

Subsidy and Environmental Tax for Construction and Demolition Waste Recycling

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Abstract

In recent two decades, construction and demolition (C&D) waste is becoming a major source for municipal waste which causes serious 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 is aiming at introducing subsidy and environmental tax policies to promote C&D waste recycling. Based on system dynamics, 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.

Introduction

According to statistics from the Chinese National Development and Reform Commission (NDRC, 2014), about 1 billion tons of C&D waste was generated nationwide in 2013 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 there were only 50 million tons of C&D waste been recycled. Therefore, it can be obtained the C&D waste recycling rate in China is too low and it is only 5%. But during the recycling process, about 30 million tons of recycled construction materials were produced. The other 20 million tons of C&D waste were 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.

It is widely accepted that C&D waste has severe adverse impacts on the environment and human society (Lu & 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 a hot issue in the last two decades. Firstly, scholars start from focusing on various waste reduction methods at different stage to reduce C&D waste amount (Osmani et al., 2008; Yuan & Shen, 2011). Among a variety of feasible measures, C&D waste recycling is found as an effective method for C&D waste reduction and sustainable management (Meng et al., 2019; He & Yuan, 2020).

Next, the key factors influencing C&D waste recycling and promoting C&D waste recycling become hot topics for researchers. Ding & Xiao (2014) pointed out low landfilling fee, high recycling cost and enterprises' lack of confidence in recycled products are important 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 attitude and behavior of construction contractors towards C&D waste recycling have a key impact on the generation and disposal of C&D waste.

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) pointed out 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.

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 the C&D waste recycling. Most policies are related to economic tools and they have achieved wonderful outcomes in promoting C&D waste recycling (Liu et al., 2021). Waste disposal charging fee is implemented in HK for nearly 15 years and it achieves great results. Tam (2008) found the amount of C&D waste dumped in landfills was reduced by about 65% between 2005 and 2006 in HK. 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 nearly 6 kilotonnes (Bartelings et al., 2005). Various studies and industrial practices have shown developed countries such as the USA, the UK and the Netherlands have made many achievements in C&D waste recycling field. However, contractors are not willing to adopt recycling measures in China due to low landfilling fee and high C&D waste recycling cost. So the major C&D waste disposal measure in China is still directly dumping (Chen et al., 2019).

In recent years, the Chinese government has recognized the need to develop 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 studies and policies are mainly in the form of landfilling fee (Liu et al., 2021), which makes it hard to motivate enterprises to do C&D waste recycling jobs.

Therefore, in order to promote the development of C&D waste recycling industry and motivate enterprises to recycle C&D waste, there is a need to issue an appropriate incentive policy that stimulates contractors to adopt C&D waste recycling behavior. To address the problem, this paper would like to carry out a model which is based on the system dynamics approach to determine the proper subsidy and environment tax.

Literature review

3R principles, which are *Reduction*, *Reuse* and *Recycle*, are widely accepted as the foundation of C&D waste management (Peng et al., 1997). Although reduction is seen as the most ideal method to reach the goal of sustainable development, it is hard to achieve in real scenes (Osmani et al., 2008). In order to

make C&D waste recycling be feasible from technical perspective, the concept of closed-cycle construction is proposed (Mulder et al., 2007), and scholars pointed out that vast majority of C&D wastes can be turned into useful recycled materials through proper recycling treatment. The physical, chemical, mechanical properties and composition characteristics of recycled materials are also 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 in Brazil and took recycling measures for C&D waste. They replaced natural aggregate with the produced recycled materials to produce bricks. After 21 days of curing process, it was found the mechanical properties of bricks generated from recycled materials were higher than the requirements of the specification. The properties such as water absorption and density of bricks were also excellent, indicating that it can produce high-quality and cheap bricks by using recycled materials from C&D waste.

