An overview study on management and implementation of WEEE in China

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Abstract
Waste electrical and electronic equipment (WEEE) which contains various valuable and harmful materials is an inevitable waste in modern society. In order to resolve the pollution problems associated with WEEE treatment, a WEEE management system has been established in China. The main role of importers and manufacturers of electrical and electronic equipment (EEE) is to pay the treatment fees to facilitate the WEEE recycling in China. The announced treatment and subsidy fee is given by set, not by the weight of WEEE. There is no lesser green treatment fee for the producers which can produce environmentally friendly EEE in China. Also, the recovery of refrigerants from the foaming agent of refrigerators is not required in China. In total, 45 million sets of recycled WEEE were certified in 2020, a year that contains the most updated data. Among them, 48%, 14%, 20%, 10% and 8% are for TV, refrigerator, washing machine, computer and air conditioners, respectively. The spatial analysis indicates that the WEEE recycling activities are mainly concentrated on the mid-east and east regions of China. It also can be concluded that the certified amount of each province has higher positive correlation with provincial population than provincial GDP per capita and green recovery rate. It also clearly notes that the amount of recycled air conditioner is the lowest for each province. Thus, more effort should be conducted to increase the recycling of scrapped air conditioner in China.

Keywords China · Management · Waste electrical and electronic equipment
1 Introduction

Due to the high demand for electronic and electrical products in modern society, the quantity of waste electrical and electronic equipment (WEEE) generation has rapidly increased globally in recent years. The definition of electrical and electronic equipment (EEE) stated in the European Union (EU) WEEE directive is “an equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1000 V for alternating current and 1500 V for direct current” (Directive, 2012). The refrigerators, air conditioners, televisions, washing machines, computers and mobile phones are EEE most commonly found in a household. It is reported that approximately 41.8 million tons of WEEE are generated worldwide in 2014 and the waste has been increased to 53.6 million tons in 2020 (Baldè et al., 2015; Forti et al., 2020). It is also estimated that the amount of WEEE is approximately 18% of the world’s total urban waste in 2020 with 3–5% increasing each year (Liu et al., 2020; Rahimifard et al., 2009; Widmer et al., 2005).

The composition of WEEE is more complex than other municipal wastes in terms of material composition and the content of hazardous materials (Fu et al., 2020; Salhofer, 2017). Usually, it will contain valuable resources, including gold, silver, copper, plastic and glass. The recovery of these valuable components of WEEE can produce great economic benefits (Liu et al., 2015; Ohajinwa et al., 2018; Wang et al., 2017). Thus, the collection and recycling of WEEE is a common practice all over the world. Yet, it also contains hazardous substances such as cadmium, lead, benzene, mercury and brominated flame retardants. If WEEE was not collected, stored and recycled in an environmentally friendly manner, these hazardous ingredients would have caused damages to human health and the environment (Awasthi & Li, 2017; Chan & Wong, 2013; Tue et al., 2016; Wang et al., 2016, 2017; Wen et al., 2006; Yang et al., 2008). For example, the inappropriate treatment (such as crushing, chemical stripping and open burning) of cathode ray tubes (CRTs), plastic casing, wire and printed circuit board (PCB) may cause the heavy metals of lead, barium, mercury, cadmium, brominated dioxins and hydrocarbons to be released into the air and leak into soil and groundwater. It not only seriously pollutes the environment but also poses a great danger to the on-site workers’ health. Hence, the establishment of a proper WEEE management system and recycling facility for each country is strongly needed to resolve the environmental problems, which are associated with the inappropriate treatment of WEEE.

