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How Do Energy-Intensive Enterprises Achieve Digital–Green Synergy? Evidence from Conch Cement

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Abstract

This study examines how digital–green synergy evolves within energy-intensive enterprises through a longitudinal case of Conch Cement. Using annual reports and ESG disclosures from 2016 to 2025, an enterprise-level evaluation system is developed and analyzed with the entropy weight method, coupling coordination model, and longitudinal case analysis. The results show that digital and green transformation followed different trajectories but became increasingly coordinated over time. Green capability developed earlier, while digital capability accumulated gradually and became more deeply embedded in production and environmental management. The transformation can be characterized by three stages: green capability accumulation, digital capability embedding, and digital–green integration. The case further indicates that environmental demands stimulate the adoption of digital technologies, while accumulated digital capability strengthens production control, resource allocation, and green management. These interactions gradually reshape the relationship between digitalization and greening from relatively separate activities into a more integrated capability system. The findings provide an enterprise-level explanation of the evolutionary process underlying digital–green synergy in energy-intensive industries.

Keywords

Digital–green Synergy; Digital Transformation; Green Transformation; Energy-intensive Enterprises; Conch Cement.

1. Introduction

For cement producers, decarbonization is not simply an environmental issue. Energy use, production efficiency, and emission control are closely tied to the operation of the production system itself. Under China's "Dual Carbon" targets, this creates a difficult task for energy-intensive firms: environmental performance has to improve without weakening production efficiency or operational stability.

Digitalization offers one possible way to address this tension, but its role is not fixed. In practice, technologies such as artificial intelligence, the Industrial Internet of Things, cloud platforms, and data analytics may first be introduced for production monitoring, equipment management, or operational control. Their environmental value becomes more visible only when these technologies are connected with energy use, resource allocation, and green management. Digital transformation and green transformation therefore need not begin at the same time, nor do they necessarily progress at the same pace.

This temporal difference has received relatively limited attention in the existing literature. Research has established that digitalization can affect green innovation and environmental performance, and a growing body of work has measured digital–green coordination at regional

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and industrial levels. What remains less clear is how coordination is formed inside a firm when the two capabilities have different starting points. For an energy-intensive manufacturer, green investment and environmental governance may already be established before digital capability becomes an important part of production. The central issue is thus not only whether digitalization supports greening, but how the relationship between the two changes as the firm develops new capabilities.

Conch Cement provides a useful setting for examining this process. Its public disclosures from 2016 to 2025 record changes in environmental governance, intelligent manufacturing, digital management, and low-carbon practices over a sufficiently long period to observe changes in their relationship. The case is particularly relevant because green development was more visible in the earlier years, whereas digital capability expanded later and became increasingly involved in production and environmental management.

Using annual reports and ESG disclosures over this ten-year period, this study evaluates the development of the two subsystems through the entropy weight method and coupling coordination model, and then interprets the observed changes through longitudinal case analysis. The analysis focuses on how an initially uneven pattern develops into closer coordination. In this way, the study treats digital–green synergy as an evolving enterprise capability rather than as a static coordination score.

2. Literature Review

2.1. Digital–Green Synergistic Transformation

2.1.1. Enterprise Digital Transformation

The meaning of digital transformation in manufacturing has gradually moved beyond technology adoption. Information systems, automated equipment, and other digital tools remain important, but recent studies place greater emphasis on the organizational changes that accompany their use. Strategy, learning, and resource reconfiguration are therefore treated as part of the development of digital capability rather than as outcomes that occur after technology investment [1][2].

This distinction matters for traditional manufacturing firms. Digital applications are often introduced separately at first and only later become connected with production management and decision-making. As firms accumulate experience and technical resources, information transparency, production coordination, and operational efficiency may improve [3]. Digital capability, in this sense, is built over time rather than created through a single investment decision.

Most of this literature, however, has been concerned with what digital transformation does for the firm. Its role changes when environmental objectives are introduced. A technology initially used to monitor equipment or coordinate production may later become part of energy management or green production. The question relevant to this study is therefore not simply whether digitalization improves firm performance, but when digital capability begins to serve environmental objectives in an energy-intensive production system.

