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Research article

Multiple benefits of new-energy vehicle power battery recycling strategies based on the theory of planned behavior and stimulus organism response

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ABSTRACT

With the yearly increasing market penetration of new-energy vehicles in China, the retirement of power batteries has gradually become a scale, and most of the waste batteries have entered informal recycling channels, which has induced a series of environmental problems. Considering this issue, we introduced the system dynamics (SD), stimulus organism response (SOR), and the theory of planned behavior (TPB) in behavioral economics to establish the environmental economic benefit evaluation model of power battery recycling strategies, and we performed a dynamic simulation analysis on the effect of government subsidy policy, policy advocacy, and other recycling strategies. The results show that: (1) the recovery subsidy policy can improve the formal recycling quantity and economic benefits of recovery, but the effect on the degree of environmental pollution is limited. (2) The combination of environmental awareness promotion strategy and subsidy policy can overcome the shortcomings of subsidy policy and has significant environmental and economic performance. (3) Compared with the benchmark scenario, the formal recycling quantity, the CO_2 emission reduction, and the economic benefits of recovery in scenario 4 (high subsidy-high policy propaganda strategy) increased by approximately 112 %, 208 %, and 223 %, respectively, and the degree of environmental pollution decreased by approximately 65 %.

1. Introduction

With the “scrap tide” of power batteries in China, the resulting resource and environmental problems will become increasingly apparent. If the batteries of retired new-energy vehicles are not effectively recycled, it will cause a great waste of resources [1], as surplus electricity is a crucial factor that affects the development of stand-alone renewable energy systems and batteries are the primary devices used to manage this surplus [2]. Approximately 80 % of retired power batteries in China have entered informal recycling channels, which has caused a series of safety and environmental risks [3]. The recycling of electronic waste benefits both the environmental sector and the economic sector [4]. To solve the disposal problem and environmental pollution caused by retired batteries from new-energy vehicles, many cities have formulated a series of policies and measures, such as recovery subsidy policy, environmental protection tax policy, and government regulation recovery rate policy. Scholars from various countries have also

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performed many related studies.

In terms of recycling policy, the government plays a vital role in promoting waste recycling [5]. Strict government regulation, subsidies, and punishment can improve the recovery rate [6] and information security of the internet recycling mode [7]; however, excessively strict policies may negatively impact the total welfare. It is worth noting that the reward–penalty intensity and total welfare are not correlated in a completely positive way, but instead in a manner where the former initially acts as a stimulant and then plays a restraining role. For example, when the reward–penalty intensity increased from 1200 RMB to 1800 RMB, the corresponding total amount of social welfare fell from 4.41 billion RMB to 4.37 billion RMB [8]. Most studies focused on government subsidies, including the comparison of different subsidy forms [9] and the impact of subsidies on the power battery recycling supply chain [10]. The studies believe that subsidies are more beneficial than no subsidy, the two subsidy policies are suitable for different situations, government subsidies will affect the income of the recycling supply chain, and the distribution of subsidies will affect the choice of the recovery mode. Examining the timing of government subsidies, Wang et al. [11] proposed that the government should formulate different battery-recycling subsidy schemes at different development stages of electric vehicles. Gu et al. [12] studied the optimal production strategy of loss-averse electric vehicle manufacturers when government subsidies and battery recycling coexist.

Battery recycling has significant environmental, economic, and social benefits. In terms of environmental impact, the waste lithium-ion batteries of China have great potential for metal recycling and environmental benefits [13]. Li et al. [14] evaluated the carbon emissions and energy consumption during the life cycle of waste lithium-ion battery recycling. This study found that the global warming potential and cumulative energy demand of recycling 1 kg of spent LIBs are 0.158–44.59 kg CO2-eq and 3.3–154.4 MJ, respectively. Chen et al. [15] concluded that different recycling methods had different environmental impacts on recycling. Zong et al. [16] performed the material flow analysis on the critical resources of waste power ion batteries in China. Research has shown that the environmental impact could be reduced by up to 54 % through closed-loop manufacturing with direct recycling [17]. In terms of economic impact, Lander et al. [18] proposed a comprehensive technical and economic model to recover lithium-ion batteries for electric vehicles, which ensured the feasibility of the recovery economy. Zeng et al. [19] improved the economic benefit evaluation model for the uncertainty in the recycling process of waste lithium batteries. Kamath et al. [20] evaluated the economic value and life cycle carbon footprint of recycled and reconstituted secondary batteries. Li et al. [21] discussed the economic and environmental impact of current battery recycling and proposed that the recycling technology should achieve a balance between recycling efficiency and economic and environmental benefits.

In terms of power battery recycling supply chain, some studies have shown that the closed loop supply chain of electric vehicle power battery can reduce resource consumption to improve the environmental and economic benefits [22]. Wu et al. [23] constructed four single-channel recycling models under the condition that automobile battery manufacturers play a leading role in the closed-loop supply chain of automobile battery recycling, and they proposed that the government should provide reasonable subsidies. Feng et al. [24] discussed the interaction among supplier development, supplier integration, and power battery recycling in the competitive electric vehicle supply chain. The recycling supply chain decision has been examined from the aspects of the carbon trading policy [25], impact of the battery life [26], impact of different recycling and warranty channels [27], and impact of the decisions of different subsidy objects [28]. Li et al. [29] established a closed-loop supply chain SD model for e-waste recycling in the cloud environment.

The existing literature provides theoretical support for the research on the recycling strategy of power batteries for new-energy vehicles in this paper. However, research on recycling strategies rarely analyzes and discusses the causal relationship among various systems and variables from the system perspective, and few studies simultaneously consider the impact of the recycling subsidy policy and psychological factors on recycling. The recycling of new-energy vehicle power batteries is a complex system problem that involves social, economic, environmental, and other aspects. The effect of each strategy and whether it is effective in the medium and long term must be explored. Therefore, this paper introduces the subsidy policy, improves environmental awareness and other recovery strategies, combines system dynamics with behavioral economics, and proposes a battery recovery improvement algorithm based on the system dynamics (SD), stimulus organism response (SOR), and theory of planned behavior (TPB) in behavioral economics (SD-SOR-TPB integrated algorithm). Then, we build the economic and environmental benefit evaluation model of the new-energy vehicle power battery recycling strategy. We design different policy schemes, select the best scheme through a comparative analysis of several scenarios, and provide reasonable policy suggestions for improving the economic benefits of recycling and reducing environmental pollution. The contributions of this paper are as follows.

(1) A battery recovery rate improvement algorithm based on SD-SOR-TPB theory is proposed, which fully considers the influence of psychological factors such as subjective norms (including policy advocacy, recycling convenience) and behavior attitude (environmental care, attitude, responsibility) on recovery behavior, so as to improve the recovery efficiency of power batteries.
(2) Combining the strategy of improving environmental awareness with the subsidy policy, from the medium- and long-term perspective, this paper explores the relative optimization scheme to improve the formal recovery amount, reduce the pollution degree and CO_2 emissions, and realize the “win-win” aspect of environmental and economic benefits.

2. Methods

2.1. Causal loop analysis

System dynamics is a method to understand the nonlinear behavior of complex systems over time by modeling key feedback loops [30]. It was established in 1956 by J. W. Forrester of the Massachusetts Institute of technology. The system dynamics model has been applied and studied in the recycling of waste batteries. Joshi et al. [31] established a dynamic model of battery recycling systems based on different channels, studied the effect of tax reduction and subsidy policies on improving the recovery rate, and proposed that appropriate subsidies could reduce lead emissions, whereas excessive subsidies might affect the development of the recycling sector. He et al. [32] built a system dynamics evolutionary game model of power battery recycling from the supply side perspective, and they proposed a dynamic reward and punishment mechanism to enable recycling parties to participate more in environmental protection recycling. The above research also provides support and reference for this paper.

By analyzing the causal relationship among the variables, the system boundary is determined, and the causal relationship diagram is established using the VENSIM software, as shown in Fig. 1. The diagram shows four main loops, where loops 1–2 are the environmental performance, and loops 3–4 are the economic performance.

Loop 1 is a negative feedback loop: with the increase in pollution degree, the government will strengthen governance efforts to enhance residents' awareness of environmental protection, select more formal recycling channels, and improve the formal recycling rate affected by environmental protection awareness; thus, it reduces the amount of unrecycled waste batteries and alleviates the degree of environmental pollution. The analysis of Loop 2 is identical: with the increase in recovery rate affected by environmental protection awareness, the corresponding amount of formal recycling cascade utilization and material regeneration increases; then, emission reduction with environmental impact increases, and the degree of environmental pollution decreases.

Loop 3 and loop 4 are positive feedback loops. The price spreads will affect the recovery rate of different recycling channels. The economic benefits of recycling and government recycling subsidies can reduce the recovery price spreads between formal and informal recycling channels, reduce the price disadvantage of the formal recyclers, improve the formal recycling quantity, improve the profits of cascade utilization and benefits of material regeneration, and further improve the economic benefits of recycling.

