Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-022-01263-9 OPEN

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Construction enterprises' adoption of green development behaviors: an agent-based modeling approach

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Many previous studies have used performance evaluation to explore the impact of environmental regulation on the green development of enterprises. However, there are few studies on the process by which enterprises adopt green development behavior. Here, we aim to simulate the whole process by which Chinese construction enterprises adopt green development. We also consider impact of environmental regulation and industry clusters in this process. Using agent-based modeling, we construct a computational experimental simulation model for the adoption of green development behavior by construction enterprises. The model considers the organizational behavior characteristics of construction enterprises and the evolutionary characteristics of the renewable construction materials market. Our results show that in terms of renewable building materials, construction enterprises that actively adopt green development behavior are more sustainable than those that do not. Moreover, with the implementation of sustainable environmental regulations, more enterprises are passively adopting green development behaviors. However, unsustainable environmental regulations do not have a positive effect. The formation of industrial clusters is also conducive to promoting companies' adoption of green development behaviors. Therefore, construction enterprises should take the initiative to adopt green development behavior and migrate to industrial agglomerations. This practice is not only beneficial to the sustainable operation of the enterprise and the expansion of the enterprise scale, it will also have an optimization effect on the external environment. Here, we take construction enterprises as the breakthrough point and expand research on enterprise green development. We also provide a theoretical basis and insights for enterprises with environmental responsibility to engage in green development behavior.

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Introduction

Phenomena such as natural resources being consumed by humans and frequent environmental pollution incidents can affect the production and operation of businesses. Since green development emphasizes the systematization of the natural environment and social economy (Li et al., 2020), green development can effectively solve the contradiction between enterprise development and environmental protection.

In 2020, U.S. residential output was 4.3% of gross domestic product (GDP) (US Bureau of Economic Analysis, 2020). Meanwhile, Chinese construction output accounted for 7.2% of GDP (National Bureau of Statistics, 2021). The contribution of the construction industry, which is a pillar industry of the national economy, to global GDP cannot be underestimated. Especially in the extremely dynamic process of globalization, developing countries such as China and India are increasing their economic power at an unprecedented rate (Balsa-Barreiro et al., 2019). However, as economic growth and urbanization advance in developing countries, the enormous potential of internal markets also leads to a "decoupling" of economic development and ecological civilization (Wang et al., 2019). China has produced 46.4% of the world's output of coal and has used 50.1% of it. India has produced 7.7% of coal and has consumed 10.2% of it (United States Energy Information Agency, 2022). In recent years, the excessive use of fossil energy has produced large amounts of carbon dioxide and greenhouse gases, causing serious air pollution problems. In developed countries, there is also a conflict between human progress and the ecological environment. The United Kingdom has experienced serious contaminant leaks during the completion of a $56 billion construction project, and these leaks are likely to negatively impact underground aquifers and water supplies (Engineering News Record, 2021). Construction sites in the United States accounted for less than 1% of the national land area (Belayutham et al., 2016). However, the amount of sediment released into water bodies was 10% of the total sediment in the such bodies. Therefore, this sediment poses a serious risk of water pollution. Hence, the development of the construction industry cannot avoid pollution, either directly or indirectly. In other words, construction enterprises urgently need to achieve a balance between economic development and environmental protection through green development. What factors will promote or inhibit the adoption of green development by construction enterprises? How do factors influence construction enterprises' adoption of green development? What external or internal conditions are involved in this process? To answer these questions, the purpose of our study is to reveal the evolutionary mechanism of the green development behaviors adopted by construction enterprises through agent-based modeling (ABM).

At present, computers can describe the evolution of behavior through programming and simulation (Xiang et al., 2021). As an extension of distributed artificial intelligence, ABM is a collection of two or more agents with homogeneous or heterogeneous architecture (Lv et al., 2021). ABM can not only be applied to simulate social and natural phenomena but also promote current research in physical science and engineering systems (Macal and North, 2014).

Therefore, we take construction enterprises as the object of study and uses ABM as the research method. Different from other empirical studies, we build a new computational experimental model of the green development behaviors of construction enterprises based on the game of life model. Moreover, the model considers the characteristics of the organizational behavior of construction enterprises and the evolving characteristics of the market for renewable construction materials. Moreover, NetLogo 6.2.0 software is used to carry out a numerical simulation based on computational experiments, and the applicability of the model is verified. Unlike other studies on green development behavior, we reveal the evolutionary mechanism of the green development behaviors adopted by construction enterprises under the influence of environmental regulations and industrial clusters. Clearly, we provide a new perspective for studying the green development behaviors of enterprises.

Literature review

Green development behaviors of construction enterprises. As the name of this paper implies, the agent of green development behavior is a construction enterprise. The green development behaviors of construction enterprises involve green development, green behavior and enterprise behavior. Li et al. (2018) were the first to draw a knowledge map of green development in China and abroad. Their study pointed out that the international green development research hot spots are the green economy, frameworks, cities and supply chain management. The research frontier of green development in China was regional and urban development, the ecological environment and green development concepts. With the deepening of research, green behavior has become a nonnegligible part of green development research (Li et al., 2019a). In general, green behavior refers to clean production, energy conservation, green consumption, and the recycling and disposal of household waste, which benefits the natural environment (Mantovani et al., 2017; Zhang et al., 2018). In addition, enterprise behavior is a kind of organizational behavior that refers to the regular activities carried out by enterprises from the perspective of organizational groups to achieve certain business goals. Theory on the green development behavior and performance of industrial enterprises regards industrial enterprises as organizational carriers. Such theory refers to industrial enterprises' green practices in response to environmental protection and enterprise development as the green development behaviors of industrial enterprises (Li et al., 2019b). By developing and verifying the theoretical scale, research has found that the green development behaviors of industrial enterprises consist of two dimensions: clean production behavior and green supply chain management practices (Li et al., 2020). Clearly, the green development behaviors of construction enterprises are organizational behaviors formed by construction enterprises to realize economic development and environmental protection goals.

The literature provides a basis for explaining the green development behaviors of enterprises. To verify the importance and necessity of green development behaviors in the process of achieving sustainable development goals, scholars have made a series of efforts. Researchers have studied the green development behaviors of enterprises by establishing various types of dynamical models, such as replicated factor dynamic systems, system dynamics models and differential equations (Ji et al., 2015; Li et al., 2021). In the modeling process, most existing studies abstractly quantify the interactions within the real-world as a direct functional representation. Unfortunately, studies have not sufficiently considered the nonlinear relationships of dynamic interaction processes among agents and have failed to depict agents with multiple heterogeneous characteristics. In addition, the research methods used may not be able to adequately show the role of many interacting agents in a complex system at the micro and macro levels. Therefore, there is an urgent need for a research method that is closer to the reality of social evolution. Such a methodology should be able to explore the dynamic impact of enterprise green development behaviors on the outside world and the enterprise at both the macro and micro levels.

Environmental regulation. Early studies on environmental regulation focused on institutional improvement (Lathrop and

Centner, 1998) and foreign direct investment (Naughton, 2014). With the gradual maturity of environmental regulation, studies in this field mainly include works that (1) explore the practical effects of environmental regulation and (2) classify and compare environmental regulations. In general, many studies have developed spatial Durbin models with provinces/states or cities as study areas to explore the effects of environmental regulations on environmental performance and regional eco-efficiency (Hao et al., 2018; Ren et al., 2018). Studies in this category have mainly verified the positive effects of environmental regulation, with only a few researchers questioning the effectiveness of such regulation (Hao et al., 2018). In addition, the heterogeneity of study areas provides an opportunity to verify the mechanism of environmental regulation. Furthermore, existing studies have not formed a uniform classification of types of environmental regulations. Considering different classification criteria, some studies have compared the advantages and disadvantages of different types of environmental regulations. The classifications include formal and informal environmental regulations (Xiong and Wang, 2020) and command-based, market-based, and voluntary environmental regulations (Ren et al., 2018). These classifications have provided an opportunity to reclassify environmental regulations because of the diversity of classifications.

