Front. Bus. Res. China 2025, 19(4): 485–508
DOI 10.3868/s070-020-025-0020-8

CASE STUDY

Mechanism of Digital Empowerment in the Green Innovation Process of Manufacturing Enterprises: A Case Study*

HU Antao[a], ZHANG Zhengang[b, c], YE Baosheng[d]

Abstract

Based on the perspective of digital resource orchestration, this study uses Gree Electric Appliances Inc. of Zhuhai as a case study and adopts a longitudinal single-case study method to explore the digital empowerment mechanism within the green innovation process of manufacturing enterprises. The study finds the following three points. (1) The digital empowerment for green innovation has evolved through three developmental stages: the traditional green development stage, the digital-driven green advancement stage, and the digital-green integration stage. Across these stages, green innovation manifests in three dimensions: process innovation, product innovation, and organizational innovation. (2) The specific process of digital resource orchestration is digital resource structuring–digital resource bundling–digital resource greening, which can be implemented through three distinct variations: incremental, integrative, and embedded. (3) In the traditional green development stage, dominated by policy-driven factors, improvement-oriented digital resource orchestration leads to localized green process innovation. In the digital-driven green advancement stage, where market-driven factors dominate, integrative orchestration supports green innovation across the entire value chain. In the digital-green integration stage, dominated by strategy-driven factors, embedded orchestration empowers green innovation at both the organizational and industrial-ecosystem levels.

Keywords green innovation; digital technology; digital empowerment; digital resource orchestration; resource orchestration theory

1 Research Background

The report to the 20th National Congress of the Communist Party of China calls for continuing to focus on the real economy and for moving the manufacturing sector toward higher-end, smarter, and greener production (Xi, 2022, p.30). In January 2023, the China Academy of Information and Communications Technology released two white papers: the *White Paper on the Integrated Development of Industrial Digitalization and Green Transformation*

* This paper is translated from *Chinese Journal of Management* 管理学报, 2024, (9), 1265–1274.

[a] School of Business Administration, Jiangxi University of Finance and Economics, Nanchang 330032, China

[b] School of Business Administration, South China University of Technology, Guangzhou 510641, China

[c] Guangzhou Digital Innovation Research Center, South China University of Technology, Guangzhou 510641, China

[d] College of Economics and Management, Fujian Agriculture and Forestry University, Fuzhou 350108, China

(2022) and the *White Paper on the Collaborative Development of Digitalization and Green Transformation (2022)*. Both white papers argue that industrial integration of digitalization and greening is an intrinsic requirement, inevitable trend, and essential pathway for high-quality development. The rapid advancement of digital technologies such as big data and artificial intelligence (AI), coupled with the strategic goals of "carbon peak and carbon neutrality," creates a critical backdrop for in-depth research into how Chinese manufacturing enterprises can leverage digital empowerment for green innovation. Such exploration is essential to achieve high-quality sustainable development through digital-green integration, carrying significant practical value and theoretical importance (Cao et al., 2023; Dai & Yang, 2022).

The integration development of digitalization and green innovation is drawing growing interest among scholars worldwide. (1) Emerging digital tools are increasingly seen as indispensable to green innovation for enterprises because they can improve efficiency and effectiveness and reduce the cost and technical barriers that constrain traditional approaches (Cao et al., 2023). Most of the existing research examines whether digitalization improves green innovation performance. The studies, including Liu et al. (2023) and Dai and Yang (2022), show a significant positive effect. Yet these studies largely answer only the static question of whether such an effect exists and cannot answer the dynamic question of how it unfolds. This study uses the case study method to shed light on the enigmatic process behind that relationship. (2) Digital technology innovation itself represents a novel form of green innovation for enterprises, and deeper integration of digital and green technologies can yield new green products and services (Zhang et al., 2024) and expand the scope of green innovation (He et al., 2023). For instance, traditional appliance manufacturers can draw on digitalization to build smart green home systems that provide household-wide energy visualization and intelligent control. Industrial internet platforms now allow users, suppliers, and other external actors to join corporate green innovation efforts. These developments define new practices and new meaning for digital empowerment in green innovation, yet they are underexplored (Cao et al., 2023). This study therefore refines the concept of green innovation under digital empowerment and offers insights for enterprises. Particularly, there is a lack of research examining the phases or evolution of digitally empowered green innovation from a dynamic temporal perspective. Only Cao et al. (2023) and He et al. (2023) have examined this important theme. Whether different stages of digital empowerment yield distinct layers of green innovation remains unclear, as does the role of key digital resources such as technologies and platforms. Few studies explore the vertical dynamics of digital resource orchestration alongside its horizontal strategic approaches.

To address these theoretical gaps and respond to the national carbon peak and neutrality agenda and enterprises' strategic need for green innovation, this study examines Gree Electric Appliances Inc. of Zhuhai (hereinafter referred to as "Gree"), a Fortune Global 500 company in China's appliance industry. From the perspective of digital resource orchestration, this study aims to explore the dynamic evolution and internal mechanism of digital empowerment in green innovation in manufacturing enterprises, thereby providing theoretical guidance and empirical insights for their Chinese modernization and high-quality green innovation.

2 Literature Review

2.1 Green Innovation

Green innovation includes new or improved processes, products or services, procedures, and management practices. It adds value to customers and enterprises while easing environmental burdens, advancing both economic and ecological gains (Xie & Zhu, 2021). This study examines digital empowerment in green innovation at the enterprise level, organizing and reviewing the existing literature based on the fundamental logical framework of "antecedent–process-outcome."

First, research on antecedents has largely focused on institutional factors such as policy and market logics (Xie & Han, 2022), which fall under the broader category of external environmental factors (Guo et al., 2022; Qiao & Wen, 2023). Yet internal motivations for adopting digital technology to pursue green innovation remain understudied. This study considers both external and internal drivers and investigates whether these drivers vary across stages of digital empowerment in green innovation.

Second, research on outcomes tends to draw on green innovation concepts shaped in non-digital settings (Hu et al., 2023), with studies mainly categorized into parallel dimensions such as green process innovation and green product innovation (El-Kassar & Singh, 2019). Digital empowerment, however, introduces new dimensions. Enterprises can apply digital-intelligent transformation across R&D, production, supply, and after-sales services (Cao et al., 2023), while industrial internet platforms connect internal and external ecosystem actors in green innovation efforts (Dai & Yang, 2022). These aspects lie beyond the scope of traditional definitions and remain insufficiently explored. This study therefore aims to enrich and clarify what green innovation means in digitalized contexts.

Finally, research on the process of digital empowerment in green innovation seeks to uncover how enterprises use digital tools to advance green innovation, exploring both the dynamics and the mechanisms at work. This is the central concern of the present study. Most existing work relies on quantitative tests of whether digitalization benefits green innovation, yet such analyses rarely explain how that benefit is achieved. Only Cao et al. (2023) and He et al. (2023) use case studies to investigate this issue. Case studies are well suited to theory building and to tracing mechanisms, and rich case evidence offers more practical guidance for enterprises. Even so, detailed case studies of leading Chinese manufacturers and their digital empowerment in the green innovation processes remain limited.

2.2 Resource Orchestration Theory

Resource orchestration theory builds on the resource-based view, dynamic capabilities, and bricolage research to form a managerial framework that explains how leaders integrate, bundle, and deploy resources to build essential capabilities and secure competitive advantage (Cao et al., 2023; Sirmon et al., 2007). It outlines three core processes: resource structuring, resource bundling, and resource leveraging. It primarily elucidates the

transformation from resources to capabilities and then to action. The theory describes how enterprises accumulate valuable resources to form a resource pool, learn and integrate them to enhance key capabilities, and ultimately connect resources with capabilities to create value (Sirmon et al., 2007). Because resource orchestration theory integrates the resource-based view and dynamic capabilities, many scholars employ it to explain the dynamic mechanisms of corporate digital transformation, green transformation (Xie & Han, 2022), and data empowerment (Zhang & Dong, 2021). This theory also provides the theoretical grounding for this study.