2.2. System dynamics model of power battery recycling benefits

The flow stock diagram is constructed based on the causal relationship diagram, as shown in Fig. 2. The simulation time is set as 2014–2030, and the step size is 1.

2.2.1. Model assumptions

Hypothesis 1. Formal power battery recyclers follow the recycling process of first cascading utilization and subsequent material regeneration.

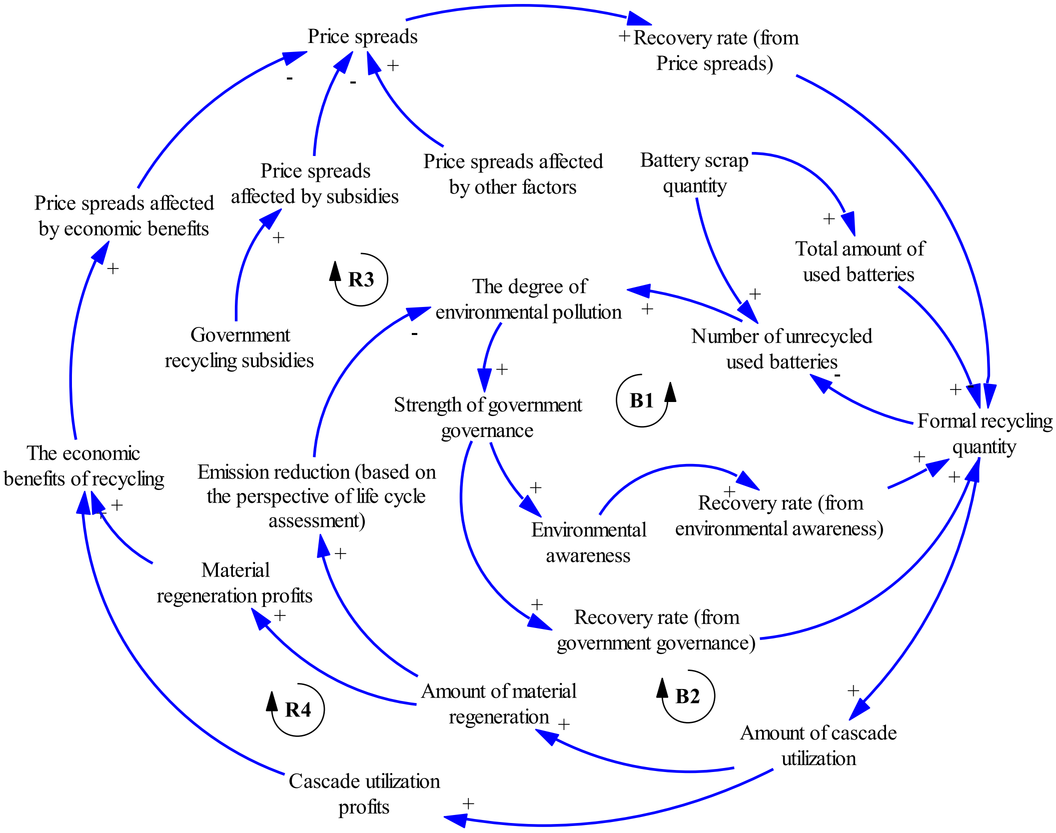

Fig. 1. Causal relationship diagram.

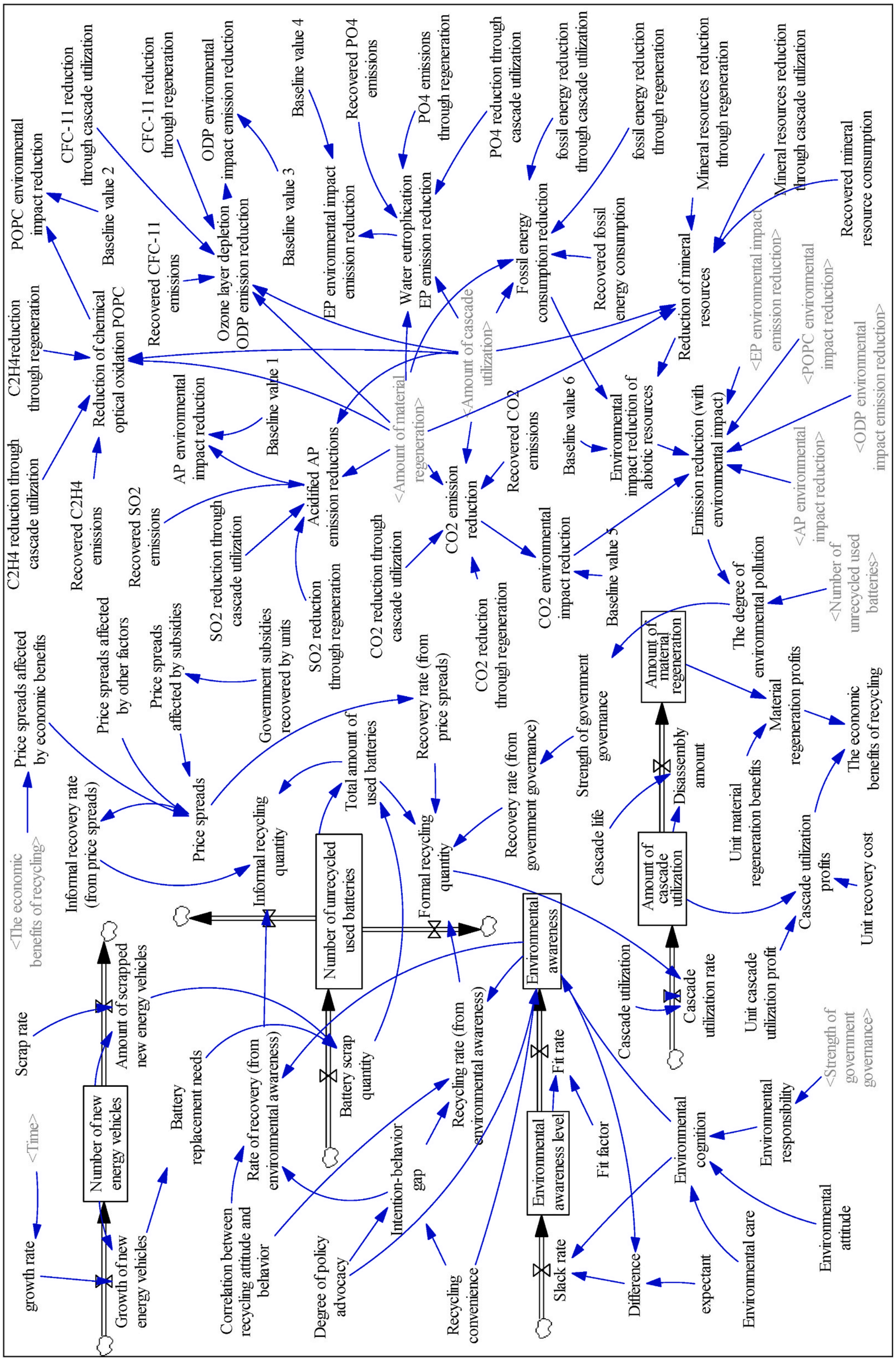

Fig. 2. System flow diagram of the power battery recycling strategy.

Hypothesis 2. The model mainly considers the factors that affect the amount of battery recycling, including the impact of recycling price spreads, environmental awareness, and government governance on key factors.

Hypothesis 3. CML2001 was developed by the Institute of Environmental Sciences, Leiden University [33]. It is a universal evaluation method. It divides the abiotic depletion ADP (e) (kg, based on Sb-Eq), abiotic depletion (fossil energy consumption) ADP (f) (MJ), global warming potential GWP (kg, based on CO_2-Eq), acidification potential AP (kg, based on SO_2-Eq), eutrophication potential EP (kg, based on phosphate-Eq), photochemical ozone creation potential POCP (kg, based on Ether-Eq), and ozone depletion potential ODP (kg, based on R_{11}-Eq). In this paper, these seven indicators are used to measure battery recycling resources, energy consumption, and the impact on the environment, i.e., the environmental performance of recycling.

The main battery recycling policies outlined in the flow chart include the subsidy policy and the recycling advocacy policy. The recovery rate from the impact of price spreads is described by the impact of recycling subsidies on the price spreads of different recycling channels. The environmental awareness level is represented by the degree of policy advocacy and convenience of recycling to analyze the effect of single policy and joint strategies and evaluate the economic and environmental benefits of battery recycling.

2.2.2. *Determination of parameters and equations*

The sources of model parameters include the official website statistical yearbook and existing literature reference. The official website statistics can determine the number of new-energy vehicles, and the growth rate of new-energy vehicles is simulated using the grey mean GM (1,1) prediction model. The existing literature can determine the profits and costs of the battery recycling cascade utilization [34] and material regeneration stage and list data of environmental benefits [35], and environmental impact data of each life cycle of retired battery recycling [36]. The specific parameter values and equations are presented in the Appendix.

2.2.3. *Battery recycling rate improvement algorithm based on the SD-SOR-TPB theory*

Environmental awareness is a psychological factor, and it is difficult to directly establish a correlation equation for the recovery rate affected by environmental awareness. To this end, the stimulus organism response theory and planned behavior theory are combined with the system dynamics. Fig. 3 shows the theoretical framework. A battery recovery improvement algorithm based on SD-SOR-TPB theory is constructed, and Fig. 4 shows the algorithm steps.

