Game Study on the Evolution of Subsidy Strategies for On-site Construction Waste Recycling Management

Yuan Feng

***Abstract*—On-site recycling of construction waste can effectively avoid the scattering of construction waste, which is of great significance for environmental protection. Considering that the recycling strategies of both construction contractors and recycling companies could be influenced by government subsidy strategies, this study utilized evolutionary game theory to examine the decision-making process and stabilization strategies of three key stakeholders - contractors, recycling enterprises, and government - involved in the recycling industry. Meanwhile, this paper also discussed the influence of five key factors on the strategies of each party. The results showed the following: (1) The likelihood of contractors engaging in construction waste recycling is positively associated with government subsidies and the benefits of on-site recycling, while being negatively associated with recycling costs. (2) The probability of recycling companies using mobile recycling facilities is positively correlated with government subsidies and the increasing income of using mobile recycling facilities, and negatively correlated with the cost of introducing mobile recycling facilities. (3) In the early stage of the recycling system development, blindly increasing subsidies to recycling enterprises cannot promote the recycling of construction waste. When a certain proportion of contractors are willing to recycle construction waste, recycling companies will start to use mobile recycling facilities. (4) Government subsidies are necessary in the early stage of recycling system development, but as the recycling system gradually matures, the government can choose not to subsidize. Finally, simulation tools were used to verify the above conclusions, and the government can formulate subsidy strategies according to corporate behavior.** [1]

***Index Terms*—construction waste; evolutionary game; recycling; whole life cycle**

I. INTRODUCTION

With the accelerating urbanization process and the further growth of population, the demand for construction in China is also increasing. According to [1], the construction of buildings has exceeded 4 billion square meters annually since 2013, and this trend is expected to persist in the forthcoming decades, resulting in a total addition of 33 billion square meters by 2040. The construction of new projects entails significant consumption of raw materials and generation of construction waste, resulting in environmental pollution and depletion of natural resources [2-3]. In order to mitigate the negative impacts of raw material consumption and environmental pollution, recycling construction waste has been recognized as an effective and sustainable approach [4-5]. The main stakeholders in the construction waste recycling process generally include three parties: the government, the waste collector and the waste generator (the construction project contractor). The construction waste generated during the construction process is sorted by the contractors, who will transport the non-recyclable waste to a designated site for dumping (in line with the waste discharge requirements).

In contrast, the recyclable waste can be handed over to the waste collectors for further treatment and reprocessing into new construction materials. For example, autoclaved aerated concrete can be prepared [6], non-polluting wood can be used to produce furniture [7], and broken glass and dismantled wooden beams can be processed to produce prefabricated insulation and radiant panels for energy-efficient buildings [8]. Recycling companies can resort to both fixed recycling facilities and mobile recycling facilities, the latter of which can reduce the transfer of construction waste and avoid the scattering of it in transit, which is more environmentally friendly. The government's leading role in the recycling process is to promote the participation of enterprises through a system of incentives, penalties and policy constraints.

Many scholars have studied construction waste recycling in recent years. For instance, Liu [9] adopted system dynamics to simulate the environmental benefits of construction waste recycling. He concluded that a proper site selection for construction waste recycling plus an appropriate reward and punishment system by government departments can promote the environmental benefits. Su [10] evaluated the construction waste recycling model through Analytic Hierarchy Process based on intuitionistic fuzzy sets, and proved that the model of classifying the construction site and then transporting to the recovery side has the best effect. Zhao [11] compared the policies and measures of construction waste regulation in cities and proposed his own suggestions based on the analysis to implement whole-process regulation policies from both source and the end [12-13]. From the literature mentioned above, most scholars have studied the impact of national policies [14] on construction waste recycling, and their analysis indicates that these factors will influence the decision-making process of enterprises regarding construction waste recycling.

Evolutionary game theory is a framework that can elucidate the processes of mutual learning, competition,

Manuscript received September 4, 2022; revised April 22, 2023.
Yuan Feng is a teacher of the Academy of Civil Engineering & Architecture, Nanyang Normal University, Nanyang, TX 473061 CHINA (e-mail: edonest@126.com)

and adaptation observed in biological evolution [15]. Unlike classical game theory, it only requires that the participants are finitely rational. In addition, it emphasizes the dynamic evolutionary equilibrium of strategic change. In the development of construction waste recycling, there exists a game relationship among government departments, waste collectors and contractors. Many scholars have used evolutionary game theory to analyze the interaction of various strategic choices in the process of construction waste recycling. For example, Lu [16] constructed a two-party game model between government departments and construction waste emitters, and a two-party game model between government and construction waste recycling enterprises. She analyzed the evolution of their decision-making processes and stabilization strategies to identify the factors that promote recycling. Zhu [17] constructed a game model between government departments and construction waste dischargers, and explored whether charging construction waste disposal fees could help increase the recycling rate. The above literature has merely considered the interaction between the two parties and ignored the role of the third party. Additionally, it has not taken into account the fact that recycling companies still use fixed construction waste recycling facilities, which may result in more vehicle trips, and that the repeated use of vehicles to transport construction waste may lead to environmental pollution caused by the scattering of construction waste, which is partly paid for by the public [19]. In summary, this paper differed from previous studies on whether recycling companies recycle construction waste. This study aimed to promote the adoption of mobile recycling facilities by recycling companies and investigated the strategies employed by three key stakeholders involved in the construction waste recycling process.

II. PROBLEM STATEMENT AND MODEL CONSTRUCTION

Long-term landfilling of construction waste has left some areas of the country with no spare capacity for landfilling construction waste [20]. The leading players in construction waste recycling include project contractors, recycling companies and governments. Contractors are primarily responsible for the collection of waste from construction sites, and the timely sorting and disposal of waste, referred to in this paper as "recycling". Recycling companies have the option of selecting between two types of recycling facilities: fixed or mobile. Most recycling companies use improved facilities located at some distance from the construction site. Introducing mobile recycling facilities can reduce waste transfer and increase the revenue of recycling and construction companies. However, there are additional costs associated with the introduction of mobile facilities. Therefore, recycling companies also have two strategies, that is, to use or not to use mobile construction waste processing equipment, referred to as "use" and "not use". As the income of contractors and recycling companies depends to some extent on each other's choice, they both bear the risk of loss due to each other's will. The government is willing to subsidize companies that dispose of construction waste to solve the environmental problems caused by construction waste [21]. However, apart from dealing with construction waste, the government also needs to solve the issues of health care, education and so on, so they also have two options, namely "subsidize" and "not subsidize".

In order to construct a game model for each stakeholder in the construction waste recycling system and investigate the influence of government subsidies on contractors and recycling enterprises, the following hypotheses are posited:

Hypothesis 1: This model comprises three game players. The first stakeholder is the government department, whose objective is to enhance the proportion of "construction waste recycling" enterprises and realize the sustainable recycling of construction waste. The other stakeholders are the construction waste generators and recyclers, whose primary goal is to maximize their profits. The strategy choices of the three parties are the government (subsidize, not subsidize) with probability $(z, 1-z)$; the project contractor (recycle, not recycle) with the possibility $(x, 1-x)$; and the project recycler (use, not use) with probability $(y, 1-y)$.

Hypothesis 2: Contractor strategy assumptions. The revenue component is S_d when the recycling company uses a fixed facility to recycle the construction waste generated by the contractor; the revenue rises to $(1+\alpha_1)S_d$ when a mobile facility is used. This is because the landfill cost in China is too low, and the cost of recycling exceeds the value of recycled waste [22].

Hypothesis 3: Construction waste recycler strategy assumptions. The revenue component includes S_r, construction waste recyclers profit by recycling construction waste to produce recyclable construction materials; the revenue increases when using mobile recycling facilities and is $(1+\alpha_2)S_r$. The cost component consists of the total expense incurred in separating construction waste for remanufacturing, which is denoted as C_3 for fixed recycling facilities and C_4 for mobile recycling facilities.

Hypothesis 4: Government sector strategy assumptions. This paper considered public and environmental-related administrative and regulatory authorities. The revenue component is social benefit H that contractors recycling construction waste and recycling enterprises using fixed recycling facilities will get, and recycling enterprises using mobile recycling facilities will get social benefit Q. Since using fixed recycling facilities may produce secondary pollution in the process of multiple transportations, $Q > H$. To encourage contractors to recycle construction waste and recycling enterprises to adopt mobile recycling facilities, the government will subsidize the recycling cost of contractors and the additional equipment cost of recycling enterprises proportionally; the subsidy proportion is β_1 and β_2, respectively. The environmental management cost caused by contractors not recycling construction waste is E_g. In addition, considering that the government adopts a subsidy strategy, it will be supported by enterprises, so the benefit of subsidizing contractors and recycling enterprises is assumed to be R. The tripartite game matrix for construction waste recycling incentives has been derived and is presented in Table 1.