Industrial clusters. The industrial cluster, also known as a competitive cluster or Porter cluster, was first proposed by Porter (1990). He believed that an industrial cluster refers to a group of related institutions that have a relationship of competition and cooperation in a specific geographical area in which they are adjacent to each other, and he also believed that there are commonalities and differences between organizations. Industrial clusters are also the product of a Darwinian process, where only market-competitive enterprises will survive and subsequent successful enterprises will be derived from the existing enterprises in a region (Gompers et al., 2005). Researchers have had different terms for industrial clusters. However, most of the literature emphasizes that the enterprises within a specific range can improve their market competitiveness through vertical integration from an organizational perspective. The early literature in the field focused on the evolutionary nature of local industrial clusters and the prerequisites for cluster formation (Brenner and Mühlig, 2013). However, the optimization and upgrading of industries leading to the original cluster concept are no longer able to meet the needs of existing industrial clusters. As a result, many studies have introduced new criteria, such as environmental support capacity, into regional innovation evaluation based on cluster innovation (Yan et al., 2021). Studies have also explored the impact of industrial clusters on regional innovation specialization and diversification (Mo et al., 2020).

In summary, existing studies regard industrial clusters as an inevitable trend of industrial development. Most studies have pointed out the positive effects of industrial clusters on the outside world, but a few studies have also suggested that industrial clusters have negative effects, especially in terms of environmental pollution (Rodriguez-Villamizar et al., 2020). Moreover, Kim et al. (2022) emphasized the importance of cluster dynamics for corporate strategy. In practice, it is necessary to use ABM to dynamically analyze the impact of industrial clusters on the green development behaviors of construction enterprises.

Game of life. The game of life, also known as Conway's chess of life, was proposed by the British mathematician John Horton Conway. It was originally a single-player computer game that was a self-running simulation game. Since the game of life has the ability to transform discrete state patterns into dynamic patterns and dynamic structures after following certain evolutionary rules, it can also be regarded as a kind of cellular automaton (Kippenberger et al., 2013). A spatial model consisting of a series of cells with the same properties is called a cellular automaton (CA) (Kemeny, 1967). A CA is a discrete model and a dynamic system that is discrete in both time and space. It consists of several cells of the same size, and cells change over time based on specific rules (Gong, 2017). In essence, a CA is a general term for a type of model or a methodological framework that can transform a disordered, irregular and unbalanced state into an orderly, regular and balanced state through the constraints imposed by specific rules.

Therefore, the literature on the game of life has not only studied the dynamic processes of cellular derivation in a medical context (Kippenberger et al., 2013) but also explored the evolutionary patterns of resource distribution within complex social systems (Del et al., 2020). However, there is a paucity of research that exploits the characteristics of the market environment from disorderly change to orderly change to explore the dynamic evolutionary process.

Methodology

Research method. The research method employed in our study is ABM in the context of computational experiments. Since ABM can provide a sophisticated integrated environment for multiagent modeling and simulation, it is able to reproduce various real-world interaction phenomena based on the heterogeneous characteristics and nonlinear interaction rules of different agents (Macal, 2016). Therefore, ABM has been applied to study complex systems in various domains, such as corporate behavior (Rzeszutek et al., 2021), supply chains (Rouzafzoon and Helo, 2016), and infectious disease outbreaks (Hunter et al., 2020). First, as a bottom-up approach, the agent perspective of ABM is its most important and unique feature (Lv et al., 2021). The method can consider the individual characteristics of each agent, the various behaviors of an agent, and the multifrequency interaction processes with other agents in a dynamic environment. Since the agents that interact in the model of this study are construction enterprises with different characteristics, there are complex and multiple interaction processes between the same types of agents. Therefore, ABM aids this research in studying the evolution of the green development behaviors adopted by construction enterprises. Second, ABM is used to simulate the interaction between microscopic individuals in a finite space to show some natural or social phenomena in the evolutionary process and to reveal some scientific laws. It provides a scientific platform for exploring the interactions between the macroscopic environment and microscopic individual behavior (Xiang et al., 2021). We aim to explore the interaction between the macrolevel market environment and the microlevel construction enterprises adopting green development behavior. Thus, the applicability of the method to this study is supported. Finally, since ABM can capture the interaction of agents within a complex system at any moment, emergent phenomena are no exception. Moreover, the emergent situations that arise during system evolution may be counterintuitive and lead to new discoveries that are different from the usual situation (Bonabeau, 2002). Therefore, simulation analysis using ABM not only minimizes the impact of the research process on the limitations of human cognitive ability but also may uncover innovative information and values. Based on this feature, ABM is suitable for exploring how the green development behaviors of construction enterprises have unanticipated relationships with the internal and external environments during the evolutionary process. This study uses NetLogo 6.2.0 software to realize model construction. In summary, we explore the evolutionary mechanism of the green development behaviors adopted by construction enterprises through ABM, which may provide a new idea for future research in this field.

Model construction

Process design. The ABM model described by NetLogo 6.2.0 includes "world" and "agent". In the simulation model we established, "world" refers to a specific real geographic space. Since the "world" is composed of multiple square "patches" that form a network, we consider each "patch" to be fixed ground where renewable construction materials can be randomly generated. In this environment, if the ground appears black, this state indicates that the area has not met the condition of recycled construction materials. If the ground appears green, this state indicates that the area has reached the condition of recycled construction materials. "Agent" refers to an individual construction enterprise that uses renewable construction materials as raw materials in the "world". This model chooses to use circles to represent action agents. A red circle symbolizes a construction enterprise that does not adopt green development behavior, and a blue circle symbolizes a construction enterprise that adopts green development behavior. The rules of interaction between the agents and the property changes of the "patches" within the "world" are based on the game of life model. Moreover, this model takes into account the characteristics of the organizational behavior of construction enterprises and the evolving characteristics of the market for renewable construction materials. Figure 1 shows the main view interface of the simulation model after initialization.

To make the model constructed in this study more closely resemble the evolution of real society, each simulation experiment was controlled to be within 30 cycles. In relation to reality, if one cycle of each experiment corresponds to one year of enterprise development, the whole experiment is equivalent to simulating the dynamic process of construction enterprise development in 30 years. The process of simulating the green development behaviors adopted by construction enterprises is shown in Fig. 2.

In Fig. 2, first, the construction enterprises are divided into two categories based on whether they adopt green development behaviors: Category X enterprises adopt green development behaviors, whereas category Y enterprises do not. The enterprises in categories X and Y carry out production and operation activities after entering the market. In the process of operations management, due to the significant relationship between environmental behavior and profit (Guan et al., 2005), both types of construction enterprises may be driven by a profit orientation and choose to ignore or weaken as much as possible the decision to adopt green development behavior. However, doing so may result in an excessive production and emission of pollutants. In addition, despite the government's support for green development in the construction industry, construction enterprises may still have carbon emissions that exceed the standard and other phenomena that affect the achievement of the carbon neutrality goal (Central People's Government of the People's Republic of China, 2022). Therefore, the government will combat poor phenomena through a series of environmental regulation instruments (Li et al., 2022). Since environmental conditions, economic development, and regulatory intensity vary from region to region, the enterprises in a region may reach a threshold of environmental administrative penalties at a certain point in time (Deng et al., 2019). On the one hand, under the effect of environmental regulation, category X enterprises adopting green development behaviors relocate to other regions or make green transformation adjustments. After migration,

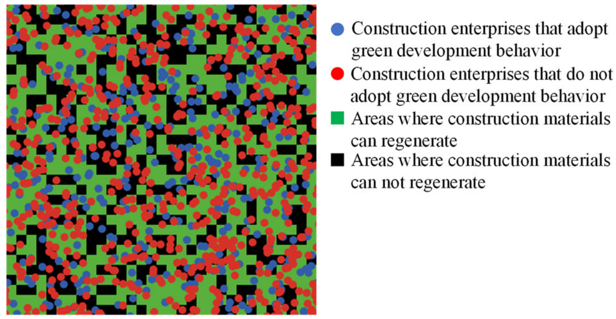

Fig. 1 The main view interface of the simulation model after initialization. It shows the random distribution of construction enterprises adopting green development behaviors and not adopting green development behaviors in the "world" at the initial state of the simulation model.

