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RESEARCH ARTICLE

Research on the green transformation of China's traditional manufacturing industry driven by digital economy based on system dynamics

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ABSTRACT

As China strides towards dual-carbon achievement, the traditional manufacturing industry is facing multiple challenges of industrial upgrading and low-carbon development. Based on the theory of technology organization environment, this paper analyzes the influence factors of the green development of traditional manufacturing industry driven by the digital economy from the organizational, technological and environmental subsystems. Furthermore, this paper constructs the system dynamics model to research the green transformation mechanism of the traditional manufacturing industry by vensim software according to the data from 2015-2020. The simulation experiments predicate the different green development paths of traditional manufacturing through environmental regulation, digital technology innovation and green technical standards, which can enhance the green total factor productivity and reduce the carbon dioxide emission degree of China's traditional manufacturing industry.

KEYWORDS

Traditional manufacturing industry; Green transformation; Digital economy; Technology-Organization-Environment; System dynamics

1 Introduction

Due to the adoption of an extensive development model with high energy consumption and high pollution, the traditional manufacturing industry brought great pressure on China's society, resources and environment in the last decades (Qiao, 2023). How to promote the green development of the traditional manufacturing industry and ensure the successful realization of the “double carbon” goal has become a huge challenge. The *20th National Congress of the Communist Party of China (CPC)* addresses that "continuing to improve the environment and promoting green and low-carbon development", with energy consumption per unit of GDP in 2025 should be reduced by 13.5% compared with 2020, the proportion of non-fossil energy in total energy consumption should increase to about 20%, and carbon dioxide emissions from the industrial sector should peak before 2030 (Zhao, 2022). The green transformation has become an inevitable requirement for high-quality development of manufacturing industry, and regional digital development provides a good opportunity for this (Xiao, 2023). The digital economy can

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effectively integrate information resources of traditional manufacturing into production decision-making through digital innovation activities, resulting in an exact and efficient match between supply and demand (Carrière-Swallow & Haksar, 2019). Balancing green manufacturing transformation and economic development, and adhering to the sustainable development strategy is a complex problem for academic and practical societies (Cao et al., 2023). Li et al. (2023) find that digital development can promote the green transformation of manufacturing by improving energy efficiency and promoting green technology innovation. Ma et al. (2023) propose that digitalization has a significant enabling effect on the green transformation and upgrading of enterprises, and the promotion of green transformation is more significant in state-owned enterprises, enterprises in high-polluting industries, and enterprises supported by the Belt and Road Initiative.

Therefore, this paper introduces the theoretical framework of technological-organizational-environmental (TOE) and utilizes system dynamics (SD) method to conduct a dynamic research model for the green transformation of the traditional manufacturing industry. SD is an applied discipline that makes systematic analysis of social and economic problems by combining qualitative and quantitative methods, studies quantitatively the dynamic behavior of system development on the basis of system feedback control theory and by means of computer simulation (Saleh, 2010). Zhou et al. (2018) constructed the SD model for energy conservation and emission reduction in China based on factors such as government, economy, population, and dynamically simulated the implementation effects of different policy tools. Therefore, this research follows the logic of SD and attempts to develop a theoretical model to capture the structure of the green transformation system of the traditional manufacturing industry, including the organizational, technical and environmental subsystems.

This paper supplements the previous literature on the green transformation of the traditional manufacturing industry in the following ways. First, we analyze the dynamic factors of green transformation of the traditional manufacturing industry based on the TOE theory. Second, this paper builds a SD model of green development of manufacturing from the perspective of dynamic evolution and examines the transmission paths and practical effects of policy implementation from the perspective of simulating the socioeconomic system. Third, our research articulates the mechanism and the effect of policies acting on the green transformation of manufacturing according to the results of the dynamic analysis. Notably, this paper also provides empirical evidence that may lay a foundation for the related policy optimizations and enterprise decision-making on the green development of China's manufacturing enterprise.

2 Theoretical model for green transformation of traditional manufacturing industry

The TOE theory is the classical theoretical framework for explaining the phenomenon of new technology adoption and application (Tornatzky et al., 1990). Due to the flexibility and practicality of the TOE theory, this paper analyzes the influence factors and mechanisms of green development of the traditional manufacturing industry driven by the digital economy from three perspectives: technology, organization, and environment. Technical factors refer to the relationship between the characteristics of the technology and the organization, mainly including whether the technology matches the structural characteristics of the organization, whether it is coordinated with the organization's application ability, and whether it can bring potential benefits to the organization. This paper considers the impact of technological innovation capabilities and technology standardization capabilities on the green development of traditional manufacturing enterprises. Organizational factors usually refer to some descriptive index characteristics, which mainly include organizational scale, institutional regulations, management structure characteristics, business scope, formal/informal institutional arrangements, communication mechanisms, and spare resources for reserve savings. This study mainly analyzes the organizational factors of green transformation for the traditional manufacturing industry, involving the talent system, energy control and pollution emission of the traditional manufacturing enterprise organization. Environmental factors refer to the organizational development environment, the policy environment in which the organization operates, the characteristics of competitors in the industry, market rules, and regulatory policies of external governments. This paper focuses on government policy support and industrial structure allocation level of green transformation for the traditional manufacturing industry. As a complex system, the green development of the traditional manufacturing industry is affected by many factors and has similarities with socioeconomic systems. Figure 1 shows the theoretical framework of green development of the traditional manufacturing industry from the perspective of TOE theory.

