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Prediction and analysis of WEEE in China based on the gray model

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Abstract: In recent years, waste electric and electronic equipment (WEEE) pollution problem has caused public concern widely in the world. In China, huge numbers of appliances are sold and discarded each year. It is difficult to carry out reliable estimation of WEEE output using the existing models due to the limited data available in many countries, especially in large developing countries. In order to plan, manage and use WEEE in a sustainable way, accurate forecasting of WEEE generation plays a key role. Based on the quantity of household ownership of appliances in China, several GM (1,1) gray theory models were set up to predict the quantity of household ownership appliances in China. The results indicate that more and more WEEE will be produced. By 2031, the quantity of WEEE will reach 516 million sets, or 13 million tons. By means of the combination of gray relation analyses (GRA) in this research, it was discovered that the realty business has high correlation with Chinese household ownership of appliances. In order to solve the WEEE collection problem, in this paper, it is suggested that the Chinese government issue a kind of WEEE voucher. If the voucher is used successfully in WEEE recycling, it will not only promote a standard recycling system for WEEE , but also can accelerate the extended producer responsibility (EPR) policy implementation in China.

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Keywords: WEEE, Gray Mode, Prediction, EPR

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Introduction

According to a report published recently by the United Nations University, in 2014, a total of 41.8 million tons of WEEE were produced all over the world, growing by 2 million tons compared to the same period in the previous year. Meanwhile, the annual electric and electronic equipment (EEE) production still has an incremental of up to 2 million tons all over the world. The report issued by the United Nations University on April 19, 2015 predicted that the quantity of WEEE all over the world would reach a new record, a total of 50 million tons of WEEE will be produced in 2018 (Hua, 2015). According to statistics, in 2013, China produced about 1.032 billion main household appliances (Sheng, 2014).

Gray system theory, which consists of GRA, gray generating space, gray forecasting, gray decision making, gray control and gray mathematics etc., was initially proposed by Deng (1989) in 1982. GM (1,1), an univariate model, is the most widely used in municipal solid waste (MSW) forecasting and other applications with high accuracy (Mohanmmed Almasri et al., 2005; Untong, 2012; Xu et al., 2013; Ying et al., 2011). A study investigated the factors affecting MSW generation by comparing standardized coefficient at a city level (Mohanmmed Almasri et al., 2005; Sukholthaman and Chanvarasuth, 2013). Gray model illustrates that population density is the most important factor affecting MSW collection, followed by urbanization, proportion employment and then household size (Rotchana Intharathirat et al., 2015). For the WEEE uncertainty, dispersion characteristics conform to the gray data characteristics. In this paper, gray system theory is adopted to set up several gray predication models to predict China's household ownership of appliances quantity. Based on this, China's theoretical scrapping quantity of appliances is calculated with the aim of offering scientific data for China WEEE project and treatment in the future. Based on the experience of developed countries and EPR policy in China, referring to a proper recycling and treatment system according to the basic national conditions, several management recommendations are proposed in this paper.

1 Yield of WEEE gray prediction Model (Sheng, 2002-2014; Deng, 2002; Deng, 1987; Mohanmmed Almasri, 2005)

1.1 Set up raw series

Based on the quantity of Chinese household ownership of appliances between 2001 and 2013, TV, refrigerator, washing machine, air-condition, and computer household ownership (ten million units) raw series are set respectively as $X_1^{(0)}$, $X_2^{(0)}$, $X_3^{(0)}$, $X_4^{(0)}$, $X_5^{(0)}$

$X_1^{(0)}$={38.845,41.446,43.439,45.276,44.924,46.344,47.345,47.333,50.072,52.039,52.247,53.454,53.013}

$X_2^{(0)}$={16.325,18.367,19.631,20.941,22.169,23.396,25.498,26.370,27.164,30.146,33.763,35.653,36.621}

$X_3^{(0)}$={20.038,21.369,22.852,24.394,25.483,26.755,28.039,28.575,30.177,32.279,33.893,34.522,36.895}

$X_4^{(0)}$={5.877,8.874,11.399,13.589,16.489,18.499,20.943,22.673,25.180,28.782,33.166,35.759,32.146}

$X_5^{(0)}$={2.194,3.605,5.102,6.356,8.269,9.730,11.636,13.334,15.482,18.311,22.732,25.196,22.329}

1.2 Class smooth test

$$\sigma(k)=\frac{x(k-1)}{x(k)} \quad (k=2\cdots13)$$

$\sigma_1(K) \in (0.937, 1.008)$; $\sigma_2(K) \in (0.889, 0.976)$; $\sigma_3(K) \in (0.935, 0.982)$; $\sigma_4(K) \in (0.662, 1.112)$;