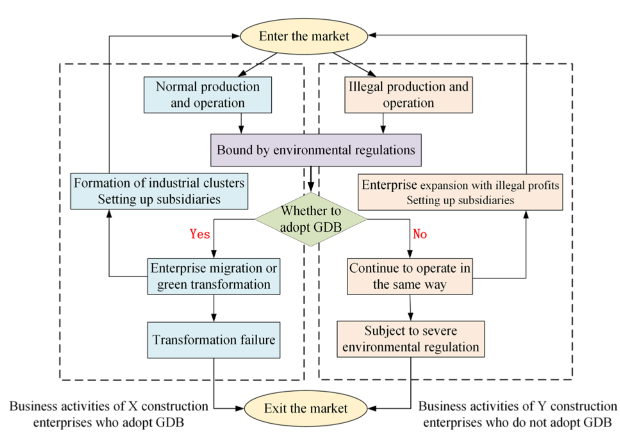

Fig. 2 Simulation flow design diagram of agent-based modeling. It shows the operation process of construction enterprises adopting GDB and those not adopting GDB in the simulation model through dotted boxes. The solid arrows represent the general operation process of enterprises. Note: GDB means green development behaviors.

category X enterprises may form industrial clusters to increase their competitive potential and re-enter the market by opening subsidiaries (Yoon and Nadvi, 2018). However, category X enterprises may also fail in the transition process, which will cause these companies to fail to operate properly and finally exit the market. On the other hand, category Y enterprises that do not adopt green development behaviors will continue their daily activities and make profits based on their original production and operation methods. Therefore, category Y enterprises may use the additional unlawful profits gained from poor environmental practices to complete business expansion and re-enter the market after opening subsidiaries. However, due to environmental violations, these enterprises may be subject to severe environmental regulatory penalties, which will prevent them from operating normally and cause them to withdraw from the market.

Parameter selection. In this model, the selection of variables is represented by sliders within the software. Researchers can adjust the number of interacting "agents" or "patches" and other properties from the "God" perspective in the operator interface. Thus, the model is configurable. The specific settings and meaning of each slider in the main view panel are described below.

(1) Percentage of construction enterprises adopting green development behaviors A%

When making decisions on whether to adopt green development behaviors, construction enterprises not only consider the additional costs generated in the process of transformation but also face high silent costs (Shao et al., 2018). Therefore, each enterprise agent has different attitudes toward adopting green development behavior. After determining the total number of construction enterprises in the model, it is necessary to distinguish the construction enterprises that adopt green development behaviors from those that do not (Yang and Jia, 2019). Therefore, this model assumes that A% of construction enterprises in this model adopt green development behavior.

(2) The rewards of choosing renewable construction materials for enterprise B
As global environmental problems worsen, many environmental organizations are calling for sustainable development. An increasing number of enterprises have chosen to use renewable and biodegradable green materials to replace nonrenewable resources (Kargupta et al., 2021). This practice can not only reduce energy consumption and carbon dioxide emissions but also reduce material costs (Wieland et al., 2007). It is clear that the choice of renewable construction materials can pay off for construction enterprises. Therefore, this model assumes that a construction enterprise can generate more return B by choosing one unit of renewable construction materials compared to choosing ordinary materials.

(3) The variance tolerance of differences in construction enterprises C%
In our study, a cluster that is formed by construction enterprises using similar renewable construction materials in a region is considered an industrial cluster. The industrial ecology framework shows that a cluster of producers can reduce environmentally uneconomical production behaviors, while enterprises can improve their competitive potential through cluster actions (Yoon and Nadvi, 2018). Therefore, some construction enterprises will actively choose to relocate to a cluster area to enhance their competitiveness. However, some construction enterprises that consider profit growth to be their main goal will not be willing to pay additional migration costs to complete this relocation behavior. Therefore, this model assumes that if at least C% of the surrounding agents are in line with an enterprise's attitudes toward adopting green development behaviors, the enterprise has finished agglomeration. Conversely, the agent is still outside the industrial cluster and will migrate.

Analysis and discussion

This section aims to analyze and discuss the evolutionary process of the simulation model. In this study, the following initial values will be used to set each parameter, and an initial environment will be randomly generated. The initial parameters of the simulation model were determined mainly based on the literature and the full-text database of important Chinese newspapers. First, there are no direct data on the adoption of green development behaviors by construction enterprises. Therefore, this study extrapolates the proportion of construction enterprises adopting green development behaviors as $A = 25\%$. This proportion is based on the number of pollution-related events in construction enterprises published in the China Building Materials News, China Construction News, China Economic Times, and China Mining News from January 2017 to December 2021 (Tsinghua Holdings Limited, 2022). Then, based on Liu and Ye (2012), we set parameter B to 1 (low), 2 (middle) and 3 (high) to more clearly explore the evolution of the green development behaviors of construction enterprises in different contexts. In addition, Zhu et al. (2019) verified that a significant "segregation" phenomenon emerges when the variance tolerance is 60%. This result is internally consistent with the industrial clustering phenomenon in this study; thus, $C\% = 60\%$ is set. To ensure the reliability of the output results, the number of iterations in this study is set to 100.

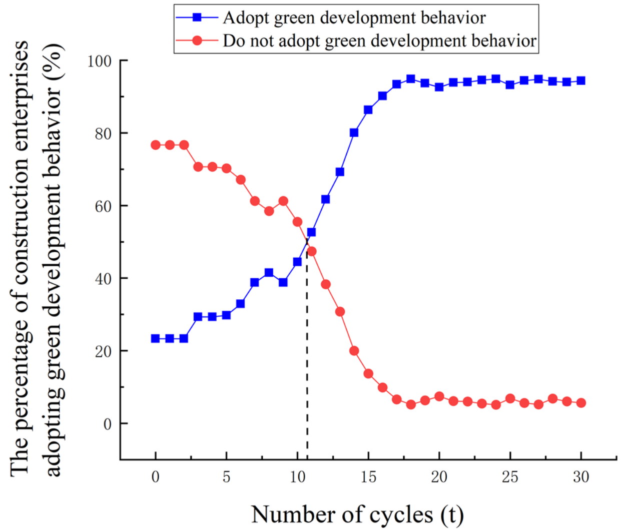

Fig. 3 The dynamic process of adopting green development behaviors in construction enterprises in the control group. The moment marked with dotted line in the figure represents that in the initial situation of $A = 25\%$, the proportion of construction enterprises adopting green development behavior in the model is consistent with that of those not adopting green development behavior.

Analysis of the research results

Construction enterprises adopting green development behaviors. The impact of the percentage of construction enterprises adopting green development behaviors on external factors can be effectively verified only over a longer period. Thus, information from continuous tracking surveys is needed to support the data, but panel data on this aspect are not easily available. Therefore, this study simulates the evolutionary trend of the green development behaviors adopted by construction enterprises through the ABM model. In this section, a set of comparative experiments is designed. The proportion of construction enterprises adopting green development behaviors in the control group is 25%, and that in the experimental group is 35%. The specific evolution of the two groups is shown in Figs. 3 and 4.