Based on the technical feasibility of C&D waste recycling, scholars have carried out many studies from managerial perspective to promote C&D waste recycling industry development. Begum et al. (2009) investigated the impact of construction contractors' attitudes and behaviors on C&D waste management, and they believed that contractors' attitudes and behaviors towards C&D waste are closely related to the contractor's scale. Their management measures and disposal methods to C&D waste are affected under the consideration of 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, and he believed that the enterprise with the first goal of maximizing profit hopes to make profits from waste recycling. The imperfection of relevant laws and regulations and the high investment in C&D waste recycling restrict the enthusiasm of enterprises to take recycling measures. 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 are seen as one core element influencing C&D waste recycling development (Marques et al., 2012; Wu et al., 2017).

In order to solve the above problem, scholars have tried to set up appropriate economic incentive policies to promote C&D waste recycling development. Hao et al. (2008) found C&D waste disposal charging scheme which charged C&D waste at 27 HKD/ton reduced the amount of landfilled waste by about 60% after the one-year implementation of the charging policy. Yuan & Wang (2014) established a model for calculating C&D waste disposal fees based on system dynamics, and they thought waste disposal fee has the best effect on the C&D waste recycling when the waste disposal fee is 80 yuan/ton. Combined 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 & Yan, 2018). In sum, researchers have made many achievements in C&D waste disposal fees, subsidies and penalties. However, environmental tax is rarely discussed in the previous studies. Therefore, this study tries to combine subsidy and environmental tax to promote C&D waste recycling and rich 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 1960s (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. Afterwards, 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 & 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. (2020) 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. 2(a).

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 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.

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. 2(b). 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 increases 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. 2(c).

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

Table 1

GDP and construction acreage in Shanghai

Time (Year)	GDP (100 Million)	Construction acreage (1000 square meter)
2018	32679.87	47577.35
2017	30133.86	41197.49
2016	26688	36019.72
2015	24964.99	36631.16
2014	23560.94	34994.68
2013	21602.12	29148.65
2012	20101.33	27961.55
2011	19195.69	24004.25
2010	16872.42	22996.81

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

$$\text{Construction acreage} = 1.5315 * \text{GDP} - 3330.4 \quad (1)$$

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).

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

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 & 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. Value of constant variables are shown in Appendix Table. A1, and other variables and table functions are also listed in Appendix Table. A2 and Table. A3 at 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 & 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.

It can be seen in Fig.3, 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 & 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 5 levels of subsidies being simulated, which are subsidy is 10, 20, 30, 40, 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 5 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 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 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.

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	
20	2.33e+009	-0.05
40	2.10e+009	-0.14
60	1.55e+009	-0.37
80	1.06e+009	-0.57
100	1.03e+009	-0.58

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 4 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.

Table 4

Four sets of policies

No	Set of Policies	Comparison description
1.	No incentive policy, Combination policy (Subsidy = 30 and Tax = 80), Subsidy = 30, Tax = 80.	The comparison of the best single policy and corresponding combination policy.
2.	No incentive policy, Combination policy (Subsidy = 10 and Tax = 20), Subsidy = 10, Tax = 20.	The comparison of the single policy and corresponding combination policy.
3.	No incentive policy, Combination policy (Subsidy = 10 and Tax = 20), Subsidy = 30, Tax = 80.	The comparison of the best single policy and one possible best combination policy.
4.	No incentive policy, Combination policy (Subsidy = 10 and Tax = 20), Combination policy (Subsidy = 10 and Tax = 10), Combination policy (Subsidy = 5 and Tax = 20), Combination policy (Subsidy = 20 and Tax = 20), Combination policy (Subsidy = 10 and Tax = 25).	The comparison of combination policies.

(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 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 finally 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. 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, 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 length limitation, it is not possible to show all combination policies. In this paper, we choose 5 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 is consisting 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.

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.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and materials: All used data have been included in the manuscript.

Competing Interest: The authors declare that there are no conflicts of interest regarding the publication of the paper.