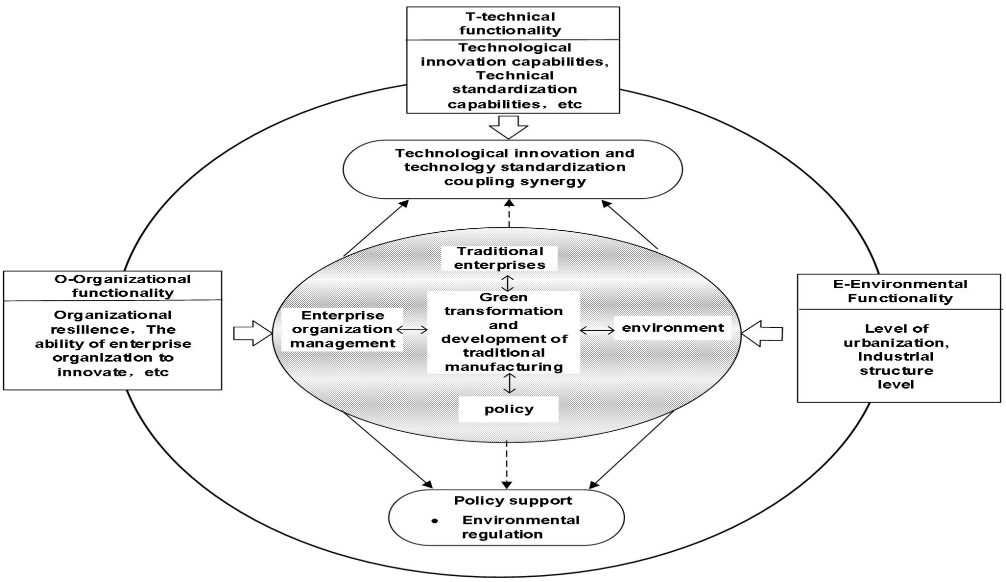

Figure 1 The technological-organizational-environmental theory framework of green development of the traditional manufacturing industry

(1) Analysis of technical factors

Technical factors refer to the technological application of control carbon emissions in the production process of the traditional manufacturing industry including digital technology innovation, low-carbon technology and technical standards (Yan et al, 2022). With the “Internet+” technology application, the traditional manufacturing industry creates a digital technological innovation ecology system based on the Internet platforms. The foundation of enterprise digital services not only relies on the investment of enterprises' digital technology but also is affected by the Internet's innovative environment. Therefore, "Internet +" is the indispensable role in the green development of traditional manufacturing. With reference to the index design by Shi et al. (2018), the "Internet penetration rate" and "optical cable line length" are selected to indicate the "Internet +" level, and the relevant data are from the "Communications Industry Statistical Bulletin".

Technical standards refer to the uniform provisions of repetitive technical matters within a certain range. The new-generation "5G+IndustrialInternet" technology standards can improve the energy-intensive and high-pollution production processes, optimize the management pattern, and form a large number of extensive scenarios for the integration of energy-saving and emission-reducing technologies. The standardization development of low-carbon technology can establish a green manufacturing technology system to prevent the ecological environment erosion caused by existing destructive technologies in industrial transformation and upgrading.

(2) Analysis of organizational factors

Organizational factors mainly include organizational management, organizational resilience and enterprise innovation. Organizational resilience can reflect the organization's ability to manage and control unknown risks (Wang & Zhang, 2022). Enterprises need to monitor the production process in real time, and strictly control the resource input and pollution emission of each link, so that it meets emission standards and promotes green and sustainable development. In terms of organizational management, enterprise innovation talents are the key to determining organizational management innovation, and are affected by the resilience of enterprise organizations. The higher the level of human capital is, the greater the positive incentive effect on green technology innovation in the manufacturing industry. Enterprises should carry out professional training for digital talents according to their own development needs. Therefore, it is suggested that enterprises should provide various types of resources, such as financial subsidies, settlement and housing, to absorb the high-level talents, college graduates, innovative and entrepreneurial talents, and other groups. The "R&D talent reserve" is used as an indicator factor for enterprise innovation talents, and the data comes from the *China Statistical Yearbook*. Natural gas and electricity energy are regarded as clean energy, and the ratio of their sum to total energy consumption in manufacturing is used as clean energy utilization. In order to unify the unit, the unit of electricity and the unit of natural gas are converted into the standard coal according to the reference coefficient of energy conversion standard coal in *China Energy Statistical Yearbook*, 100 million kWh of electricity = 12,290 tons of standard coal, and 100 million cubic meters of natural gas = 133,000 tons of standard coal.

(3) Analysis of environmental factors

Environmental factors include policy support, environmental regulation and so on, which have a significant impact on the industrial green total factor productivity (GTFP) of the traditional manufacturing industry. Environmental factors can promote to formulate reasonable environmental regulation policies, guide enterprises to carry out green transformation, and reduce production energy consumption to achieve the goal of green transformation. Yin et al. (2022) found that environmental regulation can significantly enhance the GTFP of the manufacturing industry in the Yangtze River economic belt. Zhou & Shen (2022) found that administrative orders and market-incentivized environmental regulation tools can inhibit the development of industrial GTFP. He & Luo (2018) found that there is a nonlinear parabolic relationship between environmental regulation and industrial total factor productivity, and only after the intensity of environmental regulation reaches the "U" threshold value can industrial total factor productivity be promoted.

3 SD model for green transformation of traditional manufacturing industry

3.1 System boundary definition

A green transformation of the traditional manufacturing industry covers multiple subjects, including governments, enterprises, environment, and a large number of influencing factors (Chen et al., 2021). Therefore, we separate the key model structures that have an important impact on the operation of the entire system from the complex giant system and concretize the abstract and macroscopic reality system through interconnected variables and feedback structures, which is more conducive to the green transformation of traditional manufacturing industry system analysis, as shown in Figure 2.