2.1.2. Research on Enterprise Green Transformation

Green transformation in energy-intensive firms also involves more than pollution treatment. Changes in production technology, energy use, resource allocation, and organizational arrangements are part of the process [4]. This makes green transformation particularly demanding in industries where environmental performance cannot be separated easily from the way production is organized.

External pressure is an important part of this process, but it does not determine the result on its own. Environmental regulation and low-carbon requirements may create incentives for

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change, whereas technological and managerial capabilities affect how firms respond. For this reason, green transformation may begin with environmental investment and pollution control but later extend into production and operational management.

Digital tools have become increasingly relevant at this point. Information collection, production monitoring, and resource allocation can make environmental management more closely connected with ongoing production activities [5][6]. This creates a different relationship between the two transformations: digitalization is no longer only a source of efficiency improvement, while green development is no longer confined to environmental expenditure. What remains less clear is how this relationship develops over time when green capability and digital capability are accumulated at different speeds.

2.1.3. Research on Digital–Green Synergistic Transformation

Research on digital–green synergy brings these two streams together. A common view is that digitalization can support energy management, production control, resource allocation, and carbon monitoring, while environmental objectives may create additional demand for digital technologies and infrastructure [7][8][9]. The relationship is therefore potentially two-way rather than a simple case of digitalization producing green outcomes.

The literature has approached this relationship from different angles. One group of studies measures the degree of coordination between digital and green development, often through indicator systems and coupling coordination models [10]. Another examines the effects of digital transformation on green innovation and related outcomes, including the possibility that green innovation can also stimulate further digital development [11].

These approaches clarify whether digital and green development are related and how strongly they are coordinated, but they provide less evidence on the formation of that coordination within a firm. A regional or industry-level score, for example, cannot show whether green capability appeared before digital capability, whether one capability created demand for the other, or how their functions changed as integration deepened. These temporal questions are central to the present study because the Conch Cement case covers a period in which the two forms of transformation did not begin from the same level.

2.2. Research on Transformation of Energy-Intensive Enterprises

The transformation problem is more pronounced in energy-intensive industries because production depends heavily on energy and natural resources. Technological upgrading alone is therefore unlikely to be sufficient. Changes in production processes and organizational management are also required when firms attempt to reduce environmental impacts while maintaining production performance [12].

Cement production provides a useful context for observing this tension. The industry combines high energy consumption, substantial carbon emissions, and continuous production processes. Its transformation has moved beyond conventional energy conservation and pollution treatment toward broader forms of green manufacturing and low-carbon production [13]. As a result, production optimization and environmental management increasingly need to be considered together.

Conch Cement offers a longitudinal setting in which this shift can be observed. Its disclosed practices cover intelligent manufacturing, digital management, environmental governance, and green production over an extended period. More importantly for this study, these activities did not appear at the same time. Examining their sequence makes it possible to observe how digital capability became connected with an already developing green transformation process.

2.3. Research on Coupling Coordination Degree Model

The coupling coordination degree model is commonly used when two related systems need to be assessed together. Its main advantage is that it considers both the development of each

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subsystem and the degree to which the two move in coordination [14]. This makes it applicable to digital–green research, where improvement in one dimension does not necessarily imply balanced development in the other [15].

For the Conch Cement case, the model is used to identify changes in the relative development of digital and green transformation over 2016–2025. The resulting coordination degree provides a quantitative description of whether the two subsystems are moving closer together or further apart.

The model, however, does not explain the organizational processes behind these changes. The same coordination value may arise from different combinations of digital and green development, and the numerical result alone cannot identify why a shift occurs. For this reason, the coupling coordination analysis is used here as a starting point rather than as the complete explanation. Longitudinal case evidence is then introduced to interpret the stages and mechanisms associated with the observed changes.

3. Indicator System Construction and Research Methods

3.1. Construction of the Indicator System

The measurement is organized around two dimensions, digital transformation and green transformation. Because the study follows one firm over ten years, the main concern in selecting indicators is whether the same information can be traced consistently from 2016 to 2025. Indicators were therefore retained only when they were relevant to the two dimensions, measurable from public disclosures, and available for most or all of the observation period.