The SOR theory is a theoretical model that is widely used in behavior prediction. It was proposed by environmental psychologist A. Mehrabian. The model believes that the response of individuals to external incentives is not mechanical and passive, people have subjective initiative, and individuals have the ability to process effective information under incentives to make rational behavioral decisions. The model explains the process of the effect of external environmental incentives on organism cognition and psychology [37]. The TPB is developed from the combination of the rational behavior theory and multi-attribute attitude theory. The theory explains the general decision-making process of an individual behavior from the perspective of information processing and the perspective of expected value. It has been successfully applied in many fields of behavior research, and the vast majority of studies have confirmed that it can significantly improve the explanatory power and predictive power of research on behaviors. The TPB is widely used in the study of electronic waste recycling behavior [38] and power battery recycling [39,40]. According to the TPB, the behavior intention is affected by three related factors: the individual's own attitude, i.e., the positive or negative feelings for a specific behavior; the external "subjective norms", i.e., the pressure of individuals, groups, and society on whether to adopt a specific behavior; "perceptual behavior control," which reflects the obstacles of personal past experiences and expectations. Fig. 3 shows the theoretical block diagram of SD-SOR-TPB. Taking the subjective norms and behavior attitudes in the TPB as external incentives, the perceived behavior control affects the degree of deviation between environmental awareness and behavior, and the choice of the formal recycling behavior is the final response.

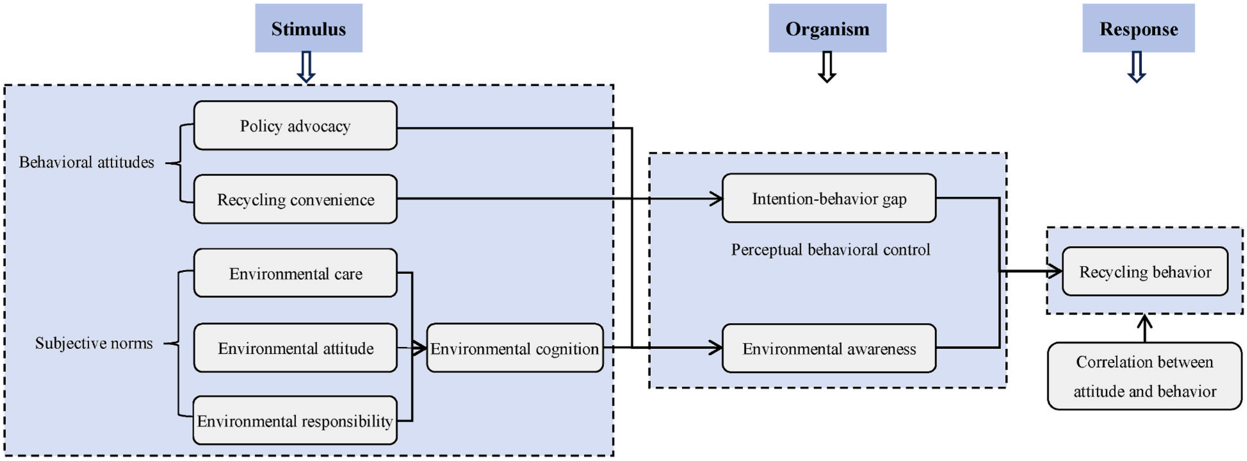

Fig. 3. Theoretical block diagram based on stimulus organism response and theory of planned behavior.

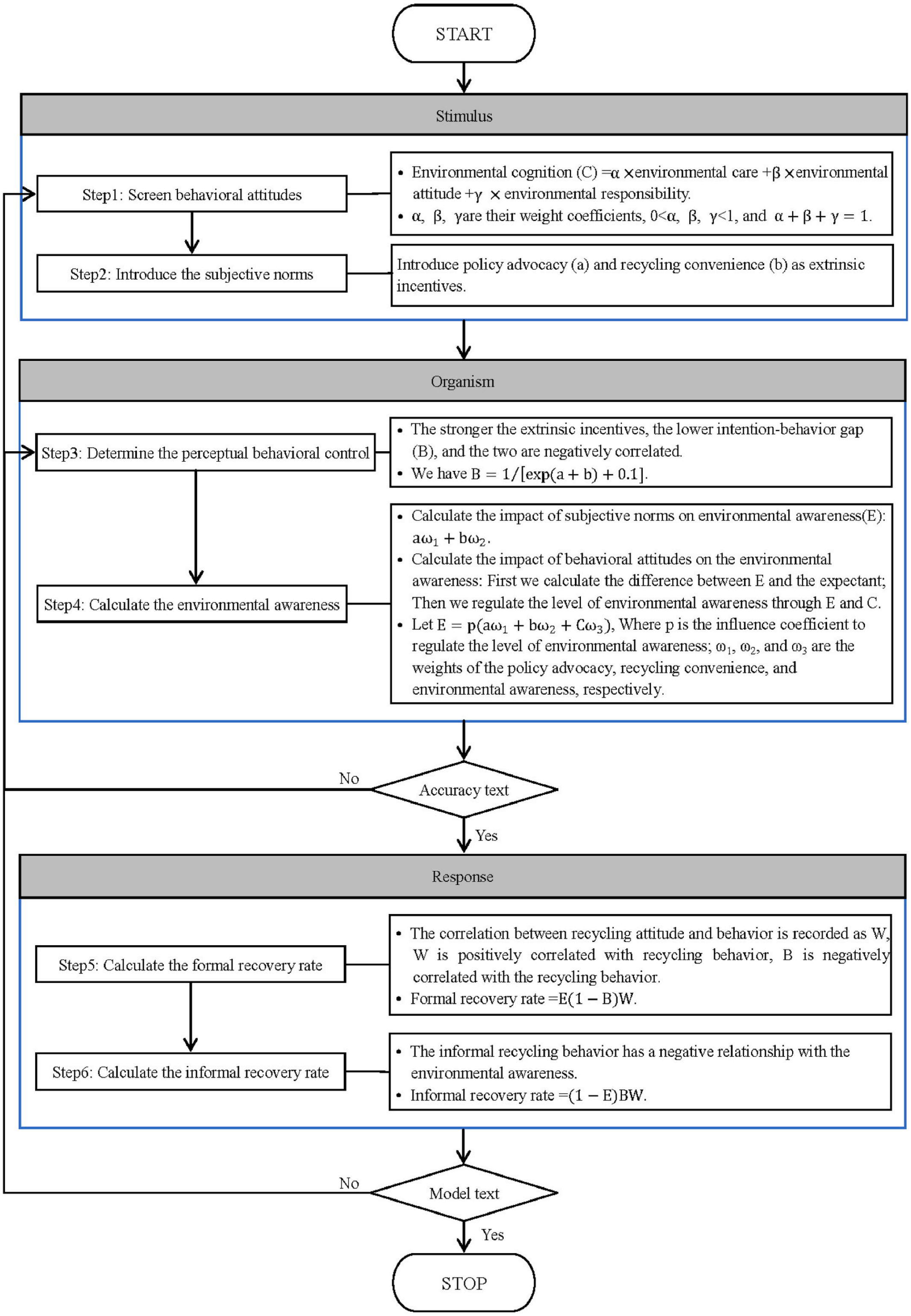

Fig. 4. Algorithm flow chart.

The algorithm fully considers the influence of psychological factors on the recycling behavior and provides a more comprehensive understanding of the determinants of individual recycling behaviors. Then, it explores how to improve the regular recycling rate to conserve energy, reduce emission, and improve the economic benefits. The specific calculation steps are as follows.

Step 1 **Screen behavioral attitudes**

Referring to existing literature [41], the environmental cognition of an individual is characterized by environmental care, environmental attitude, and environmental responsibility, i.e., the individual's internal behavior attitude.

Their weight coefficients are α, β, and ϒ. Available environmental cognition (C) = α × Environmental care + β × Environmental attitude + γ × Environmental responsibility, of which $0 < \alpha, \beta, \gamma < 1,$ and $\alpha + \beta + \gamma = 1$.

Step 2 **Introduce the subjective norms**

Subjective norms are the social pressure that individuals perceive when choosing whether to perform battery recycling activities. This paper introduces the degree of policy advocacy (a) and the convenience of recycling (b) as external environmental incentives to explore their impact on environmental awareness.