Since people’s environmental awareness has improved and waste recovery and recycling have become a top issue in many countries (Chang, 2014; Zoeteman et al., 2010), the resource recovery and recycling of WEEE, which do not only reduce the amount of garbage generated but can also conserve the natural resources, have become a key strategy for the municipal waste management globally. For example, in order to utilize government resources more efficiently and to resolve the WEEE disposal problem, the Environmental Protection Administration of Taiwan (EPAT) has begun to adopt a Producer Responsibility Recycling Program (PRRP) in 1998 to mandate the manufacturers, importers and sellers of that targeted WEEE to have the responsibility to collect and recycle their WEEE properly (EPAT, 2017). It is reported that the collected WEEE amount of Taiwan is 4.98 kg/person/yr (Chang, 2014).

China has the world’s largest population of approximately 1.44 billion people, with an estimated population density of 150 people per square kilometer, which is ranked 81 in
the world (NBSC, 2021). Since China has experienced a fast-growing economy in recent years, the quantity of WEEE generation has also rapidly increased. It is estimated that the amount of WEEE generated in China was 4.0 million tons and 37.8 million sets in 2016 (CHEARI, 2017). It also reported that China will produce 15.5 million tons of WEEE per year by 2020 and accounts for approximately 20% of global production (Awasthi & Li, 2017). In order to target the WEEE disposal problem, the Chinese government has issued a regulation (i.e., Regulations on Recovery Processing of Waste Electrical and Electronic Products) in 2009 (SCC, 2009). On the basis of this regulation, which started in 2011, the WEEE items of computers, televisions, washing machines, refrigerators and air conditioners will be mandated to be recycled properly (NMM, 2010). Currently, the producers pay fees into the fund to subsidize the certified WEEE recycling facilities that are adopted in China’s WEEE management system (CHEARI, 2017).

Since China is one of the largest countries producing WEEE, it will be helpful for other countries to understand the WEEE management system adopted by China. Thus, this study intends to serve as a subsidy to improve the efficiency of the Chinese management system and, through this experience, serve as a comparative model to improve the efficiency of the management system of other countries.

2 The WEEE management in China

With the largest population in the world and the fastest growing economy in recent years, China generates a large amount of WEEE. It is estimated that 1.2 million tons of televisions, 0.44 million tons of refrigerators, 0.32 million tons of washing machines, 0.99 million tons of air conditioners and 0.67 million tons of computers were generated in 2011, respectively. It is also estimated that 50 million units of WEEE (TVs, refrigerators, washing machines, air conditioners and computers) generated in 2010 with an annual increasing of 20% (Wang et al., 2017). Another statistic reports that the total domestic WEEE is about 800 million units in 2020 in China (MEE, 2021). Thus, the treatment and recycling of such large amount of WEEE may result in severe adverse effects on environmental and human health in China.

In order to minimize these negative effects, China’s state council issued a regulation on “Recycling and Disposal of Waste Electrical and Electronic Equipment” in August 2008 and enacted from January 1, 2011 (SCC, 2009). This regulation was proposed to implement PRRP by stipulating that the producers of the EEE are responsible for the recovery of them after they are disposed of. It means that it regulates the mandatory recycling of WEEE in China. It also has established a special fund to promote WEEE recycling. Also, the ministry of finance released an administrative rule on financial subsidy for WEEE collection and treatment. This implies that the WEEE management system in China depends mainly on a state-controlled fund to subsidize the certified recyclers (Awasthi & Li, 2017; CHEARI, 2017; Salhofer et al., 2016; Yu et al., 2014; Chen et al., 2010).

On March 1, 2016, 14 WEEE items were announced and mandatorily recycled in China, including televisions, refrigerator, washing machines, air conditioners, microcomputers, electric water heaters, gas water heaters, kitchen extract hood, mobile phones, telephones, fax machines, monitoring equipment, printers and copiers (SCC, 2009; Yu et al., 2014). There are 109 WEEE recycling plants certified in China in 2020. These plants have the capability of recycling 164 million WEEE units per year (MEE, 2021). Notwithstanding, the actual certified WEEE recycled amount in 2020 was only 84 million units. It is
reported that 2.61 billion RMB recycling fund is collected from EEE manufacturers and 4.74 billion RMB was allocated to the certified WEEE recyclers in 2016 (CHEARI, 2017).