Two variables are used for the digital dimension. Digital strategic orientation (D1) is derived from the occurrence of digitalization-related terms in the MD&A section, while the proportion of technical employees (D2) is used to represent the firm's technical workforce. The two variables capture different aspects of digital development: one reflects managerial attention and the other reflects the personnel base available for technical activities.

The green dimension is measured in a similar way but uses different information. Green strategic orientation (G1) is based on the frequency of green-development terms disclosed in annual reports. Environmental investment intensity (G2), calculated relative to operating revenue, records the resources committed to environmental protection.

The four selected indicators therefore provide a more comparable basis for tracing long-term changes in strategy, capability development, and resource allocation.

The final indicator system is shown in Table 1.

Table 1. Indicator System for Digital–Green Synergy Evaluation in Conch Cement

Subsystem	Indicator	Direction	Measurement
Digital transformation	Digital strategic orientation (D1)	+	Natural logarithm of the frequency of digital transformation-related keywords identified from the MD&A section of annual reports
	Proportion of technical employees (D2)	+	Technical employees / Total employees
Green transformation	Green strategic orientation (G1)	+	Logarithm of the frequency of green transformation-related keywords in annual reports (MD&A section)
	Environmental investment intensity (G2)	+	Environmental protection expenditure intensity = Environmental protection expenditure / Operating revenue

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Several commonly used indicators, including energy consumption per unit of output, carbon emission intensity, and the number of green patents, were excluded from the evaluation because consistent longitudinal data were unavailable in Conch Cement's publicly disclosed reports. Instead, the selected indicators provide more stable and continuous observations of changes in strategic orientation, capability development, and resource allocation, making them more appropriate for tracking the long-term evolution of digital–green synergy.

3.2. Determination of Indicator Weights

To reduce the influence of subjective judgment, this study adopts the entropy weight method to determine indicator weights. Unlike subjective weighting approaches, the entropy method derives weights from the variation observed in the data. Indicators with greater dispersion contain more information and therefore receive higher weights.

This method is appropriate for the present study because the dataset contains continuous observations of Conch Cement from 2016 to 2025. The purpose is to trace changes in digital and green transformation over time rather than to rank indicators according to theoretical importance. A data-driven weighting approach therefore provides a consistent basis for longitudinal comparison.

The weighting procedure includes five steps:

Step 1. Data normalization

All indicators are positive and are normalized to eliminate differences in measurement units.

Step 2. Calculation of indicator proportions

The normalized values are converted into proportions for each indicator.

Step 3. Calculation of information entropy

The entropy value of each indicator is calculated to measure the amount of information contained in the data.

Step 4. Calculation of divergence coefficients

The divergence coefficient is obtained from the entropy value and reflects the discriminatory ability of each indicator.

Step 5. Determination of indicator weights

The final weights are calculated according to the divergence coefficients. Indicators containing more useful information receive higher weights.

3.3. Indicator Weight Results

Table 2. Entropy Weight Results of Evaluation Indicators

Subsystem	Indicator	Entropy Value (e)	Divergence Coefficient (g)	Weight (w)
Digital transformation	Digital strategic orientation (D1)	0.7459	0.2541	0.5113
Digital transformation	Proportion of technical employees (D2)	0.7571	0.2429	0.4887
Green transformation	Green strategic orientation (G1)	0.8799	0.1201	0.2875
Green transformation	Environmental investment intensity (G2)	0.7024	0.2976	0.7125

The two digital indicators receive almost equal weights. D1 accounts for 0.5113 and D2 for 0.4887, a difference of only 0.0226. The digital index is therefore not dominated by either strategic wording in corporate reports or the share of technical employees; both contribute similar amounts of information to the ten-year series.

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The distribution is less even for the green indicators. G2 carries a weight of 0.7125, whereas G1 accounts for 0.2875. Under entropy weighting, this gap should be read as a difference in variation across the sample years rather than as evidence that environmental expenditure is theoretically more important than green strategy. Environmental investment intensity changed more sharply during 2016–2025 and consequently had greater influence on the calculated green index.