Step 3 **Determine the perceptual behavioral control**

Perceptual behavior control is the perception of an individual of the difficulty of battery recycling activities. With stronger perceptual behavior control, the behavior will be more likely induced. Influenced by other external factors, recycling behaviors may deviate from environmental protection consciousness, so the stimulation of external policy advocacy and recycling convenience indirectly affects the recycling behavior by influencing the intention-behavior gap (B), and the two are negatively correlated. B is represented as follows Eq. (1):

$$B = 1/[exp(a + b) + 0.1]. \tag{1}$$

Step 4 **Calculate the environmental awareness**

First, we calculate the impact of policy advocacy and recycling convenience on environmental awareness (E) in the subjective norms: $a\omega_1 + b\omega_2$. Then, we calculate the impact of behavioral attitudes on the environmental awareness: calculate the difference between E and the expectant. Regulate the level of environmental awareness through E and C. The final environmental awareness (E) is designed as Eq. (2):

$$E = \mathrm{p}(\mathrm{a}\omega_1 + b\omega_2 + C\omega_3) \tag{2}$$

Where p is the influence coefficient to regulate the level of environmental awareness; ω_1, ω_2, and ω_3 are the weights of the policy advocacy, recycling convenience, and environmental awareness, respectively; $0 < \omega_1, \omega_2, \omega_3 < 1$, and $\omega_1 + \omega_2 + \omega_3 = 1$.

The model accuracy is tested using the VENSIM software. If it fails, we return to step 3; if it passes, we continue to step 5.

Step 5 **Calculate the formal recovery rate**

Because the environmental attitude significantly affects the recycling behavior and has a positive correlation, we record the correlation between environmental attitude and recycling behavior as W. B is negatively correlated with the recycling behavior. Formal recovery rate is represented as Eq. (3), where B and E are derived from Eqs. (1) and (2), respectively. Therefore, the recovery rate of the impact of environmental awareness = environmental awareness × (1 – intention behavior gap) × the correlation between attitude and behavior, i.e., $E(1 - B)W$.

$$\text{Formal recovery rate} = E(1 - B)W \tag{3}$$

Step 6 **Calculate the informal recovery rate**

The informal recycling behavior has a negative relationship with the environmental awareness, so the informal recovery rate is (1 – environmental awareness) × intention behavior gap × correlation between attitude and behavior, i.e., $(1 - E)BW$. Informal recovery rate is represented as follows Eq. (4):

$$\text{Informal recovery rate} = (1 - E)BW \tag{4}$$

The model accuracy is tested using the VENSIM system dynamics software. If it fails, we return to step 1; if it passes, the algorithm is completed.

3. Results and discussion

3.1. Model validation

Using the method of relative error test, the number of new-energy vehicles in 2014–2022 [42] is selected to test the effectiveness of the model. Table 1 shows the test results.

Definition [43]: Assume that $X^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\right)$ is a sequence of raw data, and $\hat{X}^{(0)} = (\hat{x}^{(0)}(1), \hat{x}^{(0)}(2), \cdots, \hat{x}^{(0)}(n))$ is its simulation sequence of the prediction model.

$\varepsilon^{(0)} = (\varepsilon(1), \varepsilon(2), \cdots, \varepsilon(n)) = \left(x^{(0)}(1) - \hat{x}^{(0)}(1), x^{(0)}(2) - \hat{x}^{(0)}(2), \cdots, x^{(0)}(n) - \hat{x}^{(0)}(n)\right)$ is its residual error sequence.

$\Delta = \left(\left|\frac{\varepsilon(1)}{x^{(0)}(1)}\right|, \left|\frac{\varepsilon(2)}{x^{(0)}(2)}\right|, \cdots, \left|\frac{\varepsilon(n)}{x^{(0)}(n)}\right|\right) = \{\Delta_k\}_1^n$ is its relative error sequence.

(a) When $k \leq n, \Delta_k = \left|\frac{\varepsilon(k)}{x^{(0)}(k)}\right|$ is called k-simulation relative error, $\overline{\Delta} = \frac{1}{n}\sum_{k=1}^{n} \Delta_k$ is called the average relative error.

(b) $\exists \alpha > 0,$ when $\overline{\Delta} < \alpha$ and $\Delta_n < \alpha$, it is defined as the qualified verification of residual error.

Table 1 lists the accuracy test grade.

Table 2 shows that the relative error of each variable simulation value is within 5 %, placing the accuracy in grade 2; thus, the model exhibits high accuracy and can be used to simulate the recovery of power battery of new-energy vehicles.

3.2. Dynamic simulation of different recycling policies

We introduce policy advocacy, recycling convenience, environmental cognition, other environmental awareness promotion strategies, and recycling subsidy policies and conduct dynamic simulations to analyze the impact of changes in policy variables in the model on the environmental and economic benefits of new-energy vehicle power battery recycling.

3.2.1. Government recycling subsidy policy

After China promulgated the Pilot Implementation Plan to Recycle Power Batteries for New-energy Vehicles in 2018, various regions have successively issued their own recycling subsidy policies and plans. The Shanghai government provides electric vehicle manufacturers with a subsidy of 1000 yuan for recycling each electric vehicle battery. Hefei has implemented a subsidy of 10 yuan/kWh according to the battery capacity. Shenzhen's regulations on power battery recycling subsidies are to determine the recycling amount according to the standard of 20 yuan/kWh, and the government will subsidize new-energy vehicle dealers according to 50 % of the recycling standard amount. Guangxi subsidizes power battery recycling outlets according to the actual recycling amount, and the subsidy standard is 20 yuan/kWh. According to the actual situation, this paper sets the amount of government subsidies as [0,5000] yuan/block, and the unit power battery capacity is 63.8 kWh [36]. The unit recovery subsidy was changed at equal intervals, and other variables remained unchanged. Fig. 5 shows the simulation results, where S represents the government subsidy recovered by the unit.

According to Fig. 5a and b, when the unit recovery subsidy is less than 1000 yuan/block, the impact on the formal recovery amount and economic benefits of recovery are small. With the increase in unit recovery subsidy, the formal recovery amount and economic benefits also increased. When the subsidy increased to 3000 yuan/block, the change was the largest. When the unit recovery subsidy was 4000 yuan/block, the increased regular recovery amount and economic benefits of recovery gradually decreased.

According to Fig. 5c, when the unit recovery subsidy was less than 1000 yuan/block, the reduced informal recovery amount did not significantly change. When the subsidy increased, the informal recovery amount decreased with the increase in unit recovery subsidy. The reduction range was maximal when the subsidy was 3000 yuan/block. When the unit recovery subsidy was more than 4000 yuan/block, the reduced informal recovery amount was not obvious but continued to slightly decrease.

Fig. 5d shows that with the increase in subsidies, the degree of environmental pollution does not significantly change, which shows that the subsidy policy has limited effect on reducing environmental pollution, and lower subsidies cannot reduce environmental pollution.

Based on the above analysis, when the amount of subsidy is low, the government's recycling subsidy policy can effectively stimulate the growth of the recycling volume, reduce the illegal recycling volume, and support the development of formal recycling enterprises, which has significant economic benefits. A reasonable scope of subsidy is [3000, 4000]. However, its effect on the degree of environmental pollution is limited, and it cannot achieve the optimal effect of simultaneously improving the economic benefits of recycling and reducing pollution. Thus, the policies must be coordinated, such as policy advocacy, recycling convenience, and other strategies to improve environmental awareness.

Table 1
Reference list of accuracy test grade.

Accuracy test grade	Grade 1	Grade 2	Grade 3	Grade 4
Relative error	0.01	0.05	0.10	0.20

Table 2
Model inspection (unit: 10,000 vehicles).

Time	Simulation value	Historical value	Relative error
2014	22	22	0.00 %
2015	43	42	2.38 %
2016	94	91	3.30 %
2017	158	153	3.27 %
2018	267	261	2.30 %
2019	388	381	1.84 %
2020	502	492	2.03 %
2021	799	784	1.91 %
2022	1335	1310	1.91 %

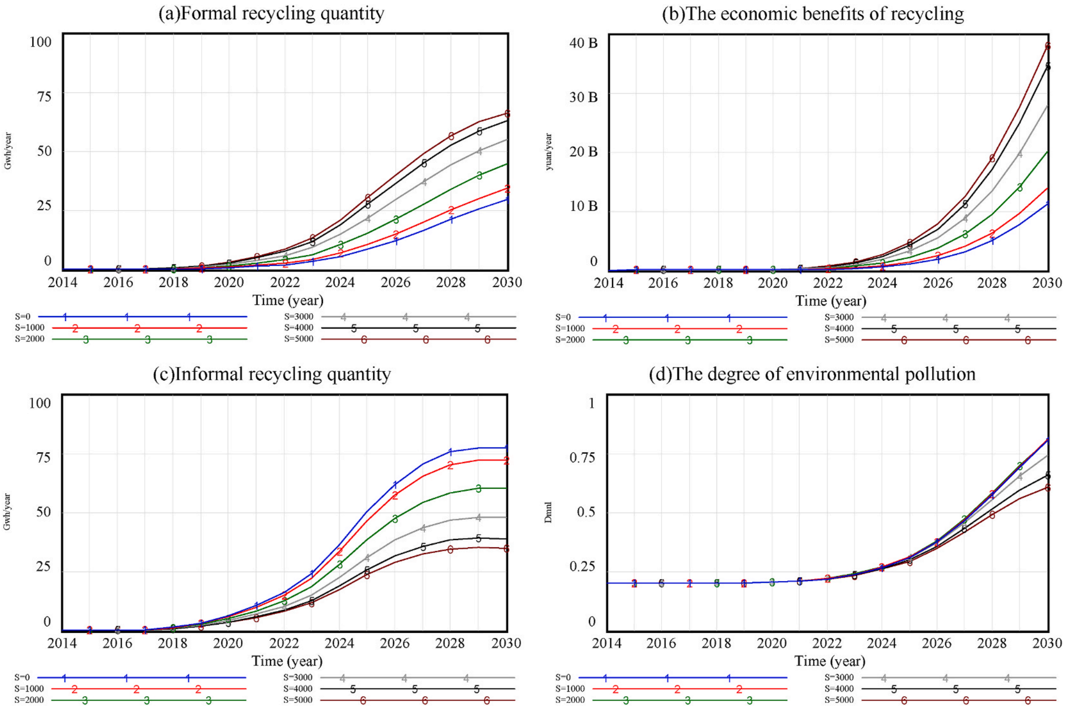

Fig. 5. Subsidy policy simulation results.