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Figures

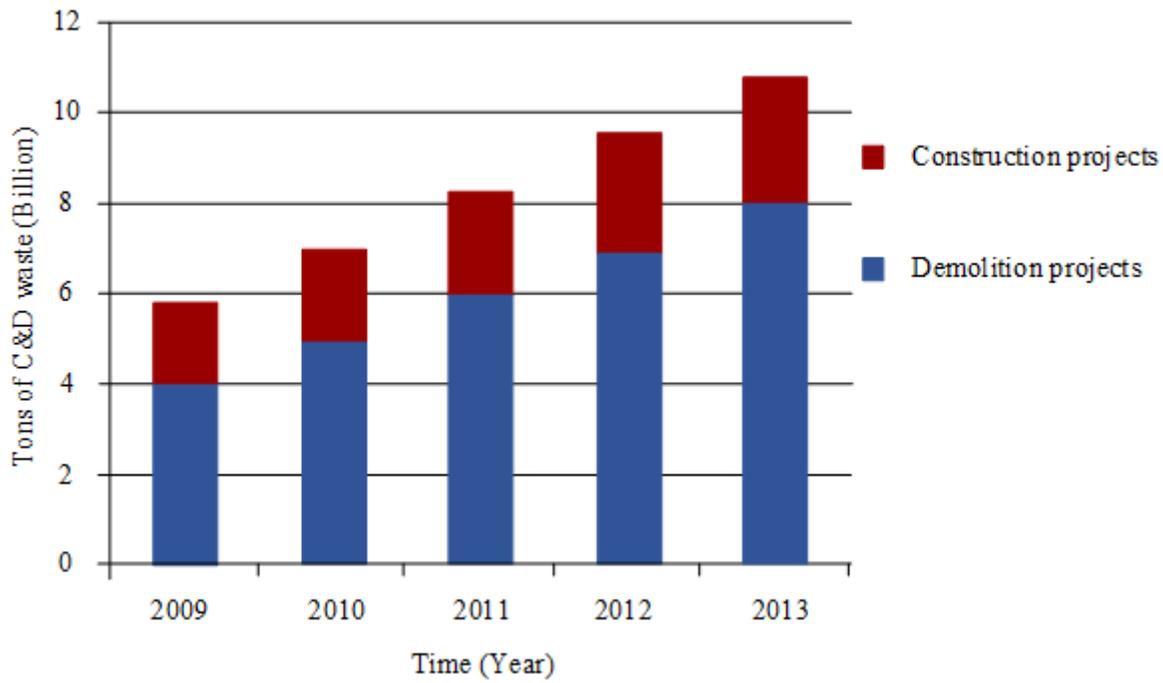


Figure 1

The amount of C&D waste

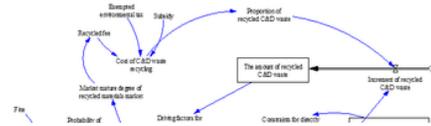
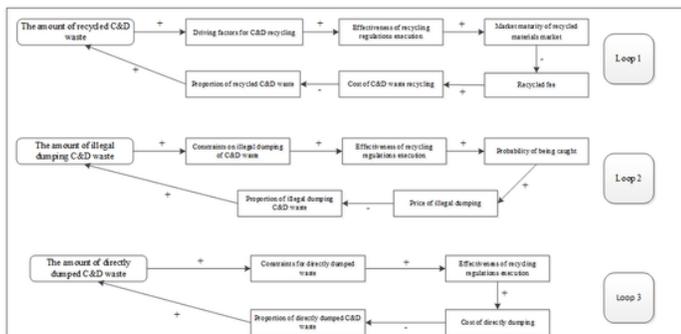