3 Main feature of China’s management system

A special regulation (i.e., Regulations on Recovery and Processing of Waste Electrical and Electronic Products) is issued by the State Council of China. China’s WEEE management systems are based on the Producer Responsibility Recycling Program and several governmental organizations are in charge. For example, the National Development and Reform Commission (NDRC) define the WEEE categories and financing scheme for management. Ministry of Environmental Protection (MEP) has established WEEE treatment standards and manages licensing system for recyclers and monitors the recyclers’ environmental performance. Ministry of Industry and Information Technology (MIIT) encourages the eco-design and regulates the toxins used in EEE. Ministry of Commerce (MOC) establishes and manages the WEEE collection channels and system. Ministry of Finance (MOF) defines responsibilities and communicates with EEE producers and importers, defines and manages the subsidies for logistics and implements the collection and recycling of WEEE (Chen et al., 2010; Gu et al., 2017; Salhofer et al., 2016; Wang et al., 2013). The schematic illustration of a WEEE management system in China is shown in Fig. 1. The first batch of regulated WEEE items are computers, televisions, washing machines, refrigerators and air conditioner in China, and there are 14 regulated WEEE items in total at the present time. The detailed regulated WEEE items and their announced time are given in Table 1.

Furthermore, a comparison of WEEE management system between China and EU is also tabulated in Table 1. From this comparison, it can be seen that EU and China all adopt the PRRP for WEEE management. It means that the manufacturers and importers of WEEE should take the responsible for the disposal of WEEE. However, the manufacturers are heavily involved in EU WEEE management system by setting up and operating the WEEE recycling chain, whereas the manufacturers in China only need to pay the treatment fee to the government and let government actually operating the WEEE management system. The major difference of WEEE management system between EU and China is that the government involvement is less in EU. A recycling target is regulated in EU to force the manufacturers to take more strong actions. The treatment fee paid by manufacturer and...
| Regulation                                           | Region                                      |
|------------------------------------------------------|---------------------------------------------|
|                                                      | China                                      | EU                                         |
| Special regulation for WEEE management              | Yes (Regulations on Recovery Processing of Waste Electrical and Electronic Products) | Yes (EU WEEE Recast Directive 2012/19/EU) |
| Adopt PRRP program                                   | Yes                                        | Yes                                        |
| Main responsible government organization             | NDRC, MEP, MIIT, MOC, MOF                  | Producer operate WEEE management system    |
| Main responsibility of government                    | Establish, implement and monitor WEEE management system | Monitor WEEE management system            |
| Regulated WEEE items and announced year              | 1. Microcomputers (2009)                    | 1. Large household appliances              |
|                                                      | 2. Televisions (2009)                      | 2. Small household appliances              |
|                                                      | 3. Washing machines (2009)                 | 3. IT and telecommunications Equipment     |
|                                                      | 4. Refrigerators (2009)                    | 4. Consumer equipment and photovoltaic panels |
|                                                      | 5. Air conditioner (2009)                  | 5. Lighting equipment                      |
|                                                      | 6. Kitchen ventilators (2014)              | 6. Toys                                    |
|                                                      | 7. Electric water heaters (2014)            | 7. Leisure and sports equipment            |
|                                                      | 8. Gas water heaters (2014)                 |                                            |
|                                                      | 9. Printers (2014)                         |                                            |
|                                                      | 10. Copiers (2014)                         |                                            |
|                                                      | 11. Fax machines (2014)                    |                                            |
|                                                      | 12. Monitors (2014)                        |                                            |
|                                                      | 13. Mobile phones (2014)                   |                                            |
|                                                      | 14. Telephones (2014)                      |                                            |
| Start year of WEEE management                        | 2011                                       | Not available                              |
| Announce treatment fee and subsidy fee               | Yes                                        | No                                         |
| Announce recycling target rate                       | No                                         | Yes (45% in 2016, 65% in 2019)             |
| Main responsibility of Manufacture and importer      | Pay treatment fee                           | Operate WEEE management system             |
| Certified recycling facility                         | Yes                                        | Yes                                        |
| Regulation                        | Region         |
|----------------------------------|----------------|
|                                  | China          | EU             |
| Announce treatment standard      | Yes            | Yes            |
| Auditing the recycled amount     | Yes            | Yes            |
| Qualified recycling plants       | 109 (2020)     | Not available  |
subsidy received by recycling plants is announced in China where cannot be found in EU system.