3.4. Coupling Coordination Degree Model

Digital and green development are first calculated as separate subsystem scores and are then evaluated jointly. This allows changes in each dimension to be distinguished from changes in their coordination. The digital transformation score, denoted by (U1), is obtained from Eq. (1):

$$\mathrm{U}_1 = \sum_{\mathrm{j}=1}^{\mathrm{m}} \mathrm{w}_\mathrm{j}\, \mathrm{X}_\mathrm{j} \tag{1}$$

where U1 is the composite score for the digital transformation subsystem..

The green transformation development index is calculated as:

$$U_2 = \sum_{j=1}^{m} w_j\, X_j \tag{2}$$

where U2 represents the green transformation development index.

The coupling degree between the two subsystems is calculated as:

$$C = \left[\frac{U_1 U_2}{\left((U_1+U_2)/2\right)^2}\right]^{1/2} \tag{3}$$

where C represents the interaction intensity between digitalization and green transformation.

The comprehensive development index is expressed as:

$$T = \alpha U_1 + \beta U_2 \tag{4}$$

Considering that digitalization and green transformation play equally important roles in enterprise transformation, this study assigns:

$$\alpha = \beta = 0.5 \tag{5}$$

The coupling coordination degree is then calculated as:

$$D = \sqrt{C \times T} \tag{6}$$

where D represents the level of digital–green synergy. A higher value of D indicates stronger coordination between digital transformation and green transformation.

Based on previous studies, the coordination levels are classified as follows.

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Table 3. Classification of Coupling Coordination Degree

D Value Range	Coordination Level
0–0.20	Severe imbalance
0.20–0.30	Moderate imbalance
0.30–0.40	Near imbalance
0.40–0.50	marginal coordination
0.50–0.60	Primary coordination
0.60–0.75	Good coordination
0.75–1.00	High-quality coordination

3.5. Measurement Results of Digital–Green Synergy

Table 4. Digital–Green Synergy Evaluation Results for Conch Cement (2016–2025)

Year	Digital Index (U1)	Green Index (U2)	Coupling Degree (C)	Comprehensive Index (T)	Coupling Coordination Degree (D)	Coordination Level
2016	0	0.8563	0	0.4281	0	Severe imbalance
2017	0.1192	0.7423	0.6906	0.4307	0.5454	Primary coordination
2018	0.0518	0	0	0.0259	0	Severe imbalance
2019	0.0869	0.0510	0.9656	0.0689	0.2580	Moderate imbalance
2020	0.2748	0.1046	0.8937	0.1897	0.4117	marginal coordination
2021	0.2826	0.2297	0.9947	0.2561	0.5048	Primary coordination
2022	0.3564	0.2144	0.9686	0.2854	0.5258	Primary coordination
2023	0.5353	0.3493	0.9777	0.4423	0.6576	Good coordination
2024	0.6865	0.2930	0.9157	0.4897	0.6697	Good coordination
2025	0.8102	0.3613	0.9237	0.5858	0.7356	Good coordination

Several features of the series are worth noting. The digital index remained below 0.12 through 2019, but the pattern changed after 2020. It reached 0.5353 in 2023 and 0.8102 by 2025. The green index followed a much less regular path. Its values were relatively high in 2016 and 2017, dropped sharply in 2018–2019, and then recovered gradually, reaching 0.3613 in 2025.

The coordination measure is also unstable in the earlier years. (D) rose to 0.5454 in 2017, fell to zero in 2018, and returned to 0.2580 and 0.4117 in 2019 and 2020. From 2021 onward, the changes were more consistent: the value increased from 0.5048 to 0.7356 by 2025. Under the classification adopted in Table 3, the observations for 2023–2025 fall within the good-coordination range.

These numerical results establish the temporal pattern used in the following case analysis. Section 4 examines the firm-level developments associated with the changes rather than repeating the index movements reported here.

4. Evolution Analysis of Digital–Green Synergy in Conch Cement

4.1. Evolution of Digital–Green Synergy Development

4.1.1. Evolution of Digital and Green Development Levels

The two dimensions did not move in parallel during the observation period. Green development was already visible in the early years, whereas the digital dimension remained limited. This difference is consistent with the sequence observed in Conch Cement's practices: environmental governance and energy-saving activities were established before digital systems became widely involved in production management.

