Research on the green recycling mode of rural electric bicycles in Liaoning Province under the goal of "double carbon"

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Abstract. With the development of the economy and the introduction of the concepts of carbon peaking and carbon neutrality, the concept of sustainable development has deeply penetrated people's hearts. In recent years, the rural economy has developed rapidly, and electric vehicles have entered every household. Nowadays, the recycling mode of electric vehicles in rural areas of China tends to be sold to waste recycling stations. In order to realize the sustainable utilization of resources, this paper analyzes the influencing factors of rural e-bike recycling process in Liaoning Province through the PTSTLE model, analyzes the existing problems of rural e-bike recycling in combination with the current situation of rural e-bikes and relevant data, proposes three modes of manufacturers' independent recycling mode, government+Internet plus+manufacturers' cooperative recycling mode, and waste recycling station recycling, and then analyzes and discusses the impact of economic, environmental and other factors on e-bike recycling according to the evolutionary game analysis model, considering the carbon emissions of multiple recycling methods, selects a recycling mode suitable for the current development of Liaoning Province, and improves the recycling rate of e-bikes.

Keywords: Electric bicycles; recycling logistics; evolutionary game analysis

1 Introduction

According to statistics from the China Bicycle Association, the production of bicycles worth over a thousand yuan in China has been increasing year by year. The annual sales of electric bicycles in China exceed 30 million units, and the current number of electric bicycles in the country has reached 350 million. The population living in rural areas in Liaoning Province is 11.865 million, accounting for 27.86%. There are over 3.5 million registered residential electric bicycles for personal use, with an average of one per household. In 2019, high-end products represented by lithium-ion electric bicycles accounted for 13.8% of the total production of electric bicycles, with an annual output of

Z. A. Zukarnain et al. (eds.), *Proceedings of the 2024 International Conference on Artificial Intelligence and Digital Management (ICAIDM 2024)*, Advances in Intelligent Systems Research 187,
https://doi.org/10.2991/978-94-6463-578-2_22

nearly 5 million units, reaching a new high in production. Through investigation, it was found that the average service life of lithium battery electric vehicles is generally 3-5 years, which means that a batch of electric vehicles needs to be replaced approximately every 3-5 years. The shells and lithium batteries of discarded electric bicycles can also be recycled, and rural residents generally sell them directly to waste recycling stations, resulting in resource waste. Therefore, recycling electric bicycles meets the requirements of national sustainable development. In summary, a single recycling channel can lead to unclear flow of waste electric bicycles, and due to the lack of effective regulatory measures, some waste electric bicycles may be illegally dismantled and processed, which not only wastes resources but also poses potential threats to the environment and human health. Therefore, establishing unified recycling standards and regulatory mechanisms, regulating the behavior of recycling entities, is the key to solving the problem of disorderly recycling channels for waste electric bicycles in Liaoning Province. Dong Wang[1] investigated the influencing factors of these recycling behaviors of e-bicycle citizens by incorporating local identity and environmental concerns into the extended normative activation model, and proposed that environmental concerns have a moderating effect on the perception of consequences, including personal norms and attitudes towards recycling behaviors. Yuan Tang[2] used the Pythagorean fuzzy decision method to determine the choice of recycling suppliers. First, a pessimistically acceptable consistent PFPR is extracted for a given IVPFPR. Subsequently, an optimization model was constructed to calculate acceptable consistent PFPR and priority weight vectors. Secondly, the subjective and objective weighting method of experts considering trust is used. Sha Lou, Xiaoxin Zhang al[3] introduced recycling facilities into planning behavior theory to verify the effect of recycling facilities on user behavior. Also, structural equation models were used to study the recycling behavior of 429 e-bike users in Tangshan City. In order to solve the serious problem of choosing a shared bicycle recycling supplier, Xu Yuan [4] proposed a two-stage multi-standard decision-making method using an orthogonal pair fuzzy technique using interval values. Qiumeng Li [5] innovated an alternative model of travel modes to identify changes in travel patterns caused by the use of shared bicycles and quantify the corresponding impact on net carbon emissions. Anja Cudok [6] By fusing models and literature from psychology, economics and marketing, the main factors influencing users to refurbish electric cargo bikes are identified. and propose measures to improve user acceptance. Ian Philips [7] population synthesis methods were used to model the adult population within each small area of England, taking into account the regional type of population and the geographical demographic situation. This is used to estimate the maximum capacity to reduce CO2 emissions by replacing e-bikes with private cars. There is no clear research on the rural electric bicycle recycling model, with the development of rural logistics, the rural multi-party cooperation of electric bicycle recycling is also a blank space for resource recycling.