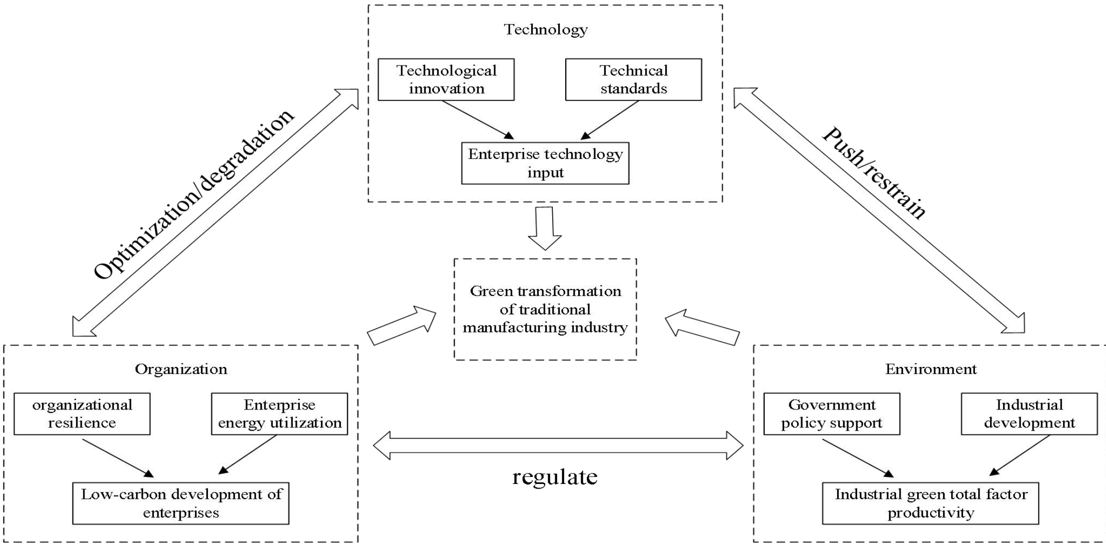

Figure 2 The green development of traditional manufacturing industry based on the technological-organizational-environmental theory

3.2 Causal loop diagram

Causal loop diagram is a qualitative description of the internal structural relationship of the system, which can reflect the relationship between various variables in the model and is the basis for SD modeling. This paper analyses the causal feedback relationship and constructs the causal diagrams for the green development of the traditional manufacturing industry driven by the digital economy from the technology, enterprise organization and environment subsystems.

(1) Technology subsystems

Technology is the key subsystem of the green transformation of the traditional manufacturing industry, and the technologically innovative environment is crucial for enterprises to engage in green innovation activities. This subsystem primarily investigates the influence of scientific and technological advancements on green innovation and other subsystems at various economic levels, total energy consumption, and environmental circumstances. The causal analysis of the technology subsystem focuses on the following variables: “Internet+” level, enterprise digital service foundation, the level of green technology of enterprises, technical collaboration efficiency, technical information synergy, driven by innovation and invention, number of valid invention patents, the level of development traditional manufacturing, technical investment intensity, technological innovation capabilities, technology standardization capabilities, innovation resource allocation capabilities, and the level of energy consumption structure, which form the multiple positive feedback loops to simulate the green transformation of traditional manufacturing industry under the technology subsystem. The causal loop diagram of the technical subsystem is shown in Figure 3.

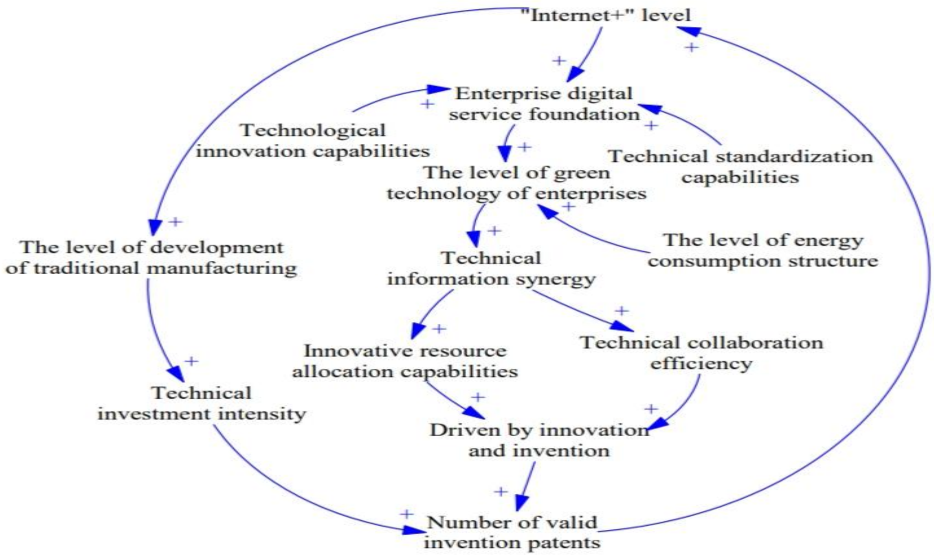

Figure 3 The causal loop diagram of the technology subsystem

(2) Organization subsystems

The organization subsystem mainly focuses on the role of enterprises, scientific research institutions, and the national government in the green transformation of the traditional manufacturing industry. The causal analysis of the enterprise organization subsystem contains the following variables, such as organizational resilience, enterprise organizational innovation ability, enterprise value co-creation ability, enterprise organizational agility ability, enterprise integration and refactoring ability, degree of emphasis on enterprise digitization, the level of product or process innovation, the level of product life cycle management, the level of digital application of enterprises, the level of comprehensive utilization of energy, the level of emission monitoring and management, industrial pollution emission level, and the low-carbon development level of traditional manufacturing, which form the number of positive feedback loops to simulate the sustainable development of traditional manufacturing under the organization subsystem. The causal loop diagram of the organization subsystem is shown in Figure 4.