A noticeable change occurred after 2019. Earlier digital initiatives were concentrated mainly on information infrastructure and production automation. Later applications extended into intelligent production, management platforms, and data-based operational control. The change is therefore better understood as an expansion in the function of digital technology rather than simply an increase in the digital index. Digital tools gradually became part of production optimization and resource allocation.

The green series is less regular. Its relatively high values in 2016–2017 correspond to the company's early emphasis on environmental protection, while the sharp decline in 2018–2019 should be interpreted with caution. Because the green index is constructed from strategic disclosure and environmental investment, year-to-year changes also reflect variation in these indicators and should not automatically be treated as equivalent changes in actual environmental performance. After 2020, the green index recovered as green governance became more closely connected with production and management activities.

The important feature of the two trajectories is therefore their different timing. Green-related practices provided the earlier basis for transformation, while digital capability developed later and gradually acquired functions relevant to environmental management. This temporal mismatch provides the starting point for the stage analysis below.

4.1.2. Analysis of Coupling Coordination Degree Evolution

The coordination results should not be read as a simple upward trend. The early values are highly unstable: the coordination degree reached the primary-coordination range in 2017 but returned to zero in 2018. This fluctuation indicates that the two subsystems had not yet developed a stable relationship. A relatively strong value in a single year was therefore insufficient to establish sustained digital–green coordination.

The pattern became more consistent after 2019. During 2019–2022, intelligent manufacturing and digital management were increasingly connected with production activities that also affected energy and resource use. The coordination measure rose accordingly, although the two subsystems still developed at different speeds. From 2023, all three observations fall within the good-coordination range reported in Table 4.

For this reason, the coordination degree is used here together with corporate practices rather than as a stand-alone basis for interpretation. The numerical results indicate when the relationship changed; the longitudinal evidence is used to identify what changed inside the firm.

4.2. Identification of Evolutionary Stages

4.2.1. Basis for Stage Identification

The stage boundaries are not assigned mechanically from the thresholds of the coupling coordination degree. Two types of evidence are considered together: changes in the digital and green indices, and the practices reported by Conch Cement in its annual and ESG disclosures. The first shows whether the two dimensions moved closer together, while the second helps identify changes in the role played by digital technology.

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On this basis, three periods can be distinguished. During 2016–2018, green practices were more developed than digital applications. Between 2019 and 2022, digital technologies became more closely involved in production and green management. From 2023 onward, digital and green activities were increasingly addressed within the same operational and management processes. These periods are described as green capability accumulation, digital capability embedding, and digital–green integration.

Table 5. Evolutionary Stages of Digital–Green Synergy in Conch Cement

Stage	Period	Synergistic Characteristics	Main Practices	Key Events
Green capability accumulation stage	2016–2018	Green development leading, digital support limited	Environmental governance, green mining, waste heat utilization	Initial ESG disclosure in 2016; digital mining exploration in 2017
Digital capability embedding stage	2019–2022	Digital technologies supporting green production	Smart factories, digital production systems	Smart factory recognized as a digital transformation case in 2020; ESG management system established in 2021
Digital–green integration stage	2023–2025	Deep integration of digital and green capabilities	Intelligent manufacturing, digital carbon management, ESG practices	Carbon management practices promoted in 2024; digital intelligence supporting energy conservation in 2025

4.2.2. Green Capability Accumulation Stage (2016–2018)

The first period is characterized by a clear imbalance between the two dimensions. Environmental governance had already become part of Conch Cement's operations, while the digital side remained comparatively limited. The practices reported for this period-environmental governance, green mining, waste-heat utilization, and resource recycling-show that the main transformation effort was directed toward environmental and energy-related issues.

Digital activity was present, but its scope was narrower. Production automation, basic information systems, and the exploration of digital mining did not yet amount to a digital production system covering the firm's wider operations. Their relevance becomes clearer when viewed against the increasing information requirements of environmental management. More detailed monitoring and production control created a problem that conventional management and stand-alone equipment could not fully address.

The significance of this period therefore lies less in the level of digitalization itself than in the conditions it created for subsequent digital adoption: green management needs were becoming more demanding before digital capability had matured.

