Promoting construction and demolition waste recycling by using incentive policies in China

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Abstract
In the recent two decades, construction and demolition (C&D) waste is becoming a major source of municipal waste which causes severe damage to the environment. To solve the problem, waste recycling measures are gradually used to turn waste into treasures. Meanwhile, several kinds of policies such as waste disposal charging fees have been issued to stimulate stakeholders’ behavior to take waste recycling measures to promote the C&D waste recycling industry. However, the C&D waste recycling rate is still too low in China. In order to promote C&D waste recycling industrial development, this paper aims at introducing subsidy and environmental tax policies to promote C&D waste recycling. Based on system dynamics method, this study establishes a model to determine the proper subsidy and environmental tax range. According to the simulation results, three kinds of incentive policies are obtained, namely, single subsidy policy, single environmental tax, and combined incentive policies. Optimal single subsidy and environmental tax are in the interval, [10, 30] and [20, 60], respectively. The best combination strategy is subsidy = 10 yuan/ton and environmental tax = 20 yuan/ton. The results from this paper could be a foundation for government to establish incentive policies to promote C&D waste recycling.

Keywords C&D waste · Recycling · Subsidy · Environmental tax · System dynamics

Introduction
Rapid urbanization has produced a significant quantity of construction and demolition (C&D) waste in China during the past 40 years. It is widely accepted that C&D waste has severe adverse impacts on the environment and human society (Lu and Yuan 2011; Jin et al. 2019). In order to deal with the serious C&D waste problem, studies on C&D waste management have gradually been the hot issue in the last two decades. Researchers start to focus on various waste reduction methods at different stages to reduce C&D waste amount (Osmani et al. 2008; Yuan and Shen 2011).

Among a variety of feasible measures, C&D waste recycling is found to be an effective method for C&D waste reduction and sustainable management (Meng et al. 2019; He and Yuan 2020). Therefore, the key factors influencing C&D waste recycling and promoting C&D waste recycling have become hot topics for researchers. Ding and Xiao (2014) pointed out that low landfilling fees, high recycling cost, and enterprises’ lack of confidence in recycled products are essential factors affecting the C&D waste recycling development. Rodríguez et al. (2007) put forward that the quantity, composition, and recycling costs of C&D waste are critical factors that affect the implementation of C&D waste recycling. Moreover, Al-Sari et al. (2012) stated that the attitude and behavior of construction contractors toward C&D waste recycling would have a crucial impact on the generation and disposal of C&D waste.

To promote C&D waste recycling development, developed countries and regions like the UK, Denmark, and the HK governments have issued a series of laws and regulations on C&D waste recycling. Most policies are related to economic tools and have achieved wonderful outcomes.
in promoting C&D waste recycling (Liu et al. 2021). In HK, waste disposal charging fee is implemented for nearly 15 years, and it achieves great results. To verify the effect of the waste disposal charging fee policy, Tam (2008) figured out the amount of C&D waste dumped in landfills was reduced by about 65% between 2005 and 2006. In Denmark, Andersen (1998) showed the C&D waste tax had an excellent effect on waste reduction which reduced C&D waste by approximately 64% during a 6-year period. In the Netherlands, 8 years after the landfill tax policy was issued, the amount of landfilled waste had decreased by nearly 6 kilograms (Bartelings et al. 2005).

By comparing the C&D waste recycling in Japan and Australia, Tam (2009) pointed out that the economic support provided by the government will be the most important factor for successful C&D waste recycling in Australia. Jin et al. (2019) stated that the economic factors are the most critical elements encouraging contractors’ waste management behaviors, especially C&D waste recycling behaviors. Through a series of studies, economic factors are regarded as the top 1 factor influencing C&D waste recycling.

However, contractors are not willing to adopt recycling measures in China due to low landfilling fee and high C&D waste recycling cost (Bao and Lu 2020). So, the major C&D waste disposal measure in China is still directly dumping (Chen et al. 2019). According to statistics from the Chinese National Development and Reform Commission (NDRC 2014), about 1 billion tons of C&D waste was generated nationwide as shown in Fig. 1. Among this large amount generated C&D waste, approximately 740 million tons of C&D waste came from demolition projects, and others were mainly from construction projects. Meanwhile, it is worth noting that only 50 million tons of C&D waste were recycled. Based on the above data, it can be obtained the C&D waste recycling rate in China is too low, and it is only 5%.

During that recycling process, about 30 million tons of recycled construction materials were produced. The other 20 million tons of C&D waste was used for other construction purposes. Although the C&D waste recycling rate is not good, C&D waste recycling has already shown great potential to turn waste into treasure.