2 Analysis of Factors Affecting the Recycling of Electric Bicycles

Analyze the influencing factors of recycling through PESTLE model; In terms of policies, the government supports the concept of recycling and sustainable development. The release of the "Interim Measures for the Management of Recycling and Utilization of New Energy Vehicle Power Batteries" and the "Guiding Opinions on Accelerating the Construction of Waste Material Recycling System" are of great significance for improving China's waste material recycling system, enhancing the level of resource recycling, improving resource security capabilities, and helping to achieve carbon peak and carbon neutrality goals. Economically, the main participants in recycling are the government, manufacturers, retailers, waste recycling stations, and residents. They are more concerned about whether the benefits they receive meet their psychological expectations and whether the cost expenditures are low; In rural areas of Liaoning Province, the cultural traditions and values of the participants may be more inclined towards whether they meet their expected benefits. And in the recycling process, convenience is also a major factor to consider. Among them, the sustainable development of society will not consider whether it can promote the utilization of social resources and make full use of them; Technologically, the optimization of battery manufacturing technology, the upgrading of battery materials, the improvement of battery recycling technology, the enhancement of electric bicycle shell materials, and the strengthening of recycling and reuse are key links and important measures to promote technological innovation; Legally speaking, the proposal of the Environmental Protection Law currently only pertains to the management measures for the recycling of renewable resources, but there are no other legal norms for the utilization of recycled resources. In terms of the environment, more consideration will be given to whether carbon emissions can be reduced. After all, electric vehicles will be sold to waste recycling stations without being replaced by third-party retailers, which will result in incomplete battery recycling or disposal, and also make valuable electric vehicle casings become waste and not fully utilized. Based on the environmental analysis of the recycling process of rural electric bicycles mentioned above, this article only considers the impact of economic, environmental, and social factors.

3 Evolutionary Game Analysis of Electric Bicycle Recycling

3.1 Condition Based Assumption

In combination with the rise of "Internet plus+recycling", recycling modes are divided into waste recycling bin recycling, manufacturer recycling, or Internet plus+manufacturer recycling under government supervision. Considering the advantages and disadvantages of the three types of recycling mechanisms, and combining the current recycling situation in Liaoning Province, this paper chooses the mode of government supervision, combining the Internet, and manufacturers responsible for recycling to build a reverse logistics recycling network for waste electric bicycles in Liaoning Province.

If the government only adopts subsidy policies, it needs to compensate for risk losses and subsidy costs, which means that the development of electric bicycle recycling at this time relies entirely on government policies. This undoubtedly does not increase the government's financial burden. Relying solely on government subsidies to develop express packaging recycling is neither sustainable nor practical. The same applies when the government punishes. Therefore, when exploring the government's policy of implementing subsidies and punishments simultaneously, the decision-making evolution of manufacturers and farmers among the participating entities and the policy strength required for the long-term development of recycling electric bicycles should be taken into account.

(1) Assumption: The probability of the manufacturer choosing to cooperate is x, and the probability of choosing not to cooperate is; The probability of villagers choosing to cooperate is, and the probability of choosing not to cooperate is,

(2) Assumption: There is a mobile app where villagers can choose whether to participate in the recycling process and receive rewards and punishments. The manufacturer then learns through the app's backend whether any villagers have chosen to return the entire vehicle or not.

(3) Assumption: If the manufacturer chooses to cooperate and the villagers choose not to cooperate, the manufacturer will inevitably suffer certain losses in technology, personnel, and capital investment. The profit obtained by the manufacturer at this time is. If the villagers choose to cooperate and the manufacturer chooses not to cooperate, the profit obtained by the villagers at this time is. Among them,.

(4) Assumption: Whether villagers participate in recycling or not will receive rewards and punishments from manufacturers, while manufacturers will receive rewards and punishments from the government. The reward is a function of cost, and the punishment is a function of profit. And the government's reward coefficient is greater than the manufacturer's reward coefficient, that is, the government's punishment coefficient is also greater than the manufacturer's punishment coefficient,

Both parties in the game may adopt either cooperative or non cooperative strategies. With the gradual acquisition of market information, after multiple games and continuous adjustment of strategy choices, an equilibrium state is ultimately reached. Based on this, this study established parameter settings as shown in Table 1.