As shown in Figs. 3 and 4, the proportion of construction enterprises adopting green development behaviors in the industry shows an S-shaped growth trend in both contexts. The results of the control group show that when the proportion of construction enterprises adopting green development behaviors is 25%, compared with the experimental group, other construction enterprises in the industry adopt green development behaviors at a slower speed. That is, the "intrusion process" of green development behavior becomes more difficult. It is not until the 11th evolutionary cycle that the number of construction enterprises adopting green development behaviors exceeds that of those not adopting green development behaviors. Then, adopting green development behaviors gradually becomes the mainstream development trend of the industry.

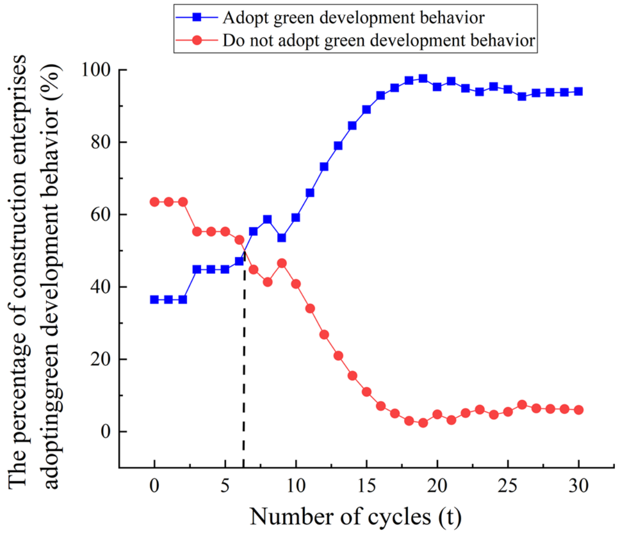

Fig. 4 The dynamic process of adopting green development behaviors in construction enterprises in the experimental group. The moment marked with dotted line in the figure represents that in the initial situation of $A = 35\%$, the proportion of construction enterprises adopting green development behaviors in the model is consistent with that of those not adopting green development behaviors.

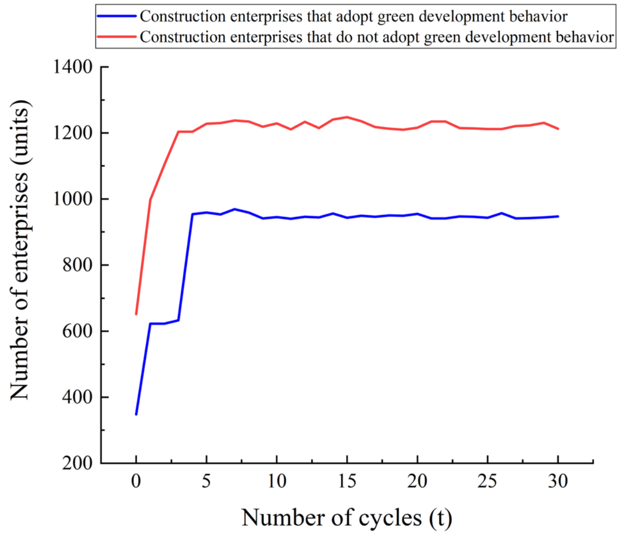

Fig. 6 The process of the influence of unsustainable environmental regulations on the scale of the green development behaviors adopted by construction enterprises. The illustration shows the growth over time of the number of construction enterprises that adopt green development behaviors and those who do not adopt green development behaviors in the "world" under the influence of unsustainable environmental regulations.

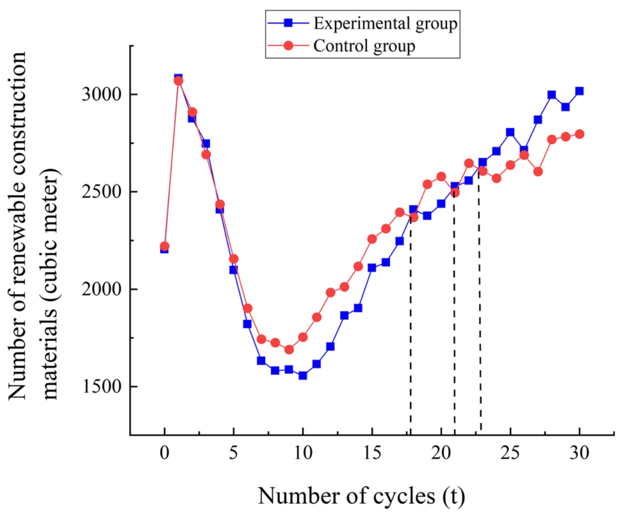

Fig. 5 The process of the influence of changing the percentage of construction enterprises adopting green development behaviors on the renewable construction materials market. The moments marked by dashed lines in the graph represent the same amount of renewable construction materials generated under different scenarios.

In the experimental group, the proportion of construction enterprises adopting green development behaviors in the industry fluctuates and increases at the beginning of the evolution, followed by a period of rapid increase until the vast majority of construction enterprises adopt green development behaviors. Then, it gradually plateaus. Around the 6th cycle, the number of construction enterprises adopting green development behaviors exceeds the number of construction enterprises not adopting green development behaviors. In the 16th evolutionary cycle, the proportion adopting green development behaviors in a region reaches 90%. The final moments show that green development behaviors are embraced by the majority of enterprises in the industry.

This group of comparative experiments shows that in the evolution of the operation and management of construction enterprises, the increase in the proportion of construction enterprises adopting green development behaviors plays an important role in promoting the sustainable development of enterprises. The higher the proportion of construction enterprises adopting green development behaviors is, the faster the speed of other enterprises in the industry adopting green development behaviors and the more conducive to the subsequent general adoption of green development behaviors in the construction industry. In other words, the process of construction enterprises embracing green development behaviors takes less time than expected.

In addition, this study aims to investigate the role of the adoption of green development behaviors by construction enterprises in the external environment. Therefore, Fig. 5 reflects the dynamic process of the influence of the proportion of construction enterprises' adoption of green development behaviors on the renewable construction materials market.

In Fig. 5, the trend changes in the control and experimental groups are almost identical during cycles 1–5. This result indicates that the proportional advantage of construction enterprises adopting green development behaviors in a short period does not have a large impact on the renewable construction materials market. Then, the amount of renewable construction materials available in the control group is higher than that in the experimental group during the 6th–16th period. There are several intersections in the graph, which indicates that the number of renewable construction materials available for the two sets of scenarios reaches the same amount at this moment. During the final 23–30 cycles, the experimental group shows a faster rate of fluctuating rise, while the control group shows a slow increase. Overall, the higher the proportion of construction enterprises adopting green development behaviors is, the more beneficial it is to the long-term improvement of the market environment. The change in the adoption proportion in a short period does not cause a significant impact on the renewable construction materials market.

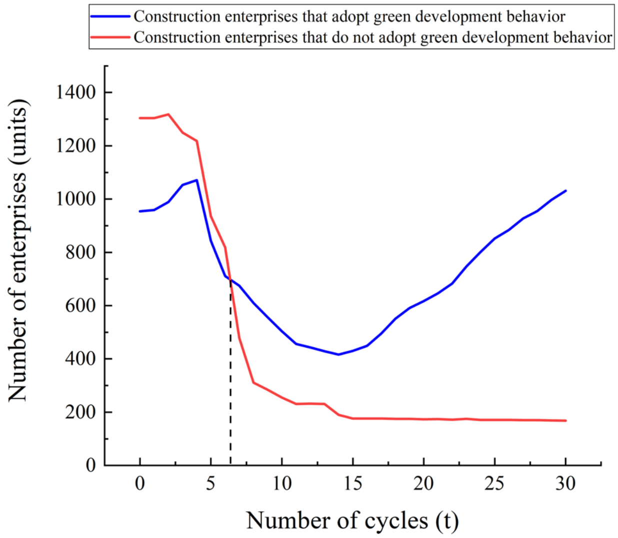

Fig. 7 The process of the influence of sustainable environmental regulations on the scale of the green development behaviors adopted by construction enterprises. The moment marked by dotted lines in the picture represents the same number of construction enterprises that adopt green development behaviors and those who do not adopt green development behaviors under the effect of sustainable environmental regulations.