Applied to digital contexts, resource orchestration theory yields the perspective of digital resource orchestration. This perspective helps explain the complex processes and internal mechanisms of digital empowerment in green innovation (Cao et al., 2023). It offers a way to investigate how digital tools empower green innovation and to illuminate the processes involved. Yet existing research still falls short in several areas. Firstly, prior work seldom emphasizes the distinct nature and importance of digital resources or the different roles they play in green innovation. Data, digital technologies, and digital platforms are now essential resources for manufacturers (Tian et al., 2022) in the era of the digital economy, though enterprises draw on them in different ways at different stages of digital empowerment in green innovation. This study focuses on how such resources empower green innovation through orchestration processes (He et al., 2023). Secondly, most studies treat resource orchestration as a single block rather than unpacking its detailed steps (Zhang et al., 2022). We still lack careful analysis of how manufacturers use essential digital resources to build appropriate digital capabilities and apply them to green practices. Following the "resource–capability–action" logic of resource orchestration, this study proposes a digital resource orchestration process that consists of digital resource structuring, digital resource bundling, and digital resource greening. Thirdly, clarifying the detailed processes alone is insufficient. Enterprises also need clear orchestration strategies that align with their green innovation goals, yet such strategies have received little attention. They must be derived from the patterns that emerge in enterprises' action choices. Guided by the antecedent–process–outcome logic of digital empowerment in green innovation, this study develops the theoretical analysis framework shown in Figure 1.

3 Research Design

3.1 Method

The case study method is well suited to theoretical questions that ask what, why, or how (Eisenhardt, 1989). This study examines how manufacturers harness digitalization to advance green innovation, focusing on the dynamics and mechanisms involved, which places it squarely in the "how" inquiry. Given that the phenomenon is relatively new, a single longitudinal case offers an effective way to extract underlying patterns and build theory inductively (Cao et al., 2023).

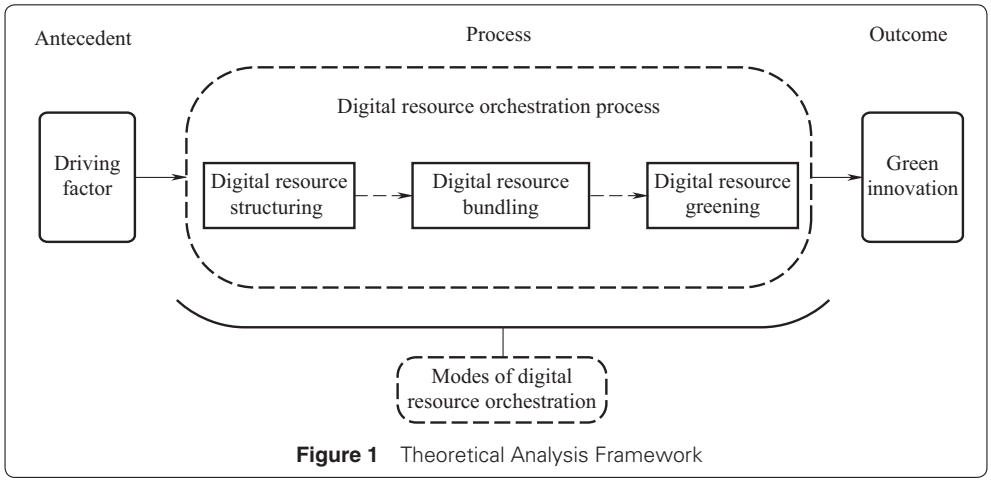

Figure 1 Theoretical Analysis Framework

3.2 Case Selection

Guided by principles of representativeness, theoretical sampling (Eisenhardt, 1989; Eisenhardt & Graebner, 2007), and data accessibility, the case company needs to meet several conditions. (1) It has to be an industry leader with strong capabilities in technological innovation and digitalization. (2) It also needs to show robust profitability and green innovation performance, which would help illustrate the enabling effect of digitalization. (3) Sustained access to the case company is essential, since meaningful casework requires long-term cooperation, longitudinal surveys, and extensive firsthand data. On this basis, the study selects Gree, a major player in the refrigeration and air conditioning industry, as the case for investigation.

3.3 Data Collection

This study benefits from a long-term collaboration with Gree through a deep industry-university-research cooperation, which enabled data collection over nine years from 2014 to 2022. The research team also worked with the company to publish two books, i.e., *The Gree Model* and *The Gree Quality Model*. The team leader served as Gree's chief management consultant, which provided broad and detailed access to internal files on strategy, digital transformation, and green innovation. Several rounds of extensive interviews were carried out with the chairperson, senior executives, key middle managers, and technology experts. Data collection combined interviews, archival materials, and observation in line with established practice provided by Eisenhardt (1989) and Eisenhardt and Graebner (2007). Interviewees mainly included senior and middle managers or experts who were closely involved in processes, procedures, products, technology, and organizational innovation, as well as digital transformation and green innovation.

3.4 Data Analysis

For data coding and analysis, the study follows grounded theory procedures (Glaser et al., 1968) and applies a structured approach that requires each insight to be firmly rooted in the data. The process moves from first-order concepts to second-order themes and then to aggregated dimensions (Gioia et al., 2013). After the research team reached agreement on the core themes of driving factors, green innovation, and digital resource orchestration, coding was carried out in stages and refined iteratively. To reduce the risk of subjective bias, coders worked in two groups of three and coded independently. Their results were compared, and any inconsistencies were resolved through repeated discussion until the coding most consistent with the case was identified. Through open, axial, and selective coding, the final data structure emerged as shown in Figure 2.

4 Research Findings

4.1 Three Stages of Digital Empowerment in Green Innovation at the Case Company

This study categorizes Gree's digital empowerment in green innovation into three stages: the traditional green development stage (1994–2012), the digital-driven green advancement stage (2012–2020), and the digital-green integration stage (2020–present). Founded in 1991, Gree introduced its management information system (MIS) in 1994, marking the beginning of its initial informatization efforts and its push for energy conservation and emissions reduction. Gree places strong emphasis on digital intelligence and platform development. It now has 15 research units, including a computer center, big data center, and internet of things (IoT) research institute, along with four national-level R&D centers, more than 900 laboratories, and nearly 12,000 R&D staff. Gree's digital development can be summarized in three basic processes: informatization, digital-intelligent transformation, and platformization, which correspond to the three major stages of digital empowerment in green innovation (see Figure 3).

Traditional green development stage (1994–2012): Gree relied on informatization to strengthen green process innovation. Before 2012, the company advanced localized green innovation in material, production, and product through the integration of industrialization and informatization, achieving regulatory compliance and gains in energy conservation and emissions reduction. This phase focused on the successive introduction of MIS, manufacturing execution system (MES), and other information systems, representing the early stage of digital transformation and characterized as "informatization + green process."