$\sigma_5(K) \in (0.609, 1.13) \subset (0.1353, 7.389)$

Show series x is smooth and gray prediction can be made.

1.3 The class ratio border test

Known n＝13, have border: $\left(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}} \right)$=(0.8669, 1.1536),

the class ratio border $\sigma_1(K)$, $\sigma_2(K)$, $\sigma_3(K)$ are all in the border, the GM(1,1) model precision is high while there is no need to process the raw series. $\sigma_4(K)$, $\sigma_5(K)$ are not entire in the class ratio border, and the GM(1,1) model precision is low. Hence the raw series need to be processed.

1.4 Preproccess the raw series

$x^{(0)}$（t）＝{ x(k-1)+2x(k)+x(k+1)}/4,

the two endpoints respectively: $x^{(0)}(1)$＝{3 $x^{(0)}(1)$+ $x^{(0)}(2)$}/4 ; $x^{(0)}(n)$={ $x^{(0)}(n-1)$+3 $x^{(0)}(n)$}/4

Finished preproccess the raw series:

$X_4^{(0)}$={6.626,8.756,11.315,13.767,16.267,18.608,20.765,22.867,25.454,28.978,32.718,34.208,33.049}

$X_5^{(0)}$={2.547,3.627,5.041,6.521,8.156,9.841,11.584,13.447,15.652,18.709,22.243,23.863,23.046}

The data in the class ration border σ(K)

1.5 Setting up model of GM(1,1)

Raw series $x^{(0)}$ AGO (accumulated generating operation)

$x^{(1)}$＝AGO $x^{(0)}$;

Semi-finished series $x^{(1)}$,$z^{(1)}$

$x^{(1)}(k)＝x^{(1)}(k－1)＋x^{(0)}(k)$;

$Z^{(1)}(k)=0.5x^{(1)}(k)+0.5x^{(1)}(k-1)$

1.6 Semi-parameters C,D,E,F

$$C=\sum_{k=2}^{13} z^{(1)}(k)\,;\ D=\sum_{K=2}^{13} x^{(0)}(k)\,;\ E=\sum_{k=2}^{13} z^{(1)}(k)x^{(0)}(k)\,;\ F=\sum_{k=2}^{13} z^{(1)}(k)^2$$

1.7 Developing coefficient a and Grey input b

$$a=\frac{CD-(n-1)E}{(n-1)F-C^2}\ ;\ b=\frac{DF-CE}{(n-1)F-C^2}$$

1.8 White response of GM(1,1)

$$\hat{x}(k+1)=(x^{(0)}(1)-\frac{b}{a})e^{-ak}+\frac{b}{a};$$

IAGO(Inverse AGO): $\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k)$;

1.9 Grey model of period residual modification

$E(t_i)= A_i \sin\frac{2\pi t_i}{T_i}$; where $E(t_i)$ is i period t moment modified value;

A_i is the maximum amplitude of i period; T_i is the length of i period; t_i is the i moment of period;

The amplitude size is the average of the absolute value of residuals and finally the individual residuals were superimposed on the same time of the calculated value.