Table 1. Model parameters and their meanings

Parameter	Meaning
x	The probability of manufacturers choosing to cooperate
$1-x$	The probability of manufacturers choosing not to cooperate
y	The probability of villagers choosing cooperation
$1-y$	The probability of villagers choosing not to cooperate
B	The benefits generated by the cooperation between both parties
α_1	Distribution ratio of profits among manufacturers during cooperation
$1-\alpha_1$	Distribution ratio of villagers' income during cooperation
C	The total cost of cooperation

β_1	Manufacturer's cost sharing ratio
$1-\beta_1$	Cost sharing ratio of villagers
P_1	Villagers choose not to cooperate, and the profits obtained from cooperation with manufacturers
P_2	The profits obtained from the cooperation of villagers when the manufacturers do not cooperate
L_1	Profit earned when the manufacturer does not cooperate
L_2	The income earned by villagers who do not cooperate
θ_1	The government's subsidy level for manufacturers
γ_1	The government's punitive measures against manufacturers
θ_2	Subsidies provided by manufacturers to villagers
γ_2	The severity of punishment imposed by manufacturers on villagers

3.2 Model Building

The decision matrix for the manufacturer and villagers regarding the recycling of electric bicycles at this time can be obtained as follows, shown in Table 2.

Table 2. Benefit matrix under the government reward and punishment model

	Manufacturer cooperation	Manufacturers do not cooperate
Village Cooperation	$\alpha_1 B\text{-}C\beta_1+\theta_1\beta_1 C\text{-}\theta_2(1-\beta_1)C$ $(1\text{-}\alpha_1)B\text{-}(1-\theta_2)(1-\beta_1)C$	$L_1(1\text{-}\gamma_1)\text{-}\theta_2 C(1\text{-}\beta_1)$ $P_2+\theta_2 C(1\text{-}\beta_1)$
Villagers do not cooperate	$P_1+\theta_1\beta_1 C+\gamma_2 L_2$ $L_2\,(1\text{-}\gamma_2)$	$L_1(1\text{-}\gamma_1)\text{-}\theta_2 C(1\text{-}\beta_1)$ $L_2\,(1\text{-}\gamma_2)$

Villagers and manufacturers can randomly choose strategies for game between cooperation and non cooperation.

According to the payoff matrix of the game between both parties, it can be inferred that the expected payoff for manufacturers choosing to cooperate is:

$$E_{s1}=y[\alpha_1 B\text{-}C\beta_1+\theta_1\beta_1 C\text{-}\theta_2(1-\beta_1)C]+(1\text{-}y)[P_1+\theta_1\beta_1 C+\gamma_2 L_2]$$

The expected benefits for manufacturers who choose not to cooperate are:

$$E_{s2}=y\left[L_1\left(1\text{-}\gamma_1\right)\text{-}\theta_2 C\left(1\text{-}\beta_1\right)\right]+(1\text{-}y)\left[L_1\left(1\text{-}\gamma_1\right)\text{-}\theta_2 C\left(1\text{-}\beta_1\right)\right]$$

So, the average expected revenue of manufacturers is:

$$E_1=xE_{s1}+(1\text{-}x)E_{s2}$$

According to evolutionary game theory, the replicative dynamic equation for manufacturers to adopt "cooperative" decisions is:

$$F(x)=\frac{dx}{dt}=x(E_{s1}\text{-}E_1)=x(1\text{-}x)\{y[\alpha_1 B\text{-}C\beta_1\text{-}P_1\text{-}\gamma_2 L_2\text{-}\theta_2(1-\beta_1)C]+P_1+\theta_1\beta_1 C+\gamma_2 L_2+\theta_2(1-\beta_1)C\text{-}L_1(1\text{-}\gamma_1)\}$$

Similarly, the replicative dynamic equation for villagers to make decisions is:

$$F(y)=\frac{dy}{dt}=y(E_{c1}-E_2)=y(1-y)\{x[(1-\alpha_1)B-(1-\beta_1)C-P_2]+P_2+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)\}$$

3.3 Modeling

$$x^*=\frac{L_2(1-\gamma_2)-[P_2+\theta_2(1-\beta_1)C]}{(1-\alpha_1)B-(1-\beta_1)C-P_2};\ y^*=\frac{L_1(1-\gamma_1)-[P_1+\theta_1\beta_1C+\gamma_2L_2+\theta_2(1-\beta_1)C]}{\alpha_1B-C\beta_1-P_1-\gamma_2L_2-\theta_2(1-\beta_1)C}$$