Digitalization-driven green advancement stage (2012–2020): Gree used digital intelligence to promote green procedure innovation. In 2012, the company began applying big data and successively introduced supercomputing simulation, IoT, cloud computing, and integrated digital intelligent platforms that linked systems such as supply chain management (SCM), product lifecycle management (PLM), customer relationship management (CRM), enterprise resource planning (ERP), advanced planning and scheduling (APS), and MES. By applying cloud computing, IoT, big data, and AI across the entire R&D, production, supply, and after-sales

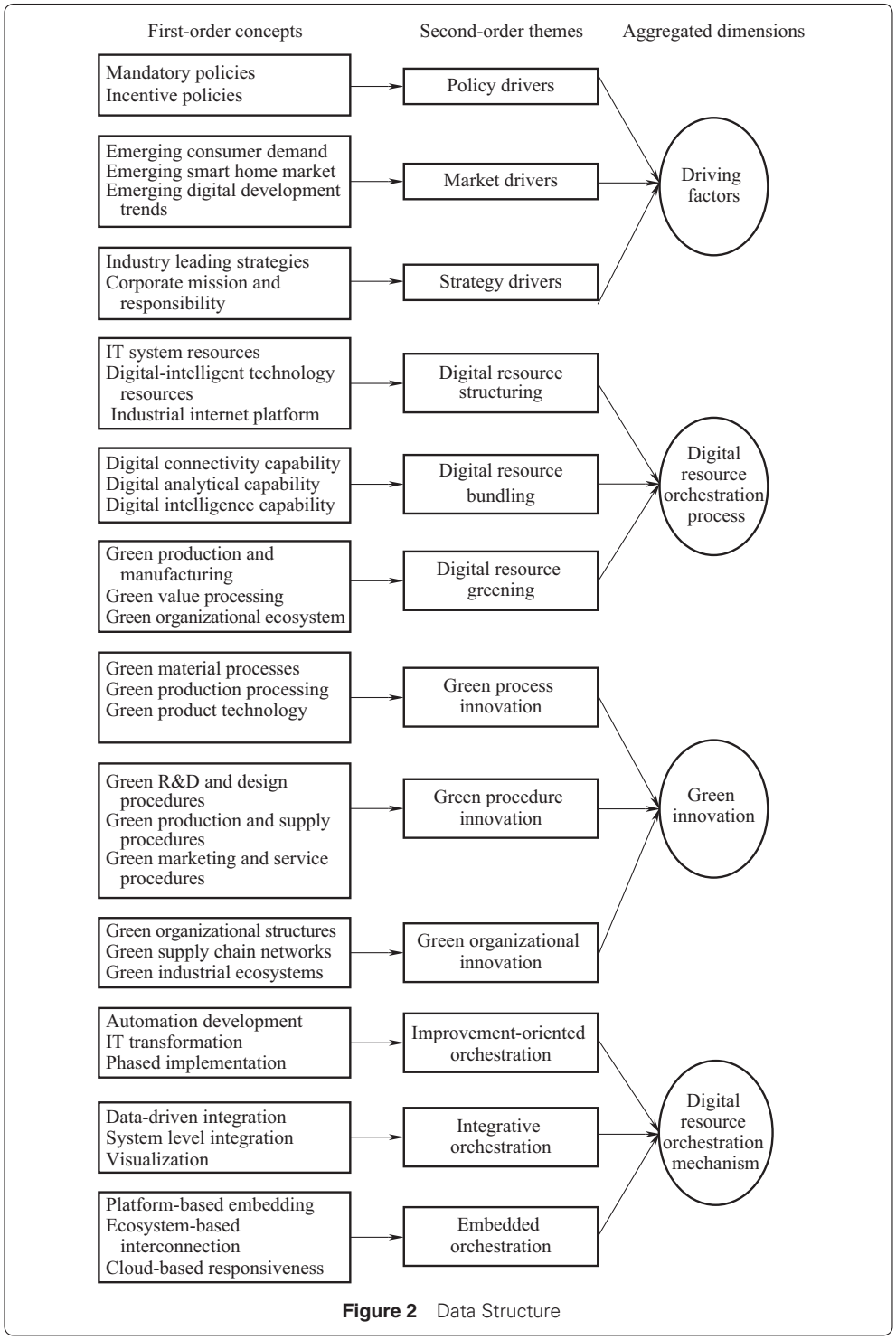

Figure 2 Data Structure

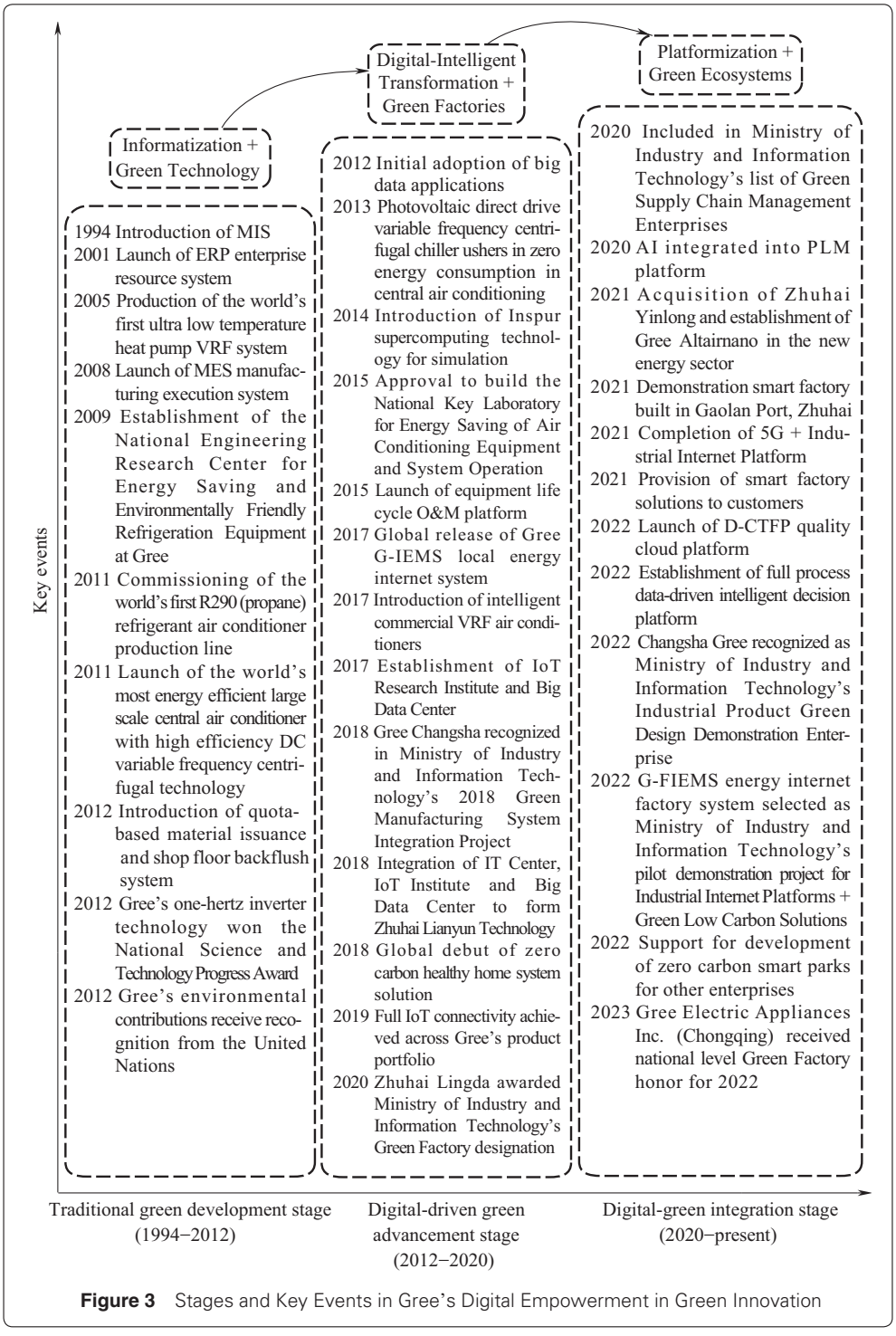

Figure 3 Stages and Key Events in Gree's Digital Empowerment in Green Innovation

value chain, Gree deepened the integrated use of digital and green technologies, processes, and equipment. This stage is marked by "digital-intelligent transformation + green factories."