1.10 The computation of China's WEEE theoretical scrapping

Theoretical scrapping quantity = household ownership of 16 years ago×60%÷7;
Computer theoretic scrapping quantity = household ownership of 6 years ago×60%÷3;
China's theoretical scrapping weight of TV: 30 kg/set; refrigerator: 55 kg/set; washing machine: 40 kg/set; air-condition: 50 kg/set; desktop computer: 30 kg/set; notebook Computer: 3 kg/set;

1.11 Gray prediction

Table1. Chinese household ownership of appliances prediction model

Appliance	Prediction model $\hat{x}(k+1)$	Actual value periodic correction $E(t_i)$	Predicted value periodic correction $E(t_i)$	Model average precision (%)
TV	$1842.81\times e^{0.0227k}-1803.965$	$-0.617Sin\frac{2\pi t_i}{12}$	$-0.617Sin\frac{2\pi t_i}{13}$	91.3
Refrigerator	$270.951\times e^{0.0649k}-254.626$	$0.5125Sin\frac{2\pi t_i}{12}$	$0.5125Sin\frac{2\pi t_i}{13}$	98.3
Washing machine	$454.221\times e^{0.0471k}-434.183$	$0.34Sin\frac{2\pi t_i}{12}$	$0.34Sin\frac{2\pi t_i}{13}$	99.1
Air-condition	$107.772\times e^{0.1047k}-101.146$	$1.558Sin\frac{2\pi t_i}{26}$		88.0

Computer	$37.411\times e^{0.1423k}$-34.864	$-1.177Sin\frac{2\pi t_i}{13}$	$-1.177Sin\frac{2\pi t_i}{13}$	91.9

Note: e=2.718

1.12 Prediction result

According to the model calculation, software Origin9 was used to deal with the data, and figures are as follows:

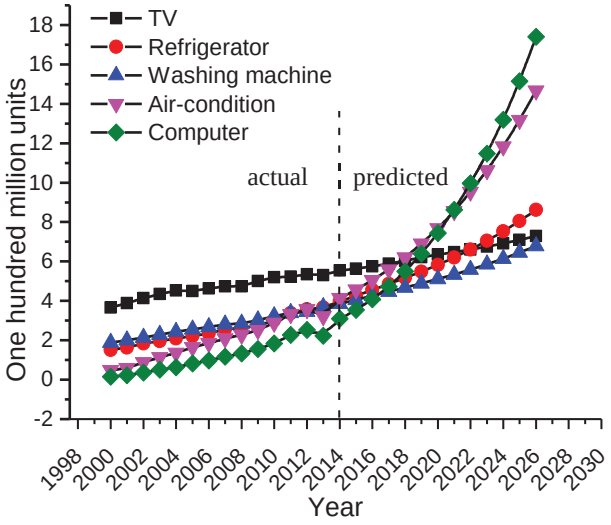

Fig. 1. Chinese household ownership of appliances gray prediction

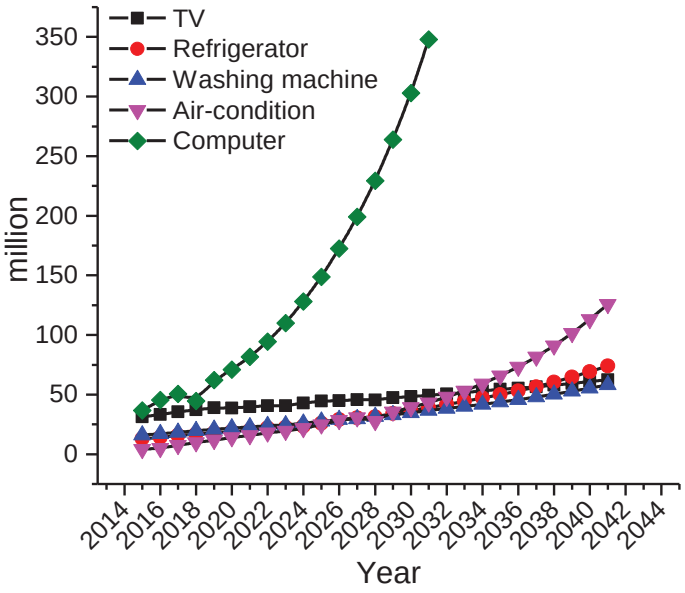

Fig. 2. China's theoretic scrapping quantity of appliances

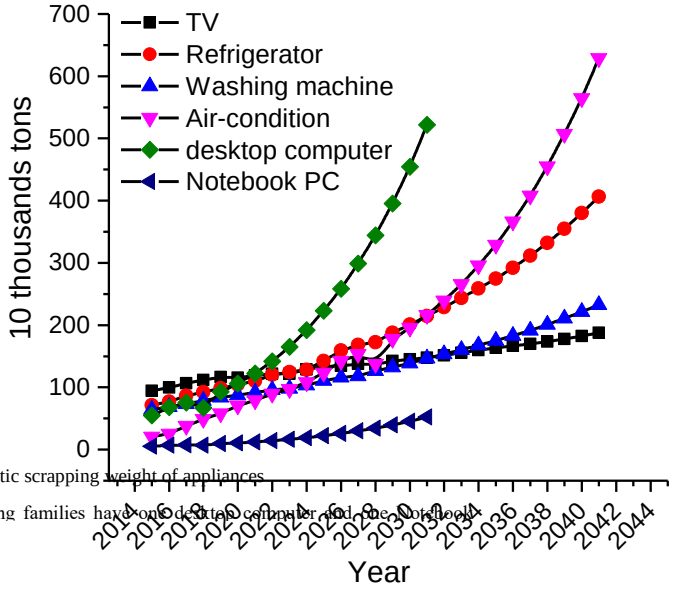

Fig. 3. China's theoretic scrapping weight of appliances

Note: Calculate based on one working families have one desktop computer and one notebook

1.13 Predication result analysis

(1) By 2014, the quantity of Chinese household ownership of appliances is 2.06 billion sets (Fig.1), while the catalogue of computer demonstrates the maximum growth. The demand of air-condition, refrigerator and washing machine is stable. Growth rate of TV demand declines slightly. With the computer, smart phone and Internet being used widely in daily life, TV is no longer as important as before. Based on the result of the predication, in 2026, the quantity of household ownership of appliances will reach 5.48 billion sets, 2.26 times of that in 2014.

(2) From Fig.2, it can be concluded that computer theoretic scrapping quantity sees the most rapid growth, increasing from 55 million in 2014 to nearly 150 million in 2031. Air-condition theoretic scrapping quantity sees a stable growth. By 2026, the quantity will reach 120 million, increasing by about 100 million compared with that in 2015. Washing-machine quantity is in a stable growth, but TV quantity declines sharply year by year.

(3) It can be seen from Fig.3 that the quantity of desktop computer, air-condition, refrigerator grew significantly, taking up the highest proportion of total appliances, but with the emergence of one-piece computer, computer case disappeared, theoretical scrapping weight of computer showed a trend of gradual decline, especially after the complete elimination of CRT display, this trend will be more obvious than before. Washing-machine and TV theoretic scrapping weight become stable, but with LCD flat screen TV becomes the mainstream, the proportion weight of TV would show a sharp decline.

2 Grey relational analysis (GRA) (Deng, 2002; Deng, 1987; Mohanmmed Almasri, 2005)

2.1 Grey relational Coefficient

$$\xi_i(k)=\frac{\min\limits_i\min\limits_k|x_0(k)-x_i(k)|+\rho\max\limits_i\max\limits_k|x_0(k)-x_i(k)|}{|x_0(k)-x_i(k)|+\rho\max\limits_i\max\limits_k|x_0(k)-x_i(k)|}$$

$\xi_i(k)$ is k moment comparison curve x_i and parameter curve x_0 relational difference, this form relational difference named x_i of x_0 at k moment relational Coefficient. ρ is discrimination coefficient, and generally takes a value of 0.5;

2.2 Grey relational Grade

Between 2 systems or factors relational as the size named relational grade, the calculation formula is as follows:

$r_i=\frac{1}{N}\sum_{k=1}^{N}\xi_i(k)$, r_i indicate curve x_i to reference curve x_0 's relational grade

Table2. Yield of WEEE and influencing factors statistical (Sheng, 2002-2014)