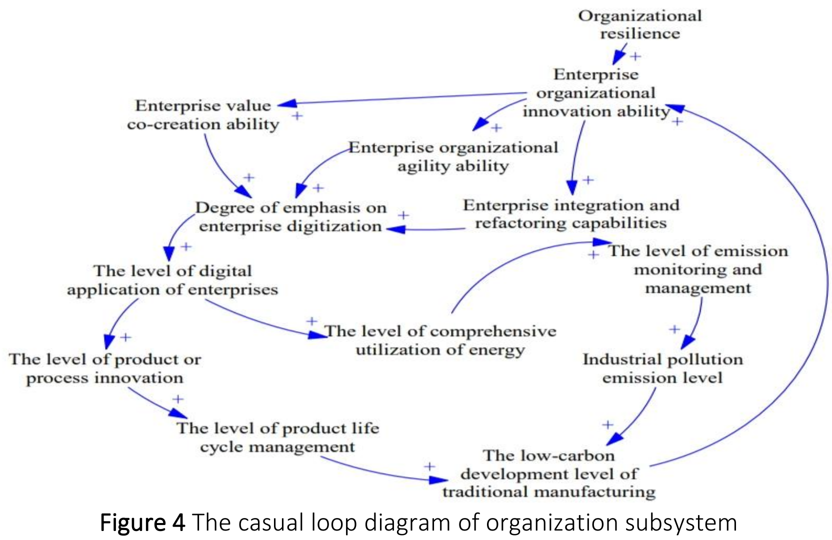

Figure 4 The casual loop diagram of organization subsystem

(3) Environment subsystem

The environment subsystem is mainly affected by digital economy development and mainly reflects the impact of the change in the ecological environment carrying level on enterprise production activities. The causal analysis of the environmental subsystem contains 14 variables, including the consumption level of the national residents, industrial added value, environmental regulation, the level of urbanization, the level of foreign investment, enterprise R&D investment, enterprise market share, the intensity of enterprise competition, the level of industrial structure, the level of low-carbon industrial structure, the level of development of green finance, green trade barriers, the level of economic development, industrial green total factor productivity, which form the multiple positive feedback loops and some negative feedback loops to simulate the green development of traditional manufacturing industry under the environment subsystem. The causal loop diagram of the environmental subsystem is shown in Figure 5.

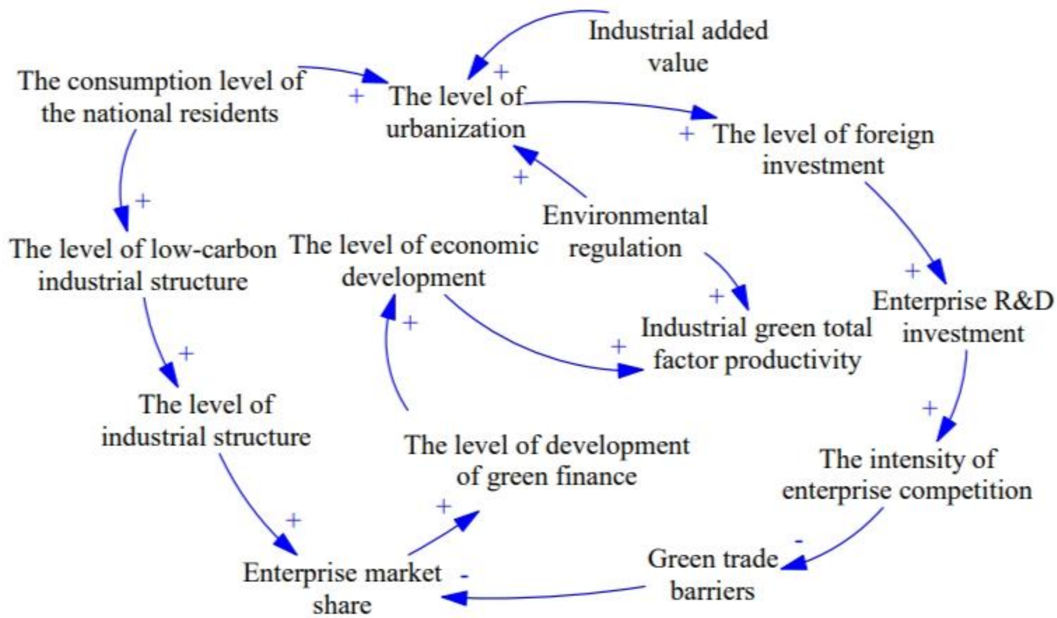

Figure 5 The causal loop diagram of the environment subsystem

3.3 Stock and flow model

Vensim PLE software can build the stock and flow model according to the qualitative causal relationship between the parameters of the model variables, and realize the simulation prediction of the model variables by assigning corresponding initial values or calculation formulas. Since many variables in the system will change over time, the constructed model uses the exogenous variable Time to represent the properties of changing over time for these variables. The equations and the variables of the system flow diagram for the green transformation of the traditional manufacturing industry are constructed. The stock and flow model is shown in Figure 6.