3.2.2. *Strategies to improve environmental awareness*

The strategy to improve environmental awareness is simulated and designed, and Fig. 6 shows the results. Among them, A represents policy advocacy, and C represents the recycling convenience. Fig. 6a shows the impact of different environmental awareness on environmental pollution. Improving the policy advocacy and recycling convenience can significantly reduce the degree of environmental pollution. Compared with the effect of a subsidy policy (S), as shown in Fig. 5d, although the degree of environmental pollution decreased, it is still within the range of 0.5–0.8. However, under the joint action of A and C, the degree of environmental pollution drops below 0.5. Compared with curve 1, the degree of environmental pollution in curve 3 decreased by approximately 52 % (from 0.732 to 0.349) at the end of the simulation.

Fig. 6b and c shows the impact of different environmental awareness on the economic benefits and regular recovery of recycling. With the improvement of environmental awareness, the economic benefits and regular recovery of recycling significantly increase, but the marginal effect of the strategy of improving environmental awareness decreases. At the end of the simulation, the economic benefit of recycling increased from 1.70691e+10 yuan/year to 3.84337e+10 yuan/year, and the regular recovery increased by approximately 16 Gwh/year.

Fig. 6d shows the change of environmental protection awareness. With the increase in policy advocacy and recycling convenience, the time of environmental protection awareness reaching the expected value significantly advanced.

In summary, strategies to improve environmental awareness, such as improving policy advocacy and recycling convenience, have reduced the degree of environmental pollution, improved the amount of regular recycling and the economic benefits of recycling, and can consequently compensate for the lack of a single subsidy policy.

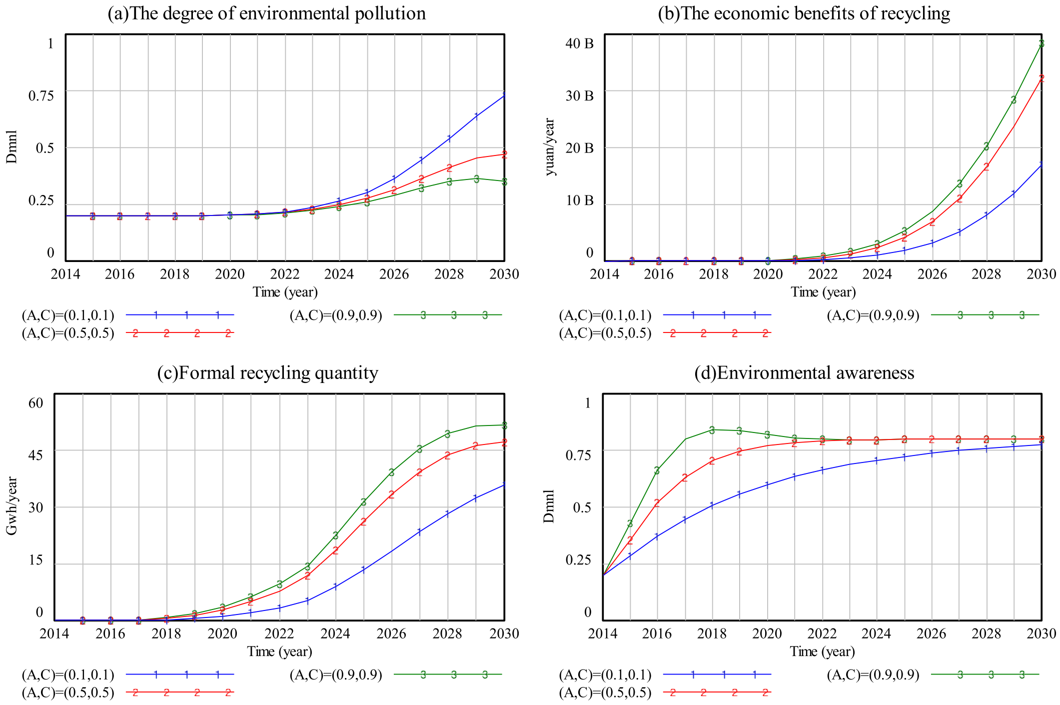

Fig. 6. Simulation results of strategies to improve environmental awareness.

3.2.3. *Joint strategy to improve environmental awareness and government subsidies*

To achieve the "win-win" goal of environmental and economic benefits, the recycling subsidy policy is combined with the policy of improving environmental awareness, different scenarios are designed, and dynamic simulation is performed to explore the effects of recycling subsidies, policy advocacy, and other recycling strategies on the recycling level, recycling economic benefits, and environmental benefits. Among them, as shown in Table 3, scenario 1 is the no-subsidy strategy, scenario 2 is the low subsidy-low policy propaganda strategy, scenario 3 is the medium subsidy-medium policy propaganda strategy, and scenario 4 is the high subsidy-high policy propaganda strategy. Under the influence of high recycling policies, the economic benefits of recycling and CO_2 emission reduction potential increase, the specific values are shown in Table 4. Fig. 7 shows the simulation results, and Table 4 shows the effects of different schemes on variables at the end of the simulation.

Fig. 7 shows the simulation results of the joint strategy of government recycling subsidies and environmental awareness improvement. A comparative analysis of the four scenarios shows that with the improvement of policy advocacy and recycling convenience, the environmental awareness of residents has improved. Under the joint action of government recycling subsidies and environmental awareness, the recovery volume of formal recyclers has significantly increased, and the CO_2 emission reduction and economic benefits brought by recycling have increased. In addition, the degree of environmental pollution has significantly decreased. The growth rate of curve 2 has gradually decreased, and it has decreased at the end of the simulation of scenario 3 and scenario 4.

Table 4 shows that the joint strategy of improving environmental awareness and recycling subsidies has the most significant effect on the economic benefits of recycling and reducing environmental pollution. Compared to the single environmental awareness scenario 1, in joint scenario 4, the economic benefits of recycling, regular recovery, and CO_2 emission reduction in 2030 will reach 5.52076e+10 yuan/year, 75.7914 Gwh/year, and 3.99458e+09 kg/year, which are increases of 223 %, 112 %, and 208 %, respectively, and environmental pollution will decrease by 65 %.

In real-life scenarios, consumers exhibit a level of environmental awareness and market demand fluctuates randomly. As a result, the optimal government subsidies and promotional efforts may vary under different recycling models and entities. This article solely focuses on the recycling scenario of a single recycler; when considering other uncertain factors, scenario 4 may not be necessarily be the most suitable option.

Table 3
Different scenario designs.

Scenarios	S	(A, C)
Scenario 1	0	no
Scenario 2	2000	low
Scenario 3	3000	medium
Scenario 4	4000	high

Table 4
Effects of different scenarios on the variables.

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Variation
The economic benefits of recycling (yuan/year)	1.70691e+10	2.92353e+10	4.38736e+10	5.52076e+10	223 %
The degree of environmental pollution	0.732	0.581	0.407	0.259	−65 %
Formal recycling quantity (Gwh/year)	35.8035	47.8499	63.2322	75.7914	112 %
CO_2 emission reduction (kg/year)	1.29527e+09	2.15543e+09	3.18999e+09	3.99458e+09	208 %