III. MODEL CONSTRUCTION

The expected returns for the contractor with regard to whether or not to recycle construction waste, as well as the average expected return ($E_{11}, E_{12}, \overline{E_1}$) are as follows:

$$\begin{cases} E_{11} = y\alpha_1 S_d + z\beta_1 C_2 + S_d - C_2 \\ E_{12} = -C_1 \\ \overline{E_1} = xE_{11} + (1-x)E_{12} \end{cases} \tag{1}$$

The replication dynamic equation for the contractor's recycling strategy choice is obtained as:

$$\begin{aligned} F(x) &= x(E_{11} - \overline{E_1}) \\ &= x(1-x)(y\alpha_1 S_d + z\beta_1 C_2 + S_d - C_2 + C_1) \end{aligned} \tag{2}$$

The derivatives of the above equation with respect to x and the set $G(y)$ are given by:

$$\frac{dF(x)}{dx} = (2x-1)(C_2 - y\alpha_1 S_d - z\beta_1 C_2 - S_d - C_1) \tag{3}$$

$$G(y) = C_2 - y\alpha_1 S_d - z\beta_1 C_2 - S_d - C_1 \tag{4}$$

According to the related research[23], If the contractor decides to engage in recycling, the probability state stability must satisfy the following condition: $F(x) = 0$ and $dF(x)/dx < 0$. Since $\partial G(y)/\partial y = -\alpha_1 S_d < 0$, $G(y)$ decreases as y increases. When y=y*=$(C_2 - z\beta_1 C_2 - S_d - C_1)/(\alpha_1 S_d)$ and $G(y) = 0, dF(x)/dx = 0$. At this point, it is impossible to determine a stable strategy for the government sector. When $y > y^*$, $G(y) < 0$. $x = 1, dF(x)/dx < 0$, then $x = 1$ is the Evolutionarily Stable Strategy (ESS) of the contractor; on the contrary; in contrast, x=0 is the ESS.

The probability that the contractor chooses to recycle is the volume of A_2 as V_{A_2}, and the possibility that he chooses not to recycle is the volume of A_1 as V_{A_1}, which gives:

$$\begin{aligned} V_{A_1} &= \int_0^1 \int_0^{\frac{C_2 - S_d - C_1}{\beta_1 C_2}} \frac{C_2 - S_d - C_1 - z\beta_1 C_2}{\alpha_1 S_d} dz dx \\ &= \frac{(C_2 - S_d - C_1)^2}{2\alpha_1 S_d \beta_1 C_2} \end{aligned} \tag{5}$$

$$V_{A_2} = 1 - V_{A_1} = 1 - \frac{(C_2 - S_d - C_1)^2}{2\alpha_1 \beta_1 S_d C_2} \tag{6}$$

Corollary 1: The probability that a contractor opts for construction waste recycling is directly proportional to the ratio of the increased revenue when using mobile facilities for recycling α_1 , proportional to the percentage of government subsidies β_1, proportional to the income from recycling construction waste S_d and proportional to the cost of landfilling construction waste C_1 , and inversely proportional to the cost of recycling construction waste C_2.

Proof: The partial derivative of each parameter in V_{A_2} yields ∂ $V_{A_2}/\partial C_1 > 0, \partial V_{A_2}/\partial \alpha_1 > 0, \partial V_{A_2}/\partial \beta_1 > 0, \partial V_{A_2}/\partial S_d > 0, \partial V_{A_2}/\partial C_2 = (\frac{-C_2 - S_d - C_1}{2C_2})\frac{C_2 - S_d - C_1}{\alpha_1 \beta_1 S_d C_2}$. Where, when $C_2 - S_d - C_1 < 0$, $\partial V_{A_2}/\partial C_2 < 0$, i.e. when $C_1, \alpha_1, \beta_1, S_d$ rises, V_{A_2} will also rise and the probability of contractors choosing to recycle construction waste will rise, while when C_2 rises, V_{A_2} will fall and the probability of contractors choosing to recycle construction waste will fall.

Corollary 1 shows that the government subsidy factor, the increase in revenue from using mobile recycling facilities by recycling companies, and the rise in landfill costs will encourage contractors to recycle construction waste. When $C_2 - S_d - C_1 > 0$, the probability that a contractor will choose to recycle construction waste decreases as C_2 rises, i.e. the primary hurdle that dissuades contractors from recycling construction waste is the recycling cost. Specifically, if the cost of recycling surpasses the value of recycling, contractors are less likely to engage in construction waste recycling. When the condition $2\alpha_1\beta_1 S_d C_2 - (C_2 - S_d - C_1)^2 \le 0$ is satisfied, the contractor will choose to recycle construction waste.

Corollary 2: During the evolution of the model, the probability of contractors choosing to recycle construction waste increases as recycling companies adopt mobile recycling facilities and the likelihood of government departments choosing to subsidize contractors increases. When y is more significant than a specific value, the contractor will recycle construction waste regardless of whether the government adopts a subsidy strategy.

Proof: From the stability analysis of the contractor's strategy, $y > y^* = (C_2 - S_d - C_1)/(\alpha_1 S_d), \forall z \epsilon [0,1]$, $x = 1$ is ESS; while $y < y^*, z < z^* = (C_2 - S_d - C_1)/(\beta_1 C_2)$, $x = 0$ is ESS. The remaining two parties change, and x moves towards 1 as y and z rise.

Corollary 2 shows that the decision of a contractor to recycle construction waste is impacted by the strategies adopted by the recycler and the government. When the probability of a recycler using a mobile recycling facility reaches a specific value (i.e. $y > y^*$=$(C_2 - -S_d - C_1)/(\alpha_1 S_d)$), the contractor will recycle construction waste regardless of government subsidies. Government subsidies are an effective means of promoting construction waste recycling by contractors, but government subsidies alone can also promote construction waste recycling by contractors. The order of three parties' strategy changes will be further analyzed later.

The expected benefits for construction waste recyclers using mobile recycling facilities or not using them and the average expected benefits ($E_{21}, E_{22}, \overline{E_2}$) are:

$$\begin{cases} E_{21} = x(S_r - C_3 + \alpha_2 S_r) + z\beta_2 C_4 - C_4 \\ E_{22} = x(S_r - C_3) \\ \overline{E_2} = yE_{11} + (1-y)E_{12} \end{cases} \tag{7}$$

The replicated dynamic equation for the choice of construction waste recycling strategy is derived as:

$$\begin{aligned} F(y) &= y(E_{21} - \overline{E_2}) \\ &= y(1-y)(x\alpha_2 S_r + z\beta_2 C_4 - C_4) \end{aligned} \tag{8}$$

The derivatives of the above equation with respect to y and the set J(z) are:

$$\frac{dF(y)}{dy} = (1-2y)(x\alpha_2 S_r + z\beta_2 C_4 - C_4) \tag{9}$$

$$J(z) = x\alpha_2 S_r + z\beta_2 C_4 - C_4 \tag{10}$$

When the recycler chooses to use a probabilistic state, stable must satisfy: $F(y) = 0$ and $dF(y)/dy < 0$. Since $\partial J(z)/\partial z = \beta_2 C_4 > 0, J(x)$ increases as x increases. When $z = z^{**} = (C_4 - x\alpha_2 S_r)/(\beta_2 C_4)$, $, J(z) = 0, dF(y)/dy = 00$. At this point, it is impossible to determine a stable strategy for the recycler. When $z > z^{**}, J(z) > 0$. $y = 1, dF(y)/dy < 0$, then $y = 1$ ESS for recycling companies; on the contrary, $y = 0$ for ESS.

The probability that the construction waste recycler chooses to use the mobile recycling facility is the volume of B_1 as V_{B_1}, and the likelihood that it does not use it is the volume of B_2 as V_{B_2}, which gives:

$$V_{B_1} = 1 - V_{B_2} = 1 - \frac{2C_4 - \beta_2 C_4}{2\alpha_2 S_r} \quad (11)$$

$$V_{B_2} = \frac{2C_4 - \beta_2 C_4}{2\alpha_2 S_r} \quad (12)$$

Corollary 3: The probability of a construction waste recycler using a mobile recycling facility and the increased profit ratio α_2 for using a mobile facility to recycle construction waste, the government department's subsidy coefficient β_2 and the initial profit S_r for recycling construction waste are positively correlated. The additional cost C_4 for using a mobile facility is negatively correlated.

Proof: The first-order partial derivative of each element in $\partial V_{B_1}/\partial(\alpha_2 S_r) = (2C_4 - \beta_2 C_4)/[2(\alpha_2 S_r)^2]$ where $2C_4 > \beta_2 C_4$, so $V_{B_1}/\partial(\alpha_2 S_r) > 0$. $\partial V_{B_1}/\partial\beta_2 = (C_4)/(2\alpha_2 S_r)$, so $\partial V_{B_1}/\partial\beta_2 > 0$. $\partial V_{B_1}/\partial C_4 = (\beta_2 - 2)/(2\alpha_2 S_r)$, where $\beta_2 - 2 < 0$, so $\partial V_{B_1}/\partial C_4 < 0$. When α_2, β_2, S_r rise, the probability of recycling enterprises choosing to use mobile recycling facilities will also rise. And as C_4 increases, the probability of using mobile recycling facilities decreases.

Corollary 3 shows that the main parameters affecting the use of mobile recycling facilities for construction waste are $\alpha_2, \beta_2, S_r, C_4$. The higher the value of$(2\alpha_2 S_r - 2C_4 + \beta_2 C_4)/(2\alpha_2 S_r)$, the higher the probability that recycling enterprises will use mobile recycling facilities.

Corollary 4: In the evolution of this model, the probability that a construction waste recycler will recycle construction waste increases as the government chooses to subsidize and the contractor elects to separate construction waste. Still, there are cases where the government decides to support some contractors choose to recycle construction waste, and recycling companies are reluctant to use mobile recycling facilities.

Proof: By analyzing the strategy stability of the construction waste recycler, it is evident that: $x > x^* = (C_4 - \beta_2 C_4)/(\alpha_2 S_r),, \forall z\epsilon[0,1], y = 1$ is ESS.