Digitalization-green integration stage (2020–present): Gree is now using platform-based

development to foster green organizational innovation. Since 2020, the company has moved toward platform and ecosystem strategies, launching its 5G + Industrial Internet Platform, the D-CTFP quality cloud platform, and data-driven decision platforms. Building on earlier digital intelligence, Gree has created an industrial internet platform with vertical and horizontal integration and strong internal-external connectivity. This stage reflects "platformization + green ecosystems," representing a more advanced form of green innovation. Gree remains in an exploratory phase but plans to deepen digital green integration development and build an intelligent green industrial ecosystem.

4.2 Traditional Green Development Stage

4.2.1 Policy Drivers

In the traditional green development stage, government regulatory compliance policies were a key factor for enterprises in formulating and implementing green innovation strategies, with policy-driven green innovation adhering to the institutional logic (Xie & Han, 2022). Government policies primarily consist of mandatory policies and incentive-based policies. Mandatory policies mainly involve environmental protection regulations, such as the *Atmospheric Pollution Prevention and Control Law of the People's Republic of China (2018 Amendment)*, while incentive policies are primarily manifested as government subsidies. In the early stages, Gree's green innovation practices were predominantly driven by policies, including environmental regulations, carbon emission policies, and subsidy schemes.

4.2.2 Digital Resource Orchestration Process and Improvement-Oriented Orchestration Mechanism

During this stage, digital resource orchestration followed the sequence of structuring–bundling–greening. This involved developing IT system resources, creating digital connectivity, and using these capabilities to support greener production. The orchestration mechanism took an improvement-oriented form.

The process began with building information systems that enabled the sensing, capturing, and connection of production line data (Lenka et al., 2017). These systems supported green practices on the shop floor. ERP, MES, and similar IT systems were the core digital resources available to Gree at this stage. Digitization and digitalization laid the groundwork for digital transformation: Production information was encoded so that computers could store, process, and transmit it (Vial, 2019). These steps allowed Gree to build data collection and connectivity capabilities that supported real-time monitoring and early warning of environmental pollution, reinforcing green practices in production.

The orchestration mechanism was improvement-oriented, meaning optimization was localized and incremental. This took the form of automation development, IT transformation, and phased implementation. Gree placed high importance on production automation development and strengthened its ability to develop and manufacture automated equipment. With careful informatization planning, the company continued to integrate informatization

and automation. It upgraded production lines through targeted breakthroughs and phased rollouts, thereby supporting green technology innovation.

4.2.3 Green Process Innovation

In this stage, Gree's green innovation was centered on technology improvements. With environmental protection and energy efficiency as its goals, the company used digital resource orchestration to support green innovation in specific areas, including material processing, production processes, and product technology. IT system development strengthened online monitoring across the shop floor. Wastewater, exhaust gas, noise, and solid waste were treated properly and discharged in line with standards. Environmental facilities ran as required, emissions met regulatory limits, and no pollution incidents occurred. In 2009, Gree's R290 refrigerant air conditioner broke the technological monopoly of developed countries in next-generation refrigerants. The breakthrough had far-reaching implications for environmental protection and marked the first time a Chinese company had reached the global frontier in research and application of new refrigerant technology. In 2012, Gree's one-hertz inverter technology won the National Science and Technology Progress Award and became a flagship example of energy-saving and environmentally friendly innovation in the air conditioning industry. These achievements show that Gree's early green innovation efforts were largely localized yet firmly aligned with a commitment to green development.

Typical evidence of Gree's digital empowerment in the green process innovation mechanism during this stage is presented in Table 1.

Table 1 Typical Evidence for the Mechanism of Digital Empowerment in the Green Innovation Process in the Traditional Green Development Stage

Second-order code	First-order code	Representative quotations and evidence
Policy drivers	Mandatory policies	Strictly complying with environmental laws and regulations, and with reference to the ISO 14001 environmental management system standard, the company established an internal environmental management system to manage environmental protection in a systematic way, ensuring that all emissions meet environmental protection standards.
	Incentive policies	"Taking the energy-saving subsidy policy in the air conditioning industry as an example, a higher subsidy is granted for lower energy consumption."
Digital resource orchestration process	IT system resources	Building on the introduction of MIS in 1994, the company subsequently put the ERP system online in 2001 and the MES and other information systems online in 2008.
	Digital connectivity capability	The information platform could support real-time data collection for 2,000 nodes on the production site.

(*To be continued*)

(*Continued*)

Second-order code	First-order code	Representative quotations and evidence
Digital resource orchestration process	Green production and manufacturing	IT systems were used to carry out online automatic monitoring and early warning of exhaust gas, wastewater, and solid pollutants in the production process.
Improvement-oriented orchestration mechanism	Automation development	An automation development strategy had been formulated. In line with automation needs, Automation Office, Automation Equipment Manufacturing Department, and the Automation Technology Research Institute had been established in succession, vigorously advancing mechanization and automation upgrades in production.
	IT transformation	"Through the automation strategy and informatization strategy, we accelerate intelligent manufacturing." Informatization Committee headed by Chairwoman Dong Mingzhu was established to speed up planning and construction of informatization and the integration of informatization with automation.
	Phased implementation	Following the idea of targeted breakthroughs and phased rollouts, automated machinery systems had been gradually established across final assembly, supporting processes, and warehousing and logistics.
Green process innovation	Green material processing	Gree actively carried out research on environmentally friendly alternative process technologies and using refrigerants such as R290, R32, R134, and R410 to replace R22, thereby reducing damage to the atmospheric ozone layer.
	Green production processes	Gree treated wastewater generated during pre-treatment on the coating production line and replacing the highly polluting phosphating process with a conversion coating process, which resolved the issue of phosphates.
	Green product technology	"Over the long term, Gree has taken product quality, with energy saving and environmental protection as important indicators, as the cornerstone of the company's survival and development and has made energy saving and environmental protection key measures for building and enhancing the company's product brand."

4.3 Digital-Driven Green Advancement Stage

4.3.1 Market Drivers

In this stage, compared with policy drivers, market drivers became the dominant factor prompting the company to implement green innovation (Xie & Han, 2022). This was mainly reflected in new consumer demand for energy-saving, environmentally friendly, intelligent, healthy, and comfortable air conditioning products; the broad market prospects for smart

green homes; and advancements in emerging digital technologies such as big data, IoT, cloud computing, and AI. At the same time, the new national standards for air conditioner energy efficiency also exerted an influence. Market-driven green innovation also follows institutional logic (Xie & Han, 2022).

4.3.2 Digital Resource Orchestration Process and Integrative Orchestration Mechanism

In this stage, digital resource orchestration again followed the sequence of structuring–bundling–greening. Gree built a pool of digital-intelligent technology resources, developed digital analytical capabilities, and used these capabilities to green the entire value chain. The orchestration mechanism in this phase is integrative.

The first step was to structure digital resources by creating a pool of key technologies and assets (Zhang & Dong, 2021). For Gree, this meant introducing, absorbing, and applying emerging digital technologies such as big data, IoT, cloud computing, and AI. Concurrently, the establishment of key digital and intelligent entities, including the IoT Research Institute, the Big Data Center, the Smart Manufacturing Office, and Lianyun Technology, had laid a solid foundation for Gree to accelerate its digital transformation and upgrading, thereby driving green innovation development through digitalization and intelligence (Cardinali & de Giovanni, 2022). Building on earlier gains in digital connectivity, Gree then reconstructed its digital analytical capability, in particular its capacity to integrate, aggregate, and analyze heterogeneous big data from multiple internal and external sources. This capability was central to enabling green innovation. For example, the company developed a GPRS-based IoT big data platform for air conditioners that could capture and analyze usage data from hundreds of millions of Gree units in real time, derive optimal energy-saving operating profiles, and push them to users on a regular basis. By assembling this pool of digital-intelligent technology resources and strengthening digital analytics, Gree was able to support green practices across the full green design–green manufacturing–green recycling value flow. The focus thus shifted from isolated process improvements, typical of the traditional green development stage, to green transformation along the entire internal value chain.