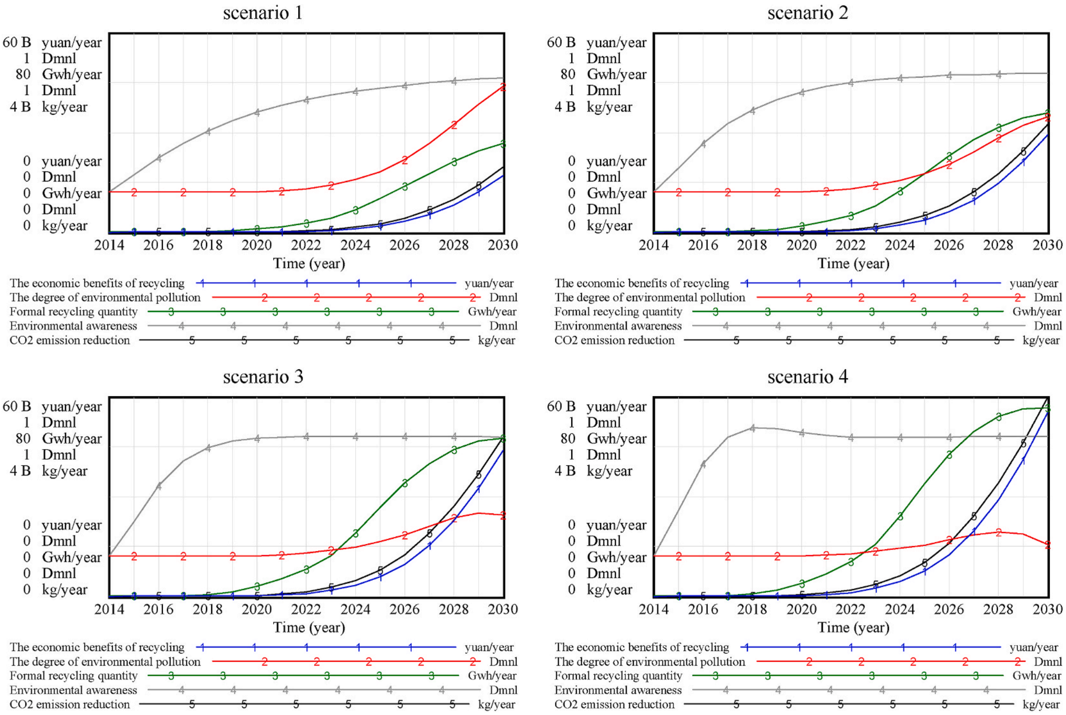
scenario 1
scenario 2
scenario 3
scenario 4

Fig. 7. Simulation results of environmental and economic benefits of the joint strategy.

3.3. Discussion

In the research on consumer waste recycling, the positive impact of recycling willingness on the recycling behavior is significant [44]. Some studies have also noted that there is a gap between recycling willingness and behavior, which may affect the effectiveness of policies [45], but there is no further exploration on how to improve residents' recycling level. The TPB provides a theoretical framework to explore the factors that affect the consumer recycling behavior, but the original TPB theory focuses on the influence of endogenous factors. Lou et al. [46] introduced recycling convenience as a pre-variable in the TPB model, which compensated for the limitations of the TPB model in predicting recycling behaviors from internal and psychological perspectives and expanded TPB from both external and internal perspectives. On this basis, combined with the SOR theory, this study overcomes the shortcomings of the TPB model in insufficiently explaining exogenous incentives and provides a more comprehensive understanding of the determinants of individual recycling behavior. Moreover, in this study, a dynamic simulation analysis performed using the system dynamics model.

Regarding the impact of recycling policies, existing studies show that most policies will positively impact the consumer behavior [47]. At present, there are few power battery recycling policies in China, and there are mainly non-monetary policies such as industry standards and technical specifications [48]. The subsidy policy has not been popularized on a large scale in China, but government subsidies can reduce the recovery cost, improve the recovery rate, and improve the environmental and social performance [49]. However, some scholars believe that excessive reward and punishment mechanism will reduce the overall welfare [8], so the potential long-term impact of these policies must be further explored. Some scholars have studied the effect of the subsidy policy and a reasonable degree of subsidy [50]. Zhang et al. [51] proposed a circular subsidy mechanism and suggested a reasonable path to reduce subsidies. Du et al. [52] considered that policy support, penalties, and subsidies should be increased, but emphasized that an excess of any factor could be inappropriate, as well as that excessive punishment mechanisms might cause resistance from enterprises. The government should formulate different reward and punishment mechanisms in different periods [53], reasonably control the level of subsidies, and pay more attention to consumers' awareness of environmental protection in the mature stage [54]. Due to different research fields and methods, some results may be slightly different. This article explores the reasonable scope of recycling policies (including subsidies and promotion), drawing on previous research. However, their applicability and accuracy still need further confirmation and exploration.

4. Conclusions and suggestions

4.1. Main conclusions

To improve the recovery rate of power batteries and analyze the economic and environmental benefits of recycling, this paper introduced the SOR theory and the TPB and constructed the system dynamics model of power battery recycling for new-energy vehicles. Through dynamic simulation, the following main conclusions were obtained.

(1) Government subsidies can improve the recycling price of formal recycling channels, but excessive subsidies will make recyclers steal profits from them, and more revenue flows to recyclers instead of consumers, which causes the diminishing marginal role of recycling subsidies, and [3000, 4000] is a more reasonable range of subsidies.
(2) Although the subsidy policy has significant economic benefits, the effect of subsidies on reducing environmental pollution is limited. It is necessary to find other factors that can be further stimulated.
(3) The strategy of improving environmental awareness plays a significant role in improving the degree of environmental pollution, especially in the medium and long terms. The combined strategy of recycling subsidy policy and environmental awareness promotion can improve the regular recycling volume and recycling profit and reduce the illegal recycling volume, and it has significant economic and environmental performance.

4.2. Policy recommendations

According to these conclusions, the corresponding policy suggestions are introduced to alleviate the environmental and economic problems caused by the scrapping of power batteries of new-energy vehicles.

First, we should accelerate the formulation of laws and regulations and continue to improve the recycling policy and standard system. We provide long-term subsidies and preferential policies to subsidize qualified regular recycling enterprises to improve the enthusiasm of power battery recycling. To improve the incentive mechanism, in addition to providing subsidies to consumers, comprehensive utilization enterprises, and other participants, strategies such as implementing the recovery deposit system and introducing the recycling of waste power batteries into the scope of preferential tax policies can be implemented.

Second, we should improve the consumers' awareness of environmental protection, which is specifically reflected in policies from the government to increase environmental protection advocacy, strengthen consumers' attention to the recycling of new-energy vehicle batteries, encourage enterprises that prioritize providing battery replacement services actively, and supervise and understand the follow-up of battery recycling.

Third, we should support new technologies. The power battery technology is in the development stage. The recycling technology must keep pace with the times, improve the cascade utilization rate and material extraction rate, and maximize the effective utilization of waste batteries.

4.3. Further research

Due to the limited data, this paper only quantified CO_2 emission reductions; it did not provide a more specific analysis of the environmental performance of battery recycling. Future studies will aim to conduct more in-depth research in conjunction with life cycle assessment. In addition, although this paper explores the environmental and economic benefits of battery recycling for new-energy vehicles, it did not conduct a more in-depth study on the health performance of different recycling strategies, which will be a key direction of future research.

Some abbreviations are shown in Table 5.

Data availability statement

The data applied in the system dynamics model are sourced from publicly archived databases.

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Ethics declaration

Review and/or approval by an ethics committee as well as informed consent was not required for this study because this article did not involve any direct experimentation/studies on living beings.

Table 5
List of abbreviations.

Abbreviation	Meaning	Abbreviation	Meaning
SD	System Dynamics	EP	Eutrophication Potential
SOR	Stimulus Organism Response	POCP	Photochemical Ozone Creation Potential
TPB	Theory of Planned Behavior	ODP	Ozone Depletion Potential
ADP(e)	Abiotic depletion	GM	Grey Model
ADP(f)	Abiotic depletion (fossil fuels)	S	Subsidy
GWP	Global Warming Potential	A	Policy Advocacy
AP	Acidification Potential	C	Recycling Convenience

CRediT authorship contribution statement

Zhen Chen: Validation, Formal analysis, Data curation. **Haizhou Zhou:** Writing – original draft, Methodology. **Shuwei Jia:** Writing – review & editing, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Description of initial values of parameters and equations

Some initial values are shown in Table 6.

1. Battery replacement needs = DELAY3I (Growth of new energy vehicles, 8, 0); Unit: 10000 vehicles/year.
2. Formal recycling quantity = Total amount of used batteries × (Recycling rate (from environmental awareness) + Recovery rate (from price spreads) + Recovery rate (from government governance)); Unit: Gwh/year.
3. Price spreads = Price spreads affected by other factors − Price spreads affected by economic benefits − Price spreads affected by subsidies; Unit: yuan/block.
4. Price spreads affected by subsidies = WITH LOOKUP (Government subsidies recovered by units, ([(0,0)–(5000, 1000)], (0, 0), (500, 50), (900, 100), (1500, 250), (2000, 400), (2500, 550), (3000, 700), (3500, 800), (4000, 900), (4500, 950), (5000, 1000))).

Table 6
Initial values of main parameters.