Corollary 4 shows that the probability of using mobile recycling facilities depends on the combined effect of contractors and government departments and that more contractors choosing to recycle construction waste will lead to more recycling companies using mobile recycling facilities. Government subsidies can promote the use of mobile recycling facilities by recycling companies. However, if $x < (C_4 - \beta_2 C_4)/(\alpha_2 S_r)$, which means the number of contractors recycling construction waste is too tiny, recycling companies will not use mobile recycling facilities even if the government subsidizes them.

The expected return and average expected return of the government's subsidized contractors and recycling enterprises $(E_{31}, E_{32}, \overline{E_3})$ are respectively:

$$\begin{cases} E_{31} = xy(Q-H) + x(H - \beta_1 C_2) - (1-x)E_g - y\beta_2 C_4 + R \\ E_{32} = xy(Q-H) + xH - (1-x)E_g \\ \overline{E_3} = zE_{31} + (1-z)E_{32} \end{cases} \quad (13)$$

The replication dynamic equation for the choice of government sector strategy is obtained as:

$$\begin{aligned} F(z) &= z(E_{31} - \overline{E_3}) \\ &= z(1-z)\{R - x\beta_1 C_2 - y\beta_2 C_4\} \end{aligned} \quad (14)$$

The derivatives of the above equation with respect to z and the set $K(y)$are:

$$\frac{dF(z)}{dz} = (1-2z)\{R - x\beta_1 C_2 - y\beta_2 C_4\} \quad (15)$$

$$K(y) = R - x\beta_1 C_2 - y\beta_2 C_4 \quad (16)$$

When the probability of government departments choosing subsidies is stable, it must meet the following requirements:$F(z) = 0$ and $dF(z)/dz < 0$. Since $\partial K(y)/\partial y = -\beta_2 C_4 < 0$, $K(y)$ decreases as y increases. When $= y^{**} = (R - x\beta_1 C_2)/\beta_2 C_4$, $K(y) = 0$, $dF(z)/dz = 0$. At this point, it is impossible to determine a stable strategy for the government sector. When $y > y^*$, $K(y) < 0$. $z = 0$,$dF(y)/dy < 0$,then $z = 0$ is the ESS of the government; on the contrary, $z = 1$ is the ESS.

The volume of the probability of the government department choosing to subsidize the recycling company C_1 is V_{C_1}, and the volume of the probability of choosing to support the contractor C_2 is V_{C_2}, which can be obtained:

$$V_{C_1} = \frac{(\beta_1 C_2 - R + \beta_2 C_4)^2}{\beta_1 C_2 \beta_2 C_4} \quad (17)$$

$$V_{C_2} = 1 - \frac{(\beta_1 C_2 + \beta_2 C_4 - R)^2}{\beta_1 C_2 \beta_2 C_4} \quad (18)$$

Corollary 5: Contrary to the expected results, the environmental benefits parameters Q and H obtained by the government sector and the cost E_g to be spent on managing the environment do not influence the government sector's strategy of subsidizing. The probability of government departments supporting enterprises decreases as the total cost of the invested firm (sum of subsidies $\beta_1 C_2 + \beta_2 C_4$) rises but increases as the potential benefits of the subsidized firm rise.

Proof: The first-order partial derivative of each element in $\partial V_{C_2}/\partial(\beta_1 C_2) = \frac{(\beta_1 C_2 + \beta_2 C_4 - R)^2}{(\beta_1 C_2)^2 \beta_2 C_4} - \frac{2\beta_1 C_2(\beta_1 C_2 + \beta_2 C_4 - R)}{(\beta_1 C_2)^2 \beta_2 C_4}$ where $\beta_1 C_2 + \beta_2 C_4 - R - 2\beta_1 C_2 < 0$, i.e. $\partial V_{C_2}/\partial(\beta_2 C_4) < 0$. $V_{C_2}/\partial R = \frac{2(\beta_1 C_2 + \beta_2 C_4 - R)}{\beta_1 C_2 \beta_2 C_4}$, the numerical value of $V_{C_2}/\partial R$ depends on the value of $\beta_1 C_2 + \beta_2 C_4 - R$. If the potential benefit from the subsidy is less than the cost of the subsidy, then $V_{C_2}/\partial R > 0$.

Corollary 5 shows that the potential benefits brought by the subsidy strategy will influence the government's choice of strategy. When the benefits from different firms are enormous, the government will change its subsidy strategy. The larger the value of $\beta_1 C_2 \beta_2 C_4 - (\beta_1 C_2 + \beta_2 C_4 - R)^2$ is, the more likely the government will choose to subsidize.

Corollary 6: During the evolution, the probability that government subsidies to contractors and recycling companies decreases as contractors recycle construction waste and recycling companies use mobile recycling facilities

Proof: Upon analyzing the stability of the government department's strategy, it can be observed that : $y > y^{**} = (R - \beta_1 C_2)/\beta_2 C_4, x > x^{**} = (R - \beta_2 C_4)/\beta_1 C_2$, $z = 0$ is ESS; while $y < (R - \beta_1 C_2)/\beta_2 C_4, x < (R - \beta_2 C_4)/\beta_1 C_2$, $z = 0$ is ESS. Clearly, as $x = 0, y = 0$ gradually evolves to $x = 1, y = 1$, the strategy of the government department also evolves from $z = 1$ to $z = 0$.

Corollary 6 shows that, in general, the more willing contractors are to recycle construction waste and recyclers are to use mobile recycling facilities, the less the government has to spend on subsidies. When the probability of contractors recycling construction waste and recycling companies using mobile recycling facilities exceeds a particular value, i.e. $y > (R-\beta_1 C_2)/\beta_2 C_4, x > (R-\beta_2 C_4)/\beta_1 C_2$, the government can stop the subsidy strategy.

Let $F(x)=0, F(y)=0, F(z)=0$, we get the equilibrium points of the model: $E_1(0,0,0), E_2(1,0,0), E_3(0,1,0), E_4(0,0,1), E_5(1,0,1)$. $E_6(1,1,0), E_7(0,1,1), E_8(1,1,1), E_9\left(0,\frac{R}{\beta_2 C_4},\frac{1}{\beta_2}\right)$,

$$E_{10}\left(\frac{R}{\beta_1 C_2},0,\frac{C_2-C_1-S_d}{\beta_1 C_2}\right), E_{11}\left(\frac{C_4}{\alpha_2 S_r},\frac{C_2-C_1-S_d}{\alpha_1 S_d},0\right),$$

$$E_{12}\left(1,\frac{R-\beta_1 C_2}{\beta_2 C_4},\frac{C_4-\alpha_2 S_r}{\beta_2 C_4}\right),$$

$$E_{13}\left(\frac{R-\beta_2 C_4}{\beta_1 C_2},1,\frac{C_2-C_1-S_d-\alpha_1 S_d}{\beta_1 C_2}\right),$$

$$E_{14}\left(\frac{C_4}{\alpha_2 S_r},\frac{C_2-C_1-S_d-\beta_1 C_2}{\alpha_1 S_d},1\right)$$

According to scholars RITZBERHG-ER [24] and SELTEN [25], in a multi-group evolutionary game, it is known that the stable solution must correspond to a Nash equilibrium. As such, this study aims to analyze the stability of the first eight strategies proposed for the three-party evolutionary game. The Jacobi matrix of the model is obtained as follows:

According to Lyapunov's first law: if all the eigenvalues of a Jacobi matrix are negative, it is asymptotically stable; if there is at least one integer, it is unstable; if all but 0 are negative, it is in a critical state, and the sign cannot determine stability. By substituting the values of each equilibrium point, the results of the analysis are shown in Table 2:

Corollary 7: When $\beta_1 C_2 + S_d + C_1 - C_2 < 0; C_2 - (1+\alpha_1)S_d - C_1 < 0, C_4 - \alpha_2 S_r < 0, R - \beta_1 C_2 - \beta_2 C_4 < 0$, the model system has two stability points $E_4(0,0,1)$ and $E_6(1,1,0)$.

Proof: From Table 2 we can know that the real part of $E_4(0,0,1)$ and $E_6(1,1,0)$ is negative and they are the stable strategy when the conditions ① $\beta_1 C_2 + S_d + C_1 - C_2$<0 and ② $C_2 - (1+\alpha_1)S_d - C_1$<0,$C_4 - \alpha_2 S_r < 0, R - \beta_1 C_2 - \beta_2 C_4 < 0$ are satisfied, while $R - \beta_1 C_2 - \beta_2 C_4 < 0$, condition 3 is not satisfied, and $E_8(1,1,1)$ cannot be an ESS.

Corollary 7 shows that when the government incentives are small, or the benefits of using mobile recycling facilities for contractors and recycling companies are very high, the system will stabilize at two points according to the different initial strategies, i.e. (no recycling of construction waste, no mobile recycling facilities, with subsidies) and (recycling of construction waste, use of mobile recycling facilities, with no subsidies). In this case, government subsidies are insufficient to promote the construction waste recycling of contractors. Construction waste will continue to be disposed of in landfills or incineration, causing environmental damage. To avoid the stable point (no recycling, no mobile recycling facilities, with subsidies), the government can set a sufficiently large incentive factor β_1 or increase the cost of landfill by the contractor C_2 to fully play its regulatory role.

Corollary 8: When $C_2 - (1+\alpha_1)S_d - C_1 < 0, C_4 - \alpha_2 S_r < 0$, the system may have two stable points $E_6(1,1,0)$ and $E_8(1,1,1)$, while if both $\beta_1 C_2 + S_d + C_1 > C_2$ and $\beta_1 C_2 + \beta_2 C_4 > R$ are satisfied, the system has only one stable point $E_6(1,1,0)$.

