-28.

JuLong D. Introduction to grey system theory[J].Journal of Grey System,1989, 1(1), pp.1-24.

Li K, Xie N. Reduced-order reconstruction of discrete grey forecasting model and its application[J]. Communications in Nonlinear Science and Numerical Simulation,2024,139,pp.108310.

Liu S, Yang Y. Explanation of terms of grey forecasting models[J]. Grey Systems: Theory and Application, 2017,7(1),pp.123-128.

Shen X, Yue M, Duan P, et al. Application of grey prediction model to the prediction of medical consumables consumption[J]. Grey Systems: Theory and Application,2019,9(2),pp.213-223.

Shen ya, Chen Tao,Zhang Lijie. Research progress in recycling and reuse of waste textiles and clothing[J]. Journal of Textile research,2023,44(07),pp.232-239.

Teng Yue. Huge potential of waste textiles recycling[J]. Environmental economy, 2023,(07),pp.46-47.

Tong M, Yan Z, Chao L. Research on a grey prediction model of population growth based on a logistic approach[J]. Discrete Dynamics in Nature and Society, 2020,2020(1),pp.2416840.

Wagner M M, Heinzel T. Human Perceptions of Recycled Textiles and Circular Fashion: A Systematic Literature Review[J]. Sustainability, 2020,12(24), pp.10599

Wang C C. A comparison study between fuzzy time series model and ARIMA model for forecasting Taiwan export[J]. Expert Systems with Applications, 2011,38(8),pp.9296-9304.

Xie N. A summary of grey forecasting models[J]. Grey Systems: Theory and Application,2022,12(4),pp.703-722.

Xie Naiming, LIU Sifeng. Discrete GM (1,1) and mechanism of grey forecasting model[J]. Systems Engineering Theory and Practice,2005,25(1),pp.93-99.

Yu Xue, Chen Lijun. Prediction and grey-model of China urban and rural Engel coefficient difference[J]. Journal of Xi'an Polytechnic University, 2014.28(2),pp.257-261.

Zhang Y Z. Application of improved BP neural network based on e-commerce supply chain network data in the forecast of aquatic product export volume[J]. Cognitive Systems Research,2019,57(10), pp.228-235.

Zhou Jie, Li Jian. Characteristics and forecast of silk export in Zhejiang province[J].Journal of silk, 2019,56(08),pp.19-24.