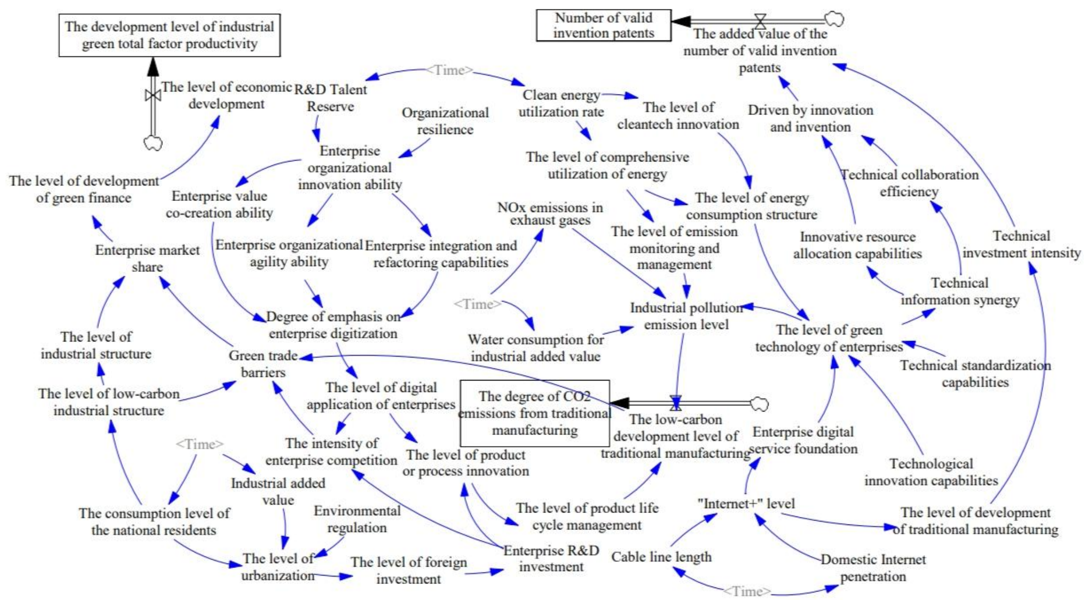

Figure 6 Stock and flow model for the green transformation of traditional manufacturing

From the stock and flow model, it can be seen that there are 3 state variables, 3 rate variables, 33 auxiliary variables, 3 constants and 8 table functions. These equations and variables of the stock and flow model are shown in Table 1.

Table 1 Equation variables of the simulation dynamics model

Variable (parameter)	Equation (valued)	Unit
R&D talent reserve	WITHLOOKUP(Time,([(2015,253.7)-(2020,336.2)]),(2015,253.7),(2016,260),(2017,263.9),(2018,289.9),(2019,305.7),(2020,336.2))	Ten thousand people
Clean energy utilization rate	WITHLOOKUP(Time,([(2015,19.6)-(2020,24.7)]),(2015,19.6),(2016,20.6),(2017,22.1),(2018,24),(2019,24.4), (2020,24.7))	%
National consumption level	WITHLOOKUP(Time,([(2015,18857)-(2020,27439)]),(2015,18857),(2016,20801),(2017,22968),(2018,25245),(2019,27504),(2020,27439))	yuan
Industrial added value	WITHLOOKUP(Time,([(2015,234969)-(2020,312903)]),(2015,234969),(2016,245406),(2017,275119),(2018,301089),(2019,311859),(2020,312903))	100 million yuan
Cable line length	WITHLOOKUP(Time,([(2015,2487)-(2020,5169)],(2015,2487),(2016,3041),(2017,3747),(2018,4358),(2019,4750) ,(2020,5169))	Ten thousand kilometre
Domestic Internet penetration	WITHLOOKUP(Time,([(2015,50.3)-(2019,61.2)],(2015,50.3),(2016,53.2),(2017,54.3),(2018,59.6),(2019,61.2),(2020,))	%
NOx emissions in exhaust gases	WITHLOOKUP(Time,([(2015,1851.02)-(2020,1019.66)],(2015,1851.02),(2016,1503.3),(2017,1348.4),(2018,1288.44),(2019,1233.85),(2020,1019.66))	Ten thousand ton

Variable (parameter)	Equation (valued)	Unit
Water consumption for industrial added value	WITHLOOKUP(Time,([(2015,56.8)-(2020,32.9)],(2015,56.8),(2016, 53.3),(2017,46.4),(2018,41.9),(2019,39) ,(2020,32.9))	Cubic meter / Ten thousand yuan
Environmental regulation impact factor	1	/
Organizational resilience	1	/
Technological innovation capabilities	1	/
Technical standardization capabilities	1	/
Level of urbanization	(National consumption level *0.65+ Industrial added value *0.35)* Environmental regulation impact factor	/
Enterprise market share	(Industrial structure level *0.217)/(Green trade barriers *1.5)	/
The level of development of green finance	Enterprise market share *7.3	/
The level of economic development	The level of development of green finance *0.0481	/
The development level of industrial green total factor productivity (GTFP)	INTEG(Level of economic development *0.2， 1)	/
Degree of emphasis on enterprise digitization	(Enterprise value co-creation ability + Enterprise organizational agility + Enterprise integration and refactoring capabilities)*2.31	/
The level of product or process innovation	0.45* The level of digital application of enterprises +0.55* Enterprise R&D investment	/
The low-carbon development level of traditional manufacturing	Industrial pollution emission levels *0.82+ The level of product lifecycle management *0.18	/
The degree of CO_2 emissions from traditional manufacturing	INTEG(-The low-carbon development level of traditional manufacturing, 3766.38)	One million ton
“Internet+” level	Cable line length * Domestic Internet penetration	/
Enterprise digital service foundation	“Internet+” level *0.005	/
The level of green technology of enterprises	0.1* The level of energy consumption structure +0.1* Enterprise digital service foundation +0.8*(Technological innovation capabilities + Technical standardization capabilities)	/
Driven by innovation and invention	0.7* Innovative resource allocation capabilities +0.3* Technical collaboration efficiency	/
Number of valid invention patents	INTEG(The added value of the number of valid invention patents，57.38)	Ten thousand piece

4 Model testing

4.1 Data sources

We study the dynamic impact of digital economy on the green development of traditional manufacturing industry based on the related data from *China Statistical Yearbook* (2016-2022), *Statistical Bulletin of the Communications Industry* issued by the Ministry of Industry and Information Technology, PRC, and *China Ecological Environment Status Bulletin* issued by the Ministry of Ecology and Environment, PRC. The time frame of our study is 2015-2030, and the step size of the simulation is 1 year. The data from 2015 to 2020 are used to test whether the model is consistent with reality, and the data from 2021 to 2030 are used to simulate the dynamic evolution process of the green transformation of the traditional manufacturing industry in the digital economy era.