Main variable	Value	Unit	Source
Cascade utilization	0.9	/	[35]
Cascade life	4	year	/
Unit cascade utilization profit	6e+7	yuan/Gwh	[33]
Unit recovery cost	4.27085e+7	yuan/Gwh	[33]
Unit material regeneration benefits	3.1884e+8	yuan/Gwh	[33]
Recovery/cascade utilization/regeneration CO_2 emissions and reduction	2.31E+6/110000/1.8E+7	kg/Gwh	[35]
Recovery/cascade utilization/regeneration SO_2 emissions and reduction	16802.9/110000/79503	kg/Gwh	[35]
Recovery/cascade utilization/regeneration C_2H_4 emissions and reduction	209.15/1690/2008	kg/Gwh	[35]
Recovery/cascade utilization/regeneration CFC_{-11} emissions and reduction	9.66E-5/0.0161/0.0571	kg/Gwh	[35]
Recovery/cascade utilization/regeneration PO_4 emissions and reduction	1.41325/461/757.31	kg/Gwh	[35]
Recovery/cascade utilization/regeneration fossil energy emissions and reduction	2.61E+7/1.01E+8/2.13E+8	MJ/Gwh	[35]
Recovery/cascade utilization/regeneration mineral resources emissions and reduction	1.51E+6/1.52E+7/4.05E+7	MJ/Gwh	[35]
Baseline value 1	2.99E+11	/	[34]
Baseline value 2	4.55E+10	/	[34]
Baseline value 3	5.15E+08	/	[34]
Baseline value 4	1.29E+11	/	[34]
Baseline value 5	4.45E+13	/	[34]
Baseline value 6	1.57E+11	/	[34]

5. Recovery rate (from price spreads) = WITH LOOKUP (Price spreads, ([(0, 0)–(1500, 0.2)], (0, 0.2), (100, 0.18), (300, 0.145), (600, 0.095), (800, 0.065), (1000, 0.042), (1200, 0.025), (1500, 0))).
6. Informal recovery rate (from price spreads) = WITH LOOKUP (Price spreads, ([(0, 0)–(1500, 0.2)], (100, 0.005), (200, 0.015), (400, 0.04), (600, 0.06), (800, 0.086), (1000, 0.11), (1200, 0.14), (1500, 0.2))).

(7) Recovery rate (from government governance) = 0.1 × LN (Strength of government governance).
(8) Cascade utilization profits = Amount of cascade utilization × (Unit cascade utilization profit − Unit recovery cost); Unit: yuan/year.
(9) Material regeneration profits = Unit material regeneration benefits × Amount of material regeneration; Unit: yuan/year.
(10) CO_2 emission reduction = Amount of cascade utilization × CO_2 reduction through cascade utilization + Amount of material regeneration × CO_2 reduction through regeneration − Recovered CO_2 emissions × Amount of cascade utilization, Unit: kg/year.
(11) Emission reduction (with environmental impact) = Environmental impact reduction of a biotic resources × 0.667 + AP environmental impact reduction × 0.5 + EP environmental impact emission reduction × 0.143 + ODP environmental impact emission reduction × 0.333 + POPC environmental impact reduction × 0.333 + CO_2 environmental impact reduction × 0.1.

References

[1] S.Q. Sun, C.X. Jin, W.Z. He, G.M. Li, H.C. Zhu, J.W. Huang, Management status of waste lithium-ion batteries in China and a complete closed-circuit recycling process, Sci. Total Environ. 776 (2021) 145913, https://doi.org/10.1016/j.scitotenv.2021.145913.

[2] M.A.V. Rad, A. Kasaeian, X.F. Niu, K. Zhang, O. Mahian, Excess electricity problem in off-grid hybrid renewable energy systems: a comprehensive review from challenges to prevalent solutions, Renew. Energy 212 (2023) 538–560, https://doi.org/10.1016/j.renene.2023.05.073.

[3] Z.H. Li, X.B. Zhong, X.Y. Xu, The mechanism of retired power batteries recycling through blockchain token incentives, J. Clean. Prod. 415 (2023) 137560, https://doi.org/10.1016/j.jclepro.2023.137560.

[4] M.L. Firmansyah, I. Amalina, I.N. Rizki, A.M. Alfaza, P.K. Jiwanti, A.A. Jalil, M. Goto, Functionalization of biomass-derived activated carbon and electrochemical reduction for the recovery of gold from mobile phone leachate, Arab. J. Sci. Eng. 48 (2023) 16455–16467, https://doi.org/10.1007/s13369-023-08327-1.

[5] M. Erdem, Optimisation of sustainable urban recycling waste collection and routing with heterogeneous electric vehicles, Sustain. Cities Soc. 80 (2022) 103785, https://doi.org/10.1016/j.scs.2022.103785.

[6] Y.Y. Tang, Q. Zhang, Y.M. Li, G. Wang, Y. Li, Recycling mechanisms and policy suggestions for spent electric vehicles' power battery -A case of Beijing, J. Clean. Prod. 186 (2018) 388–406, https://doi.org/10.1016/j.jclepro.2018.03.043.

[7] T.T. Liu, P.Z. Wang, S.Y. Wu, Y.F. Wu, Achieving a win-win situation by promoting internet recycling of waste electronics and preventing information leakage in a multi-party game, Heliyon 9 (2023) e19903, https://doi.org/10.1016/j.heliyon.2023.e19903.

[8] Q. Zhang, Y.Y. Tang, D. Bunn, H.L. Li, Y.M. Li, Comparative evaluation and policy analysis for recycling retired EV batteries with different collection modes, Appl. Energ. 303 (2021) 117614, https://doi.org/10.1016/j.apenergy.2021.117614.

[9] J.M. Chen, W. Zhang, B.G. Gong, X.Q. Zhang, H.P. Li, Optimal policy for the recycling of electric vehicle retired power batteries, Technol. Forecast. Soc. 183 (2022) 121930, https://doi.org/10.1016/j.techfore.2022.121930.

[10] Y.M. Wang, Z. Zhang, X.F. Li, B.Y. Zhang, H.F. Song, Collaborative decision-making based on effort level: power battery recycling alliance, Procedia Comput. Sci. 221 (2023) 1155–1161, https://doi.org/10.1016/j.procs.2023.08.101.

[11] X.H. Wang, Z.P. Fan, Z.F. Yang, X.J. Teng, X. Chi, Optimal order quantities, buyback prices, and government subsidies for cars in a sharing economy environment, Comput. Ind. Eng. 182 (2023) 109369, https://doi.org/10.1016/j.cie.2023.109369.

[12] H.Y. Gu, Z.X. Liu, Q.K. Qing, Optimal electric vehicle production strategy under subsidy and battery recycling, Energy Pol. 109 (2017) 579–589, https://doi.org/10.1016/j.enpol.2017.07.043.

[13] M. Liu, W.Q. Liu, W. Liu, Z.H. Chen, Z.J. Cui, To what extent can recycling batteries help alleviate metal supply shortages and environmental pressures in China? Sustain, Prod. Consump. 36 (2023) 139–147, https://doi.org/10.1016/j.spc.2023.01.004.

[14] J.J. Li, L.L. Li, R.R.L. Yang, J.L. Jiao, Assessment of the lifecycle carbon emission and energy consumption of lithium-ion power batteries recycling: a systematic review and meta-analysis, J. Energy Storage 65 (2023) 107306, https://doi.org/10.1016/j.est.2023.107306.

[15] Q.W. Chen, X. Lai, J.J. Chen, Y. Yao, Y. Guo, M.J. Zhai, X.B. Han, L.G. Lu, Y.J. Zheng, Comparative environmental impacts of different hydrometallurgical recycling and remanufacturing technologies of lithium-ion batteries considering multi-recycling-approach and temporal-geographical scenarios in China, Sep. Purif. Technol. 324 (2023) 124642, https://doi.org/10.1016/j.seppur.2023.124642.

[16] Y.H. Zong, P.F. Yao, X.H. Zhang, J. Wang, X.L. Song, J. Zhao, Z.L. Wang, Y. Zheng, Material flow analysis on the critical resources from spent power lithium-ion batteries under the framework of China's recycling policies, Waste Manage. (Tucson, Ariz.) 171 (2023) 463–472, https://doi.org/10.1016/j.wasman.2023.09.039.

[17] K. Shen, C. Yuan, M. Hauschild, Direct recycling of lithiumion batteries from electric vehicles for closed-loop life cycle impact mitigation, Cirp Ann-Manuf. Techn. 72 (2023) 13–16, https://doi.org/10.1016/j.cirp.2023.04.033.

[18] L. Lander, T. Cleaver, M.A. Rajaeifar, V.N. Tien, R.J.R. Elliott, O. Heidrich, E. Kendrick, J.S. Edge, G. Offer, Financial viability of electric vehicle lithium-ion battery recycling, iScience 24 (2021) 102787, https://doi.org/10.1016/j.isci.2021.102787.

[19] J. Zeng, S.F. Liu, Research on recycling benefits of spent lithium batteries with parameter uncertain: application to adjust incentive policy, J. Energy Storage 74 (2023) 109314, https://doi.org/10.1016/j.est.2023.109314.

[20] D. Kamath, S. Moore, R. Arsenault, A. Anctil, A system dynamics model for end-of-life management of electric vehicle batteries in the US: comparing the cost, carbon, and material requirements of remanufacturing and recycling, Resour. Conserv. Recy. 196 (2023) 107061, https://doi.org/10.1016/j.resconrec.2023.107061.

[21] P.W. Li, S.H. Luo, L. Zhang, Q.Y. Liu, Y.K. Wang, Y.C. Lin, C. Xu, J. Guo, P. Cheali, X.N. Xia, Progress, challenges, and prospects of spent lithium-ion batteries recycling: a review, J. Energy Chem. 89 (2024) 144–171, https://doi.org/10.1016/j.jechem.2023.10.012.