Proof: As shown in Table 2, when $C_2 - (1+\alpha_1)S_d - C_1 < 0, C_4 - \alpha_2 S_r < 0$, both conditions ② and ③ may be satisfied, i.e. both $E_6(1,1,0)$ and $E_8(1,1,1)$ may become ESS. When $\beta_1 C_2 + S_d + C_1 > C_2$, $\beta_1 C_2 + \beta_2 C_4 > R$ are satisfied, only condition ② is satisfied, and the system has only one stable point, $E_6(1,1,0)$.

Corollary 8 shows that when the profit of the contractor and the recycling company from the adoption of mobile recycling facilities is large enough, the government can choose to subsidize or not to subsidize according to its revenue. If $C_2 - (1+\alpha_1)S_d - C_1 > 0, C_4 - \alpha_2 S_r > 0$, then the government has to spend a certain amount of $\beta_1 C_2$ and $\beta_2 C_4 4$ on promoting contractors and recycling companies to adopt mobile recycling facilities. Contrary to the expected results, the environmental benefits Q, H from recycling construction waste and the cost of ecological management E_g of not recycling do not affect the government's choice of strategy. In summary, government subsidies can effectively promote the recycling of construction waste.

Corollary 9: When both $E_6(1,1,0)$ and $E_8(1,1,1)$ are stable points, it is clear that government subsidies are not necessary. If the conditions $C_2 - (1+\alpha_1)S_d - C_1 > 0, C_4 - \alpha_2 S_r > 0, R - \beta_1 C_2 - \beta_2 C_4 > 0$ are satisfied, then $E_6(1,1,0)$can't become an ESS, while $C_2 - (1+\alpha_1)S_d - \beta_1 C_2 - C_1 < 0, C_4 - \alpha_2 S_r - \beta_2 C_4 < 0$, then $E_8(1,1,1)$ becomes the only stable point of the system.

Proof: From Table 2, we can see that if condition ②, $C_2 - (1+\alpha_1)S_d - C_1$<0,$C_4 - \alpha_2 S_r < 0$ is satisfied then condition ③ , $C_2 - (1+\alpha_1)S_d - \beta_1 C_2 - C_1 < 0; C_4 - \beta_2 C_4 - \alpha_2 S_r < 0$ can also be satisfied. Then, if $R - \beta_1 C_2 - \beta_2 C_4 > 0$ is also satisfied, then $E_8(1,1,1)$ will be the only stable point.

Corollary 9 shows that government subsidies are not necessary, as Corollary 6 above shows, when $y > y^{**} = (R-\beta_1 C_2)/\beta_2 C_4, x > x^{**} = (R-\beta_2 C_4)/\beta_1 C_2$, $z = 0$ can be the ESS. In the initial phase of the construction waste recycling system's development, government subsidies are crucial. However, as contractors choose to recycle construction waste and recycling enterprises choose to use mobile facilities, their revenue, i.e. $(1+\alpha_1)S_d + C_1 > C_2, \alpha_2 S_r > C_4$ increases. Then the system can be stabilized without government subsidies.

A shift from the stabilization point $E_4(0,0,1)$ to the stabilization point $E_8(1,1,1)$ to the stabilization point $E_6(1,1,0)$ indicates the changing situation of our construction waste recycling system in different stages. To further investigate the influence of the response sequence and critical parameters of each strategy in the design on the evolution of the model, further simulations using accurate data will be carried out in this study.

IV. NUMERICAL SIMULATION ANALYSIS

To validate the theoretical model, the study conducted a simulation using real data. The data were obtained from two sources: a study of two construction waste resource integration projects in Wuhan and Sanya to determine the benefits of recycling buildings S_d and using mobile recycling facilities S_r. In contrast, some values of the incentives β_1, β_2 and the potential benefits to government departments R were obtained from another source: telephone interviews with five experts in construction management, two cost engineers, and two civil engineers. The specific arrays 1 are: $S_d = 100, S_r = 150, C_1 = 50, C_2 = 180, C_3 = 60, C_4 = 80, \alpha_1 = 40\%, \alpha_2 = 60\%, \beta_1 = 20\%, \beta_2 = 20\%, R = 30, E_g = 30, Q = 80, H = 60$.

Firstly, the Matlab2021b software was used to randomly generate 50 strategies corresponding to the three stakeholders to verify that the strategy $E_6(1,1,0)$ of optimal interest must be the asymptotically stable point in the dynamic system. The variables and parameters in the 50 strategy sets satisfy the constraints of Corollary 8.

The simulation results can be obtained from Figure 1: there is only one stable strategy for this system at this point, i.e. (recycling construction waste, using mobile recycling facilities, and with no subsidies), which is consistent with the conclusion of Corollary 8 above.

The strategies of the stakeholders in this system will change as the parameters change, and the impact of these parameters on the evolutionary outcome needs to be explored. In this paper, the revenue that contractors recycle construction waste is S_d , the government subsidies for contractors and recycling companies are β_1, β_2 , the cost of introducing equipment to recycling companies is C_4 and the potential revenue when government subsidies are adopted is R, and this paper analyzes their influence on the process and result of the system evolution based on array 1. In the following part, the effect of such specified parameters on stakeholder strategies is investigated by varying the value of one of the parameters while the others are fixed.

First, to analyze the effect of changing S_d on the process and outcome of the evolutionary game, S_d is assigned the values $S_d = 100,120,140$, and the simulation results are shown in Figure 2; to analyze the effect of changingβ_1, β_2 on the process and outcome of the evolutionary game, making $\beta_2 = 0$, and $\beta_1 = 0.1,0.15,0.2$, respectively, and the simulation results are shown in Figure 3; let $\beta_1 = 0$, and assign $\beta_2 = 0.1,0.5,0.9$ respectively, the simulation results are shown in Figure 4.

As can be seen from Figure 2, during the evolution of the model to the stabilization point (1,1,0), the increase in the revenue of contractors recycling construction waste accelerates the rate of development of contractors recycling construction waste, i.e., as S_d increases. Based on the results of this study, it can be concluded that there is an increase in the likelihood of contractors recycling construction waste, while the probability of government subsidies decreases. Therefore, additional support from the government in the early stages of the development of contractor recycling is practical. In particular, contributions can be granted to contractors with low revenue expectations to ensure that contractors recycle construction waste and reduce the environmental impact of construction waste.

Figures 3 and 4 show that subsidizing contractors is more effective than subsidizing recycling companies. When the government subsidy rate for the recycling companies is 0, increasing the subsidy rate for the contractors to 0.2 can make the model evolve to the stability point (1,1,0); while when the government subsidy rate for the contractors is 0, the system will evolve to the stability point (0,0,1) only when the subsidy rate for the recycling companies reaches 0.9. And $\beta_1 = 0$, $\beta_2 = 0.9$ meets the requirements in corollary 7. When $\beta_1 C_2 + S_d + C_1 - C_2 < 0; C_2 - (1 + \alpha_1) S_d - C_1 < 0, C_4 - \alpha_2 S_r < 0, R - \beta_1 C_2 - \beta_2 C_4 < 0$, the model system has two stability points $E_4(0,0,1)$ and $E_6(1,1,0)$.

To verify that the system has two stable points when $\beta_1 = 0, \beta_2 = 0.9$, let array 2 be$S_d = 100, S_r = 150, C_1 = 50, C_2 = 180, C_3 = 60, C_4 = 80, \alpha_1 = 40\%, \alpha_2 = 60\%, \beta_1 = 0\%, \beta_2 = 90\%, R = 30, E_g = 30, Q = 80, H = 60$ .The array 2 was evolved 50 times from different combinations of initial strategies and the findings are illustrated in Figure 5.

Figure 5 shows that when $\beta_1 = 0, \beta_2 = 0.9$, the system has two stability points when the conditions $\beta_1 C_2 + S_d + C_1 - C_2 < 0; C_2 - (1 + \alpha_1) S_d - C_1 < 0, C_4 - \alpha_2 S_r < 0, \beta_1 C_2 + \beta_2 C_4 - R < 0$ are satisfied, i.e. E_6 (1,1,0) (contractors recycle construction waste, recycling companies use mobile recycling facilities, the government does not subsidize) and E_4 (0,0,1) (contractors do not recycle construction waste, recycling companies do not use mobile recycling facilities, government subsidies). And whether the system evolves to E_6 (1,1,0) or E_4 (0,0,1) depending on the initial strategies of the three parties. In the early stage of the construction waste recycling system development, when the recycle inclination of contractors and recycling companies is low, even if the government is willing to subsidize, it will not promote the development of the recycling system. Combining Figures 3 and 5, it can be seen that in the early stages of a recycling system, it may be more effective to subsidize contractors at a low level than to subsidize recyclers at a high level. And subsidizing recyclers can also contribute to system stability in the later stages. The government should therefore prioritize the interests of contractors in recycling construction waste to ensure that the benefits outweigh the costs and avoid situations where contractors do not recycle construction waste. When a certain percentage of contractors choose to recycle construction waste, recycling companies will spontaneously use mobile recycling facilities.

Secondly, to analyze the impact of the cost C_4 on the evolution of the model, let$C_4 = 10,30,50$ respectively, the simulation results are illustrated in Figure 6.

Figure 6 shows that the probability of government subsidies increases as C_4 increases when the likelihood of recycling companies choosing to use mobile facilities evolves to 1. While the possibility of the government subsidy slowly decreases when the probability of the recycler using the mobile facility and the likelihood of the contractor recycling construction waste stabilize at the sum of 1. An increase in C_4 increases the probability of the contractor not recycling construction waste.