4.2 Historical data verification

It is generally believed that if the government increases the green innovation level of traditional manufacturing enterprises, then it can encourage enterprises to reduce the total amount or concentration of pollutants discharged through green innovation. Thus, this paper regards the number of valid invention patents as an indicator to test the validity of historical data, in which the energy consumption structure level is measured by the ratio of total coal consumption to total energy consumption in manufacturing. Among them, the data on total coal consumption and total energy consumption in manufacturing are obtained from the *China Statistical Yearbook* published by the National Bureau of Statistics. We use the data from 2015 to 2020 to conduct historical data verification on variables such as the number of valid invention patents and the energy consumption structure level, and the results are shown in Table 2.

Table 2 Historical data test results of system dynamics model

Year	Historical value (Ten thousand pieces)	Simulated value (Ten thousand pieces)	Relative error (%)
2015	57.38	57.38	0
2016	76.98	73.79	−4.14
2017	93.40	90.64	−2.96
2018	109.42	108.01	−1.29
2019	121.81	126.06	3.49
2020	144.80	144.49	−0.21

The specific test results show that the relative error range of the main variables is controlled within ±5%, which indicates that the data fitting degree is high, and the simulation value of each variable is the same as the actual value. The system model can accurately describe the actual situation and has a good predictive effect on the next stage of simulation.

4.3 Sensitivity test

The sensitivity test is the most important method for verifying the impact of the parameters and the behavioral validity of the SD model, but it may also lead to system instability and parameter insensitivity. We set a certain number of parameters in the SD model to reflect the real behavior as completely as possible, which the simulation time steps of the model are set to 1 year, 0.5 years, and 1.5 years, respectively, and the CO_2 emission degree of the traditional manufacturing industry is used as the research object. Taking the variables under different simulation steps as the input, the evolution trajectories of the output variable (degree of CO_2 emissions) with varied parameter values are shown in Figure 7. The sensitivity results by Vensim DSS indicate that the model is reliable and scientific. Through the historical data tests and sensitivity tests, the SD model of this paper manifests the potential to simulate and forecast the green development trend of the development of the traditional manufacturing industry driven by the digital economy in China.

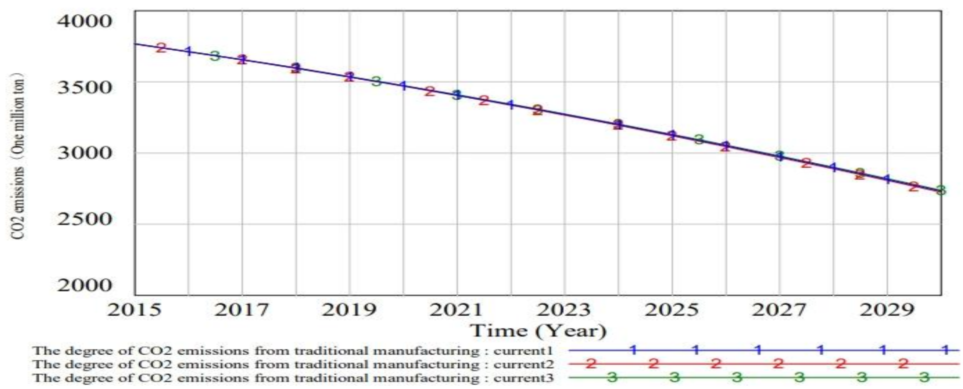

Figure 7 Evolution trajectories of the green transformation of the traditional manufacturing industry

5 Simulation experiments and results analysis

5.1 Simulation experiments

After the input and output variables are identified, the SD model can dynamically simulate the evolution of the green development of Chinese traditional manufacturing enterprises based on feedback systems theory and analytical approach, where each variable can be visualized independently with complements systems thinking. This paper makes a simulated experiment of the unbalanced growth of the traditional manufacturing industry from the perspectives of the development level of green finance, the digital application level of enterprises, the low-carbon development level of the manufacturing industry and so on, as shown in the Figure 8, Figure 9, Figure 10 and Figure 11.