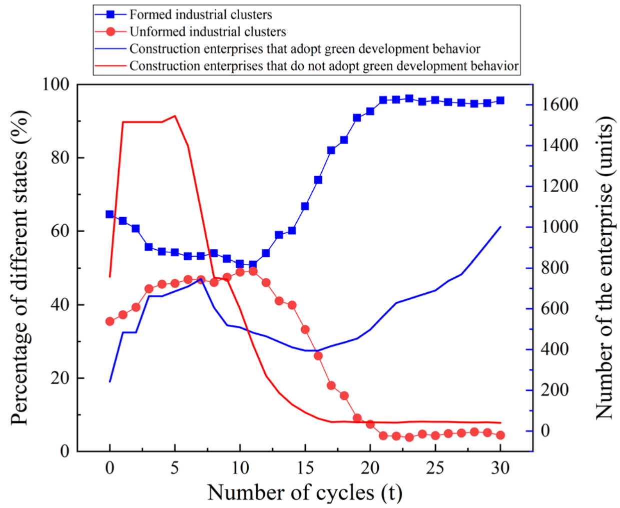

Fig. 8 The process of the influence of industrial clusters on the scale of the green development behaviors adopted by construction enterprises. It shows the impact of industrial clusters on the green development behaviors of construction enterprises and the external environment from two aspects: the proportion of construction enterprises that adopt different behaviors and the generation of renewable construction materials.

Unsustainable and sustainable environmental regulations. Figure 6 and 7 reflect the impact of unsustainable and sustainable environmental regulations on the adoption of green development behaviors by construction enterprises in a region, respectively. In this study, the environmental regulation behaviors within the 1st–5th cycles of evolution are considered unsustainable environmental regulations, whereas the environmental regulation behaviors within the 1st–30th cycles are considered sustainable environmental regulations.

First, Fig. 6 shows construction enterprises that adopt green development behaviors and those that do not are less affected by unsustainable environmental regulations in the 1st cycle. The number of construction enterprises in both categories grows steadily. However, in the subsequent period, the total number of construction enterprises adopting green development behaviors remains constant for 1 cycle, followed by stable growth for 1 cycle. Finally, there is a fluctuating balance. The total number of construction enterprises that do not adopt green development behaviors does not show a clear trend from the 3rd cycle onward, and it subsequently shows a fluctuating balance. The analysis shows that unsustainable environmental regulations inhibit the scale of adoption of green development behaviors by all construction enterprises in a region.

Second, Fig. 7 shows that the total number of construction enterprises that adopt green development behaviors presents an extremely slow growth trend when sustainable environmental regulations are implemented in a region. Then, Fig. 7 shows a rapid decreasing trend in 8 cycles. Finally, stable growth is maintained. The total number of construction enterprises that do not adopt green development behaviors continues to slowly decrease from the 1st to the 6th cycles. In the 6th cycle, the number of construction enterprises adopting and not adopting green development behaviors is the same. However, starting in the 7th cycle, the total number of construction enterprises that do not adopt green development behaviors decreases at a fast speed. Although there is a short period of flatness, the state still does not change the general trend of downsizing of this category of construction enterprises. In general, sustainable environmental regulations promote the scale of adoption of green development behaviors by construction enterprises in a region. Conversely, sustainable environmental regulations inhibit the growth in construction enterprises that do not adopt green development behaviors.

Industrial clusters. Construction enterprises with different attitudes toward green development behavior will make decisions about whether to migrate based on the business situation. Therefore, Fig. 8 reflects the changes in industrial clustering during the evolution of the green development behaviors adopted by construction enterprises.

As illustrated in Fig. 8, the proportion of construction enterprises forming industrial clusters in a region shows a U-shaped growth trend over time. At the initial moment, the proportion of construction enterprises forming clusters is 50%. In the early stage of evolution, the proportion begins to decline unevenly until the lowest point. Subsequently, the proportion of industrial clusters bottoms out and rebounds, gradually rising to 85% and presenting a fluctuating balance. Throughout the evolution, the number of construction enterprises that adopt green development behaviors increases slowly, then intermittently appears to be flat, and finally increases steadily. The number of construction enterprises that do not adopt green development behaviors also increases slowly at the beginning of the evolution. However, after a long period of flatness, the number of construction enterprises in this category decreases rapidly until the number finally reaches a fluctuating equilibrium. The results show that an increase in the industrial cluster proportion promotes the adoption of green development behaviors by construction enterprises and inhibits the development of construction enterprises that do not adopt such behaviors.

Discussion

The previous section analyzed the results of the output graphics of the simulation analysis. However, there are differences between the relevant conclusions drawn from existing studies and the findings of this study. Therefore, this section aims to conduct an in-depth discussion of three aspects related to the adoption of green development behaviors by construction enterprises.

Construction enterprises adopting green development behaviors. With the conflict between environmental protection and economic development becoming increasingly prominent, many countries are simultaneously facing the double test of the excessive consumption of resources and frequent environmental problems. A global consensus on the comprehensive implementation of the concept of green development has been reached. According to calculations by the relevant industry associations in China, the annual output of urban construction waste in China in recent years has exceeded 2 billion tons. This output has accounted for 40% of total municipal household waste and even reached 10 times the output of household waste (Ministry of Housing and urban-rural development of the People's Republic of China, 2020). Therefore, construction enterprises play an extremely important role in the whole process of green transformation. China is not the only country that urgently needs to accelerate green development in urban and rural construction. The United States, the United Kingdom and Japan have also realized the importance and necessity of green development (Li et al., 2017; Department for Business, 2020; The Ministry of Economy, 2020), and these countries have pledged to reach the promised net-zero emission target by 2050, 2040 and 2070, respectively (Thomas et al., 2021; Hannah et al., 2020). A report has shown that 70% of enterprises in the Asia-Pacific region are willing to pay a higher price for green buildings (Pan, 2021). Doing so holds great significance for promoting the green development of the construction industry. However, 70% of the construction companies surveyed said that green development behaviors lacked government incentives and high support from owners. Therefore, the process of realizing green development still faces many severe challenges.

Since the challenges come from many levels, an increasing number of researchers from different academic fields are also focusing on the green development of enterprises. In fact, the concept of green development can be reflected in green innovation (Feng and Chen, 2018), green finance (Zhang et al., 2022) and green procurement (Blome et al., 2014), which can encourage enterprises to achieve comprehensive green transformation. These green measures are aimed at accelerating the adjustment of the balance between social progress and ecological civilization. However, Li et al. (2017) argued that the costs of adopting such green development behaviors are not proportional to the benefits obtained. Therefore, although the practice can bring a better reputation and brand effect to enterprises, most enterprises are reluctant to undertake this behavior with a proactive attitude to deal with the challenges brought by environmental problems. This situation is inherently consistent with the initial parameter setting of the proportion of construction enterprises adopting green development behaviors in this study. Miroshnychenko et al. (2017) also verified from a global perspective that the active adoption of green behavior is the main driving factor in maintaining enterprises' sustainable operation and profitability. Green practices have a significant positive impact on enterprises' social performance, economic performance and green competitiveness (Agyabeng-Mensah and Tang, 2021). Therefore, this study believes that enterprises should be encouraged to take the initiative to adopt green development behaviors.