In recent years, the Chinese government has recognized the need to develop the C&D waste recycling industry. One governmental document proposes to use various means to improve the C&D waste recycling rate to 13% (NDRC 2017). Furthermore, many Chinese scholars (Fu et al. 2020; Xiao et al. 2018) have called for the establishment of some incentive mechanisms for the waste recycling industry to achieve green and sustainable development. However, most previous studies and policies are mainly in the form of landfilling fee in China (Liu et al. 2021), which makes it hard to motivate enterprises to do C&D waste recycling jobs.

However, it must be recognized incentive policies are not always useful. Jia et al. (2017) found higher subsidy would add governmental financial burden and cannot get the expected effect of promoting C&D waste recycling. Bansal and Gangopadhyay (2003) proposed tax policy would worsen environmental quality. In addition, higher tax and penalty may cause illegal dumping.

Therefore, in order to promote the development of the C&D waste recycling industry and motivate enterprises to recycle C&D waste, there is a need to issue some appropriate incentive policies that stimulate contractors to adopt C&D waste recycling behavior. To address the problem, this paper carries out a model which is based on the system dynamics approach to give some incentive policies by determining the proper subsidy and environment tax. The results from this study could not only provide some supports to China but also help other developing countries deal with the serious C&D waste problem. Thus, this study can enrich the body of knowledge of C&D waste management.

The rest of this study is organized as follows. “Literature review” is a literature review, which gives a comprehensive review of C&D waste recycling and incentive policies. “Methodology and data” describes the methodology and data used in this paper. “Results” verifies the constructed model. “Conclusions” conducts the simulation and discusses the results. The final section gives the conclusion obtained from this study.

**Literature review**

**C&D waste recycling**

Recycling is the process of converting waste materials into fresh raw materials, and it is the third component of 3R principles (*Reduction, Reuse, and Recycle*) which are widely accepted as the foundation of C&D waste management (Peng et al. 1997). Moreover, recycling emphasizes achieving environmental sustainability by removing raw material...
input and redirecting waste output in the economic system (Geissdoerfer et al. 2017).

Although the reduction is seen as the most ideal method to reach the goal of sustainable development, it is hard to achieve the objective in real scenes (Osmani et al. 2008). Therefore, waste recycling is more practicable compared with reduction and reuse (He and Yuan 2020).

Around C&D waste recycling studies, it could be divided into two aspects. One is from a technical perspective, and the other is from a managerial perspective. In order to make C&D waste recycling be feasible, the concept of closed-cycle construction is proposed (Mulder et al. 2007). From a technical perspective, scholars pointed out that the vast majority of C&D wastes can be turned into useful recycled materials through proper recycling treatment. The physical, chemical, and mechanical properties and composition characteristics of recycled materials are analyzed (Silva et al. 2014), and the feasibility of using recycled materials as one component of concrete is confirmed. Contreras et al. (2016) conducted a test for C&D waste recycling measures in Brazil, and it was found the mechanical properties of bricks generated from recycled materials were higher than the requirements of the specification. Other properties such as water absorption and density of bricks were also excellent, indicating that recycling measures can produce high-quality and cheap bricks by using recycled materials from C&D waste.

Guaranteed by the technical feasibility of C&D waste recycling, scholars have carried out various studies from a managerial perspective to promote C&D waste recycling industry development. Wang et al. (2010) identified several key factors influencing on-site C&D waste recycling, namely, better management, site space, classification equipment, human resources, classification capability, and recycling material markets. Among many factors, lack of incentive measures is seen as one core element influencing C&D waste recycling development (Marques et al. 2012; Wu et al. 2017; Huang et al. 2018).

Begum et al. (2009) investigated the impact of construction contractors’ attitudes and behaviors on C&D waste recycling, and they believed that contractors’ attitudes and behaviors toward C&D waste are closely related to the contractor’s scale, such as their own economic strength and enterprise scale. Simpson (2012) used the knowledge resources as an intermediary factor to analyze the impact of the pressure of C&D waste recycling on the environmental performance of enterprises; he pointed out that the enterprise with the first goal of maximizing profit hopes to make profits from waste recycling while high investment in C&D waste recycling restricts the enthusiasm of enterprises to take recycling measures.