Finally, to analyze the impact of the potential benefits R

of government subsidies on the evolution of the model, let $R = 10,20,30$ respectively and the simulation results are presented in Figure 7.

Figure 7 depicts that the probability of government subsidies increases as the potential benefit R rises. A decrease in the possible benefit R, compared to $R = 30$ in Figure 7, slows the response rate of government subsidies. At the same time, the government subsidy lasts for some time after the remaining two parties reach (1,1) for $R = 30$. In contrast, Figure 8 shows that the government subsidy cancels immediately after the remaining two parties get (1,1) for $R = 10$. The simulation analysis proves that Corollary 1 - Corollary 8 is valid and has real value for construction waste recycling.

V. CONCLUSION

Considering the current low recycling rate of construction waste in China and the prevalent use of fixed recycling facilities by recycling enterprises, this paper constructs an evolutionary game model between government departments, construction waste recyclers, and construction waste generators (contractors), analyses the stability of the equilibrium strategy combinations and the influence of each factor in the game system, and verifies the validity of the conclusions through accurate data simulation analysis, and obtains the conditions under which enterprises choose mobile recycling. Based on the analysis of the factors that influence the recycling of construction waste, this study provides relevant recommendations for government departments.

The system has three stable strategies ESS: (0,0,1), (1,1,1) and (1,1,0), which are the paths to achieve on-site mobile recycling of construction waste. In the early stages, contractors were reluctant to recycle construction waste, and recycling companies chose to regularly recycle construction waste. Then the government subsidies during this period are very crucial. As the construction waste recycling industry matures, when contractors find it profitable to recycle construction waste and recycling companies choose mobile recycling, and when a certain percentage of companies actively recycle, government intervention can be gradually reduced and eventually become non-subsidized. Collaboration between universities and enterprises can drive the development of more efficient and environmentally friendly mobile recycling facilities for construction waste, which in turn can accelerate the recycling of construction waste.

This paper concludes that: 1) the probability of contractors recycling construction waste is positive in proportion to the number of government subsidies, the initial revenue from recycling construction waste, the additional revenue when recycling companies use mobile recycling facilities, the likelihood of recycling companies using mobile recycling facilities, and the cost of recycling construction waste to landfill, and the probability of recycling construction waste is inversely proportional to the cost of recycling it;

2) At the beginning of the development of construction waste recycling systems, when contractors and companies are reluctant to recycle, the government department can take subsidy measures to improve their enthusiasm. The higher the amount of subsidy, the more it can accelerate the development of construction waste recycling system;

3) When the government chooses to subsidize, contractors will take the lead in recycling construction waste. When the proportion of contractors who choose to recycle construction waste reaches a certain threshold, recycling companies are more likely to adopt mobile recycling facilities;

4) During the initial phase of the recycling system's development, only increasing subsidies to recycling companies cannot promote on-site recycling management. The incentive for recycling companies to use mobile recycling facilities will increase as the proportion of construction waste recycled by contractors rises even without the government’s subsidy. Therefore, government departments should give priority to the interests of contractors and increase their incentive to recycle construction waste;

5) Unexpectedly, the environmental benefits of recycling construction waste and the cost of ecological management when construction waste is not recycled do not affect the choice of government departments' strategies. In addition to providing direct financial subsidies to enterprises, the government can promote mobile recycling by regulating the cost of landfills and the price of purchasing mobile recycling facilities;

6) When the construction waste recycling system gradually matures, a higher proportion of contractors choose to recycle construction waste. Then a higher proportion of recycling enterprises use mobile recycling facilities, the government can stop paying additional subsidies.

This paper takes into account the interactions between contractors and recycling companies while ignoring the influence of the game order and buyers. Therefore, it would be a future research direction to construct a four-way game model for the recycling system government departments - construction waste recycler - construction project contractor - consumer by introducing the participation of purchasers and incentives for them from the government department and to propose new suggestions to improve the construction waste recycling system.

TABLE I
Payoff matrix between Government departments - construction waste recyclers - contractors

Construction Projects Contractors	Government departmental subsidies z		No subsidies from government departments $(1-z)$	
	Recycler use y	Not used by recyclers $(1-y)$	Recycler use y	Not used by recyclers $(1-y)$
Recycling x	$(1+\alpha_1)S_d-(1-\beta_1)C_2$ $(1+\alpha_2)S_r-C_3-(1-\beta_2)C_4$. $Q-\beta_1C_2-\beta_2C_4+R$	$S_d-(1-\beta_1)C_2$ S_r-C_3 $H-\beta_1C_2+R$	$(1+\alpha_1)S_d-C_2$ $(1+\alpha_2)S_r-C_3-C_4$ Q	S_d-C_2 S_r-C_3 H
No recycling $(1-x)$	$-C_1$ $-(1-\beta_2)C_4$ $-E_g-\beta_2C_4+R$	$-C_1$ 0 $-E_g+R$	$-C_1$ $-C_4$ $-E_g$	$-C_1$ 0 $-E_g$

$$J=\begin{bmatrix}J_1 & J_2 & J_3\\ J_4 & J_5 & J_6\\ J_7 & J_8 & J_9\end{bmatrix}=\begin{bmatrix}\partial F(x)/\partial x & \partial F(x)/\partial y & \partial F(x)/\partial z\\ \partial F(y)/\partial x & \partial F(x)/\partial y & \partial F(x)/\partial z\\ \partial F(z)/\partial x & \partial F(z)/\partial y & \partial F(z)/\partial z\end{bmatrix}=$$

$$\begin{bmatrix}(1-2x)(y\alpha_1S_d+z\beta_1C_2+S_d-C_2+C_1) & x(1-x)\alpha_1S_d & x(1-x)\beta_1C_2\\ y(1-y)\alpha_2S_r & (1-2y)(x\alpha_2S_r+z\beta_2C_4-C_4) & y(1-y)\beta_2C_4\\ z(1-z)(-\beta_1C_2) & z(1-z)(-\beta_2C_4) & (1-2z)(R-x\beta_1C_2-y\beta_2C_4)\end{bmatrix}$$

TABLE II
Equilibrium point stability analysis

equilibrium point	Jacobi matrix eigenvalues $\lambda_1,\lambda_2,\lambda_3$	Symbols	Stability conclusion	Conditions
$E_1(0,0,0)$	$S_d+C_1-C_2;-C_4;R$	$(-,-,+)$	Unstable	/
$E_2(1,0,0)$	$C_2-S_d-C_1;\alpha_2S_r-C_4;R-\beta_1C_2$	$(+,\times,+)$	Unstable	/
$E_3(0,1,0)$	$(1+\alpha_1)S_d+C_1-C_2;C_4;R-\beta_2C_4$	$(\times,+,+)$	Unstable	/
$E_4(0,0,1)$	$\beta_1C_2+S_d+C_1-C_2;\beta_2C_4-C_4;-R$	$(\times,-,-)$	ESS	①
$E_5(1,0,1)$	$C_2-\beta_1C_2-S_d-C_1;\alpha_2S_r+\beta_2C_4-C_4;\beta_1C_2-R$	$(\times,+,-)$	Unstable	/
$E_6(1,1,0)$	$C_2-(1+\alpha_1)S_d-C_1;C_4-\alpha_2S_r;R-\beta_1C_2-\beta_2C_4$	$(\times,\times,\times)$	ESS	②
$E_7(0,1,1)$	$\beta_1C_2+(1+\alpha_1)S_d+C_1-C_2;C_4-\beta_2C_4;\beta_2C_4-R$	$(+,+,-)$	Unstable	/
$E_8(1,1,1)$	$C_2-(1+\alpha_1)S_d-\beta_1C_2-C_1;C_4-\beta_2C_4-\alpha_2S_r;\beta_1C_2+\beta_2C_4-R$	$(-,-,\times)$	ESS	③

Note: The $\times$ in the table indicate an uncertain positive or negative sign. If the point does not meet the corresponding condition, then the issue is unstable or meaningless. ①:$\beta_1C_2+S_d+C_1-C_2<0$; ②:$C_2-(1+\alpha_1)S_d-C_1<0, C_4-\alpha_2S_r<0, R-\beta_1C_2-\beta_2C_4<0$; ③:$\beta_1C_2+\beta_2C_4-R<0$.