Under the current WEEE management system, the main responsibility of government is to establish, implement and monitor WEEE management system, whereas the main responsibility of EEE producers and importers is to pay the treatment fees to facilitate the implementation of the WEEE management system. Thus, treatment fees of different WEEE items are announced for EEE producers and importers to pay. In order to treat and recycle the regulated WEEE items properly, a treatment standard has been issued for the recyclers to follow. Also, subsidy fees for different WEEE items are announced to subsidize the WEEE recyclers in China. Nevertheless, only the certified WEEE recyclers can receive the subsidy fees after the recycling amount is audited by a third party. There is no official targeted rate of WEEE recycling announced. It may be due to the government is the actual executor of the WEEE recycling in China’s systems, and it could be more effective to increase recycling rate by adjusting subsidies. The main feature of a WEEE management system of China is also summarized in Table 1.

4 Announced WEEE treatment and subsidy fee of China

The announced WEEE treatment and subsidy fees played an important role in China’s WEEE management systems. The treatment fees are the fund that paid by producers and importers of EEE in order to help the implementation of WEEE management system, whereas the subsidy fees are allocated to the certified recyclers in order to treat the WEEE properly. Without the treatment fees paid by the producers and importers, the WEEE management system cannot be successfully implemented in China. On the basis of the announced WEEE treatment fees of China (MMNM, 2012), the current announced treatment fees for waste computers, televisions, washing machines, refrigerators and air conditioners of China are given in Table 2. Table 2 shows that the treatment fee is charged by every set, not by the weight of the WEEE. For example, a single TV treatment of 2.0 US $/set is given in China. Also, there is no differential treatment fee for different environmental impact of the WEEE to give economic incentive for the producers to design and produce more environmentally friendly EEE in China.

There are total two versions of announced subsidy fee in China: The first version was announced in 2012 and the latest adjusting announced subsidy fee was enforced on 2021 (MMNM, 2015; MMNM 2021). Five categories of WEEE have been announced for subsidization which are waste computers, televisions, washing machines, refrigerators and air conditioners. The subsidy fee before and after on 2021 in China is given in Table 3.

| Table 2 Current announced WEEE treatment fee of China |
|---------------------------------|
| WEEE item          | Treatment fee (US $/set) |
|--------------------|--------------------------|
| TV                 | 2.0                      |
| Refrigerator       | 1.8                      |
| Washing machine    | 1.1                      |
| Air conditioner    | 1.1                      |
| Computer           | 1.5                      |
The subsidy fee received by the certified recyclers is on the basis of the set number, but not the weight of the recycled WEEE. Also, the amount of the subsidy fee may be dependent on the size of the WEEE. The larger size of WEEE, the higher subsidy will be given. For example, > 25-inche waste TV can have a subsidized fee of 6.9 US$/set which is higher than the fee of 6.1 US$/set for < 25-inche TV on 2021. Furthermore, findings indicate that the subsidy fee of all five major WEEEs after 2021 are about 30% lesser than before 2021.

With the rapid growth of WEEE in recycling amount and life cycle recently, the growth rate of produced and imported WEEE lag behind the growth rate of WEEE dismantling. Moreover, the recycling amount of televisions are greater than other WEEE. Thus, the unbalanced structure of WEEE recycling causes the recycling fund was deficient for a certain period of time.