Environmental regulations and enterprise green development behaviors. Environmental pollution has been a pressing issue for a long time. However, as polluters, enterprises may see an impact on their economic performance after adopting green development behaviors. Therefore, most enterprises still carry out environmental actions in a passive rather than active manner (Li et al., 2017). Given this reality, environmental regulation came into being in this general environment of passivity. The Ministry of Ecology and Environment of the People's Republic of China (2022) has been exposing and punishing cases of excessive pollutant emissions, illegal sludge disposal and other regulatory failures on a quarterly basis. This sustainable regulation has led to a sustainable improvement in the quality of the national ecological environment, such as an average urban PM2.5 concentration of 43 micrograms per square meter, down 4.4% year on year. The U.S. realized more than a decade ago that particulate matter emissions from building construction activities were a significant contributor to PM emissions throughout the country (Muleski et al., 2005). Therefore, the United States Environmental Protection Agency (2022) has developed detailed laws and regulations for the construction industry in five segments: air, lead, waste, water, and conventional materials. The Japanese government has also emphasized environmental standards and pollution control in the organization and construction process, and it has promulgated the Regulations for the Implementation of the Water Pollution Control Law and the Regulations for the Implementation of the Air Pollution Control Law (Ministry of the Environment, 2022).

Moreover, the literature exploring the impact of environmental regulations on the green development of enterprises has become a hot research direction. Many scholars have confirmed the importance of environmental regulation in promoting green development. Song et al. (2020) argued that as environmental regulations become stronger and more consistent, their impact on enterprises' green development will gradually shift from negative to positive. The environmental regulations implemented in most areas of China are reaching a turning point; thus, the government should continue to monitor and regulate enterprises on a sustainable basis. The findings provide support for the conclusion of this study that sustainable environmental regulations have positive effects. However, Guo et al. (2020) proposed that environmental regulation does not always lead to a positive impact. The effectiveness of environmental regulations depends on the level, type and sustainability of environmental regulation (Hao et al., 2018). Therefore, this study takes a new perspective to classify the types of environmental regulations and verify the positive and negative effects of environmental regulations on the adoption of green development behaviors by construction enterprises in a region. In addition, Yang and Li (2019) showed that dynamic exploration of the relationship between environmental regulations and the green development level of industrial enterprises holds great significance for improving development capacities. This study is based on ABM to explore the whole process of the influence of environmental regulation on construction enterprises' adoption of green development behaviors. In particular, ABM is suitable for modeling complex systems that evolve over time, and the agents in ABM interact with each other, which meets the needs of dynamic research.

Industrial clusters and enterprise green development behaviors. As the economic level rises, the level of competition between different regions becomes increasingly intense. The market price of the products of enterprises in a cluster is more advantageous than that of enterprises outside the cluster (Delgado et al., 2014). The price gap enhances the core competitiveness and innovation ability of enterprises and further promotes the formation of industrial clusters. Evidence from the Yusuf et al. (2008) shows that the convergence of clusters can stimulate value spillovers and stimulate innovation in enterprises. Thus, the clusters in Silicon Valley, Hsinchu Park, Northern Italy, and the vicinity of Cambridge, U.K., are favored by business people, government officials and urban planners. In addition, the advantage of geographical proximity between enterprises is reflected not only in the lower cost of environmental behavior through cooperation in waste treatment and recycling but also in enterprises' lower marginal cost of knowledge and technology spillovers (Engelberg et al., 2018). This may allow more enterprises to reach a consensus on green development and proactively adopt green development behaviors. However, it has been reported that the spatial clustering of large industrial clusters in Asian countries has a negative environmental impact on local areas. Thus, people in Ghana, a country in Western Africa, have complained extensively about a construction material distribution site near residential homes because of the severe water pollution that the enterprise has caused (Yoshino, 2011).

Therefore, as an industrial development trend in current society, industrial clusters are increasingly valued by all stakeholders. As the actors in industrial clusters, enterprises are more concerned about the formation of clusters to have any impact on the role of enterprises. Thus, the natural synergy between the formation of industrial clusters and realistic export opportunities was verified by Pisa et al. (2017). Moreover, Brachert et al. (2011) argued that assembling high-quality input–output approaches and effectively integrating the structural space of industrial clusters would facilitate regional growth and healthy competition. Therefore, promoting the formation of industrial clusters has received some recognition from industries. However, it has been shown that industrial clusters have a hindering effect on the green development of enterprises during periods of economic boom (Guo et al., 2020). In contrast, this study argues that an increase in the proportion of industrial clusters can promote the adoption of green development behaviors by enterprises. The reason for the discrepancy in the findings may be that prior research took enterprises whose main energy consumption is electricity as the clustering agents in the sample period. However, this study takes construction enterprises whose renewable construction materials are raw production materials as the clustering agents in the constructed model. Therefore, the different research objects have an impact on the research results related to industrial clusters. Future research can extend green development behavior to a wider range of fields and obtain more generalized conclusions through induction and integration.

Research limitations and future prospects. There are still some unavoidable limitations in our study. We assume that every enterprise agent in the model is completely rational. However, in reality, each construction enterprise will make its respective behavior decisions based on its operating conditions and risk preferences. Therefore, enterprises' ability to process information and implement behavior is limited. An enterprise cannot fully achieve the ideal situation in the simulation process. The completely rational hypothesis made in this study not only helps in simplifying model construction but also influences the conclusion. This study assumes that the attitudes of construction enterprises in a region toward the adoption of green development behaviors do not change from the beginning to the end of the iteration of the model. However, in real society, enterprises may change their decisions due to policy and institutional influences midway through the management process. Therefore, the Ising model can be used to simulate the dynamic evolution of the shifts and divergences of different perspectives in a region using viewpoint dynamics.

In summary, researchers can add the Ising model to the model constructed in this study to realize the change in the attitudes of agents toward the adoption of green development behaviors. Moreover, researchers can refer to the modeling thinking of this study to verify the evolutionary mechanism of enterprises' green development behaviors in the agriculture, manufacturing, service and other industries.

Conclusions and implications

Conclusions. In our study, with ABM, a computational experimental simulation model for the adoption of green development behaviors by construction enterprises is constructed. The model considers the characteristics of the organizational behaviors of construction enterprises and the evolutionary characteristics of the renewable construction materials market. Numerical simulations are performed using NetLogo 6.2.0 software. Therefore, in the context of construction material recycling, the main findings of this study are as follows:

(1) The increase in the proportion of construction enterprises adopting green development behaviors plays an important role in promoting the sustainable development of enterprises and the optimization of the external environment.
(2) Unsustainable environmental regulations inhibit the expansion of the green development behaviors adopted by all construction enterprises in a region, while sustainable regulations promote this expansion.
(3) The formation of industrial clusters leads more construction enterprises to adopt green development behaviors and is conducive to the spread of green development concepts.

Implications. Our study provides computational experimental simulation evidence based on construction enterprises for the literature on green development and regional sustainability. In addition, it simulates the dynamic evolutionary process of the renewable construction materials market from the ABM perspective under a multiagent system. Therefore, we gain the following insights:

First, enterprises should attach importance to adopting green development behaviors to achieve long-term sustainable development. Above all, media information, public pressure and other channels should be used to accelerate enterprises' acceptance and implementation of green development behaviors. Only by continuously releasing the inherent potential of the green development concept can more enterprises in society feel the practical benefits of adopting green development behaviors. Then, the integration of green development behaviors with concepts such as green innovation, green production and green supply chain management should be strengthened. Practices should be applied effectively to the entire production and operation process of enterprises.