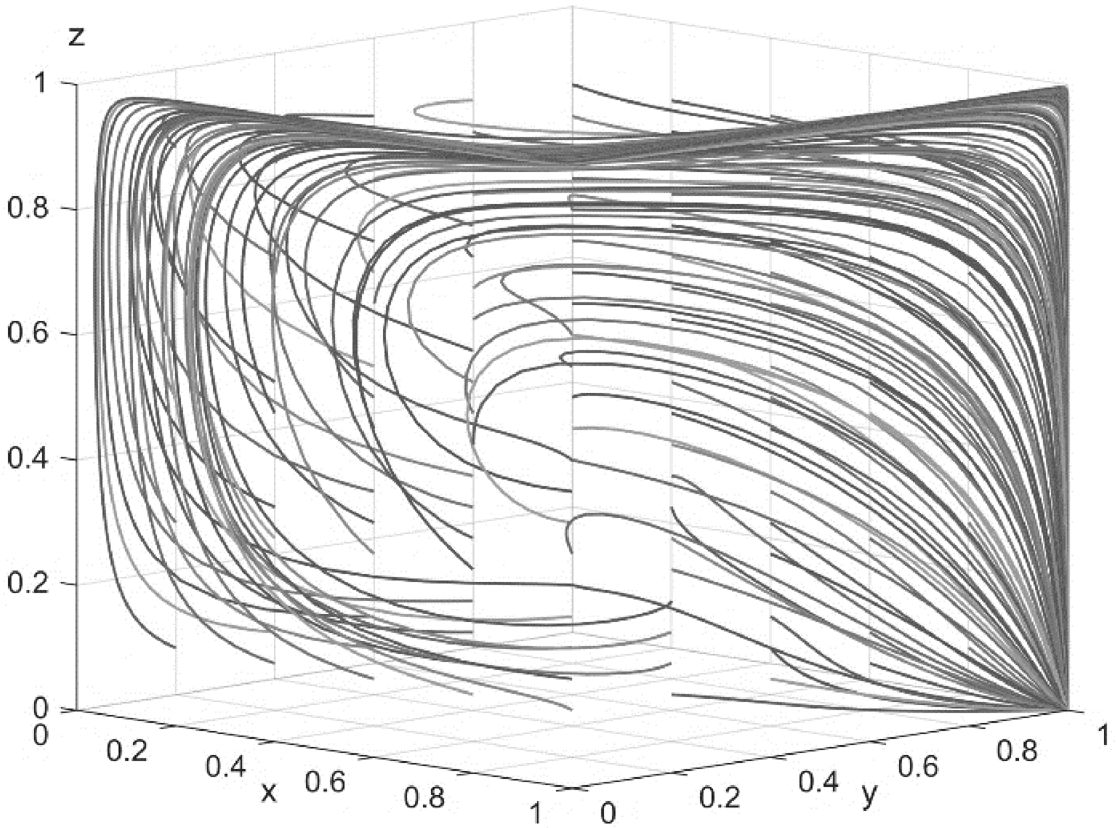

Fig. 1. The result of the 50th evolution of array 1

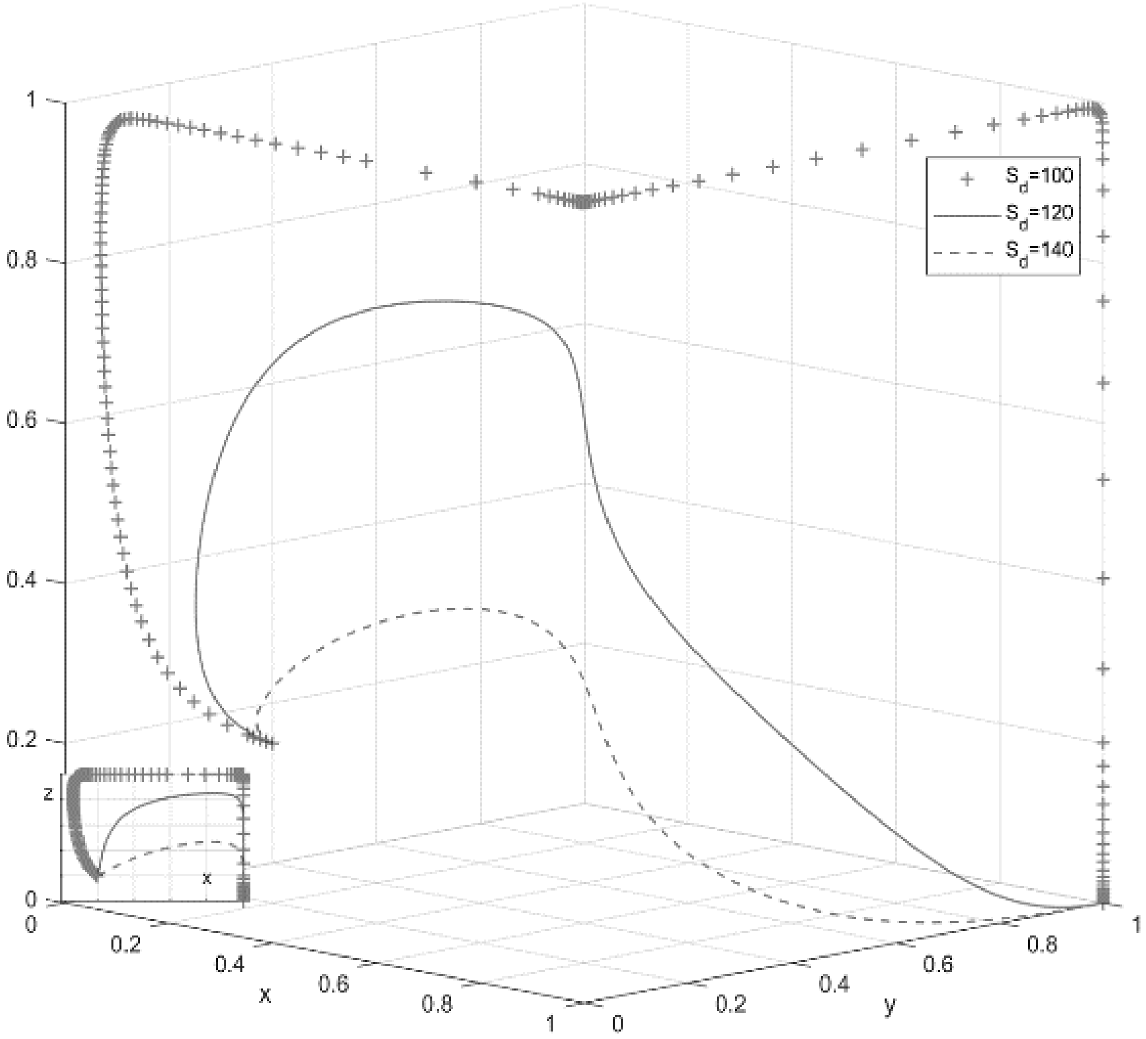

Fig. 2. Impact of the initial revenue from recycling waste

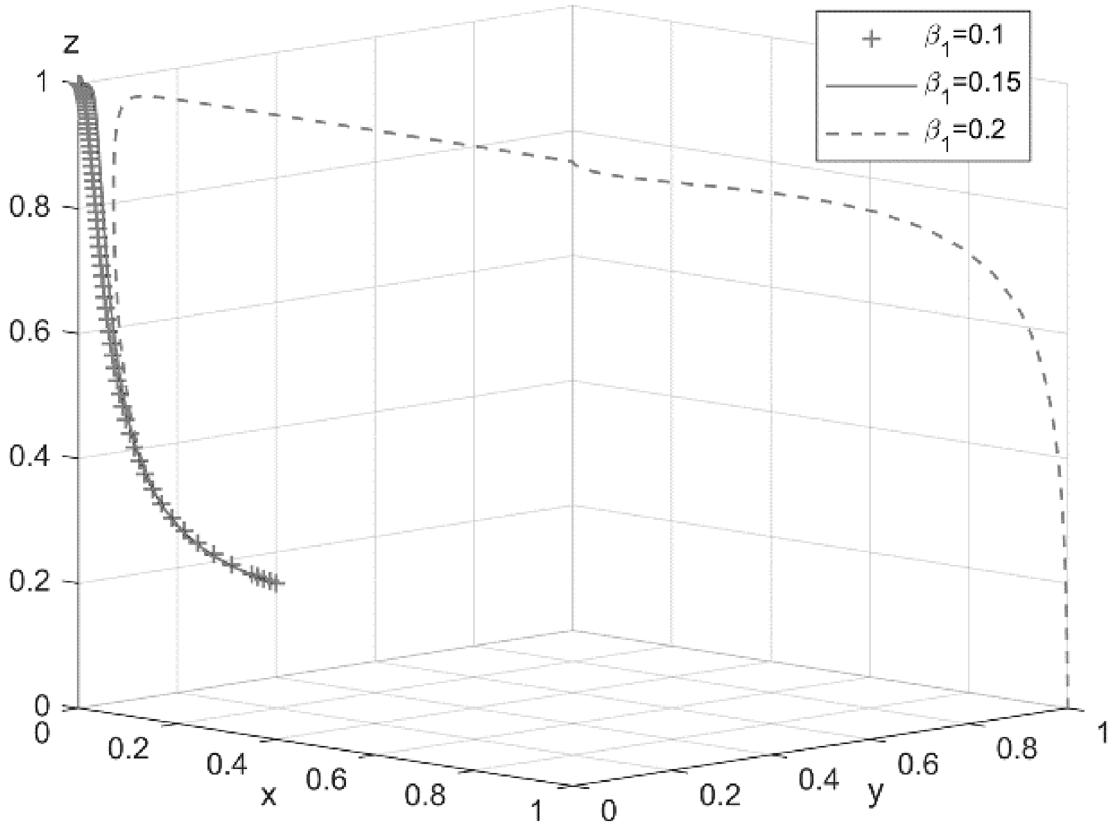

Fig. 3. The effect of the subsidy coefficient $\beta_1(\beta_2 = 0)$

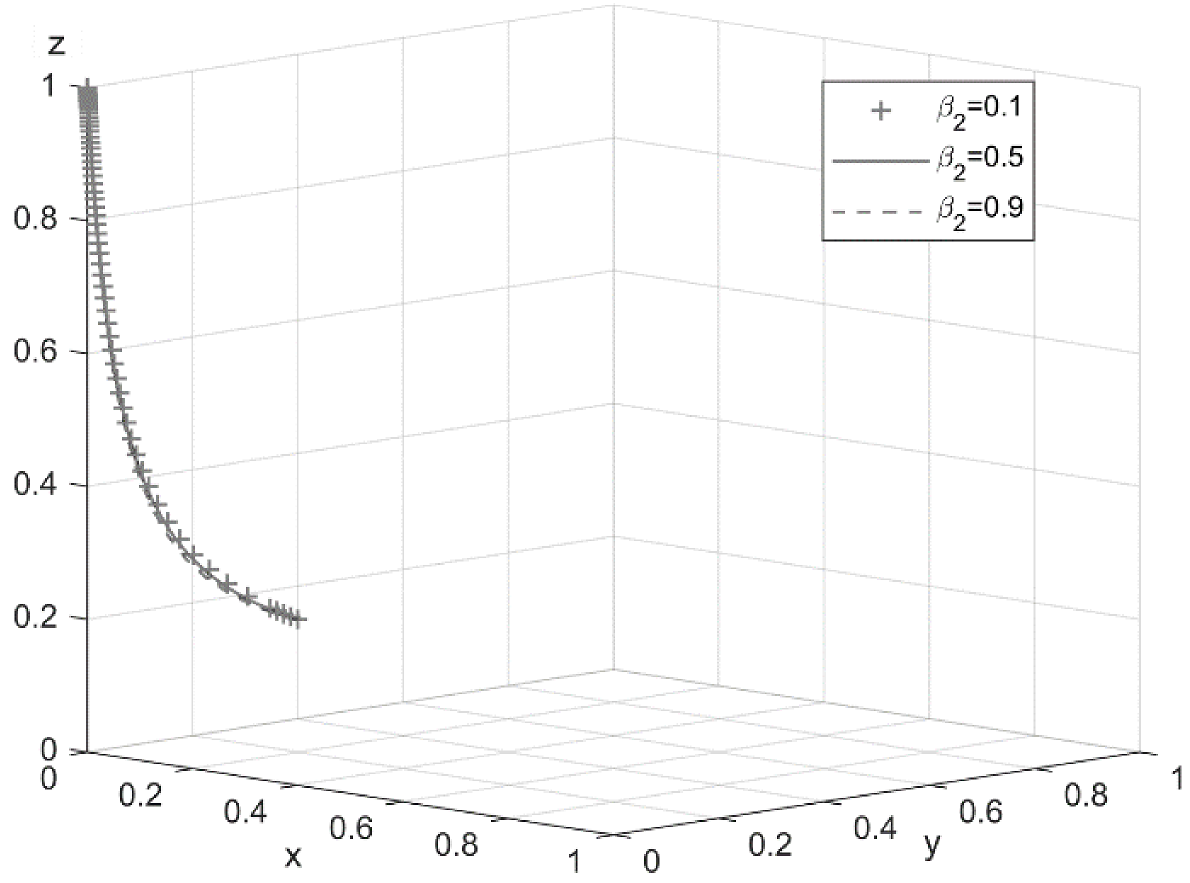

Fig. 4. The effect of the subsidy coefficient $\beta_2(\beta_1 = 0)$

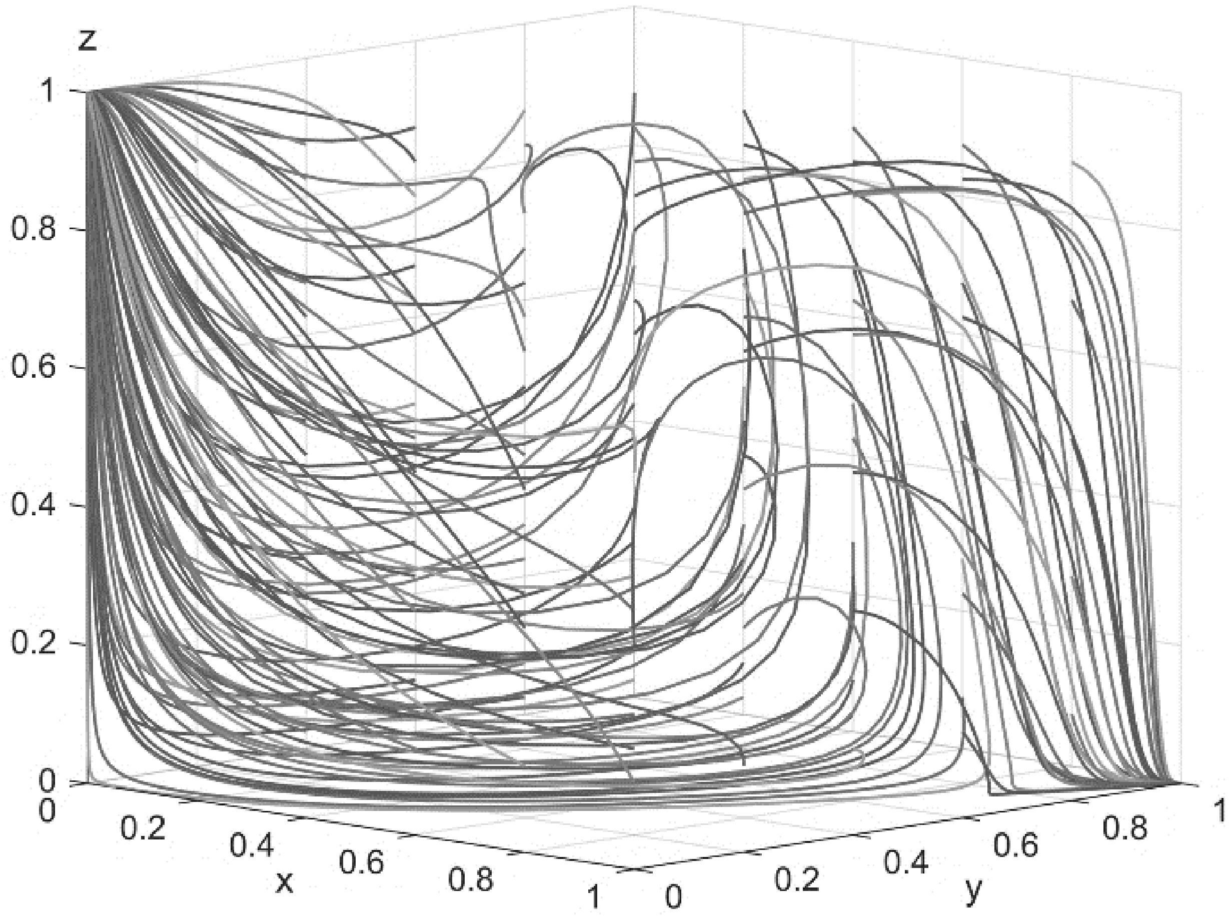

Fig. 5. The result of the 50th evolution of array 2

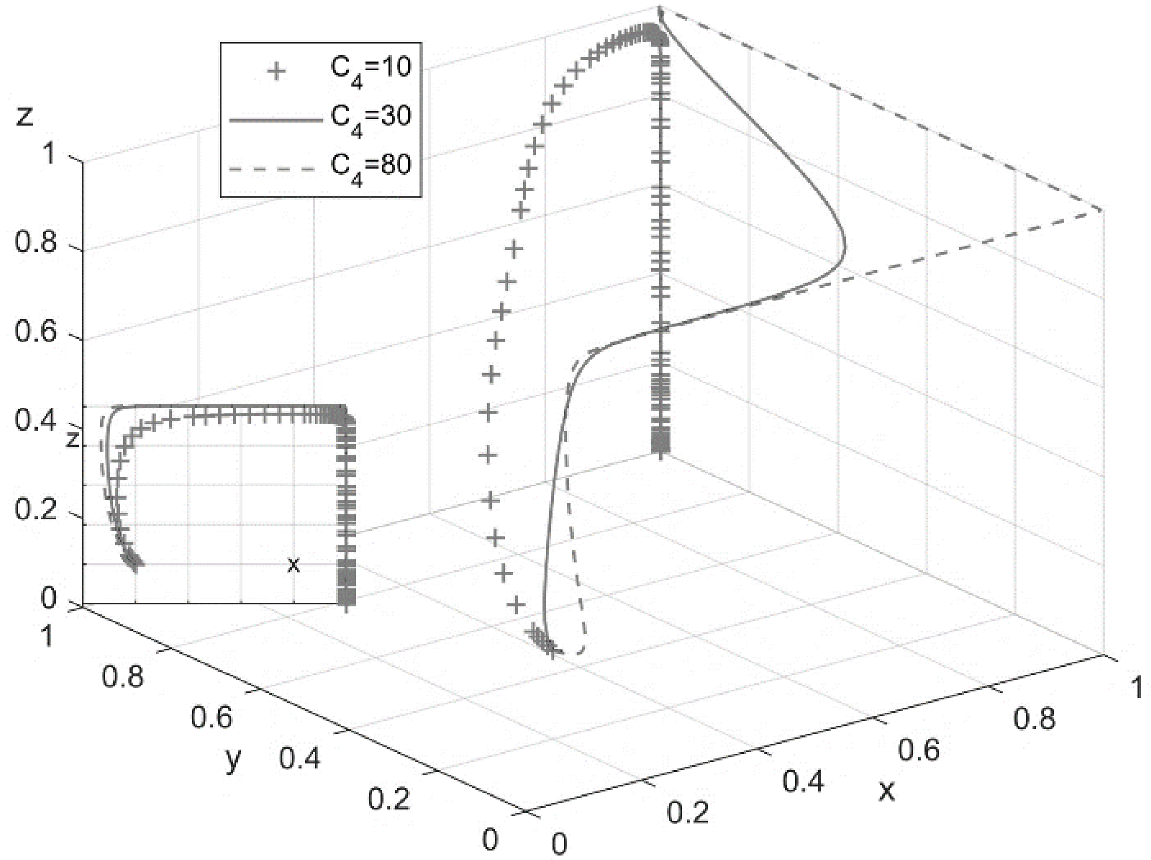

Fig. 6. The Impact of equipment cost C_4

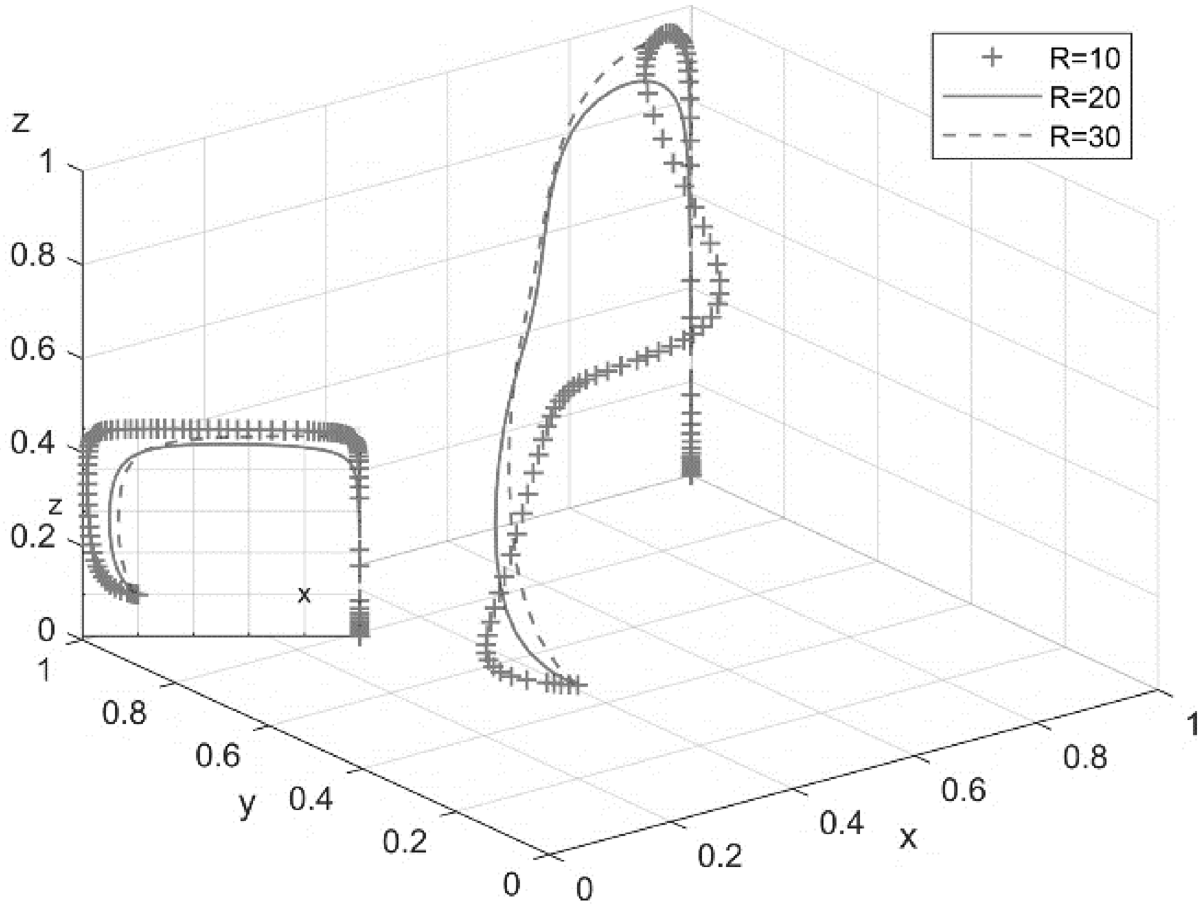

Fig. 7. The impact of potential earnings R

REFERENCES

[1] Guo F, Wang J, Song Y. How to promote sustainable development of construction and demolition waste recycling systems: production subsidies or consumption subsidies?[J]. Sustainable Production and Consumption, 2022, 32: 407-423.

[2] Agbenyeku Emmanuel Emem-Obong, Muzenda Edison, Msibi, Innocent Mandla, "Potential risks of CCA-Treated wood destined to landfills," Lecture Notes in Engineering and Computer Science, vol. 2220, pp593-597, 2015.

[3] Ayeleru Olusola Olaitan, Ntuli Freeman, Mbohwa Charles, "Municipal solid waste composition determination in the City of Johannesburg," Lecture Notes in Engineering and Computer Science, vol. 2226, pp625-629, 2016.

[4] Yildirim, Semih Gokse, "Reuse properties of structural members during building components design," Lecture Notes in Engineering and Computer Science, vol. 2, pp1126-1130, 2013.

[5] Matheri Anthony Njuguna, Mbohwa Charles, Belaid Mohamed, Seodigeng Tumisang, Ngila Jane Catherine, "Multi-criteria analysis of different technologies for the bioenergy recovery from ofmsw," Lecture Notes in Engineering and Computer Science, vol. 2226, pp888-893, 2016.

[6] Zhang Huiling, Xu Kemang, Chen Yongliang, Wu Shiyi, Qi Chenhui, Xiao Huaping. Preparation of autoclaved aerated concrete using construction waste and alkali slag[J]. Journal of Environmental Engineering, 2019 , 13(02): 441-448.