**Incentive policies**

Incentive policies are commonly used in environmental-related topics. There is a wide range of studies that apply subsidy, tax, and other incentive policies in various fields such as electric waste recycling, low carbon, and green supply chain to promote environmental protection and sustainable development (Fan et al. 2017; Liu et al. 2020a; Hu et al. 2020). Take electric waste recycling and low-carbon fields as examples. Wang et al. (2019) analyzed the impact of government subsidies on the pricing strategy in the reverse supply chain of electric waste recycling; it was considered that subsidy has a huge effect on the number of reproduced products. Aksen et al. (2009) proposed a bilevel programming model of subsidy agreement between the government and recycling enterprises; it suggested that the government should uniformly provide subsidies to enterprises engaged in collection and recycling operations, which can promote the development of the recycling industry. Tan and Guo (2019) studied the impact of government subsidies on the operation of the closed-loop logistics system of recycling enterprises and proposed that government subsidies can effectively improve the recycling quality and remanufacturing technology level.

In some studies, subsidy and tax are combined to promote sustainable development better. Liu et al. (2020a) used the Stackelberg game model to study the effect of incentive policy on electronic waste recycling based on subsidy and environmental tax; results showed that the incentive policy can improve the profits of manufacturers and remanufacturers. Bansal and Gangopadhyay (2003) focused on the impact of subsidy policy and environmental tax policy on enterprises; they found enterprises with good environmental quality should receive subsidy, while enterprises with poor environmental quality could only be subject to tax policy. In addition, subsidy policy improved the average environmental quality, but tax policy worsened it. Therefore, subsidies can reduce pollution and improve overall social welfare better than taxes. Sheu and Chen (2012) designed an incentive policy based on subsidy and green tax; they indicated low-price strategies should be suggested to recycled-product suppliers under green subsidization to stimulate manufacturers’ green product production intention under green taxation.

In the C&D waste recycling field, incentive policies have also been carried out. The impact of government subsidy and environmental taxes on C&D waste recycling in Spain was evaluated by Calvo et al. (2014); the results showed that if the subsidy and environmental taxes are implemented, Spain can achieve a C&D waste recycling rate at 30% within 12 years. Duran et al. (2006) evaluated the vitality of the C&D waste recycling market under the policies of government subsidies and environmental taxes, and they proved the role of government subsidies and environmental taxes.
in promoting the development of the C&D waste recycling market. Mahpour and Mortaheb (2018) pointed out that subsidy measures can stimulate the willingness to reduce C&D waste better than fine measures, because economic incentives can effectively promote moral cultivation and are more in line with the goal of sustainable development. Andersen (1998) showed the C&D waste tax had an excellent effect on waste reduction which reduced C&D waste by approximately 64% during a 6-year period.

Meanwhile, some studies focus on calculated proper subsidy and penalty. Hao et al. (2008) found C&D waste disposal charging scheme which charged C&D waste at 27 HKD/ton can reduce the amount of landfilled waste by about 60% after the 1-year implementation of the charging policy. Yuan and Wang (2014) established a model for calculating C&D waste disposal fees based on system dynamics; they thought waste disposal fee has the best effect on the C&D waste recycling when the waste disposal fee is 80 yuAn/ton. Combining subsidy and penalty, scholars put forward that higher subsidy and penalty are not always better. When the subsidy is within 25–35 yuAn/ton and the penalty is among 250–350 yuAn/ton, it plays a better role. Hence, the government can rationally combine subsidies and penalty according to their demand (Jia et al. 2017; Jia and Yan 2018).

In sum, researchers have made many achievements in C&D waste disposal fees, subsidies, and penalties. However, combining subsidy and environmental tax is rarely discussed in China. Therefore, this study tries to combine subsidy and environmental tax to promote C&D waste recycling and enrich the incentive policy in the field.

### Methodology and data

System dynamics is a simulation method that uses variables such as inventory variables, flow variables, auxiliary variables, and internal feedback loops to analyze nonlinear behavior in complex systems. It was created by Forrester who is from the Massachusetts Institute of Technology in the 1860s (Forrester 1961). Since then, system dynamics has been widely used in researches to solve the characteristic of high complexity in the system, especially via explaining the causal relationship between variables in the internal feedback loop to analyze the rules of variation in the complex system. It means the system dynamics method would analyze issues from the internal perspective rather than the outside perspective.

The relationship between variables in the system dynamics model is connected by a feedback loop. There are two types of feedback loops: positive feedback loop and negative feedback loop. In the feedback loop, any changes in one variable would lead to variations in the entire system. The positive feedback loop indicates that the increase or decrease trend of any variables in the loop will drive the system to change in the same direction, while the negative feedback loop is just the opposite.