### 5 WEEE treatment standards of China

In order to minimize the adverse effects of WEEE treatment, a WEEE treatment requirement is issued in China. Also, only the recycler, which can meet the treatment requirements, can become a certified WEEE recycler and can receive the subsidy fees (Wang et al., 2017; Chang, 2014; CHEARI, 2017; EPA, 2012).

On the basis of China’s WEEE treatment standard and requirement, the summarized information is presented in Table 4. It indicates that the separation of a panel and funnel glass and the removal of fluorescent powder are required during the waste CRT treatment. This standard can minimize the pollution of barium contained in the panel glass, lead contained in the funnel and the toxic heavy metals contained in the fluorescent powder. Table 4 also reveals that the liquid crystal display (LCD) panel is required to be processed in a confined space to avoid mercury leakage from the backlight of cold cathode fluorescent lamp. It also shows that the recovery of refrigerants from refrigerators and air conditioners is required. This standard is used to minimize ozone depletion risk due to the chlorofluorocarbons that are contained in the refrigerants.

| WEEE item       | Categories                                 | Subsidy fee (US$/set) |
|-----------------|--------------------------------------------|-----------------------|
|                 |                                            | Before 2021 | After 2021 |
| TV              | 14 inches < size < 25 inches (no subsidy under 14 inches) | 9.2 | 6.1 |
|                 | > 25 inches                                | 10.7 | 6.9 |
| Refrigerator    | 50 L ≤ volume ≤ 500 L (No subsidy under 50 L) | 12.2 | 8.4 |
| Washing machine | Single-barrel washing machine and dryer (3 kg < drying capacity ≤ 10 kg) (No subsidy under 3 kg) | 5.3 | 3.8 |
|                 | Double barrels, pulsator and tumbling-box washing machine (3 kg < drying capacity ≤ 10 kg) | 6.9 | 4.6 |
| Air conditioner | Refrigerating capacity ≤ 14,000 watts       | 19.7 | 15.3 |
| Computer        | Main frame + Monitor                      | 10.7 | 6.9 |

### Table 3 WEEE subsidy fee before and after on 2021 in China (MMNM, 2015; MMNM, 2021)
According to China’s WEEE treatment standards, the recovery of chlorofluorocarbons refrigerant from the foaming agent of refrigerators is not required. However, this chlorofluorocarbons foaming agent recovery may be important for the minimization of ozone depletion risk. For example, the waste refrigerator should be shredded in a closed, negatively pressured, sound-proof, dust controlled and explosion-proof facility to recover the refrigerant in the foam insulating materials by using a refrigerant liquefaction system (Lu et al., 2015; EPA, 2012). It is reported that approximately 50% of certified waste refrigerator recyclers have adopted the technology to recover chlorofluorocarbons refrigerant from the foaming agent in China (CHEARI, 2017). It also reveals that the printed circuit board (PCB) obtained from waste computers is not required to be crushed on-site in China’s WEEE recycling facility. This can aid in the minimization of leakage of the important know-how in the PCB.

Currently, there are no quantitative treatment standard for China’s recyclers. For example, the minimum removal target of fluorescent powder (kg/TV set) and the minimum recovery targets of refrigerant from the refrigeration system (kg/refrigerator) are not issued in China’s standards. These quantitative treatment standards issued in other countries are intended to ensure that local recyclers obey the WEEE treatment standardization regulations. It would seem more appropriate for the government of China to issue the quantitative treatment standards for recyclers to obey.