Second, from the governmental perspective, environmental regulations in line with the actual situation of a region can create a good external environment for enterprises to adhere to green development. In the beginning, the implementation of environmental regulations must be analyzed on a case-by-case basis. Before implementing sustainable or unsustainable environmental regulations, the market environment and the actual pollution status of enterprises in a region need to be assessed. The government should avoid a "one-size-fits-all" approach to formulating environmental regulations to avoid discouraging environmentally friendly enterprises from adopting green development behaviors. Then, in the process of guidance and adjustment, the government must achieve a clear distinction between rewards and punishments. Policy subsidies or tax breaks should be given to enterprises with a high level of environmental responsibility to relieve the financial pressure caused by adopting green development behaviors. In contrast, enterprises that do not act in accordance with local laws and environmental regulations should be punished and firmly rectified to avoid the malignant phenomenon of "bad money driving out good money" to the greatest extent possible.

Third, industrial clusters have become the general trend under the global goal of carbon neutrality and the gathering demand of production factors. Organizations of all parties should cooperate to jointly promote the formation of high-quality industrial clusters. First, from the microscopic individual perspective, enterprises should clarify the core location of industrial clusters. They also need to consider the desired optimal geographical location from the beginning of entering a certain field. The correctness of this decision can directly shrink the migration cost of enterprises to a certain extent. From the macrolevel, accelerating the ecological clusters of similar enterprises is a long-term goal for which the state, the government and enterprises need to work together. It is also essential to build a green development system and jointly promote the green development of industries.

Data availability

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

Received: 13 February 2022; Accepted: 11 July 2022;
Published online: 23 July 2022

References

Agyabeng-Mensah Y, Tang L (2021) The relationship among green human capital, green logistics practices, green competitiveness, social performance and financial performance. J Manufact Technol Manag 32(7):1377–1398

Balsa-Barreiro J, Li Y, Morales A (2019) Globalization and the shifting centers of gravity of world's human dynamics: Implications for sustainability. J Clean Prod 239:117923

Belayutham S, Gonzalez VA, Yiu TW (2016) A cleaner production-pollution prevention-based framework for construction site induced water pollution. J Clean Prod 135:1363–1378

Blome C, Hollos D, Paulraj A (2014) Green procurement and green supplier development: antecedents and effects on supplier performance. Int J Prod Res 52(1):32–49

Bonabeau E (2002) Agent-based modeling: methods and techniques for simulating human systems. Proc Natl Acad Sci 99(suppl 3):7280–7287

Brachert M, Titze M, Kubis A (2011) Identifying industrial clusters from a multidimensional perspective: Methodical aspects with an application to Germany. Paper Region Sci 90(2):419–439

Brenner T, Mühlig A (2013) Factors and mechanisms causing the emergence of local industrial clusters: A summary of 159 cases. Region Stud 47(4):480–507

Central People's Government of the People's Republic of China (2022) Available online: http://www.gov.cn/xinwen/2022-02/24/content_5675510.htm (accessed on 5 May 2022)

Del Faro-Odi HA, López-Martínez RR, Rodríguez-Achach ME, Hernández-Montoya AR (2020) Thermal and superthermal income classes in awealth alike distribution generated by Conway's Game of Life Cellular Automaton. J Cell Autom. 15:3

Delgado M, Porter ME, Stern S (2014) Clusters, convergence, and economic performance. Res Policy 43(10):1785–1799

Deng J, Zhang N, Ahmad F, Draz MU (2019) Local government competition, environmental regulation intensity and regional innovation performance: an empirical investigation of Chinese provinces. Int J Environ Res Public Health 16(12):2130

Department for Business, EIS (2020) The ten point plan for a green industrial revolution. Available online: https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution (accessed on 5 May 2022)

Engelberg J, Ozoguz A, Wang S (2018) Know thy neighbor: Industry clusters, information spillovers, and market efficiency. J Finan Quant Anal 53(5):1937–1961

Engineering News Record. Pollution Leak Taints $56B HS2 Project in UK (2021). Available online: https://www.enr.com/articles/52423-pollution-leak-taints-56b-hs2-project-in-uk (accessed on 5 May 2022)

Feng Z, Chen W (2018) Environmental regulation, green innovation, and industrial green development: an empirical analysis based on the Spatial Durbin model. Sustainability 10(1):223

Gompers P, Lerner J, Scharfstein D (2005) Entrepreneurial spawning: Public corporations and the genesis of new ventures, 1986 to 1999. J Finance 60(2):577–614

Gong Y (2017) A survey on the modeling and applications of cellular automata theory. In: IOP conference series: materials science and engineering (242, No. 1, p. 012106). IOP Publishing

Guan J, Huang X, Liu X, Liu H, Chen W (2005) Environmental behavior and analysis of driving model for printing and dyeing enterprises in Taihu Basin. J Lake Sci 17(4):351–355

Guo Y, Tong L, Mei L (2020) The effect of industrial agglomeration on green development efficiency in Northeast China since the revitalization. J Clean Prod 258:120584

Hannah R, Max R, Pablo R (2020) "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Available online: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions. (accessed on 5 May 2022)

Hao Y, Deng Y, Lu ZN, Chen H (2018) Is environmental regulation effective in China? Evidence from city-level panel data. J Clean Prod 188:966–976

Hunter E, Mac Namee B, Kelleher J (2020) A hybrid agent-based and equation-based model for the spread of infectious diseases. J Artif Soc Soc Simul 23:4

Ji P, Ma X, Li G (2015) Developing green purchasing relationships for the manufacturing industry: an evolutionary game theory perspective. Int J Prod Econ 166:155–162

Kargupta W, Seifert R, Martinez M, Olson J, Tanner J, Batchelor W (2021) Sustainable production process of mechanically prepared nanocellulose from hardwood and softwood: a comparative investigation of refining energy consumption at laboratory and pilot scale. Indus Crop Prod 171:113868

Kemeny JG (1967) The universal constructor: theory of self-reproducing automata. John von Neumann. Arthur W. Burks (eds). University of Illinois Press, Urbana, 1966. 408 pp., illus. $10. Science 157(3785):180–180

Kim MJ, Shaver JM, Funk RJ (2022) From mass to motion: conceptualizing and measuring the dynamics of industry clusters. Strateg Manag J 43(4):822–846

Kippenberger S, Bernd A, Thaçi D, Kaufmann R, Meissner M (2013) Modeling pattern formation in skin diseases by a cellular automaton. J Investig Dermatol 133(2):567

Lathrop KW, Centner TJ (1998) Eco-labeling and ISO 14000: an analysis of US regulatory systems and issues concerning adoption of type II standards. Environ Manag 22(2):163–172

Li Q, Zhang L, Zhang L, Jha S (2021) Exploring multi-level motivations towards green design practices: a system dynamics approach. Sustain Citi Soc 64:102490

Li S, Ngniatedema T, Chen F (2017) Understanding the impact of green initiatives and green performance on financial performance in the US. Bus Strateg Environ 26(6):776–790

Li X, Du J, Long H (2018) A comparative study of Chinese and foreign green development from the perspective of mapping knowledge domains. Sustainability 10(12):4357

Li X, Du J, Long H (2019a) Dynamic analysis of international green behavior from the perspective of the mapping knowledge domain. Environ Sci Pollut Res 26(6):6087–6098

Li X, Du J, Long H (2019b) Green development behavior and performance of industrial enterprises based on grounded theory study: evidence from China. Sustainability 11(15):4133

Li X, Du J, Long H (2020) Understanding the green development behavior and performance of industrial enterprises (GDBP-IE): scale development and validation. Int J Environ Res Public Health 17(5):1716

Li X, Huang Y, Li J, Liu X, He J, Dai J (2022) The mechanism of influencing green technology innovation behavior: evidence from Chinese construction Enterprises. Buildings 12(2):237

Liu Y, Ye H (2012) The dynamic study on firm's environmental behavior and influencing factors: an adaptive agent-based modeling approach. J Clean Prod 37:278–287

Lv Z, Chen D, Lou R, Alazab A (2021) Artificial intelligence for securing industrial-based cyber–physical systems. Fut Gen Comput Syst 117:291–298