Constructing a system dynamics model and analyzing the internal variation rule of a complex system is mainly divided into two steps. The first step is to clarify the causal relationship in the system under real conditions and establish a qualitative causality conceptual model. Afterward, the causality diagram should be formed.

The second step is based on the established causality conceptual model, changing the existing variables into horizontal variables, auxiliary variables, and other variables that can be quantified to form a stock-flow diagram. Afterward, simulation analysis would be implemented with the help of system dynamics software such as Vensim. Finally, the simulation results can be obtained.

In recent years, the system dynamic method has been extensively applied to the C&D waste management field. Yuan et al. (2011) considered the dynamics nature in the C&D waste chain to analyze the cost–benefit of C&D waste management. Yuan and Wang (2014) established a system dynamic model to determine the C&D waste disposal charging fee. Jia et al. (2017) gave a dynamic incentive mechanism for C&D waste management based on the penalty and subsidy. Mak et al. (2019) predicted the optimum waste disposal charging fee in Hong Kong by constructing a system dynamic model. Liu et al. (2020b) analyzed the C&D waste recycling industry from a systematic perspective which provided a deep understanding of C&D waste recycling industry chain related issues.

Based on previous studies, the C&D waste recycling management can be divided into three parts, namely, C&D Waste Recycling, C&D Waste Directly Dumping, and C&D Waste Illegal Dumping. Therefore, the conceptual model in this study for C&D waste recycling under the incentive policy consists of three feedback loops, shown in Fig. 2a.

Loop 1: Once the amount of recycled C&D waste increases, the overall economic and environmental benefits will be improved, and more favorable factors can appear to promote the development of C&D waste recycling industry. With the gradual increase of driving factors, the effectiveness of recycling regulations can also be strengthened under the general trend of waste recycling, so more effective and feasible policies can lead to the development of the C&D waste recycled materials market. Hence, the market will be well developed, thereby, it will effectively reduce the recycling fee. Once the recycling fee is reduced, the cost of C&D waste recycling will also be reduced. Therefore, the enterprise would like to send more C&D waste to recyclers for waste recycling. Finally, the proportion of recycled C&D waste will eventually increase. Hence, this loop is a positive feedback loop.
Fig. 2  a Feedback loops.  b  Causal loop diagram.  c  Stock-flow diagram.
Loop 2: When the amount of illegal-dumping C&D waste increases, the damage to both society and the environment will increase too. The government will be no doubt to increase the supervision level and set more restraints on waste illegal-dumping in order to protect social interests. Therefore, the effectiveness of recycling regulations implementation would be improved under the attention of the government. With effective governmental supervision, the probability of being caught in illegal dumping will be greatly increased, which will cause enterprises to pay a greater price. For profit-oriented enterprises, it is obviously not acceptable. In this way, enterprises will gradually avoid choosing illegal dumping, thereby reducing the amount of illegal-dumping waste. Therefore, this loop is a negative feedback loop.

Loop 3: Dumping C&D waste directly is the simplest and cheapest way for enterprises. When the amount of directly dumped C&D waste increases, the government will inevitably issue more restrictions to ask enterprises to take recycling measures. Therefore, the number of factors restricting the C&D waste directly dumping would increase, and it will promote the effectiveness of recycling regulations implementation. As a result, the cost of directly dumping will increase. When the cost of directly dumping rises, it will encourage enterprises to carry out waste recycling measures and reduce the proportion of directly dumping waste. Ultimately, the amount of directly dumped waste will reduce. Therefore, this loop is also a negative feedback loop.

Based on the above three feedback loops, the causal loop diagram is shown in Fig. 2b. The arrow symbol in the diagram represents the causal relationship between the two connected factors, and the trend of arrow-head factor will change with the arrow-tail factor. The “+” sign indicates that the changing trend of the arrow-head factor is consistent with the variation trend of the arrow-tail factor. It means the arrow-head will increase with the arrow-tail increase or the arrow-head will decrease with the arrow-tail decrease. The “−” sign indicates that the changing trend of the arrow-head factor is opposite to the changing trend of the arrow-tail factor. The latter increases and the former decreases, and when the latter decreases, the former increases.

After the preparation, the stock-flow diagram can be drawn which is able to simulate the process according to the causal loop diagram. The stock-flow diagram is shown in Fig. 2c.

In China, GDP and construction acreage are often used to predict the amount generated C&D waste (Chen and Yuan 2017; Liu et al. 2014). These data come from Shanghai Statistics Yearbook from 2010 to 2018.