### Table 4  WEEE treatment standards of China (Lu et al., 2015; EPA, 2012; He et al., 2006; M&N, 2014)

| Item                                                      | Requirement |
|-----------------------------------------------------------|-------------|
| Separation of CRT panel and funnel glass                 | Yes         |
| Removal of CRT fluorescent powder                        | Yes         |
| Removal target of fluorescent powder                      | No          |
| Recovery of refrigerant from the refrigeration system of refrigerators | Yes         |
| Recovery target of refrigerant from the refrigeration system of refrigerators | No          |
| Recovery of refrigerant from the foaming agent of refrigerators | No          |
| Recovery target of refrigerant from the foaming agent of refrigerators | No          |
| Recovery of refrigerant from the refrigeration system of air conditioners | Yes         |
| Recovery target of refrigerant from the refrigeration system of air conditioners | No          |
| Crushing of printed circuit board obtained from the computer | No          |
| The LCD panel is processed in a confined space to avoid Hg leakage | Yes         |

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### 6 Auditing procedure of the quantity of recycled WEEE in China

The key success factor for China’s WEEE management system is that the certified recyclers can receive the subsidy fees when they can treat the regulated WEEE items properly. Since the subsidy fee is paid by the actual treated amount, it is important to audit the actual recycled WEEE amount. On the basis of China’s audit guidelines (M&N, 2014), the auditing procedure of the quantity of recycled WEEE in China is presented in Table 5. Table 5 shows that the auditing work is performed once a quarter in China. The actual recycled amount of each recycler will be audited and certified by checking its on-site closed-circuit television (CCTV), the mass balance between the input and the output, as well as the electricity consumption.
As mentioned before, the recycled WEEE amount which reported by the certified recycler has to be officially audited and certified by the government before the recycler can receive the WEEE subsidy fees. In China, entrusted by the ministry of environmental protection, China solid waste and chemicals management technical center is in charge of the auditing results of recycled WEEE. Thus, an officially certified WEEE recycled amount was reported in WEEE management information system of MEP (M&N, 2014). The certified WEEE amount reported in this system is mainly for five WEEEs with announced treatment fee which are computers, televisions, washing machines, refrigerators and room air conditioners of each certified recycler within each province of China from the year of 2012–2020.

According to the statistics of 31 provinces, in total 71 million sets and 45 million sets of recycled WEEE were certified in 2015 and 2020, respectively. Among them, 70%, 4%, 8%, 17% and 0.2% are for TV, refrigerator, washing machine, computer and air conditioner in 2015, respectively, whereas 48%, 14%, 20%, 10% and 8% are for TV, refrigerator, washing machine, computer and air conditioner in 2020, respectively. The reduction in the certified amount of recycled WEEE in 2020 may be due to the outbreak of COVID-19 pandemic. In the further analysis of data in 2015, the Hubei province has the largest certified amount of recycled WEEE of 7,324,468 sets including 59% of TV, 5% of the refrigerator, 7% of the washing machine, 0.1% of air conditioner and 27% of the computer. Henan province has a certified amount of recycled TV of 4,978,424 sets which is the highest and accounts for around 10% of China’s recycled TV, 5% of the refrigerator, 7% of the washing machine, 0.1% of air conditioner and 27% of the computer. Henan province has a certified amount of recycled TV of 4,978,424 sets which is the highest and accounts for around 10% of China’s recycled TV, whereas Hubei province has the highest certified amount of recycled refrigerator, washing machine and computer of 424,666 sets (14% of total in China), 562,977 sets (10% of total in China) and 200,2969 sets (16% of total in China), respectively. And the Hebei province has the highest certified amount of recycled air conditioners of 20,836 sets which accounts for about 14% of China’s recycled air conditioners.

According to the data issued in WEEE management information system of MEP (M&N, 2014), Fig. 2 shows the number of certified recycler in each province of China which reported the WEEE recycled amount in 2012, 2015, 2018 and 2020. It shows that the total number of certified recycler was increased from 39 to 109 within 8 years. Only

| Table 5 Auditing system of the actual WEEE recycled amount of China (M&N, 2014) |
|---------------------------------|------------------|
| Item                            | Regulation       |
|---------------------------------|------------------|
| Auditing and certification      | “Private third-party auditing company” or “Environmental protection government”. |
| Dispatch on-site auditor        | No               |
| Frequency of auditing by        | Every quarter or month |
| Auditing organization           |                  |
| Closed-circuit television       | Yes              |
| Mass balance certification      | Yes              |
| Key component certification     | No               |
| Electricity consumption         | Yes              |
| Main auditing and certification | Randomly checked by CCTV inspection and calculation |
| method                          | No               |
| Overall recovery rate           | No               |
| certification                   |                  |
| Quantitative recovery           | No               |
| target certification            |                  |