4.2.3. Digital Capability Embedding Stage (2019–2022)

The second period differs from the first because digital technologies began to enter routine production decisions. Conch Cement's disclosures during 2019–2022 refer to artificial intelligence, the industrial internet, intelligent management platforms, and smart-factory applications. Digitalization was no longer confined to infrastructure or isolated automation.

Smart mining illustrates this change. Monitoring, production scheduling, and resource management increasingly relied on digital information, allowing production conditions to be observed and adjusted during operation. This brought digital technology into activities that were also relevant to energy use, resource efficiency, and environmental management.

The term embedding is used here deliberately. Digital capability had begun to influence green production, but it still operated mainly through specific production and management

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applications. Digital and green objectives had not yet become fully integrated at the strategic level.

4.2.4. Digital–Green Integration Stage (2023–2025)

The third period shows a broader overlap between digital and green management. From 2023 to 2025, the company's reported applications extended across intelligent manufacturing, energy management, carbon governance, and ESG-related activities. Table 4 places each of these years in the good-coordination range, but the more important change concerns where digital capability was being used.

Digital systems were increasingly involved in decisions that combined production and environmental objectives. Energy use, carbon management, production control, and management information were no longer treated only as separate technical tasks. Their connection meant that improvements in digital capability could affect environmental management directly, while new environmental requirements also increased the need for data and digital infrastructure.

This distinguishes integration from the preceding embedding stage. In the earlier period, digital technology mainly supported particular green or production activities; in the later period, digital and green considerations increasingly entered the same management processes.

4.3. Evolutionary Pathway of Digital–Green Synergy

The three periods reveal a change in the function of digital capability. Environmental management initially created problems that required better information and control; digital applications were then introduced into production to address part of that demand. Once those applications became established, digital and green objectives began to overlap in a wider range of operational and management decisions. The evolutionary pathway is therefore defined by changes in how the two capabilities are connected, rather than by simultaneous growth in their index values.

4.3.1. Green Demand-Driven Pathway

For energy-intensive enterprises, environmental requirements often provide the initial impetus for digital–green transformation. In the case of Conch Cement, green development during 2016–2018 preceded the accumulation of digital capability. The company's early efforts focused on environmental governance, energy conservation, resource recycling, and green mining.

The turning point in this period was a management constraint rather than the introduction of a particular digital technology. As environmental activities expanded, managers needed more frequent information on production conditions and greater control over operating processes. Equipment investment and experience-based management could address individual environmental problems, but they were less suited to continuous monitoring and adjustment. The resulting information gap created a practical reason to introduce digital tools into subsequent production and environmental management.

4.3.2. Digital Capability Embedding Pathway

During 2019–2022, the role of digital technology changed from providing basic information support to supplying information used in production control. Intelligent manufacturing systems, production data platforms, and equipment-management applications brought operating data into day-to-day decisions.

This mattered for green transformation because equipment status, energy use, production conditions, and resource allocation could now be considered together during production. Problems could be identified earlier and operating parameters adjusted on the basis of current information rather than managerial experience alone. Environmental management therefore became more closely connected with the production process itself.

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At this point, however, digital capability was still mainly embedded in particular operational activities. Its contribution to green development came through improved monitoring and production control rather than through a fully integrated digital–green management system.

4.3.3. Digital–Green Integration Pathway

By 2023 – 2025, the issue was no longer simply whether digital tools could assist individual green activities. Conch Cement's reported applications placed digital technology across intelligent manufacturing, energy management, carbon governance, and ESG-related management. Digital and environmental considerations were therefore appearing in a broader set of common operational and strategic decisions.

This stage differs from the previous one in the role of digital capability. During the embedding stage, digital technologies mainly supported specific production and environmental activities. In the integration stage, digital and green objectives increasingly influenced the same operational and strategic decisions. Energy optimization, carbon management, and low-carbon production required more extensive data infrastructure, while these environmental requirements also created further demand for digital upgrading.

The relationship therefore became increasingly reciprocal: stronger digital capability improved the firm's capacity to manage energy and environmental performance, while more demanding green objectives encouraged further development of digital systems and organizational capabilities. The final pathway can be summarized as:

Accumulated digital and green capabilities→Integrated operational and environmental management→Reciprocal capability reinforcement→Digital–green integration

5. Conclusion and Implications

5.1. Conclusion

This research examined how digital–green synergy evolves within an energy-intensive enterprise using longitudinal evidence from Conch Cement between 2016 and 2025. An enterprise-level evaluation system was constructed and combined with the entropy weight method, coupling coordination analysis, and longitudinal case evidence.