[7] Zhao, W., Leeftink, R.B., Rotter, V.S., 2010.Evaluation of the economic feasibility for the recycling of construction and demolition waste in China-the case of ChongQing. Resources Conservation & Recycling 54 (6), 377–389.

[8] Ghaffar S H, Burman M, Braimah N. Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery[J]. Journal of cleaner production, 2020, 244: 118710.

[9] Liu Tingting, Zhang Jier, Hu Mingming. Analysis of environmental benefits of construction waste resourceization:an example from Chongqing[J]. China Environmental Science, 2018, 38(10): 3853-3867.

[10] Su Yongbo. Research on the comprehensive assessment method of urban construction waste resource utilization - taking Xi'an city as an example[J]. Journal of System Science,2019,27(02):69-74.

[11] Zhao Yu, Lei Guoyuan, Wang Qiaozhi. Reflections and suggestions on the management and disposal of renovation waste in Wuhan[J]. Environmental Protection,2020,48(13):53-56.

[12] Chen Hong Quan, Glowinski Roland, Périaux Jacques, "A Domain Decomposition/Nash Equilibrium Methodology for the Solution of Direct and Inverse Problems in Fluid Dynamics with Evolutionary Algorithms," Lecture Notes in Computational Science and Engineering, vol. 60, pp21-32, 2008.

[13] Leskinen Jyri,Périaux Jacques. "A New Distributed Optimization Approach for Solving CFD Design Problems Using Nash Game Coalition and Evolutionary Algorithms," Lecture Notes in Computational Science and Engineering, vol. 91, pp607-614, 2013.

[14] Li Wenxiang, Li Ye, Cai Jinjin. A government-enterprise-resident collaborative carbon trading mechanism for road traffic[J]. China Environmental Science,2021,41(09): 4426-4438.

[15] Wei Q, Ding YANAN. A study on the evolutionary game of carbon subsidy policy in the field of calculation and consumption[J]. China Environmental Science:1-11.