Figure 2

(a) Feedback loops; (b) Causal loop diagram; (c) Stock-flow diagram

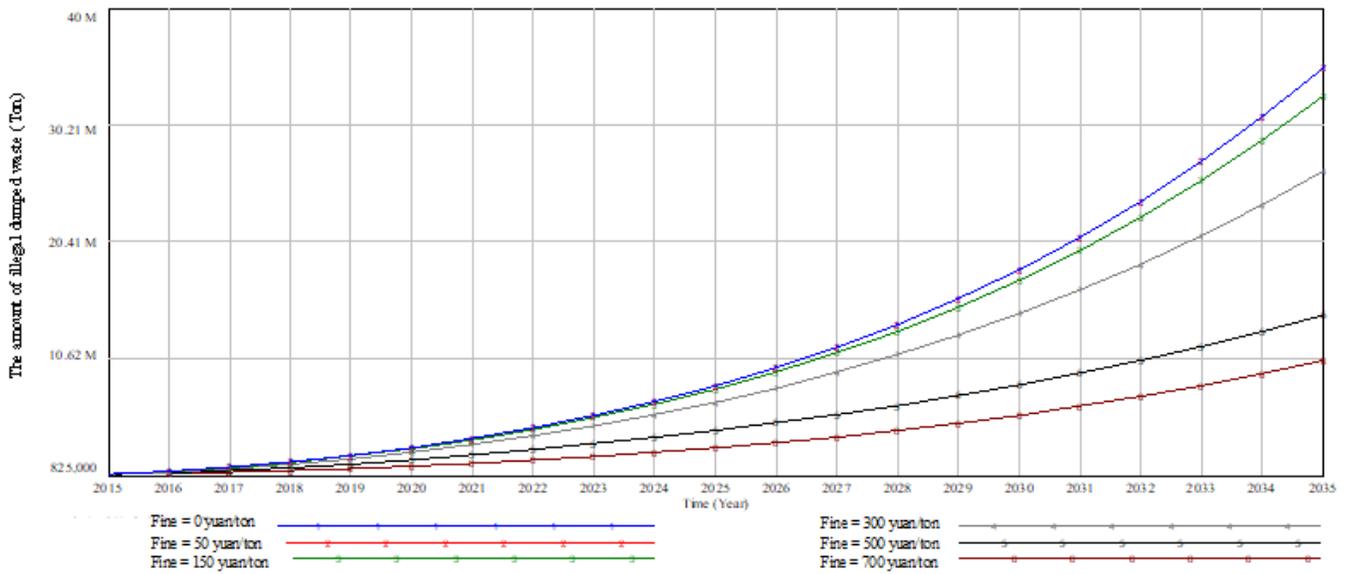


Figure 3

Model verification

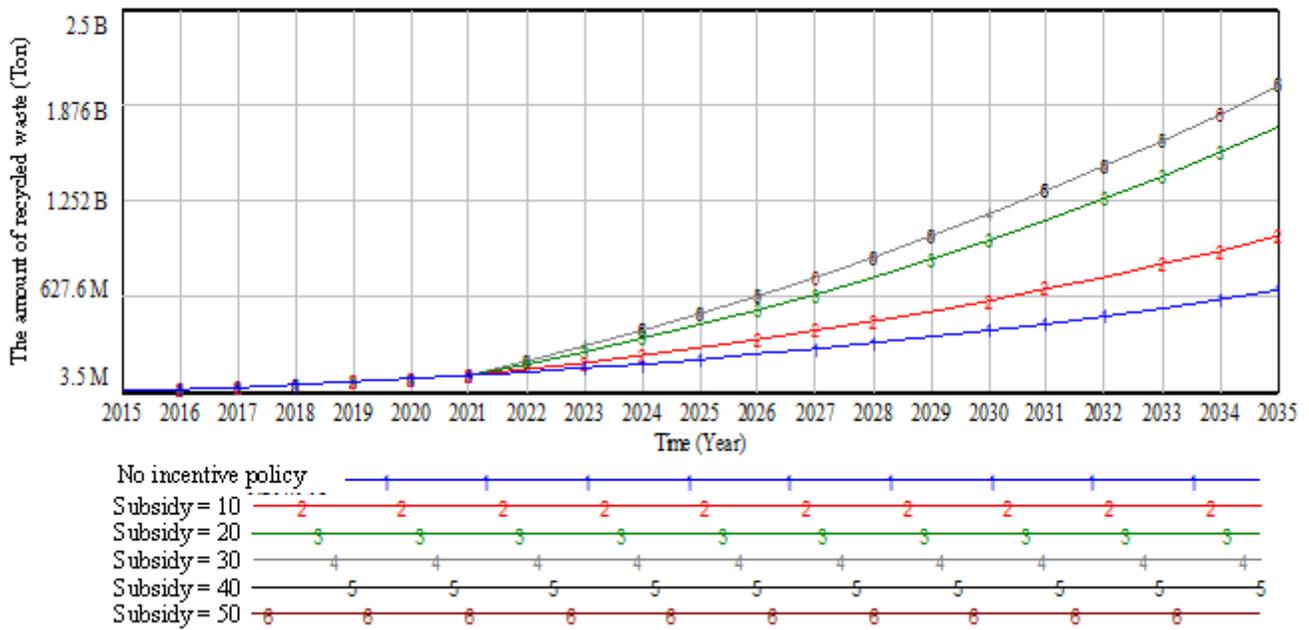


Figure 4