Name	Population (ten million people)	Gross domestic product (one hundred billion yuan)	Total retail sales of social consumer goods (one hundred billion yuan)	Residents consumption(one hundred billion yuan)	Real estate enterprise commercial housing sales area (10 million square meters)	Floor Space Completed (10 million square meters)
2001	127.627	109.6552	43.0554	49.4359	22.41190	182.4371
2002	128.453	120.3327	48.1359	53.0566	26.80829	196.7379
2003	129.227	135.8228	52.5163	57.6498	33.71763	202.6437
2004	129.988	159.8783	59.5010	65.2185	38.23164	207.0191
2005	130.756	183.8679	67.1766	72.9587	55.48622	227.589
2006	131.448	210.8710	76.410	82.5755	61.857	212.542
2007	132.129	257.3056	89.210	96.3325	77.35472	238.425
2008	132.802	314.0454	114.830	111.6704	65.96983	260.307
2009	133.450	340.9028	132.678	123.5846	94.75500	302.117
2010	134.091	401.5128	156.998	140.7586	104.76465	304.306
2011	134.735	473.1040	183.919	168.9566	109.36675	329.073
2012	135.404	519.4701	210.307	190.5846	111.304	335.504
2013	136.072	568.8452	237.810	212.1875	130.551	349.896

Table3. Yield of WEEE and influence factors Grey relational Grade r_i statistical

Name	Population (ten million people)	Gross domestic product (one hundred billion yuan)	Total retail sales of social consumer goods (one hundred billion yuan)	Residents consumption(one hundred billion yuan)	Real estate enterprise commercial housing sales area (10 million square meters)	Floor Space Completed (10 million square meters)
TV	0.893	0.598	0.587	0.638	0.617	0.807
Refrigerator	0.682	0.601	0.584	0.66	0.63	0.88
Washing machine	0.766	0.59	0.58	0.646	0.614	0.894
Air-condition	0.548	0.81	0.76	0.729	0.801	0.675
Computer	0.548	0.842	0.818	0.8	0.808	0.682
Average	0.6874	0.6882	0.6658	0.6946	0.694	0.7876

The average grey relational grade influence factors sort:

Floor space completed>residents consumption>real estate enterprise commercial housing sales area >gross domestic

product>population>total retail sales of social consumer goods

3 Suggestions for China's WEEE management

In 2014, Chinese household ownership of appliances theoretic scrapping weight was about 14% of world's total weight. In this study, it is predicted that Chinese WEEE weight will reach 13 million tons in 2031, and the world's total WEEE weight will reach more than 100 million tons. WEEE will play an important role in the "urban mine", so proper WEEE recycling and treatment will become the key to maintain the never dried up "urban mine" in the future. Letting the precious resources always flow in the "urban mine" and form a high efficient closed-loop system is an important task. Now, China produces more than one-tenth of the whole world's WEEE each year. Developing a WEEE recycling system suitable for China's national conditions as soon as possible and requiring standard enterprises to dispose WEEE to the maximum extent is an important task of the Chinese government.
This research puts forward some suggestions as follows:

(1) In terms of formal recycling system construction, the government should take a full consideration about the basic national conditions of China. In different areas, the policy should be different. For example, in some cities, if there is not a large number of petty dealers who engage in WEEE recycling, the government should increase the investment, and establish a formal WEEE recycling system as soon as possible. In other cities where there are a large number of WEEE recycling petty dealers, government should guide them gradually to the formal WEEE recycling system.

(2) The development of EPR system is the direction and goal which is suitable to China's conditions, the core of EPR are household appliance manufacturers and formal recycling enterprises, but the WEEE collection is the premise, because of the formal recycling enterprises power limited in WEEE collection, the government should do some work to serve the EPR system. Now, there are a lot of supermarkets and logistics companies in Chinese cities, the local government should encourage them to carry out WEEE recycling business. Meanwhile the local government can authorized some WEEE recycling companies or set up some WEEE collection points to carry out the same business. Shanghai city had ever issued a kind of WEEE card, named anla-card. By selling WEEE in return for anla-card integral, people can used the card integral in supermarket shopping. In this study, we designed a kind of voucher, which has certain value and can be used widely. Local governments issue a certain number of voucher which can be bought in related businesses and used to be paid for recycling WEEE. Petty dealers and ordinary people send WEEE to the supermarkets or other collection points, and they will receive the voucher as compensation. Then they can buy discount goods with the voucher in supermarkets and it can be exchanged for cash or trade in the market at any time too. The specific process is shown in Fig.4.