Based on Table 1, the relationship between GDP and construction acreage can be obtained in Eq. (1).

\[
\text{Construction acreage} = 1.5315 \times \text{GDP} - 3330.4 \quad (1)
\]

According to Liu et al. (2014) and expert interviews, it is assumed that each square meter of construction acreage corresponds to 10% of square meters of C&D waste. Each square meter of C&D waste weighs about 2 tons, so the amount of generated C&D waste generated can be obtained in Eq. (2):

\[
\text{The amount of generated C&D waste} = 0.1 \times \text{Construction acreage} \times 2 \times 10^4 \quad (2)
\]

This paper will conduct a simulation analysis for C&D waste recycling development under incentive policies from 2015 to 2035. It assumes that the incentive policy will be officially implemented in 2021. According to the published data in the Announcement of Shanghai Solid Waste Pollution Prevention Information, the amount of solid waste reported in the city is 99.65 million tons in 2015. Chen and Yuan (2017) had found that the amount of C&D waste in Shanghai is 30% of the amount of solid waste. Therefore, it is assumed that the initial amount of C&D waste in this study is 29.895 million tons. Values of constant variables are shown in Appendix Table 5, and other variables and table functions are also listed in Appendix Table 6 and Table 7 at the end of the manuscript.

Model verification

In order to ensure the rationality of the given system dynamics model in this paper, this system dynamic model needs to be verified after the establishment of the system stock-flow diagram and the confirmation of the functional relationship between the auxiliary variables in the model.

The relationship between the fine and the amount of illegal dumping C&D waste is selected for verification (Jia et al. 2017; Jia and Yan 2018). The fines are selected as 0 yuan/ton, 50 yuan/ton, 150 yuan/ton, 300 yuan/ton, 500 yuan/ton, and 700 yuan/ton for simulation, respectively.

| Time (tear) | GDP (100 million) | Construction acreage (1000 square meter) |
|------------|-------------------|--------------------------------------|
| 2018       | 32,679.87         | 47,577.35                            |
| 2017       | 30,133.86         | 41,197.49                            |
| 2016       | 26,688            | 36,019.72                            |
| 2015       | 24,964.99         | 36,631.16                            |
| 2014       | 23,560.94         | 34,994.68                            |
| 2013       | 21,602.12         | 29,148.65                            |
| 2012       | 20,101.33         | 27,961.55                            |
| 2011       | 19,195.69         | 24,004.25                            |
| 2010       | 16,872.42         | 22,996.81                            |
It can be seen in Fig. 3 that the amount of illegal dumping C&D waste gradually decreases as the amount of fines increases. This result is consistent with the reality and is consistent with the simulation results of Jia et al. (2017) and Jia and Yan (2018), which proves that the model built in this paper is realistic and feasible.

**Results**

**Single subsidy policy**

It can be seen in Fig. 4, only single subsidy policies are considered in this scenario. There are five levels of subsidies being simulated, where subsidy is 10, 20, 30, 40, and 50 yuan/ton, respectively. To better illustrate the effect of subsidy policy on C&D waste recycling, a basic policy which has no incentive measures is set for comparison. According to Fig. 4, it can be seen that when the government implements the subsidy policy, the amount of recycled C&D waste has increased significantly compared with the situation without incentive policy, indicating that the subsidy policy can effectively promote enterprises to take more C&D waste to recycle.

When the subsidy is 20 yuan/ton, the amount of recycled C&D waste has a significant increase compared to the subsidy of 10 yuan/ton. However, when the subsidy gradually increases and reaches at 30 yuan/ton, the amount of recycled C&D waste will not increase even though the amount of subsidy continues to increase. It indicates that subsidy = 30 yuan/ton is the upper limit of the subsidy policy. If it exceeds 30 yuan/ton, it can only increase governmental financial...
burden and cannot get the expected effect of continuing to promote the C&D waste recycling.

As shown in Table 2, if the 10 yuan/ton subsidy policy is implemented from 2021, the amount of recycled C&D can reach at 1.02 billion tons in 2035 compared to 6.67 billion tons without the subsidy policy. Hence, the amount of recycled C&D has increased by 53%. When the policy of subsidy = 20 yuan/ton is implemented, the amount of recycled C&D waste can be greatly increased, reaching 1.73 billion tons, which is an increase of 1.6 times.

When the subsidy exceeds 20 yuan/ton, the growth rate begins to rise slowly. After the subsidy reaches at 30 yuan/ton, the amount of recycled C&D waste reaches 2 billion tons. It is obvious that the growth rate is doubled. Therefore, when the subsidy policy is in the interval [10, 30], it can achieve a better effect.

