Environmental and resource recovery efficiency assessment of the obsolete mobile phones recycling system

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Abstract. Considering environmental protection and resource recovery efficiency, the building of low pollution and high efficiency for recycling system of obsolete mobile phones has been a huge issue. Through system dynamics, the recycling model of obsolete mobile phone is built, which involving the recycling effect under different recycling situations between formal and informal recyclers. The vensim PLE software is used to simulate and assess influence variables in the model. The results show that the formal recycling system can improve the efficiency of recovery and reuse or recycling of obsolete mobile phones.

1. Introduction
Mobile phone is an indispensable electronic product in people's daily life. The continuous progress of its core technology and the innovation of function drive consumers to replace it frequently. China's obsolete mobile phones are characterized by large amount, low recycling rate and high resource value. In addition, due to the complex components of obsolete mobile phone, irrational resource disposal will cause serious environmental pollution and human health damage.

International and domestic academics have conducted a series of studies on Waste Electrical and Electronic Equipment (WEEE). Sabbaghi et al argued that high costs for maintenance services drive most mobile phones into recycling. Insufficient use of mobile phone can lead to value leakage [1]. Yu et al believe that the lack of standardized recycling and treatment channels of WEEE leads to increasingly serious damage to the ecological environment [2]. Ardi et al. proposed that, especially in developing countries, the informal sector plays an important role in the management system of WEEE [3]. Li et al. proposed that due to the lack of formal and convenient recycling models and effective incentive measures, it is difficult to establish a formal recycling mode operation mechanism [4]. Song et al. presented that the amount of formal disposal of WEEE in China is increasing steadily at present, but it still faces challenges such as imbalance between fund levy and subsidy, homogeneity of recycling industry and imperfect regulation [5]. Therefore, the selection of recycling channels has become a hot issue of recycling used mobile phones. Wu et al. researched consumers' behavioral intention of WEEE recycling from the perspectives of formal-informal and emotional-rational. The results show that emotional recycling behavior intention is formal recycling orientation, while rational recycling behavior intention reflects informal recycling tendency [6].

None of the above literatures consider the influence of government dismantling subsidies and service level differences on the recycling amount and profit under the market competition in different recycling channels. Based on System Dynamics (SD), a recycling model considering formal incentives and
informal constraints is established. From the perspective of government subsidies and service investment, this paper forecasts the recycling scale and profit of China's recyclers from 2010 to 2025, which can provide a reference for the government to optimize the recycling mode of obsolete mobile phones.

2. Methodology

2.1. Generic conceptual model
From the perspective of consumers, the lifecycle of mobile phones can be divided into three stages: use, storage and recycle. Figure 1 shows the general recycling process and state changes of obsolete mobile phones. After the lifespan of the mobile phone, recyclers are involved in different types of recycling operations according to the degree of damage, i.e. dismantling, refurbishment, remanufacture and secondary market. Some of the disassembled waste material may end up in landfill or incineration.

2.2. Model Hypothesis
Hypothesis 1: There are both formal and informal recyclers in the market. Formal recyclers refer to the recycling departments that receive government dismantling subsidies, including recyclers led by retailers or manufacturers and third-party recyclers. Informal recyclers are small business hawkers who do not have the qualification to dismantle. Hypothesis 2: The obsolete mobile phones are all from the residents' homes.

2.3. Casual-loop diagram of the model
In order to appropriately depict the behavior of a system and feedback structure, the causal loop diagram (CLD) is employed, which is represented by the arrows. A sign (+) denotes the change of two variables in the same direction, while a sign (-) is opposite.

Fig2 shows the CLD of the model considering dismantling subsidies, which consists of reinforcing (R) loops and balancing (B) loops. Loop R1 expresses the increasing trend of obsolete mobile phones in residents' homes. The balancing loops consist of loop B1 to B2 and represent the impact of service inputs on the recycling competition of formal and informal recyclers.

As shown in Fig3, Loop R2 represents the positive impact of dismantling subsidy on formal recyclers, while the dismantling subsidies limits the development of informal recyclers in the Loop B3. Fig3 indicates that the recycling price of obsolete mobile phone changes with the international average market price of valuables after dismantling.
2.4. Stock-flow diagram of the model

Based on the CLD, the stock-flow diagram (SFD) of the recycling is presented in the Fig4. In this figure, the stock of idle mobile phone is increased by replacement rate, which is influenced by household and lifespan. Formal profit per phone depends on formal recycling price, dismantling subsidies, formal dismantling costs per phone and formal service input per phone. The equation of these relationship is as follows:

\[
\text{Idle mobile phones} = \text{INTEG (Replacement rate)} \\
\text{Replacement Rate} = \frac{\text{Household/Lifespan}}{} \\
\text{Formal profit per phone} = \text{Formal recycling price} + \text{Dismantling subsidies} - \text{Formal dismantling costs per phone} - \text{Formal service input per phone}
\]
3. Simulation analysis

3.1. Simulation under the influence of dismantling subsidy

Unlike informal recyclers, the dismantling activities of formal recyclers are standardized and environmentally friendly. With the standardization of obsolete mobile phone recycling, the Chinese government has set up recycling funds and dismantling subsidies to make up for the high dismantling cost of formal recyclers. In this paper, it is assumed that the dismantling subsidies for formal recyclers is 5 RMB (current1), 10 RMB (current2) and 15 RMB (current3), the simulation results of different recycling amount are shown in figure 5.

![Fig.4 The stock-flow diagram of obsolete mobile phone recycling](image)

![Fig.5 The annual recycling amount under different dismantling subsidies](image)

Figure 5 compares the recycling trends of formal and informal recyclers under different dismantling subsidies. With the increase of dismantling subsidy, the recycling amount of formal recyclers shows an upward trend, while the informal recyclers keeps decreasing. Therefore, dismantling subsidies promote the development of formal recyclers and inhibit the informal recyclers.
3.2. Simulation under the influence of different service levels
With the improvement of living standard, people pay more attention to service quality. As a private item, mobile phone contains a lot of personal information and requires a safer dispose. When the service cost of each obsolete mobile phone is 5 RMB (current1), 8 RMB (current2) and 12 RMB (current3) respectively, the profit of formal recyclers is shown in Figure 6.

Fig. 6 The profit of formal recyclers under different service costs

Fig 6 reveals that the quality service conditions of formal recyclers, which attracts more consumers to hand over the obsolete mobile phones to formal recyclers. However, the high investment in service level means the increase of recycling cost, which leads to the reduction of mobile phone recycling profit. As shown in figure 6, when the service cost increases from 5 to 8 RMB, the profit of formal recycling increases, and when the service cost increases from 8 to 12 RMB, the recycling profit decreases. Therefore, it can be seen that the reasonable service charges range of formal recyclers is between 8 and 12 RMB.

4. Conclusion
This paper aims to assess the effect of dismantling subsidies and service level to the formal and informal recyclers in recycling.

The research shows that: (1) due to the influence of dismantling subsidies, the competitive advantages of formal recyclers are increasingly prominent; (2) the investment of formal recyclers in service level promotes the increase of recovery profit, but the service cost should be controlled within the reasonable range of 8-12 RMB.

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