The findings show that digital and green transformation did not advance synchronously. Green development emerged earlier through environmental governance, energy conservation, and related investments, whereas digital capability accumulated more gradually.

The later development of digital capability changed this relationship. Once digital tools entered production control and management routines, their relevance was no longer limited to automation or information processing. They also became useful for resource allocation, energy management, and environmental monitoring. In the Conch Cement case, this change marks the point at which digitalization began to participate directly in green production rather than developing alongside it.

The three periods identified in the case capture this change in function. Green capability provided the earlier foundation; digital applications were subsequently introduced into production activities; and, in the later years, the two sets of objectives increasingly appeared in the same management processes. The important finding is therefore not simply that the coordination index increased, but that the role assigned to digital capability changed as the transformation proceeded.

This interpretation also adds a process dimension to the measurement of digital–green synergy. From the perspective of dynamic capability, the case can be read as a sequence in which environmental requirements were first recognized, digital resources were then mobilized to address emerging operational needs, and existing routines were gradually adjusted as the two forms of transformation became more closely connected.

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5.2. Managerial and Policy Implications

5.2.1. Strengthening Digital–Green Strategic Integration and Capability Development

The Conch Cement case suggests that the timing of digital investment matters. When environmental governance is still being established, firms may gain more from improving basic monitoring and data availability than from introducing a large number of disconnected digital projects. Once production data become more widely available, the next issue is whether those data are actually linked with equipment operation, energy use, and environmental management.

For firms at a later stage, separate digital and green programs may become less useful. Energy optimization, carbon management, and production planning increasingly depend on the same information and operating systems. Digital investment should therefore be assessed by the problems it solves within production and environmental management, rather than by the amount of technology adopted.

5.2.2. Promoting Industrial Collaboration and Digital–Green Transformation Ecosystems

The case also points to a capability requirement that cannot be met by technology alone. Digital systems need to be understood in relation to production processes and environmental objectives, which places greater demands on employees and managers who work across these areas.

External cooperation can help where such knowledge is difficult to develop internally. Technology suppliers and research institutions, for example, may provide experience in intelligent production, energy management, or carbon-related applications. For energy-intensive firms facing similar operating conditions, sharing technical standards and application experience may also lower the cost of moving from isolated digital projects to more connected production systems.

5.2.3. Improving Policy Support Systems and Reducing Transformation Costs

A similar distinction is relevant to policy support. Firms with weak digital foundations and firms that already operate mature digital systems do not face the same constraints. The former may need support for environmental upgrading, basic data infrastructure, and monitoring systems; the latter are more likely to benefit from measures that encourage links between digital systems, energy management, and carbon governance.

Subsidies, tax incentives, and green finance can reduce part of the investment burden, but broad financial support alone may not address the capability gap identified in this case. Support tied to specific transformation tasks, together with common technical standards and cooperation among manufacturers, technology providers, universities, and research institutes, may be more useful for the diffusion of digital–green practices.

5.3. Limitations and Future Research

The findings need to be interpreted within the limits of the research design. Conch Cement provides a detailed longitudinal case, but one firm cannot represent the full range of transformation paths found in energy-intensive industries. Whether the same sequence appears in steel, electricity, chemicals, or other manufacturing settings remains an empirical question.

A second constraint comes from the data. The evaluation relies on information that Conch Cement disclosed consistently over 2016–2025. This makes longitudinal comparison possible, but it also restricts the indicator set. Measures such as operational energy use and carbon emissions could provide a more direct view of green performance if comparable firm-level observations become available.

The analysis also identifies mechanisms from the combination of index changes and case evidence rather than from formal causal estimation. The proposed relationships among environmental requirements, digital capability, and organizational change should therefore be tested with larger samples or other quantitative designs. In addition, the present case is centered mainly on internal transformation; supply-chain relationships, technology providers, and wider institutional conditions deserve separate examination.

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