### Table 2 The amount of recycled C&D waste with various subsidy

| Subsidy (yuan/ton) | The amount of recycled C&D waste (ton) | Growth rate |
|-------------------|---------------------------------------|-------------|
| 0                 | 6.67e+008                             |             |
| 10                | 1.02e+009                             | 0.53        |
| 20                | 1.73e+009                             | 1.60        |
| 22                | 1.83e+009                             | 1.74        |
| 24                | 1.90e+009                             | 1.85        |
| 26                | 1.95e+009                             | 1.92        |
| 28                | 1.99e+009                             | 1.99        |
| 30                | 2.00e+009                             | 2.00        |

Single environmental tax policy

If the government only adopts the environmental tax policy from 2021. There are also five kinds of environmental tax policies being taken into consideration for simulation, namely, environmental tax = 20, 40, 60, 80, 100 yuan/ton. The simulation results are shown in Fig. 5. With the gradual increase of environmental taxes, the amount of directly dumped C&D waste gradually decreases, indicating that environmental tax policies can effectively reduce the amount of directly dumped C&D waste and lead enterprises to choose C&D waste recycling jobs.

When the environmental tax continues to increase and exceeds 40 yuan/ton, the amount of directly dumped C&D waste is reduced significantly. However, when the environmental tax reaches at 80 yuan/ton and continues to increase to 100 yuan/ton, the downward trend of the directly dumped C&D waste quantity is no longer significant. It indicates that when the environmental tax is 80 yuan/ton, the upper limit of the reduction effect of the environmental tax policy has been reached. At this time, continuing to increase the environmental tax will not reduce the amount of directly dumped C&D waste significantly.

As shown in Table 3, if no incentive measures are taken, the cumulative amount of directly dumped C&D waste will reach 2.45 billion tons by 2035. Once different environmental tax policies could be adopted, various levels of reduction effect will be achieved. When the environmental tax is 40, 60, 80, and 100 yuan/ton, respectively, the corresponding

Fig. 5 The amount of directly dumped waste with single tax policy
The amount of directly dumped C&D waste will decrease 14%, 37%, 57%, and 58%. Hence, it can be seen that the environmental tax is within the range of [40, 80], which can have a better effect on reduction in directly dumped C&D waste quantity.

Environmental taxes can not only reduce the amount of directly dumped C&D waste, but also affect C&D waste illegal dumping. As shown in Fig. 6, compared to the situation that there is no environmental tax, with the increase of environmental tax, the amount of illegal dumping C&D waste is decreasing. However, it is worth noting that when environmental tax is 20 yuan/ton, the amount of illegal dumping C&D waste is almost the same as there is no environmental tax. It indicates that the lower environmental tax is hard to prevent C&D waste illegal dumping. When the environmental tax is greater than 60 yuan/ton, the amount of illegal dumping C&D waste has not changed much, indicating that when the environmental tax is in the range of [20, 60], the occurrence of C&D waste illegal dumping can be suppressed.

**Combination policy**

In order to obtain the potential optimal combination policy, this section will select four representative sets of policies for comparison and discussion, as shown in Table 4. Suppose the government would adopt a combination policy consisting of subsidy and environmental tax to promote C&D waste recycling from 2021.

1. **First set of policies**

As shown in Fig. 7, there are 4 kinds of policies, namely, the combination policy consisting of subsidy = 30 yuan/ton and environmental tax = 80 yuan/ton, the best single subsidy policy that is subsidy = 30 yuan/ton, the best single tax policy that is tax = 80 yuan/ton, and when there is no incentive policy.

It can be seen that the combination policy has the same effect on the amount of recycled C&D waste with the other two best single policies. It shows that under this scenario, the combination policy has not achieved the effect of “1 + 1 = 2” or “1 + 1 > 2”. If the government chooses this specific

### Table 3 The amount of directly dumped C&D waste with various environmental tax

| Environmental tax (yuan/ton) | The amount of directly dumped C&D waste (ton) | Decreasing rate |
|-----------------------------|---------------------------------------------|-----------------|
| 0                           | 2.45e+009                                   | −0.05           |
| 20                          | 2.33e+009                                   | −0.14           |
| 40                          | 2.10e+009                                   | −0.21           |
| 60                          | 1.55e+009                                   | −0.37           |
| 80                          | 1.06e+009                                   | −0.57           |
| 100                         | 1.03e+009                                   | −0.58           |

Fig. 6 The amount of illegal dumping waste with single tax policy
combination policy in this case to promote C&D waste recycling, although it can achieve a significant effect, it would be actually resource-wasting. It may greatly waste government subsidies and aggravate the government financial burden.