Macal CM (2016) Everything you need to know about agent-based modeling and simulation. J Simul 10(2):144–156

Macal C, North M (2014) Introductory tutorial: Agent-based modeling and simulation. In: Proceedings of the Winter Simulation Conference 2014. IEEE. pp. 6–20

Mantovani A, Tarola O, Vergari C (2017) End-of-pipe or cleaner production? How to go green in presence of income inequality and pro-environmental behavior. J Clean Prod 160:71–82

Ministry of Ecology and Environment of the People's Republic of China. Available online: https://www.mee.gov.cn/ (accessed on 5 May 2022)

Ministry of Housing and urban-rural development of the People's Republic of China. 2020 Grasp the source of construction waste reduction, promote the green development of urban and rural construction. Available online: https://www.mohurd.gov.cn/xinwen/gzdt/202005/20200515_245447.html (accessed on 5 May 2022)

Ministry of the Environment (2022) Japan. Available online: http://www.env.go.jp/ (accessed on 5 May 2022)

Miroshnychenko I, Barontini R, Testa F (2017) Green practices and financial performance: a global outlook. J Clean Prod 147:340–351

Mo C, He C, Yang L (2020) Structural characteristics of industrial clusters and regional innovation. Econ Lett 188:109003

Muleski GE, Cowherd Jr C, Kinsey JS (2005) Particulate emissions from construction activities. J Air Waste Manag Assoc 55(6):772–783

National Bureau of Statistics, 2021. China Statistical Yearbook. Available online: http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm (accessed on 24 Nov 2021)

Naughton HT (2014) To shut down or to shift: Multinationals and environmental regulation. Ecol Econ 102:113–117

Pan X (2021). 70% of enterprises in Asia-Pacific willing to pay higher rents for green buildings. China Economic Herald, 006. (In Chinese)

Pisa N, Viviers W, Rossouw R (2017) Enhancing industrial cluster formation through the realistic export opportunities of the TRADE-DSM. South Afr J Econ 85(3):386–404

Porter ME (1990) The competitive advantage of nations. Compet Intellig Rev 1(1):14–14

Ren S, Li X, Yuan B, Li D, Chen X (2018) The effects of three types of environmental regulation on eco-efficiency: a cross-region analysis in China. J Clean Prod 173:245–255

Rodriguez-Villamizar LA, Moreno-Corzo FE, Valbuena-Garcia AM, Uribe Pérez CJ, Brome Bohórquez MR, García García HI,…, Osornio-Vargas AR (2020) Childhood leukemia in small geographical areas and proximity to industrial sources of air pollutants in three Colombian cities. Int J Environ Res Public Health 17(21):7925

Rouzafzoon J, Helo P (2016) Developing service supply chains by using agent based simulation. Ind Manag Data Syst 116(2):255–270

Rzeszutek M, Godin A, Szyszka A, Augier S (2021) Managerial overconfidence in capital structure decisions and its link to aggregate demand: An agent-based model perspective. PLoS ONE 16(8):e0255537

Shao L, Gao Y, Wang S (2018) Environmental regulation and green behavior choice of resource-based enterprises: "Reverse Transformation" or "Regulation Capture". J Hohai Univ (Philosophy and Social Sciences) 20(06):62-68–92-93. (In Chinese)

Song M, Wang S, Zhang H (2020) Could environmental regulation and R&D tax incentives affect green product innovation? J Cleaner Prod 258:120849

The Ministry of Economy TAI (2020) "Green Growth Strategy Through Achieving Carbon Neutrality in 2050" Formulated. Available online: https://www.meti.go.jp/english/press/2020/1225_001.html (accessed on 5 May 2022)

Thomas H, T Kuramochi, J Lang, B Mapes, S Smith, R Aiyer, R Black, M Boot, P Chalkley, F Hans, N Hay, A Hsu, N Höhne, S Mooldijk, T Walsh (2021) Net Zero Tracker. Energy and Climate Intelligence Unit, Data-Driven Enviro Lab, New Climate Institute, Oxford Net Zero

Tsinghua Holdings Limited (2022) Full text database of important Chinese newspapers. Available online: https://kns.cnki.net/kns/brief/result.aspx?dbprefix=CCND (accessed on 5 May 2022)

United States Energy Information Agency (2022) Available online: https://www.eia.gov/ (accessed on 5 May 2022)

United States Environmental Protection Agency. 2022 Available online: https://www.epa.gov/regulatory-information-sector/construction-sector-naics-23 (accessed on 5 May 2022)

US Bureau of Economic Analysis, 2020. "Gross domestic product." Available online: https://fred.stlouisfed.org/release/tables?rid=53&eid=41187 (accessed 24 November 2021)

Wang Q, Jiang R, Zhan L (2019) Is decoupling economic growth from fuel consumption possible in developing countries? A comparison of China and India. J Clean Prod 229:806–817

Wieland H, Moeller F, Bockisch FJ (2007) Thermotechnical and technological aspects of insulation and building materials from renewable raw materials. Landbauforschung Volkenrode 57(1):87–93

Xiang L, Tan Y, Shen G, Jin X (2021) Applications of multi-agent systems from the perspective of construction management: a literature review. Eng Const Archit Manag

Xiong B, Wang R (2020) Effect of environmental regulation on industrial solid waste pollution in China: from the perspective of formal environmental regulation and informal environmental regulation. Int J Environ Res Public Health 17(21):7798

Yan Y, He M, Song L (2021) Evaluation of regional industrial cluster innovation capability based on particle swarm clustering algorithm and multi-objective optimization. Complex Intellig Syst 7:1–12

Yang R, Li N (2019) Environmental regulation and green industrial development of China: theoretical analysis and empirical evidence. J China Univ Geosci (Social Sciences Edition) 19(05):79–91. (In Chinese)

Yang X, Jia J (2019) Research on the influence of individual network's structural characteristics on enterprise green behavior. On Econ Prob12:68–74. (In Chinese)

Yoon S, Nadvi K (2018) Industrial clusters and industrial ecology: Building 'eco-collective efficiency' in a South Korean cluster. Geoforum 90:159–173

Yoshino Y (2011) Industrial clusters and micro and small enterprises in Africa: From survival to growth. World Bank Publications

Yusuf S, Nabeshima K, Yamashita S (eds) (2008) Growing industrial clusters in Asia: serendipity and science. World Bank Publications

Zhang J, Li F, Ding X (2022) Will green finance promote green development: based on the threshold effect of R&D investment. Environ Sci Pollut Res 29:1–12

Zhang Y, Wei Y, Zhou G (2018) Promoting firms' energy-saving behavior: The role of institutional pressures, top management support and financial slack. Energy Policy 115:230–238

Zhu Y, Zhang Y, Hu C (2019) Study on farmers' Behavior of adopting new varieties under the crisis of crop disease—from individual choice to diffusion mechanism. J Agro Econ 12:80–95. (In Chinese)

Acknowledgements

This work was supported by Special Funds of the National Social Science Fund of China (grant number 18VSJ038), the Scientific Research Startup Foundation for Introducing Talents of Sichuan Agricultural University (grant number 2122996022), the Social Science Special Project of Sichuan Agricultural University Disciplinary Construction Dual Support Program (grant number 2021SYYB05), the Undergraduate Training Program for Innovation and Entrepreneurship of Sichuan Agricultural University (grant number 202110626136), and the Sichuan Students' Platform for Innovation and Entrepreneurship training program (grant number S202110626136).

Author contributions

Conceptualization, methodology, writing—original draft preparation: XL, JL; Formal analysis and investigation: JL; Writing—review and editing: JL, YH, JH, XL, QS; Funding acquisition, supervision, and resources: XL.

Competing interests

The authors declare no competing interests.

Ethical approval

This research did not require any ethical approval.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

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