The amount of recycled waste with single subsidy policy

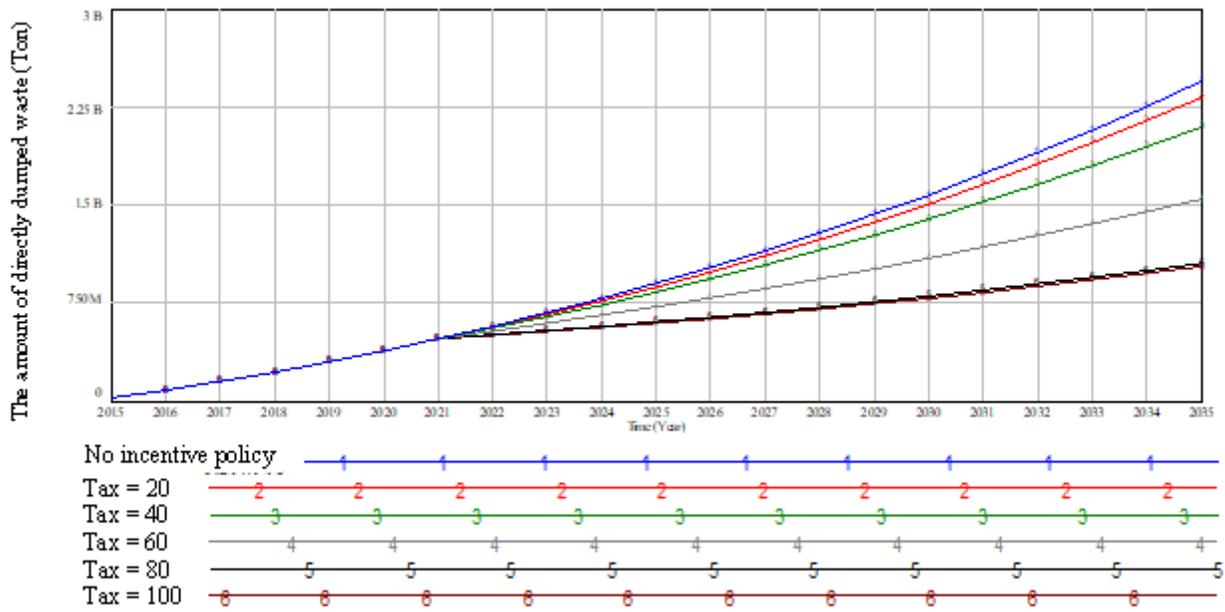


Figure 5

The amount of directly dumped waste with single tax policy

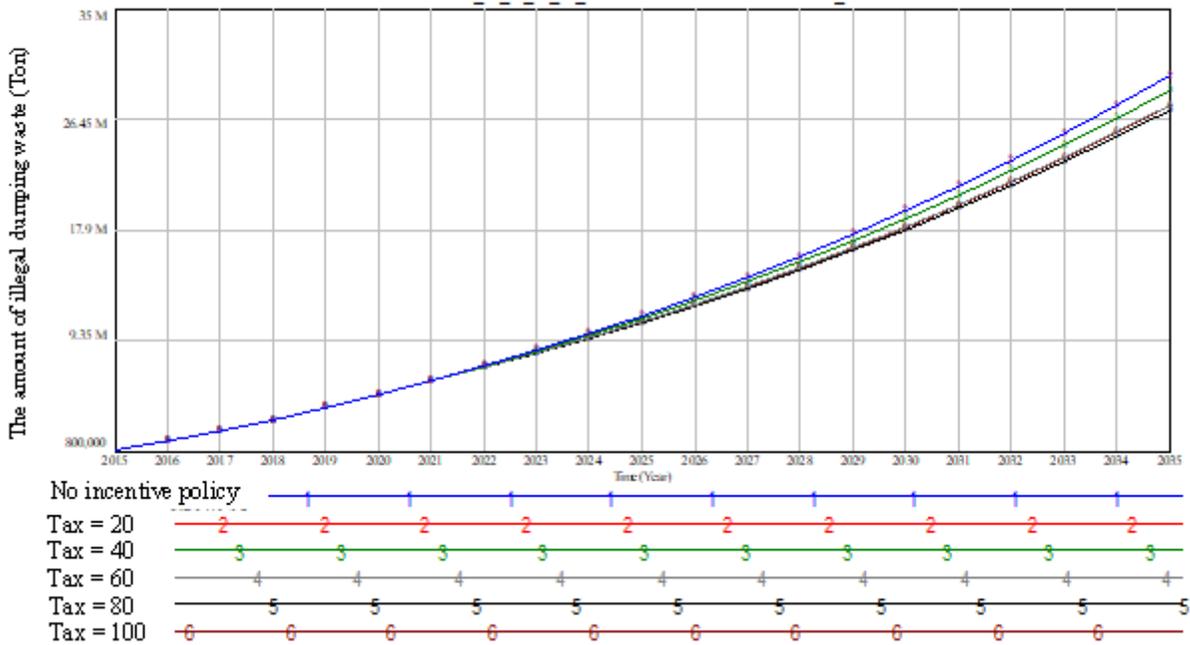