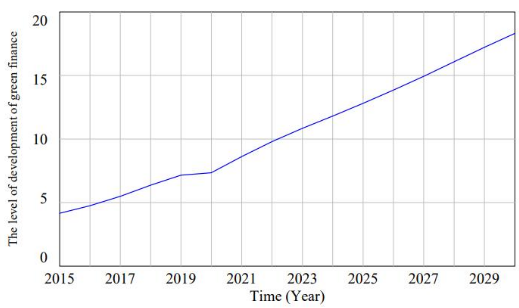

Figure 8 Curve of green finance development level

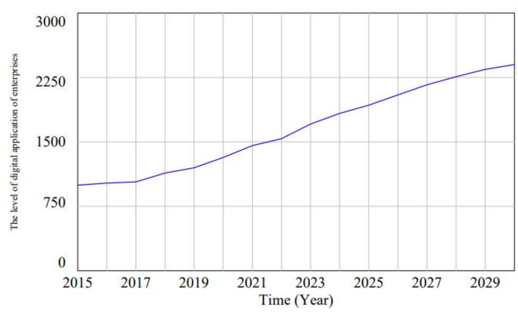

Figure 9 Curve of digital application level of enterprises

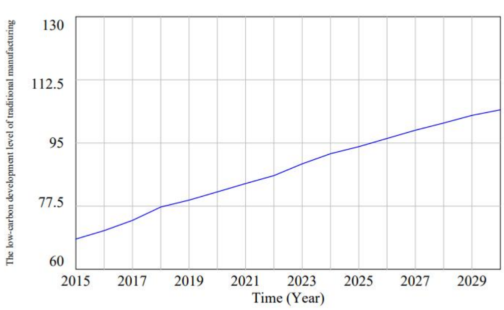

Figure 10 Curve of the low-carbon development level

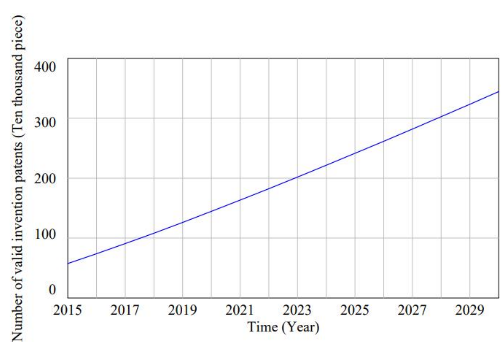

Figure 11 Curve of the number of valid invention patents

Green finance can provide additional funds for the intelligent upgrading of China's traditional manufacturing industry to meet the requirements of large-scale electrification, fuel and raw material substitution, equipment renewal and technology development. Figure 8 shows that the impact of the digital economy on the green development of manufacturing enterprises is mainly achieved through green finance and investment greening. Digital technology is the key to the green transformation of enterprises, and the popularization of enterprise digital applications will bring changes to enterprises. Figure 9 indicates that enterprise green development is inseparable from digital application. Traditional manufacturing industries should promote independent controllable green low carbon technology innovation systems through the digital economy cooperation platform to realize the integration of the whole process and whole industrial chain applications. Due to the digital technology application of enterprises, the rational use of energy, the improvement of end-of-pipe treatment technology innovation and the low-carbon development level of the manufacturing industry (as shown in Figure 10) can enhance the green development of the traditional manufacturing industry. With the number of effective invention patents increased, green technology can ensure that minimizes pollution in the process of production and discharge, satisfies the requirements of environmental protection, and promotes the green and sustainable development of the traditional manufacturing industry (as shown in Figure 11).

5.2 Policy test

To analyze the different policies on the green transformation of the traditional manufacturing industry driven by the digital economy, we select four types of policy factors as input variables, including environmental regulation, organizational resilience, technological innovation and technical standardization abilities. The output variables of GTFP development level and industrial manufacturing carbon dioxide emission degree are selected as policy application scenario analysis. After the input and output variables are identified, the SD model can simulate the green development of the traditional manufacturing industry. More significantly, the variable values representing various policies are changed, and simulation analysis are carried out from the perspective of the interaction mechanism by policy test.

5.2.1 Environmental regulation policy

According to the technological innovation mechanism mainstreamed by the Porter hypothesis, the traditional manufacturing industry takes more innovative activities to comply with environmental regulations. The enterprise will increase the investment in scientific and technological innovation to replace traditional, backward equipment with more advanced and environmentally friendly ones in their production, which improve their market competitiveness. The trend of industrial GTFP and the degree of carbon dioxide emissions of the industrial manufacturing industry has been effectively improved through the environmental regulation policy, and the simulation results are shown in Figure 12.

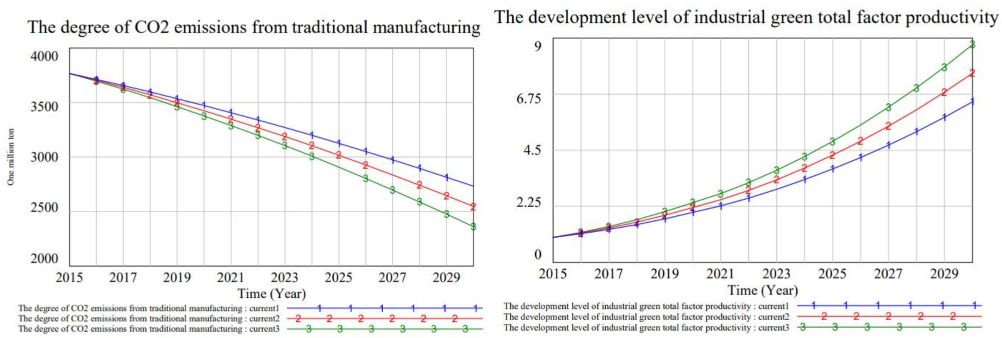

Figure 12 The trend of carbon dioxide emissions and industrial green total factor productivity under the impact of environmental regulation

The government should impose the environmental regulations according to the local conditions. The local governments will gradually raise investment and the threshold for market access, which affect positively on the GTFP and the green innovation level of the traditional manufacturing industry. The financial policies can be adjusted to provide additional funds for the intelligent upgrading of China’s manufacturing industry, which can meet the requirements of large-scale electrification, fuel and raw material substitution, equipment renewal and technology development. To promote the GTFP of enterprises, the intensity of environmental regulation should be appropriately increased, so that the pollution emissions can be monitored in real-time and minimize the pollution emissions in the production process. Enterprises should actively respond to government policies and enhance their social responsibility by establishing a long-term environmental protection strategy. Meanwhile, the public should participate in environmental governance and be encouraged to report violations, which provides public supervision channels.

5.2.2 Organizational resilience policy

As a measure of an enterprise's ability to cope with external uncertainties, organizational resilience plays a significant role in the green development of enterprises. Enterprises with high organizational resilience can reduce the consumption of enterprise innovation resource allocation, improve the innovation efficiency of enterprises and maintain long-term competitive advantages of enterprises, and also enable enterprises to respond faster to market changes by improving resource reconstruction capabilities. The trend of industrial GTFP and the degree of carbon dioxide emission of traditional manufacturing can be obtained by increasing organizational resilience, and the simulation results are shown in Figure 13.