Further analysis reveals that: when the government implements both subsidy and penalty policies simultaneously, villagers and manufacturers will choose to cooperate to complete the recycling of electric bicycles when the government subsidy and penalty intensity meet certain conditions. Order,

$$\omega_1=P_1+\theta_1\beta_1C+\gamma_2L_2+\theta_2(1-\beta_1)C-L_1(1-\gamma_1),$$

$$\omega_2=P_2+\theta_2(1-\beta_1)C-L_2(1-\gamma_2),$$

$$\omega_3=\alpha_1B-C\beta_1+\theta_1\beta_1C-L_1(1-\gamma_1),$$

$$\omega_4=(1-\alpha_1)B-(1-\beta_1)C+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)$$

Therefore, the equilibrium points for replicating the dynamic equation are O (0,0), A (0,1), B (1,0), and C (1,1), $\alpha_1B-C\beta_1>L_1$, $(1-\alpha_1)B-(1-\beta_1)C>L_2$, $M(x^*,y^*)$ which are also the equilibrium points of the system at that time. However, the equilibrium point is not necessarily the stable point of the evolutionary game system. The stability of the equilibrium point can be obtained by analyzing the local stability of the corresponding Jacobian matrix of the system. The Jacobian matrix of the system is as follows, shown in Table 3 and Table 4.

Table 3. Jacobian matrix (1)

equilibrium	$detJ$
(0,0)	$[P_1+\theta_1\beta_1C+\gamma_2L_2+\theta_2(1-\beta_1)C-L_1(1-\gamma_1)][P_2+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)]$
(1,0)	$-[P_1+\theta_1\beta_1C+\gamma_2L_2+\theta_2(1-\beta_1)C-L_1(1-\gamma_1)][(1-\alpha_1)B-(1-\beta_1)C+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)]$
(0,1)	$-[\alpha_1B-C\beta_1+\theta_1\beta_1C-L_1(1-\gamma_1)][P_2+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)]$
(1,1)	$[\alpha_1B-C\beta_1+\theta_1\beta_1C-L_1(1-\gamma_1)][(1-\alpha_1)B-(1-\beta_1)C+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)]$

Table 4. Jacobian matrix (2)

equilibrium	trJ
(0,0)	$[P_1+\theta_1\beta_1C+\gamma_2L_2+\theta_2(1-\beta_1)C-L_1(1-\gamma_1)]+[P_2+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)]$
(1,0)	$-[P_1+\theta_1\beta_1C+\gamma_2L_2-L_1(1-\gamma_1)]+[(1-\alpha_1)B-(1-\beta_1)C-L_2(1-\gamma_2)]$
(0,1)	$[\alpha_1B-C\beta_1+\theta_1\beta_1C-L_1(1-\gamma_1)]-[P_2+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)]$
(1,1)	$-\{[\alpha_1B-C\beta_1+\theta_1\beta_1C-L_1(1-\gamma_1)]\}-\{(1-\alpha_1)B-(1-\beta_1)C+\theta_2(1-\beta_1)C-L_2(1-\gamma_2)\}$

From the analysis of the equilibrium point of the replicated power system in Table 3, it can be concluded that, (1)$\alpha_1 B$-$C\beta_1 > L_1$, $(1$-$\alpha_1)B$-$(1-\beta_1)C>L_2$,Because $L_1>P_1$, $L_2>P_2$, $L_1\gamma_1>0$,$L_2\gamma_2>0$, therefore$\omega_3 > 0, \omega_4 > 0$, at this point (1,1) is the equilibrium point of the system's evolution. To make both parties' choices cooperative and the only equilibrium strategy (ESS) for system evolution, i.e. (1,1) is the only equilibrium point that satisfies the determinant$detJ>0,trJ<0$. It can be inferred$\omega_1 > 0, \omega_2 > 0$ that at this point,(x^*,y^*), it is not an equilibrium point, (0,0) is an unstable point, (1,0) and (0,1) are saddle points, and only (1,1) is the stable point of the system.