Figure 6

The amount of illegal dumping waste with single tax policy

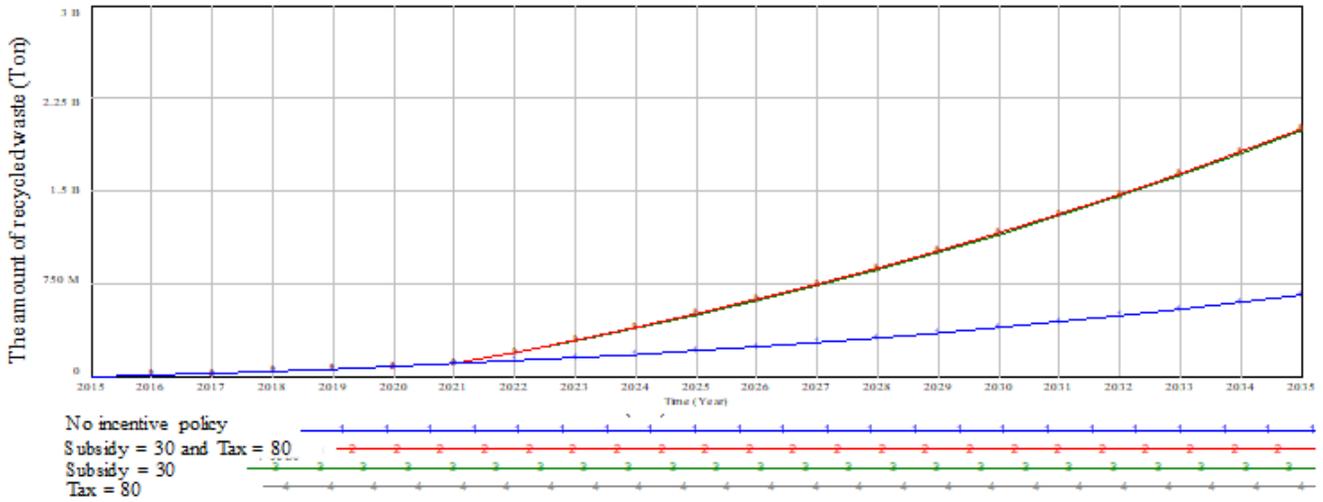


Figure 7

The best single policy and corresponding combination policy