[22] L. Li, F. Dababneh, J. Zhao, Cost-effective supply chain for electric vehicle battery remanufacturing, Appl. Energ. 226 (2018) 277–286, https://doi.org/10.1016/j.apenergy.2018.05.115.

[23] G.T. Wu, Y.M. Wang, Z. Zhang, H.F. Song, Recycling mode and strategy of closed-loop supply chain by automotive battery manufacturer led, Procedia Comput. Sci. 214 (2022) 1057–1064, https://doi.org/10.1016/j.procs.2022.11.277.

[24] Z.W. Feng, F.N. Li, C.Q. Tan, Supplier development or supplier integration? Equilibrium analysis in competing electric vehicle supply chains with power battery recycling, Expert Syst. Appl. 238 (2024) 121519, https://doi.org/10.1016/j.eswa.2023.121519.

[25] J.K. Liu, J.Y. Wang, Economic benefit analysis of the carbon potential of construction waste resource management based on a simulation of carbon trading policy, Environ. Sci. Pollut. Res. 30 (2023) 85986–86009, https://doi.org/10.1007/s11356-023-28417-9.

[26] Q.Q. Sun, H. Chen, R.Y. Long, Q.W. Li, H. Huang, Comparative evaluation for recycling waste power batteries with different collection modes based on Stackelberg game, J. Environ. Manage. 312 (2022) 114892, https://doi.org/10.1016/j.jenvman.2022.114892.

[27] Y. Ji, H. Yang, S.J. Qu, M. Nabe, Optimal strategy for a closed-loop supply chain considering recycling and warranty channels, Arab. J. Sci. Eng. 46 (2021) 1585–1601, https://doi.org/10.1007/s13369-020-04751-9.

[28] Z. Zhang, Y.M. Wang, Y. Guo, H.F. Song, Power battery closed-loop supply chain decision of green investment under different subsidy objects, Procedia Comput. Sci. 221 (2023) 1162–1169, https://doi.org/10.1016/j.procs.2023.08.102.

[29] F. Li, X.Y. Qian, J. Kong, Z.C.Y. Luo, Evolutionary Game analysis of information sharing among closed-loop supply chain members in cloud environment, Arab. J. Sci. Eng. 47 (2022) 3945–3961, https://doi.org/10.1007/s13369-021-06264-5.

[30] J. Swanson, Business dynamics-systems thinking and modeling for a complex world, J. Oper. Res. Soc. 53 (2002) 472–473, https://doi.org/10.2307/25062926.

[31] B.V. Joshi, B. Vipin, J. Ramkumar, R.K. Amit, Impact of policy instruments on lead-acid battery recycling: a system dynamics approach, Resour. Conserv. Recy. 169 (2021) 105528, https://doi.org/10.1016/j.resconrec.2021.105528.

[32] L. He, B.Z. Sun, Exploring the EPR system for power battery recycling from a supply-side perspective: an evolutionary game analysis, Waste Manage. (Tucson, Ariz.) 140 (2022) 204–212, https://doi.org/10.1016/j.wasman.2021.11.026.

[33] J.B. Guinee, Handbook on life cycle assessment operational guide to the ISO standards, Int. J. Life Cycle Ass. 7 (2002) 311–313, https://doi.org/10.1007/BF02978897.

[34] J.X. Li, X.L. Song, J.J. Pan, C.N. Zhuang, J. Zhao, Y.Q. Dou, Carbon reduction efficiency evaluation and optimization analysis of retired ternary lithium battery recycling system, China Environ. Sci. 43 (2023) 488–496, https://doi.org/10.19674/j.cnki.issn1000-6923.20220914.009 (in Chinese).

[35] F.W. Zhang, Study on Life Cycle Assessment (LCA) and Environmental Impact Assessment of Oriented Particleboard, 2017, pp. 53–58. Chinese Academy of Forestry (in Chinese).

[36] J.X. Li, Study on Material Metabolism Characteristics and Ecological Efficiency of Retired Power Battery Recycling, 2022, pp. 35–36. Shanghai Second Polytechnic University (in Chinese).

[37] A. Mehrabian, J.A. Russell, An Approach to Environmental Psychology, The MIT, Cambridge, 1974, pp. 62–65.

[38] A. Kumar, Exploring young adults' e-waste recycling behaviour using an extended theory of planned behaviour model: a cross-cultural study, Resour. Conserv. Recy. 141 (2019) 378–389, https://doi.org/10.1016/j.resconrec.2018.10.013.

[39] Y.Y. Tang, Q. Zhang, B.Y. Liu, Y. Li, R.Y. Ni, Y. Wang, What influences residents' intention to participate in the electric vehicle battery recycling? Evidence from China, Energy 276 (2023) 127563, https://doi.org/10.1016/j.energy.2023.127563.

[40] B.Q. Dong, J.P. Ge, What affects consumers' intention to recycle retired EV batteries in China? J. Clean. Prod. 359 (2022) 132065 https://doi.org/10.1016/j.jclepro.2022.132065.

[41] Y.J. Jia, X.Q. Zhang, The impact of environmental cognition and perceived benefits on consumers' willingness and behavior deviation to participate in the classified recycling of express packaging, Resour. Sci. 44 (2022) 2060–2073, https://doi.org/10.18402/resci.2022.10.09 (in Chinese).

[42] China Mobile Source Environmental Management Annual Report, Ministry of Ecology and Environment of the People's Republic of China, 2014-2023. https://doi:10.14026/j.cnki.0253-9705.2024.02.015.

[43] S.F. Liu, Y.J. Yang, L.F. Wu, Grey System Theory and Application, Science Press, Beijing, China, 2017, pp. 138–139 (in Chinese).

[44] T.K. Yu, F.Y. Lin, K.Y. Kao, C.M. Chao, T.Y. Yu, An innovative environmental citizen behavior model: recycling intention as climate change mitigation strategies, J. Environ. Manage. 247 (2019) 499–508, https://doi.org/10.1016/j.jenvman.2019.06.101.

[45] S. Zhang, Z.Q. Xia, C. Zhang, X. Tian, J.L. Xie, Green illusions in self-reporting? Reassessing the intention- behavior gap in waste recycling behaviors, Waste Manage. (Tucson, Ariz.) 166 (2023) 171–180, https://doi.org/10.1016/j.wasman.2023.04.036.

[46] S. Lou, X.X. Zhang, D.H. Zhang, What determines the battery recycling behavior of electric bike users?: introducing recycling convenience into the theory of planned behavior, J. Clean. Prod. 379 (2022) 134560, https://doi.org/10.1016/j.jclepro.2022.134560.

[47] Z.K. Ding, X.P. Wen, J. Zuo, Y.Y. Chen, Determinants of contractor's construction and demolition waste recycling intention in China: integrating theory of planned behavior and norm activation model, Waste Manage. (Tucson, Ariz.) 161 (2023) 213–224, https://doi.org/10.1016/j.wasman.2023.03.005.

[48] H.M. Zhang, J.Y. Huang, R.H. Hu, D.Q. Zhou, H.U.R. Khan, C.X. Ma, Echelon utilization of waste power batteries in new energy vehicles: review of Chinese policies, Energy 206 (2020) 118178, https://doi.org/10.1016/j.energy.2020.118178.

[49] Y.Y. Tang, Q. Zhang, Y.M. Li, H.L. Li, X.Z. Pan, B. Mclellan, The social-economic-environmental impacts of recycling retired EV batteries under reward-penalty mechanism, Appl. Energ. 251 (2019) 113313, https://doi.org/10.1016/j.apenergy.2019.113313.

[50] G.Z. Wang, M.N. Yuan, H. Xu, The impact of subsidy and preferential tax policies on mobile phone recycling: a system dynamics model analysis, Waste Manage. (Tucson, Ariz.) 152 (2022) 6–16, https://doi.org/10.1016/j.wasman.2022.08.004.

[51] H.M. Zhang, K.X. Zhu, Z.X. Hang, D.Q. Zhou, Y. Zhou, Z.D. Xu, Waste battery-to-reutilization decisions under government subsidies: an evolutionary game approach, Energy 259 (2022) 124835, https://doi.org/10.1016/j.energy.2022.124835.

[52] B.B. Du, H.M. Hou, H. Xu, M. Zhang, How to solve the problem of irregular recycling of spent lead-acid batteries in China?-An analysis based on evolutionary game theory, J. Clean. Prod. 421 (2023) 138514, https://doi.org/10.1016/j.jclepro.2023.138514.

[53] H.P. Yuan, W.B. Du, J. Liu, L.Y. Li, Critical factors to influence the illegal dumping behavior of construction and demolition waste: an ISM-DEMATEL analysis, Develop, Built. Environ. 14 (2023) 100159, https://doi.org/10.1016/j.dibe.2023.100159.

[54] Z. Wang, Q.X. Wang, B.X. Chen, Y. Wang, Evolutionary game analysis on behavioral strategies of multiple stakeholders in E-waste recycling industry, Resour. Conserv. Recy. 155 (2020) 104618, https://doi.org/10.1016/j.resconrec.2019.104618.