3 Conclusions

(1) China WEEE generation has been rapidly increased in recent years. By 2026, the quantity of main household ownership appliance will reach 5.48 billion sets. In 2031, the China's theoretical scrapping quantity of appliances will reach 516 million sets, or 13 million tons.

(2) Computer and air-condition grow fastest in quantity of Chinese household ownership, as well as in theoretic scrapping quantity. The fastest growth theoretic scrapping weights are desktop computer, air-condition and refrigera tor. As light thin flat TV becomes the mainstream, television weight proportion growth is limited.

(3) From the perspective of average Grey relational grade influence factors sort, in the top two are floor space completed and residents consumption, reflecting that the Chinese household ownership of appliances have high correlation with realty business. The biggest correlation grade was television, refrigerators and washing machines, but population has the most significant correlation with television. The quantity of household ownership appliances has a bigger correlation with the residents' consumption, which reflects the Chinese family consumption of the electrical and electronic products have a high proportion in the expenditure of households.

(4) Because of the sharp competition between petty dealers and formal enterprises which leads to the normal WEEE processing enterprises short stock of goods, we designed a kind local government issued voucher. Use the

voucher during the WEEE recycling, it can promote WEEE flow to the standard processing enterprises, and then the WEEE supply problem can be partly solved.

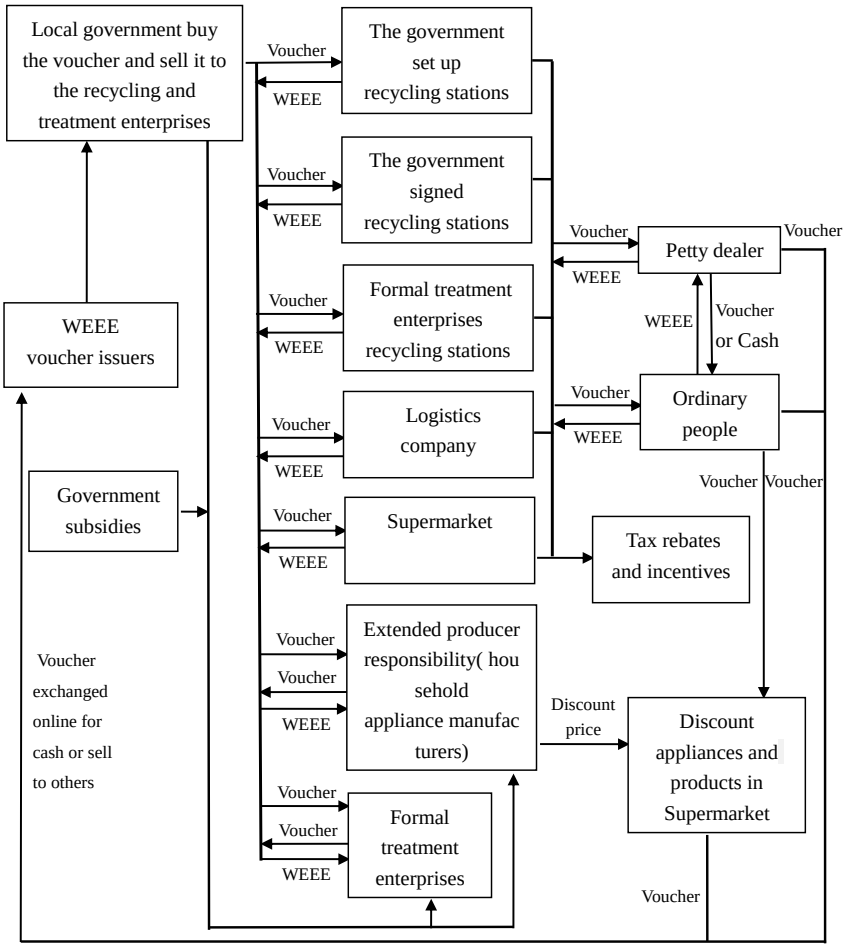

Fig. 4. WEEE voucher be used in the recycling systems flow chart

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