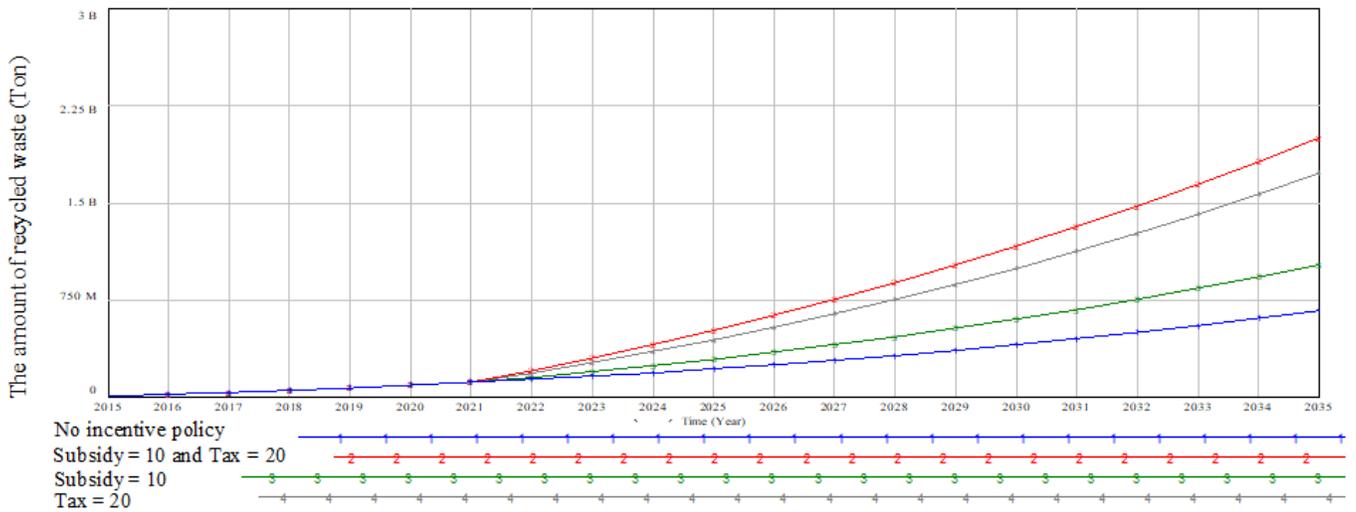


Figure 8

The single policy and corresponding combination policy

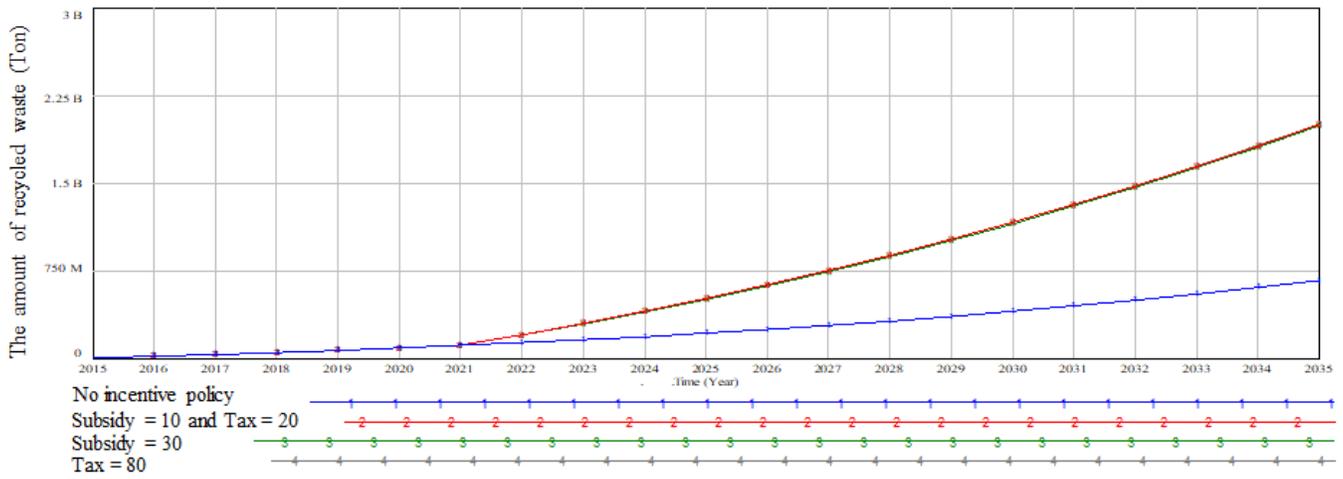


Figure 9

The best single policy and one potential