2. Second set of policies

As shown in Fig. 8, the combination policy is consisting of subsidy = 10 yuan/ton and environmental tax = 20 yuan/ton. The other 2 single policies are subsidy = 10 yuan/ton and environmental tax = 20 yuan/ton respectively.

The amount of recycled C&D waste is the highest when the combination policy is implemented, followed by the single environmental tax policy and the single subsidy policy. It shows that within a certain range, the better promotion effect on C&D waste recycling can be achieved by adopting a combination policy and it would be greater than only implementing a single subsidy policy or only an environmental tax policy.
policy. Therefore, the government could select a combination policy within a reasonable range to encourage C&D waste recycling.

3. Third set of policies

In this set, we choose combination policy consisting of subsidy = 10 yuan/ton and environmental tax = 20 yuan/ton, the best single subsidy policy that is subsidy = 30 yuan/ton and the best single tax policy that is tax = 80 yuan/ton for comparison.

It can be seen from Fig. 9 that the amount of recycled C&D waste is almost the same under three different incentive policies, indicating that the combination policy at this point can achieve the same effect as the best single strategy. Therefore, this combination policy may become the potential optimal combination strategy.

4. Fourth set of policies

Due to the length limitation, it is not possible to show all combination policies. In this paper, we choose five representative combination policies to compare with the potential optimal combination policy that is subsidy = 10 yuan/ton and environmental tax = 20 yuan/ton.

As shown in Fig. 10, the amount of recycled C&D waste under other combination policies does not exceed the specific potential optimal combination policy, which consists of subsidy = 10 yuan/ton and environmental tax = 20 yuan/ton. It is indicated the specific combination policy (subsidy = 10 yuan/ton and environmental tax = 20 yuan/ton) could be the optimal combination strategy the government can choose.

Conclusions

While the construction industry benefits human society a lot, it also generates a large amount of C&D waste. It is obvious that C&D waste is very harmful to the environment. However, C&D waste also has great potential economic and environmental benefits once it is recycled. In developed countries, the C&D waste recycling industry has achieved great results. But developing countries such as China are still making every effort to achieve sustainable development and establish a C&D waste recycling industry.

Due to the current situation in China, incentive policies are needed to promote C&D waste recycling industry development. In order to achieve the goal, this paper introduces some incentive policies based on subsidy and environmental tax.

This study first elaborates the causal relationship chain of C&D waste recycling under the incentive policy based on system dynamics. It analyzes the causal relationship between internal elements. According to the causal relationship, this paper establishes a feedback loop diagram, a causal relationship diagram, and a stock-flow diagram.
Subsidy = 10 and Tax = 20
Subsidy = 30 and Tax = 80
No incentive policy

Fig. 9 The best single policy and one potential optimal combination policy

Subsidy = 10 and Tax = 20
Subsidy = 10 and Tax = 10
Subsidy = 5 and Tax = 20
Subsidy = 20 and Tax = 20
Subsidy = 10 and Tax = 25
No incentive policy

Fig. 10 The comparison of combination policies
Based on system dynamics simulation, the subsidy-environmental tax policy for C&D waste recycling is made, and the effects of single subsidy policy, single environmental tax policy, and combined policy on C&D waste recycling are obtained.

The results show that when the single subsidy policy is in the interval $[10, 30]$, the amount of recycled C&D waste has the largest increment. When the single environmental tax policy is within $[40, 80]$, the declining trend of the amount of directly dumped C&D waste is the largest. Meanwhile, when the single environmental tax policy is in the range of $[20, 60]$, it can effectively suppress the occurrence of C&D waste illegal dumping.

In order to maximize the effectiveness of incentive policies and ease the government’s burden, the combination policy is also introduced. Through simulation, the potential optimal combined policy is subsidy $= 10$ yuan/ton and environmental tax $= 20$ yuan/ton. This combined policy could achieve the max effect on promoting C&D waste recycling.

This study clearly illustrates the relationship between many factors and sets several incentive policies using system dynamics. It could provide a deeper understanding of using incentive policy to promote C&D waste recycling. Furthermore, accurate incentive policies are calculated and so are the effect of incentive policies on C&D waste recycling. Hence, it would provide the decision foundation for the government.