### 7 Analysis of the implementation result of China's WEEE management

As mentioned before, the recycled WEEE amount which reported by the certified recycler has to be officially audited and certified by the government before the recycler can receive the WEEE subsidy fees. In China, entrusted by the ministry of environmental protection, China solid waste and chemicals management technical center is in charge of the auditing results of recycled WEEE. Thus, an officially certified WEEE recycled amount was reported in WEEE management information system of MEP (M&N, 2014). The certified WEEE amount reported in this system is mainly for five WEEEs with announced treatment fee which are computers, televisions, washing machines, refrigerators and room air conditioners of each certified recycler within each province of China from the year of 2012–2020.

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14 provinces have the certified WEEE recycler in 2012, whereas there is at least one certified recycler for 27 provinces in China at 2020. The province of Henan and Anhui both increased 6 certified recyclers from 2012 to 2020. These two provinces are located in the central of China. The province of Sichuan, Tianjin, Zhejiang, Jiangsu, Shanxi and Guizhou remained the same amount of certified recyclers since 2012. Apart from the Guangdong, all the provinces with more than 4 certified recyclers are distributed in the central and eastern part of China. During the period from 2012 to 2020, most of the provinces in China have increased their certified recyclers as time goes by. However, the Jilin province decreased the certified recyclers from 2 to 0 during the year of 2018–2020, and Gansu province decreased the certified recyclers from 2 to 1 during the year of 2015–2018. It also notes that among all the provinces of China only Xizang and Hainan provinces did not apply the certification of recycled WEEE from 2012 to 2020.

In order to understand the relationship between the certified amount of recycled WEEE and GDP (Gross Domestic Production) per capita of each province, Fig. 3 presents the certified WEEE amount of 5 recycled items (i.e., TV, refrigerator, washing machine, computer and air conditioner) with the GDP per capita for each province of China in 2015 and 2020. Figure 3 clearly illustrates that the amount of recycled TV is the highest, whereas the amount of recycled air conditioner is the lowest for every province in 2015 and for most of the provinces in 2020. This may be due to that scrap TV has no commercial value for
the private recycler which makes it easy to be collected by the official WEEE management system and the scrap air conditioner contains high value of material which makes it difficult to be collected in China's WEEE management system. Thus, more effort should be enforced to increase the recycling of scrap air conditioner in China. It also can be seen that those provinces with the high certified amount of recycled WEEE are concentrated on the eastern part of China. Figure 3 shows that provinces with high GDP per capita have higher certified amount of recycled WEEE than provinces with low GDP per capita. This may be due to that the resident living in the province with high GDP per capita may have more electrical products which result in a high certified amount of recycled WEEE. However, this explanation is not valid for the provinces of Ningxia, Xinjiang, Shanghai, Liaoning and Beijing which have over 7600US$ of GDP per capita and less than 650,000 sets of certified amount of recycled WEEE in 2020.

Figure 4 presents the relationship between the certified amount of 5 major recycled WEEE and the population of each province in 2015 and 2020. Figure 4 illustrates that almost all the provinces with high population will have a high certified amount of recycled WEEE.

The green recovery rate is calculated by China government (MEE, 2021) to reveal the proportion of the actual amount of WEEE recycled by certified recyclers to the theoretical production amount of scrap WEEE. Figure 5 presents the relationship between the certified
amount of 5 major recycled WEEE and the green recovery rate of each province in 2020. It illustrates that middle and north part of China have high green recovery rates.