The orchestration mechanism itself is integrative in both vertical and horizontal dimensions. Vertically, it integrates the decision chain from top management through departments, factories, and workshops down to individual production lines and pieces of equipment. Horizontally, it links the value chain from R&D and design, through material supply and manufacturing, to marketing and after-sales services. A big data platform underpins this integration by consolidating data, connecting business systems for system-level integration, and visualizing the consumption of water, electricity, gas, and other resources. At its core, the integrative mechanism combines digital intelligent technologies with green, low-carbon technologies, using digital intelligence to power the green innovation process.

4.3.3 Green Procedure Innovation

During this stage, Gree shifted its green innovation efforts toward procedures. Aiming to build intelligent green factories and smart, environmentally friendly home systems, the company used digital resource orchestration to support green innovation along the entire internal value chain, from R&D and design through production and supply, marketing and service, to resource recovery. It developed smart green factories and the Zero-Carbon Healthy Home system. In 2018, Changsha Gree was selected by the Ministry of Industry and Information Technology for its Green Manufacturing System Integration Project and, in the same year, earned national Green Factory status. In 2020, Zhuhai Lingda was also added to the national Green Factory list. These milestones signal substantial progress in Gree's digital empowerment in green innovation and formal recognition at the national level. Also in 2018, at the China International Intelligent Industry Expo, Gree unveiled the Zero-Carbon Healthy Home solution, which integrates and orchestrates five systems—household energy, air, health, security, and lighting—into a single, scenario-based, and systematic control platform and allows users to visualize the energy status of the entire home. Gree has also linked resource regeneration and circular economy development with its corporate social responsibility agenda, working to create a closed-loop green value chain that runs from product design and manufacturing to end-of-life recycling and treatment.

During this stage, typical evidence of Gree's digital empowerment in the green procedure innovation mechanism is presented in Table 2.

Table 2 Typical Evidence on the Mechanisms of Digital Empowerment in Green Procedure Innovation in the Digital-Driven Green Advancement Stage

Second-order code	First-order code	Representative quotations and evidence
Market drivers	Emerging consumer demand	As household consumption upgrading accelerates, consumers are placing higher demands on brand recognition and product quality. At the same time, new standards have emerged for the energy-saving performance, health, comfort, and intelligence of air conditioners, and demand for product replacement and upgrading is strong.
	Emerging smart home market	"Recently, orders for smart photovoltaic air conditioners have been pouring in. They are not only from China; there are even more orders from abroad. This shows that people everywhere long for environmentally friendly and energy-saving products."
	Emerging digital development trends	The world is facing a new round of scientific and technological revolution and industrial transformation, which is a major historical opportunity. Digitalized, networked, and intelligent manufacturing are the core technologies driving revolutionary change in the manufacturing sector.

(*To be continued*)

(*Continued*)

Second-order code	First-order code	Representative quotations and evidence
Digital resource orchestration process	Digital-intelligent technology resources	Since 2012, Gree has gradually experimented with big data. In 2014, it adopted Inspur supercomputing for simulation work and has since continued to introduce AI and 5G technologies.
	Digital analytical capability	"Based on the big data collected, the intelligent service center can analyze product operating conditions in real time, predict potential problems, and make maintenance service easier. We even hope it can automatically sense the customer's state and intelligently adjust the product to the parameters that are most comfortable."
	Green value process	Gree innovatively proposed a circular value model of "Green design—Green manufacturing—Green recycling" and in 2018 launched its green and low carbon Gree-Zero Carbon Healthy Home.
Integrative orchestration mechanism	Data-driven integration	Gree has built its own big data platform, which, via smart meters, automatically collected, analyzed, alerted, and applied data on energy use, carbon emissions, and pollutant discharges.
	System-level integration	Gree has further integrated SCM, PLM, CRM, ERP, APS, and MES platforms with the big data platform, creating interconnection along the value chain from R&D and production to supply and after-sales service.
	Visualization	Through its GIEMS energy management system, Gree could visualize real-time energy consumption at the level of production lines and individual pieces of equipment.
Green procedure innovation	Green R&D and design procedures	Rooted in the principles of health, energy-saving and environmental protection, Gree has pursued an environmentally friendly path from the outset of product design. As a result, many of its products have been listed as green design products by the Ministry of Industry and Information Technology.
	Green production and supply procedures	"We have an innovation system for intelligent manufacturing and will establish a number of innovation and research centers to support it. At the same time, intelligent manufacturing must operate within a green manufacturing environment."
	Green marketing and service procedures	Gree has developed its own intelligent cloud platform and set up multiple cloud service centers worldwide to serve users quickly. Through the Gree+ app, users could control all products intelligently and enjoy smart services, saving resources and cutting pollution.

4.4 Digital-Green Integration Stage

4.4.1 Strategic Drivers

In this stage, strategic considerations come to the fore. After China announced in September 2020 that it would aim to peak carbon emissions by 2030 and reach carbon neutrality by 2060, Gree deliberately tied its corporate trajectory to national priorities, aligning the country's green development agenda with the company's own sustainability strategy. The deeper push into green innovation is driven above all by a sense of corporate mission and a desire for industry leadership. Building on policy and market forces grounded in institutional logic, Gree anchors the idea of green innovation in its vision, mission, and values. Chairwoman Dong Mingzhu has stressed that a company should not only create profits and promote its own development, but also proactively shoulder the social responsibility of fostering green consumption awareness and advancing the low-carbon economy.

4.4.2 Digital Resource Orchestration and the Embedded Orchestration Mechanism

In this stage, digital resource orchestration again follows the sequence of structuring–bundling–greening. Gree develops industrial internet platform resources, builds digital intelligence capabilities, and uses them to green its organizational ecosystem. The orchestration mechanism in this phase is embedded in nature.

The core task is to construct a digital platform that links the company with its wider ecosystem. Platform development allows Gree to cross organizational boundaries, facilitate information flows and knowledge exchange between organizations, and foster a collaborative, symbiotic ecosystem (Zhou & Cheng, 2021). Its efforts center on a 5G + Industrial Internet Platform and the G-FIEMS energy internet platform. These platforms in turn support the development of digital intelligence capabilities, visible both in internal decision-making and in the external provision of intelligent solutions. By embedding AI into the industrial internet platform and relying on comprehensive sensing of industrial data, real-time transmission, and advanced modelling and analysis, Gree has developed intelligent decision and control capabilities. At the same time, it offers system solutions for smart factories and zero-carbon smart parks to customers in sectors such as automotive, electronics, and electromechanical equipment. The ultimate aim is a thorough green transformation of internal operations, the creation of unified green standards across the supply chain, and the shaping of a broader green ecosystem that supports the development of a green industrial system.

The orchestration mechanism is embedded in two senses. It features platform embedding, ecosystem interconnection, and cloud-based responsiveness. Within Gree, the 5G + Industrial Internet Platform incorporates digital platforms for all major modules, including R&D and design, production and manufacturing, supply and logistics, marketing and service, and organizational management. Externally, it connects dynamic data from suppliers, distributors, retailers, end users, and industry bodies. The result is a green ecological network that links upstream and downstream actors and aligns internal and external collaboration. In this way, embedded orchestration extends

the integration achieved along the internal value chain outward to the supply chain, industrial chain, and ecosystem chain.