optimal combination policy

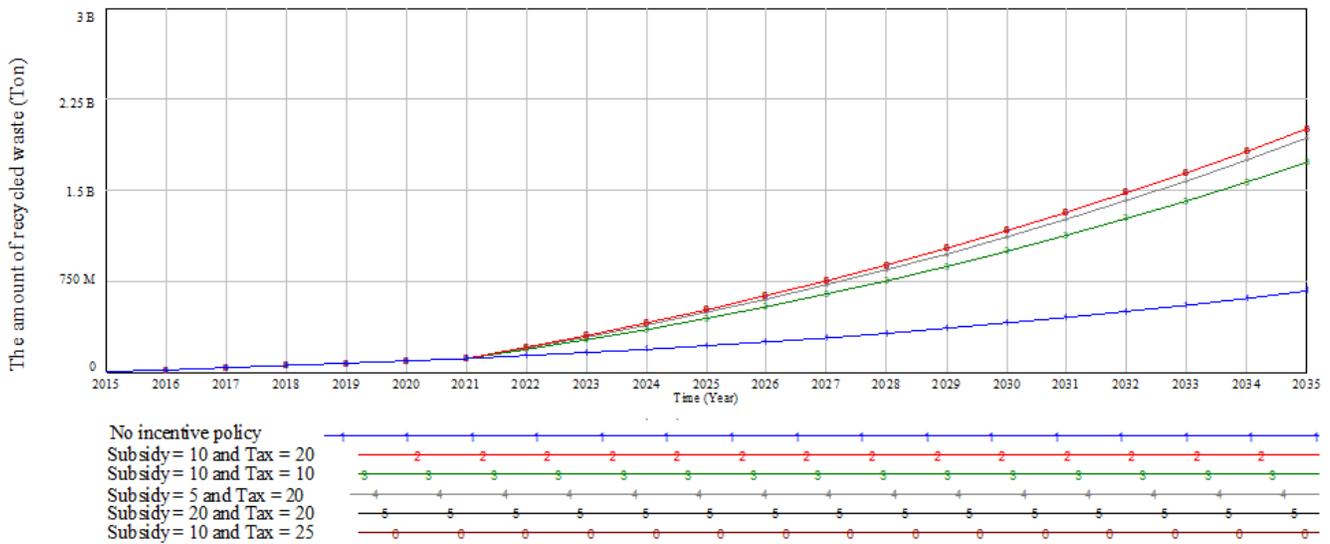


Figure 10

The comparison of combination policies

Supplementary Files

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