By comparing Figs. 3b, 4b and 5, it can be concluded that the certified amount of each province has a higher positive correlation with provincial population than provincial GDP per capita and green recovery rate. It means that the province with a high population is expected to have the high certified amount of recycled WEEE.

On the basis of the data presented in the WEEE management information system of MEP (M&N, 2014; MEE, 2021), the average certified sets of recycled WEEE per person for each province can be calculated. Figure 6 demonstrates the spatial relation between the average certified sets of recycled WEEE per person and the population of each province of China in 2015 and 2020. The calculated average certified WEEE set per person is 0.05 set/person in 2015, and ten of the provinces have values greater than average. The Tianjin, Hubei and Jiangxi are the top 3 provinces with provincial values of 0.18 set/person, 0.12 set/person and 0.11 set/person, respectively. The provinces of Guizhou, Guangxi and Liaoning all have a lower value of < 0.01 set/person. Similar results can be found for 2020. Figure 6 shows the high positive correlation between the average certified sets of recycled WEEE per person and the population of each province of China.

8 Conclusions

This paper reviews the WEEE management system of China, which basically focused on five perspectives, mainly, management systems, treatment and subsidy fees, treatment standard, auditing system and implementation result. From the aforementioned management system, China has adopted the producer responsibility for recycling program. There are many governmental sectors that co-managed the WEEE recycling system and total of 14 regulated WEEE items that were announced, and a specific WEEE management regulation is issued in China. Currently, the main role of importers and manufacturers of EEE is to pay the treatment fees to facilitate the WEEE recycling.

From the perspective of the auditing system, an auditing system has been established to certify the actual recycled WEEE amount as the basis for the remuneration of subsidy fee in China. The recycled amount is randomly certified mainly by CCTV and mass balance calculation in China.

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Fig. 6 Spatial relation between the averages certified sets of recycled WEEE per person and the population of each province of China in a 2015 and b 2020
The implementation result of China’s WEEE management reveals that the most updated and completed certified amount of recycled WEEE was given in 2020. In total, 45 million sets of recycled WEEE were certified in 2020 which a year contains the most updated data. Among them, 48%, 14%, 20%, 10% and 8% are for TV, refrigerator, washing machine, computer and air conditioner, respectively. It shows that the total number of certified recycler is increased from 39 to 109 in 2012–2020. The spatial analysis indicates that WEEE recycling activities are mainly concentrated on the mid-east and east region of China. It also can be concluded that the certified amount of each province has a higher positive correlation with provincial population than provincial GDP per capita and green recovery rate. It means that the province with a high population is expected to have the high certified amount of recycled WEEE. It also clearly notes that the amount of recycled air conditioner is the lowest in the country. Therefore, more efforts should be made to increase the recycling of air conditioner scrap in China. Since there is no quantitative treatment standards for recyclers in China to ensure that they have to comply with standard treatment regulations, the issue of quantitative treatment standards by China government is strongly recommended.

In the future, China’s WEEE management system can be further improved by using the available high tech such as artificial intelligence, big data, online real-time monitoring and global positioning system to build a more efficient recycling network. The overall WEEE treatment capacity can be increased by encouraging the certified recyclers to upgrade their recycling technology and equipment. From the perspective of announced WEEE treatment fee, it is suggested that differential treatment fee for different environmental impact of the WEEE is adopted to give economic incentive for the producers to design and produce more environmentally friendly EEE in China. In addition, the recovery of chlorofluorocarbons refrigerant from the foaming agent of refrigerators be issued in China’s WEEE treatment standards to minimize the ozone depletion risk.

Also, the extraction of valuable material such as precious and rare earth metals containing in WEEE should be enhanced to increase the added value of WEEE recycling. In addition, by building international cooperation channels to work with European Union, USA, Japan and other advanced WEEE recycling countries to adopt their successful experiences can constantly improve China’s WEEE management system.

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**Conflict of interest** The authors declare that they have no conflict of interest.

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