4.4.3 Green Organizational Innovation

In this stage, Gree directs its green innovation efforts toward organizational transformation. With the twin goals of building green parks and a green industrial ecosystem, the company uses digital resource orchestration to support green innovation in operations and management, supply chain collaboration, and ecosystem collaboration. Its industrial internet and energy internet platforms have delivered substantial gains in green organizational innovation. Gree has first developed an international demonstration industrial zone that combines intelligence, environmental protection, energy-saving, and high efficiency. In October 2021, for example, it launched the Hangzhou Asian Games low-carbon hydrogen electric coupling demonstration project. The initiative cuts annual carbon emissions by 860 tons, reduces energy consumption per unit of output in the park by about 22 % and lowers the daily load on the main power grid from 6,400 kW to 5,010 kW. Within the park, power is generated cleanly, stored safely, used efficiently, and managed intelligently. The company has also built a green supply chain network. Through a supply chain internet platform and an innovative "3 Excellence + 1 Support" supply chain management model (excellent quality, price, supply, and mutual support with Gree), expert teams provide supporting suppliers with green process technologies and green quality management practices. This strengthens supply chain coordination, reduces material waste, and encourages green material selection, green procurement, and green warehousing and transport. Finally, Gree seeks to shape a wider green industrial ecosystem. It actively supplies green, low-carbon technologies and solutions to external partners and, via its industrial internet platform, offers services to a large number of small and medium-sized enterprises along the industrial and ecosystem chains. The platform now serves more than 6,000 enterprises, and its industrial applications provide dedicated services to over 100 of them.

Typical evidence of the mechanism of Gree's digital empowerment in green organizational innovation in the digital-green integration stage is presented in Table 3.

Table 3 Typical Evidence for the Mechanism of Digital Empowerment in Green Organizational Innovation Process in the Digital-Green Integration Stage

Second-order code	First-order code	Representative quotations and evidence
Strategy drivers	Industry-leading strategies	"As the world's largest air-conditioner manufacturer, Gree must shoulder the important responsibility of leading industry development and strive to contribute to global energy-saving efforts and to improving the living environment of humankind. As a representative of national enterprises, we should have a broader vision, for only by standing higher can we see further."

(*To be continued*)

(*Continued*)

Second-order code	First-order code	Representative quotations and evidence
Strategy drivers	Corporate mission and responsibility	"To become a century-old enterprise, a company must be willing to assume social responsibility and must never pursue development at the expense of environmental damage and resource waste. Especially under the current national context of promoting a new development philosophy, low-carbon and environmental protection are development principles that every enterprise must follow. For modern enterprises to achieve sustainable development, they must follow the path of energy saving and environmental protection."
Digital resource orchestration process	Industrial internet platform resources	In 2021, with the goal of "1 platform, 1 standard architecture, and 18 domain systems," Gree coordinated the group's digital construction resources to build the 5G + Industrial Internet Platform.
	Digital intelligence capability	Gree's industrial internet platform achieves intelligent decision-making and control through comprehensive and in-depth sensing of industrial data, real-time dynamic transmission, and advanced modelling and analysis.
	Green organizational ecosystem	Under the low-carbon philosophy, Gree not only promotes the low-carbon transformation of its own production and business activities but also provides more zero-carbon technologies, products, equipment, and system solutions for partners upstream and downstream in the industrial chain, as well as for society at large.
Embedded orchestration mechanism	Platform-based embedding	Smart factories across the country are integrated into both the industrial internet platform and the energy internet platform, while some suppliers, distributors, and other partners are connected primarily to the industrial internet platform.
	Ecosystem-based interconnection	The system guides enterprises along the industrial chain to accelerate the migration of business and equipment to the cloud, promoting data interconnection and capability collaboration among enterprises on the chain. The platform serves more than 6,000 enterprises, and its industrial applications have already provided dedicated services to over 100 enterprises.
	Cloud-based responsiveness	Gree's industrial internet architecture adopts a cloud-native platform architecture, which will drive the establishment of a cloud service collaboration system for the home appliance manufacturing industry and foster linkage and resource integration along the upstream and downstream of the sector.

(*To be continued*)

(*Continued*)

Second-order code	First-order code	Representative quotations and evidence
Green organizational innovation	Green organizational structures	Gree's Zhuhai base has been recognized by the Ministry of Industry and Information Technology as a Pilot Demonstration Project for Industrial Internet Platforms + Green Low Carbon Solutions.
	Green supply chain network	By building a supply chain internet platform, Gree disseminates advanced and environmentally friendly component testing methods to upstream suppliers, encouraging them to improve quality, enhance supply chain collaboration, reduce material waste, and promote green material selection, green procurement, and green warehousing and transportation.
	Green industrial ecosystems	Gree has been approved to build the Guangdong Energy Internet Innovation Center. Operating under a Company + Innovation Alliance model, the center conducts research and technological breakthroughs in distributed energy internet systems and green, low-carbon technologies.

5 Discussion

Drawing on the case evidence, this study examines how digitalization empowers the dynamic evolution of green innovation in manufacturing enterprises. It uncovers how digital resource orchestration, across different stages of green innovation, supports distinct layers of green innovation outcomes. On this basis, the study develops a theoretical framework that elucidates the process mechanisms of digital empowerment in green innovation (see Figure 4).

5.1 Analysis of the Stage Perspective and Level Perspective of Digital Empowerment in Green Innovation

5.1.1 Stage Perspective

The stage perspective can intuitively reflect the "concentration" of green innovation in manufacturing enterprises (Wang et al., 2021), that is, the shift from the early "light green" to "deep green," and further to "ink green" (Xie & Han, 2022). The darker the shade, the deeper the integration of digital and green technologies. Digital-green integration represents a higher stage and points to the future direction and trend of development. Gree is currently in a phase of deepening digital-driven green advancement while still exploring digital-green integration. Gree plans to continue advancing digital-green integration, aiming to build a green and smart industrial ecosystem and enhance the depth and sophistication of green innovation to a greater extent and a higher level.