(2)$\alpha_1 B$-$C\beta_1 < L_1$, $(1$-$\alpha_1)B$-$(1-\beta_1)C<L_2$,To make (cooperation, cooperation) the only system equilibrium point, it is necessary to satisfy $detJ>0,trJ<0$ the determinant (1,1).It is known that when$\omega_1>0$,$\omega_2 > 0$, $\omega_3>0$,$\omega_4 > 0$,At this point, $M(x^*,y^*)$ is not the system equilibrium point.(0,0) is an unstable point, (1,0) and (0,1) are saddle points, and (1,1) is the evolutionary equilibrium point of the system.

4 Conclusion

According to the results of evolutionary game theory, it can be concluded that in the exploration period of electric bicycle recycling in rural areas of Liaoning Province under government supervision, the benefits may not necessarily compensate for the cost investment, such as the maintenance costs of the APP operated by the manufacturer to cooperate in recycling electric bicycles. If the manufacturer is punished while providing cost subsidies, it can encourage the manufacturer and villagers to move towards cooperation. With the continuous practice of electric bicycle recycling, technological updates, cost reduction, and improved recycling utilization rate, the revenue generated will increase, which can compensate for the cost investment. Both parties can benefit from it. With appropriate policy rewards and punishments, both parties will eventually reach cooperation. In the mode of Internet plus manufacturers' cooperation in recycling waste electric bicycles, this can not only take care of farmers' income, but also reduce the costs of manufacturers, effectively reduce carbon emissions, promote the recycling of materials, and help economic development. The measures include the following two points: strengthening publicity and guiding villagers to participate in the process of electric bicycle recycling; The environmental awareness of villagers is relatively low, so it is necessary to promote and improve their environmental awareness, and do a good job in resource recycling and utilization. By recycling electric bicycles, villagers can truly participate in protecting the environment. Secondly, strengthen regulatory efforts and formulate policies; Not only can it effectively reduce the pollution of harmful substances to the environment and protect the health of the ecosystem, but it can also save natural resources and achieve sustainable development of the industry. The government, enterprises, and individual villagers should work together to promote the improvement of the recycling system for waste electric bicycles and contribute to the "dual carbon" goal.

Acknowledgement

Dalian Academy of Social Sciences Project: Research on Collaborative Optimization of Digital Governance and Green Development of Enterprises in Our City under the "Dual Carbon" Goal

Research institution number: KY0412021304

Reference

1. Dong Wang, Yifei Xu, Yi Wang, Yujing Chen,What determines the batteries recycling behavior of e-bike citizens in Guangzhou?: Integrating place identity and environmental concern into the extended norm activation model, Heliyon, Volume 10, Issue 9,2024,e30234,ISSN 2405-8440,https://doi.org/10.1016/j.heliyon.2024.e30234.
2. Yuan Tang ,Yi Yang. Sustainable e-bike sharing recycling supplier selection: An interval-valued Pythagorean fuzzy MAGDM method based on preference information technology[J].Journal of Cleaner Production,Volume 287, 10 March 2021:125530,ISSN 0959-6526,
https://doi.org/10.1016/j.jclepro.2020.125530.
3. Sha Lou, Xiaoxin Zhang, Dehua Zhang,What determines the battery recycling behavior of electric bike users?: Introducing recycling convenience into the theory of planned behavior,Journal of Cleaner Production,Volume 379, Part 1,2022,134560, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2022.134560.
4. Yuan Xu,A two-stage multi-criteria decision-making method with interval-valued q-Rung Orthopair fuzzy technology for selecting bike-sharing recycling supplier, Engineering Applications of Artificial Intelligence, Volume 119,2023,105827,ISSN 0952-1976, https://doi.org/10.1016/j.engappai.2023.105827.
5. Qiumeng Li, Franz Fuerst, Davide Luca,Do shared E-bikes reduce urban carbon emissions?,Journal of Transport Geography,Volume 112,2023,103697,ISSN 0966-6923, https://doi.org/10.1016/j.jtrangeo.2023.103697.
6. Anja Cudok, Lukas Neugebauer, Thomas Vietor,Increasing Acceptance for Refurbished Products at the Example of E-Cargo Bikes, Procedia CIRP, Volume 105,2022,Pages 571-576,ISSN 2212-8271,https://doi.org/10.1016/j.procir.2022.02.095.
7. Ian Philips, Jillian Anable, Tim Chatterton,E-bikes and their capability to reduce car CO2 emissions, Transport Policy, Volume 116,2022,Pages 11-23,ISSN 0967-070X, https://doi.org/10.1016/j.tranpol.2021.11.019.