However, the paper still has several limitations: (1) There are many stakeholders involved in the industrial chain of C&D waste recycling. Considering more casual relationships between stakeholders will make the consequence more accurate. Hence, more stakeholders should be studied in the future. (2) The amount of generated C&D waste is estimated based on GDP. However, due to Covid-19, GDP has been affected a lot in the last year. So, the relationship between the amount of generated C&D waste and GDP in the future should be inspected. Some prediction models may be worth studying.

### Appendix

#### Table 5

| Constant variables                      | Value         | Unit | Data source                                                                 |
|-----------------------------------------|---------------|------|----------------------------------------------------------------------------|
| The initial amount of recycled C&D waste| $3.89 \times 10^6$ | Ton/year | The amount of recycled C&D waste, directly dumped C&D waste and illegal dumping C&D waste are set at 13%, 84%, and 3%, respectively (Jia and Yan 2018) |
| The initial amount of directly dumped C&D waste| $2.51 \times 10^7$ | Ton/year |                                                                                      |
| The initial amount of illegal dumping C&D waste| 897,000       | Ton/year |                                                                                      |
| Cost of illegal dumping                 | 10            | Yuan/ton | Yuan and Wang (2014)                                                             |
| Fine                                    | 100           | Yuan/ton | Jia et al. (2017) and Jia and Yan (2018)                                         |
| Landfill fee                            | 11            | Yuan/ton | Notice on the Implementation of Government-guided Prices for Transportation and Disposal fees for Construction and Demolition waste in Pudong New Area |
| Transportation fee                      | 18            | Yuan/ton | Yuan and Wang (2014)                                                             |

#### Table 6

| Auxiliary variable                      | Equation                                                                                                                                                                                                 |
|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The influence of recycling regulations  | Constraints on the amount of C&D waste * 0.2 + Constraints for directly dumped waste * 0.2 + Driving factors for C&D recycling * 0.3 + Constraints on illegal dumping of C&D waste * 0.3 |
| Effectiveness of recycling regulations execution | (Emission reduction effect * 0.5 + integrity of regulations * 0.25 + effectiveness of supervision * 0.25) * The influence of recycling regulations |
| Price of illegal dumping                | Fine * Probability of being caught + cost of illegal dumping                                                                                                                                               |
| Increment of illegal dumping C&D waste | Amount of annual generated C&D waste * proportion of illegal dumping C&D waste                                                                                                                                 |
| Cost of C&D waste recycling             | Recycled fee-exempted environmental tax-Subsidy                                                                                                                                                           |
| Increment of recycled C&D waste         | Amount of annual generated C&D waste * proportion of recycled C&D waste                                                                                                                                 |
| Increment of directly dumped C&D waste  | Amount of annual generated C&D waste * proportion of directly dumped C&D waste                                                                                                                                 |
| Cost of directly dumping                | (Landfill fee + environmental tax + transportation fee) * Effectiveness of recycling regulations execution                                                  |
### Table 7 Table function

| Variable | Function |
|----------|----------|
| GDP growth rate | WITH LOOKUP (Time, (0.0–3000, 1)), (2015.01, 2020.06), (2030.05) |
| Constraints for directly dumped C&D waste | WITH LOOKUP (Amount of directly dumped C&D waste, (0.0–2e+08, 1.1), (4e+07, 1.01), (1.1e+08, 1.03), (3.4e+08, 1.04), (7e+08, 1.045), (9.5e+08, 1.06), (1.3e+09, 1.053), (1.9e+09, 1.056)) |
| Emission reduction effect | WITH LOOKUP (Environmental tax, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Proportion of directly dumped C&D waste | WITH LOOKUP (Proportion of recycled C&D waste, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Effectiveness of supervision | WITH LOOKUP (Effectiveness of recycling regulations execution, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Integrity of regulations | WITH LOOKUP (Effectiveness of supervision, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Probability of being caught | WITH LOOKUP (Probability of being caught, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Proportion of illegal dumping C&D waste | WITH LOOKUP (Proportion of illegal dumping waste, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Constraints on the amount of C&D waste | WITH LOOKUP (Constraints on the amount of C&D waste, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Market mature degree of recycled materials market | WITH LOOKUP (Market mature degree of recycled materials market, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Recycled fee | WITH LOOKUP (Recycled fee, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Proportion of recycled C&D waste | WITH LOOKUP (Proportion of recycled C&D waste, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |
| Driving factors for C&D recycling | WITH LOOKUP (Driving factors for C&D recycling, (0.0–250, 1), (20.0, 0.2), (40.0, 0.5), (60.0, 0.7), (80.0, 1.2), (120.0, 0.65), (200.0, 0.5), (240.0, 0.3)) |

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