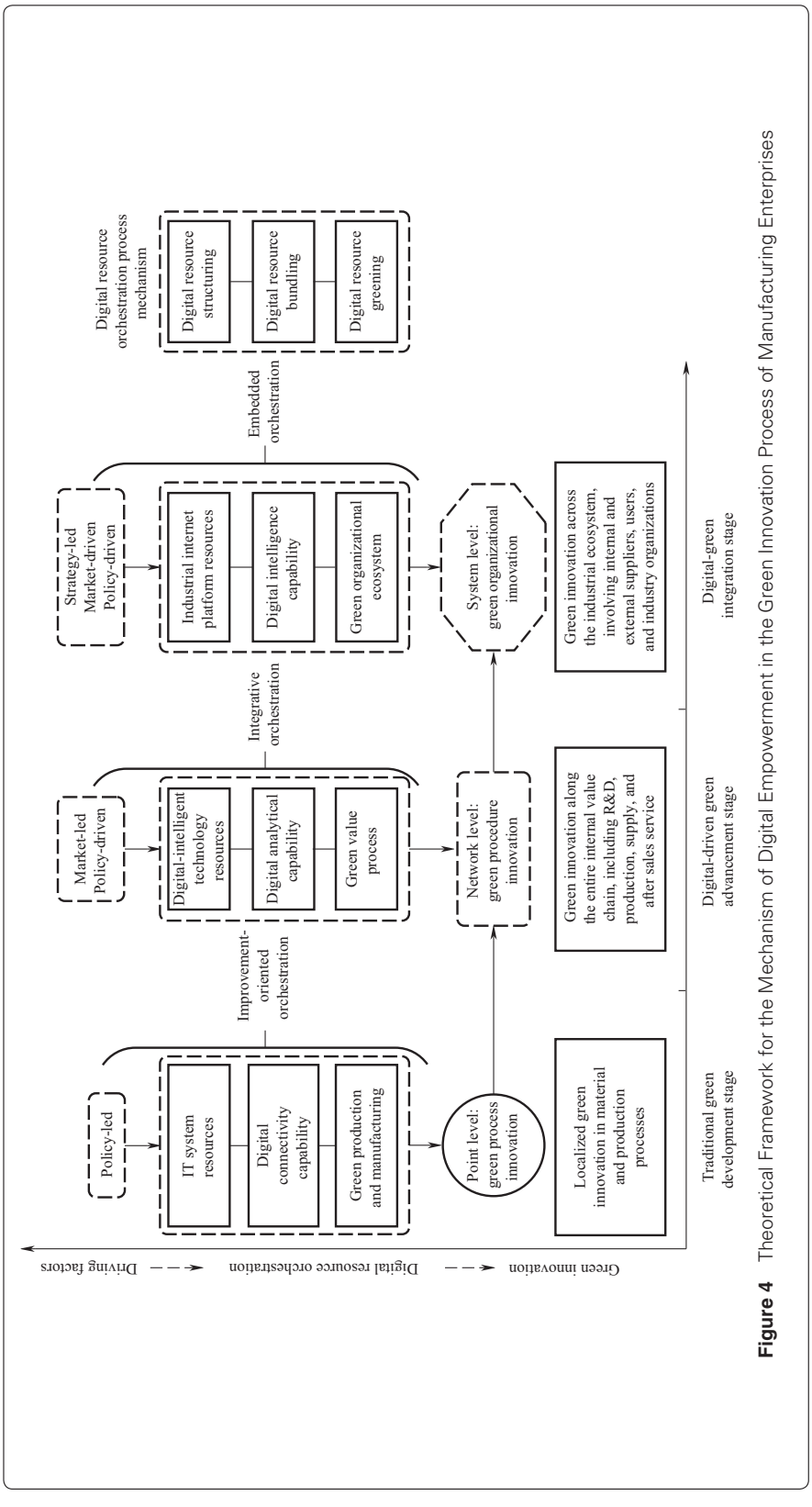

Figure 4 Theoretical Framework for the Mechanism of Digital Empowerment in the Green Innovation Process of Manufacturing Enterprises

5.1.2 Level Perspective

The level perspective is manifested in the fact that manufacturing enterprises implement different levels of green innovation practices at different stages, that is, moving from green process innovation in local production links, to green procedure innovation across the entire product life cycle, and then to higher level green organizational innovation across the whole industrial ecosystem. From the perspective of strategic fit, the level of green innovation in manufacturing enterprises matches the stage of development. The analysis of the Gree case shows that the path by which manufacturing enterprises use digital resource orchestration to empower green innovation mainly follows the route of single-point breakthrough–system integration–ecosystem embedding, reflecting the development idea and direction of extending from a point to the process and then to the whole system.

5.1.3 Digitalization

The digitalization of manufacturing enterprises can be summarized into three stages: informatization, digital-intelligent transformation, and platformization (Verhoef et al., 2021). IT system resources belong to informatization and mainly convert original manual methods into computer-based and data-based methods. The in-depth application of emerging technologies represented by big data, IoT, and cloud computing embodies digital-intelligent transformation, which changes the situation of data islands and fragmented systems in the original informatization stage and empowers vertical integration and horizontal aggregation across the entire value chain. Building industrial internet platforms belongs to a higher stage, namely platformization, which can realize inter-organizational resource collaboration, capability collaboration, and value co-creation (Cao et al., 2023).

5.2 Analysis of the Processes and Mechanisms of Digital Resource Orchestration

5.2.1 Digital Resource Orchestration Process

The orchestration process follows the basic logic of resource–capability–actions (Sirmon et al., 2007; Zhang & Dong, 2021). It extends the classic framework of resource structuring–bundling–leveraging into the context of digital empowerment in green innovation. Digital resource structuring centers on building the resource base, namely acquiring and accumulating valuable internal and external digital resources. Prior work has seldom underlined how distinctive and critical digital resources are. Yet IT systems developed during informatization, emerging technologies such as big data, cloud computing, IoT, and AI deployed in the digital-intelligent stage, and industrial internet platforms built in the platformization stage are all core digital resources for green innovation. For manufacturers, pooling and integrating these assets is the starting point for bundling and subsequent greening. Digital resource bundling addresses the question of what capabilities are actually being empowered. It follows the typical progression of digital capabilities, from sensing to cognition to decision making (Zhang & Dong, 2021), with different focal points at different stages of green innovation. In

the traditional green development stage, the emphasis is on informatization, so the ability to sense, capture, and connect data on the production line is vital. In the digital-driven green advancement stage, the adoption of big data technology allows enterprises to integrate, aggregate, and analyze heterogeneous data from multiple internal and external sources. In the digital-green integration stage, industrial internet platforms give enterprises internal intelligent decision-making capacity and the external ability to deliver intelligent solutions. These essential capabilities significantly empower the implementation of green innovation practices. Digital resource greening refers to the application of digital resources and digital capabilities to green innovation itself. The required resource and capability base varies by stage and level of green innovation. Green organizational innovation in the digital-green integration stage is a higher-order form of digital resource greening, which depends on developing industrial internet platform resources and digital-intelligent capabilities to support green innovation with collaboration across organizations and throughout the industrial ecosystem.

5.2.2 Digital Resource Orchestration Mechanisms

Digital resource orchestration mechanisms explain the strategies and modes through which manufacturers use digitalization to empower green innovation. Existing studies pay limited attention to these modes and mostly focus on the process of orchestration (Zhang et al., 2022). From the Gree case, this study inductively identifies three mechanisms: improvement-oriented, integrative, and embedded orchestration. They illustrate the unity of means and ends. Different levels of green innovation call for different orchestration strategies. To achieve green organizational innovation, for example, enterprises must build an industrial internet platform that empowers inter-organizational connectivity, making an embedded orchestration mechanism indispensable. The three digital resource orchestration strategies proposed here therefore offer theoretical guidance for manufacturing enterprises seeking green innovation at different stages and levels of development.

6 Conclusion

This study makes three main theoretical contributions. First, it clarifies the dynamic evolutionary mechanism of digital empowerment in green innovation within manufacturing enterprises. On this basis, the study develops an analytical framework that integrates the "drivers of green innovation, processes and modes of digital resource orchestration, and green innovation outcomes." This framework helps answer, from a temporal perspective, the critical question of how digitalization actually empowers green innovation. It responds directly to the call by Cao et al. (2023) and He et al. (2023) to unpack the internal mechanisms of digital drivers of green innovation. Second, it broadens the concept of green innovation by introducing stage and level perspectives on digital empowerment in green innovation, organized around the logic of from a point to the process and then to the whole system. Unlike earlier work that largely examines non-digital contexts and focuses mainly on green

practices inside the company (Xie & Zhu, 2021), this study incorporates emerging practices now widespread in industry (He et al., 2023), such as green smart products, digital-intelligent green factories, and green innovation ecosystems built on industrial internet platforms (Yu & Chen, 2023). In doing so, it extends He et al.'s (2023) research on the evolution of enterprises' green innovation strategies and deepens Xue and Han's (2022) discussion of the multidimensional, multi-level nature of green innovation under digital conditions. Third, it offers a framework for both the processes and modes of digital resource orchestration and clarifies how key digital resources play different roles at different stages of digital empowerment in green innovation.