[16] Lu, Mei, Huang, Zhong. Game analysis among key node subjects of construction waste resourceization industry chain[J]. Ecological Economy,2018,34(07):131-136.

[17] ZHU Yuanyuan, ZHONG Yongguang, LIU Chang, ZHANG Li-ming. Analysis of construction waste disposal fund collection strategy based on evolutionary game[J]. Journal of Qingdao University (Natural Science Edition),2019,32(03):69-76.

[18] Chen, J.G., Hua, C.X., Liu, C.Y., 2019a.Considerations for better construction and demolition waste management: identifying the decision behaviors of contractors and government departments through a game theory decision-making model. J. Clean.Prod. 212, 190–199.

[19] Guo F, Wang J, Song Y. Research on high quality development strategy of green building: a full life cycle perspective on recycled building materials[J]. Energy and Buildings, 2022, 273: 112406.

[20] Maria, A.D., Eyckmans, J., Acker, K.V., 2018.Downcycling versus recycling of construction and demolition waste: combining LCA and LCC to support sustainable policy making[J]. Waste Manag. 75, 3–21.

[21] Wu Hua Ping, Li Hui, Sun Xiao Lan. "Evolutionary Game for Enterprise Cloud Accounting Resource Sharing Behavior Based on the Cloud Sharing Platform," IAENG International Journal of Applied Mathematics, vol.51, no.1, pp125-131, 2021.

[22] Ma L, Zhang L. Evolutionary game analysis of construction waste recycling management in China[J]. Resources, Conservation and Recycling, 2020, 161: 104863.

[23] Li Yang, Li Jinhui, Tan Quanyin, Liu Lili. Analysis of the development and driving forces of China's municipal domestic waste treatment industry[J]. China Environmental Science, 2018, 38(11):4173-4179.

[24] SELETEN R . A note on evolutionarily stable strategies in asymmetric animal conflicts[J]. Journal of Theoretical Biology, 1980, 84(1): 93-101.

[25] RITZBERGERK, WEIBULL J W. Evolutionary selection in normal-form games [J]. Econometrica: Journal of the Econometric Society, 1995, 63(6): 1371-1399.