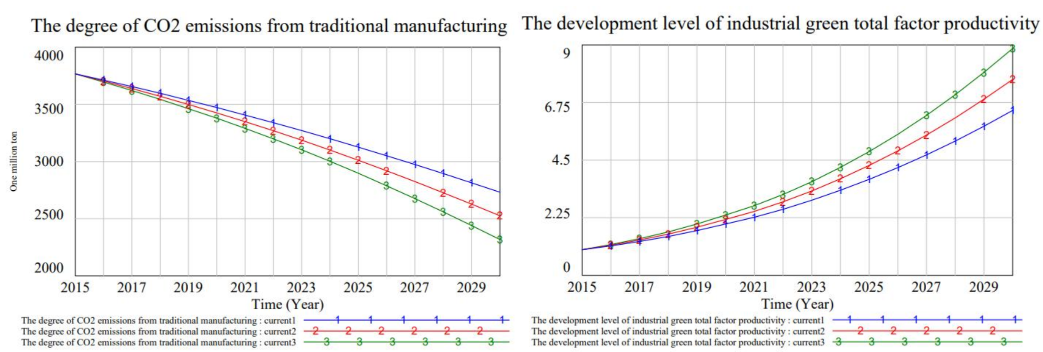

Figure 13 The trend of carbon dioxide emissions and industrial green total factor productivity under the impact of organizational resilience

Due to the most resource elements of the organization being reorganized and allocated, traditional manufacturing enterprises should enhance their organizational resilience ability by the energy supply and personnel training in digital literacy to cope with unknown risks in the green transformation process. Enterprises need to actively respond to government policies, give full play to their advantages and make up for their shortcomings according to their actual conditions, establish a long-term low-carbon and green development strategy, and enhance environmental social responsibility. At the same time, traditional manufacturing enterprises should increase the investment in human capital, adhere to talent training and talent introduction, and make full use of the factor endowment of human capital and green technology innovation, to accelerate the high-quality growth of China's manufacturing industry.

5.2.3 Technological innovation and standardization policy

The technological innovation capability can optimize the management pattern to improve the energy-intensive and high-pollution production processes. Technical standardization promotes the establishment of a green and low-carbon manufacturing technology system, forming a large number of extensive scenarios for the integration of energy-saving and emission-reducing technologies. The trend of industrial GTFP and the degree of carbon dioxide emissions of the traditional manufacturing industry are shown in Figure 14 by enhancing the technological innovation and technology standard capability.

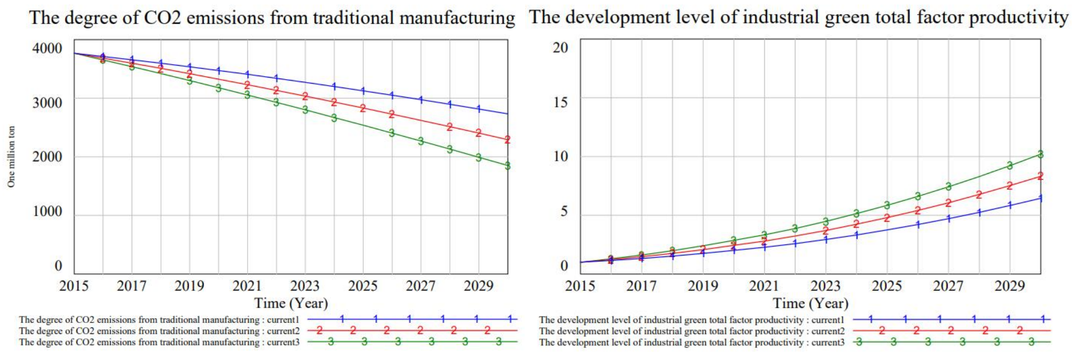

Figure 14 The trend of carbon dioxide emissions and industrial green total factor productivity under the impact of technological innovation and technology standard ability

Traditional manufacturing enterprises should utilize technological innovation and technical standards to strengthen the green digital transformation of enterprises in the digital economy era. The development and innovation of information technology such as big data and cloud computing, will broaden the access channels of digital technology for enterprises, realize the exchange and sharing of resources and information, promote the participation of digital technology in the management of the whole process of production and manufacturing. With the development of the dual carbon policy, the carbon market with unified industry standards should be formulated, the revision of relevant standards should be accelerated, the carbon quota scheme of different industries should be improved, and the traditional manufacturing industry should be accelerated to enter the carbon trading market, to give full play to the role of the market in low-carbon development. Relying on the large-scale market and the digital economy platform, China's traditional manufacturing enterprises promote the independence and coordination ability of green low carbon technology innovation system and the whole industrial chain integrated through the Internet applications.

6 Conclusion

The green transformation of the traditional manufacturing industry is an inevitable trend of the low-carbon development of China's society. Based on the TOE theory, this paper researches the mechanism and factors of green development of traditional manufacturing industry driven by digital technology. Furthermore, this paper constructs the causal loop diagram and stock and flow diagram based on SD, and applies the Vensim software to simulate the green development of the traditional manufacturing industry by adjusting the variable coefficient of the constructed SD model. According to the simulated results in the measure of carbon dioxide emissions from 2015 to 2030, the technological innovation policy is the highest, followed by environmental regulation and organizational resilience for the green development of the traditional manufacturing industry. Green technology determines the contribution of enterprises in low-carbon environmental protection, it is necessary to increase the supply of talent with digital skills, and leverage the synergistic effect of talents and green technological innovation for the green development of manufacturing to achieve China's "dual carbon" strategy.

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