The study also yields several practical implications. Digital-intelligent transformation and platformization are essential routes for manufacturers seeking digital empowerment in green innovation. Enterprises should strengthen the combined use of cloud computing, IoT, big data, and AI (Zhang et al., 2024), achieving vertical integration of decision chains and horizontal integration of value chains. Industry leaders can then build interconnected, ecosystem-collaborative industrial internet platforms that drive integrated digital and green development across the wider industrial ecosystem. In advanced manufacturing clusters such as high-end equipment, intelligent vehicles, and smart homes, there is a need to build mechanisms through which large, medium, and small enterprises can pursue digital empowerment in green innovation together. A pattern in which leading enterprises build the platforms and smaller enterprises join them can accelerate green development across the whole industry cluster.

The study is subject to certain limitations. The longitudinal analysis rests on a single case, Gree, which inevitably constrains generalizability. Although the case is both typical and representative, manufacturing spans many industries with distinct features. Future work could therefore conduct multi-case studies within the smart home appliance sector, bringing in enterprises such as Midea and Haier, and could extend the analysis to other segments such as automotive and equipment manufacturing. In addition, the theoretical framework of digital empowerment in green innovation proposed here would benefit from large-sample empirical testing. Subsequent studies could refine the measurement of key constructs, including the processes and mechanisms of digital resource orchestration and the various dimensions of green innovation.

Acknowledgments This paper is supported by the Major Project of the National Social Science Fund of China (No. 18ZDA062).

References

Cao, Y., Li, X., & Hu, H. (2023). How does digitalization drive the green transformation of manufacturing enterprises? An exploratory case study from the perspective of resource orchestration theory. *Journal of Management World*, (3), 96–112 (曹裕, 李想, 胡韩莉 (2023). 数字化如何推动制造企业绿色转型?——资源编排理论视角下的探索性案例研究. 管理世界, (3), 96–112).

Cardinali, P. G., & De Giovanni, P. (2022). Responsible digitalization through digital technologies and green practices. *Corporate Social Responsibility and Environmental Management*, (4), 984–995.

Dai, X., & Yang, S. (2022). Digital empowerment, sourcing digital input, and green manufacturing. *China Industrial Economics*, (9), 83–101 (戴翔, 杨双至 (2022). 数字赋能、数字投入来源与制造业绿色化转型. 中国

工业经济, (9), 83–101).

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, (4), 532–550.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, (1), 25–32.

El-Kassar, A., & Singh, S. K. (2019). Green innovation and organizational performance: The influence of big data and the moderating role of management commitment and HR practices. *Technological Forecasting and Social Change*, (1), 483–498.

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational Research Methods*, (1), 15–31.

Glaser, B. G., Strauss, A. L., & Strutzel, E. (1968). The discovery of grounded theory: Strategies for qualitative research. *Nursing Research*, (4), 555–556.

Guo, L., Liu, Y., & Liu, G. (2022). An empirical study on the relationship between environmental regulation, green innovation, and environmental pollution. *Chinese Journal of Management*, (6), 892–900 (郭凌军, 刘嫣然, 刘光富 (2022). 环境规制、绿色创新与环境污染关系实证研究. 管理学报, (6), 892–900).

He, Z., Kuai, L., & Wang, J. (2023). Driving mechanism model of enterprise green strategy evolution under digital technology empowerment: A case study based on Zhejiang enterprises. *Business Strategy and the Environment*, (1), 408–429.

Hu, H., Fei, M., & Wang, Y. (2023). The realization process of corporate green innovation in the context of green transformation: A case study of Zhengbang. *Science and Technology Progress and Policy*, (5), 84–95 (胡海波, 费梅菊, 王怡琴 (2023). 绿色转型情境下企业绿色创新实现过程: 正邦案例研究. 科技进步与对策, (5), 84–95).

Lenka, S., Parida, V., & Wincent, J. (2017). Digitalization capabilities as enablers of value co-creation in servitizing firms. *Psychology & Marketing*, (1), 92–100.

Liu, X., Liu, F., & Ren, X. (2023). Firms' digitalization in manufacturing and the structure and direction of green innovation. *Journal of Environmental Management*, (3), 117525.

Qiao, F., & Wen, W. (2023). Research on the impact of social credit system reform on corporate green innovation. *Chinese Journal of Management*, (8), 1189–1197 (乔菲, 文雯 (2023). 社会信用体系改革对企业绿色创新的影响研究. 管理学报, (8), 1189–1197).

Sirmon, D. G., Hitt, M. A., & Ireland, R. D. (2007). Managing firm resources in dynamic environments to create value: Looking inside the black box. *Academy of Management Review*, (1), 273–292.

Tian, H., Li, Y., & Zhang, Y. (2022). Digital and intelligent empowerment: Can big data capability drive green process innovation of manufacturing enterprises? *Journal of Cleaner Production*, (3), 134261.

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Dong, J. Q., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research*, (1), 889–901.

Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *Journal of Strategic Information Systems*, (2), 118–144.

Wang, Y., Chen, H., Long, R., Li, W., & Wang, L. (2021). Evaluating green development level of mineral resource-listed companies: Based on a "dark green" assessment framework. *Resources Policy*, *71*, 102012.

Xi, J. (2022). *Hold high the great banner of socialism with Chinese characteristics and strive in unity to build a modern socialist country in all respects—Report to the 20th National Congress of the Communist Party of China (October 16, 2022)*. People's Publishing House (习近平 (2022). 高举中国特色社会主义伟大旗帜 为全面建设社会主义现代化国家而团结奋斗——在中国共产党第二十次全国代表大会上的报告 (2022-10-16). 人民出版社).

Xie, X., & Han, Y. (2022). How can local manufacturing enterprises achieve "magnificent transformation" in green innovation? A multi-case study based on the attention-based view. *Journal of Management World,*

(3), 76–106 (解学梅, 韩宇航 (2022). 本土制造业企业如何在绿色创新中实现“华丽转型”?——基于注意力基础观的多案例研究. 管理世界, (3), 76–106).

Xie, X., & Zhu, Q. (2021). How can green innovation solve the dilemmas of “harmonious coexistence”? *Journal of Management World*, (1), 128–149 (解学梅, 朱琪玮 (2021). 企业绿色创新实践如何破解“和谐共生”难题? 管理世界, (1), 128–149).

Yu, F., & Chen, J. (2023). The impact of industrial internet platform on green innovation: Evidence from a quasi-natural experiment. *Journal of Cleaner Production*, (1), 137645.

Zhang, P., & Dong, K. (2021). How manufacturing enterprises achieve data empowerment: A case study based on the digital factory of Kinco. *Journal of Management Case Studies*, (6), 698–712 (张培, 董珂隽 (2021). 制造企业如何实现数据赋能——基于步科数字工厂的案例研究. 管理案例研究与评论, (6), 698–712).

Zhang, Y., Sun, X., & Qian, Y. (2022). Value creation and evolution in digital transformation of traditional manufacturing enterprises: A longitudinal case study based on resource orchestration. *Business Management Journal*, (4), 116–133 (张媛, 孙新波, 钱雨 (2022). 传统制造企业数字化转型中的价值创造与演化——资源编排视角的纵向单案例研究. 经济管理, (4), 116–133).

Zhang, Z., Hu, A., & Ye, B. (2024). How digital innovation of manufacturing enterprises promotes firm performance. *Science and Technology Progress and Policy*, (11), 44–54 (张振刚, 户安涛, 叶宝升 (2024). 制造企业数字创新如何促进企业绩效提升. 科技进步与对策, (11), 44–54).

Zhou, W., & Cheng, Y. (2021). How do digital platforms construct value co-creation organizations through boundary spanning? *R&D Management*, (6), 31–43 (周文辉, 程宇 (2021). 数字平台如何通过边界跨越构建价值共创型组织? 研究与发展管理, (6), 31–43).