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Unpacking the Mechanisms of Network Embeddedness for Low-Carbon Innovation in Chinese Enterprises: A Dynamic and Cognitive Theory Perspective

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Abstract: In the context of low-carbon economies, there is a clarion call for enterprises to change traditional economic management styles in order to achieve optimal gains. Against this background, the mechanism to improve low-carbon innovation capabilities of enterprises has become the holy grail for top management teams. Based on the social network, dynamic ability and upper echelon theories, this study explores the impact of network embeddedness on low-carbon innovation of enterprises and further analyzes the intermediary role of low-carbon dynamic abilities and the moderating role of executives' low-carbon cognition. To achieve the objectives of this study, a sample of 386 enterprises in China were selected for the study. The results show that (1) Both structural embeddedness and relational embeddedness have significant positive effects on enterprises low-carbon innovation; (2) A low-carbon dynamic ability functions as a partially mediated factor between structural embeddedness and enterprise low-carbon innovation; (3) Low-carbon dynamic capacity plays a complete intermediary role between relational embeddedness and enterprise low-carbon innovation; (4) Executives' low-carbon cognition moderates the relationship between low-carbon dynamic ability and low carbon innovation of enterprises. That is, the stronger the executives' low-carbon cognition, the stronger the positive impact of dynamic ability on enterprise low-carbon innovation and vice versa. This study expands research in social network theory and the low-carbon innovation of enterprises. Furthermore, this study provides a solid theoretical basis for enterprises to effectively carry out low-carbon innovation while providing a solid reference for enterprises to improve their low-carbon innovation aspirations.

Keywords: network embeddedness; low-carbon dynamic ability; executives' low-carbon cognition; enterprise low-carbon innovation; China

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1. Introduction

Within the framework of low-carbon development, innovation is the first driving force of development, determining the speed and sustainability of industrial development. As an important pillar of economic development, low-carbon innovation has emerged as an indispensable conduit for the high-quality development of enterprises [1]. With the continuous promotion of economic globalization, the dynamic nature of the market environment is increasingly strengthened with unprecedented dimensions of complexity. In the wake of low-carbon demand by consumers, the collective introduction of carbon labels and low carbon policies poses great challenges to the sustainability of enterprises [2]. To this end, enterprises can establish and consolidate their competitive advantages only by continuously providing customers with low-carbon products and by adopting low-carbon production methods and service processes through the value chain [3]. Based on this background, the mechanisms to enhance the low carbon innovation capabilities of enterprises have emerged as the holy grail for top managers.

By integrating low-carbon ideas or culture into enterprise innovation activities, low-carbon innovation can be regarded as a disruptive force to engineer profitable streams of activities. Arguably, this innovation drive does not necessarily have to be a major technological breakthrough, but rather on the basis of extending original ideas [3]. Because the low-carbon innovation drive of enterprises is more often than not associated with risk and uncertainty, their willingness and motivation to innovate are mostly insufficient. The prior literature mainly discusses the antecedents of external low-carbon regulatory pressure, institutional pressure and legitimacy pressure on enterprises' low-carbon innovation [4,5]. It is an undeniable fact that low-carbon innovation is the result of mutual cooperation and interaction between enterprises which have experienced innovative breakthrough. It is also attainable through the transformation of the existing technological paradigm. Essentially, it requires organizations to carry out all-around systematic layouts and strategic planning [3]. In the context of an open economy, it is difficult to effectively carry out low-carbon innovation activities by relying solely on the accumulated resources of enterprises. Thus, it requires enterprises to break through organizational boundaries to obtain the heterogeneous resources needed for innovation in order to comprehensively improve the organizational innovation ability through efficient restructuring [6]. Moreover, previous research shows that the actual effect of low-carbon innovations of enterprises is not satisfactory due to inadequate resources and a lack of reliable research and developmental paths [4].

A large number of studies have found that enterprises' low-carbon innovation largely depends on employees' innovation motivation and ability. However, the development of employees' innovation motivation and ability is significantly affected by network embeddedness [7,8]. The acts of embedding the external cooperation network and establishing a continuous and mutually beneficial network relationship with partners create an enabling environment for scarce innovation resources. This process has the propensity to improve the success rate of enterprise innovation [9]. Based on this, some scholars have attempted to explore the promotion mechanism of enterprise innovation ability from the perspective of network embeddedness [1,8]. Traditional relationship theory emphasizes the use of vertical and horizontal matching to promote enterprise innovation [5]. The outcomes of related studies on this theory have greatly improved the understanding of the relationship between management and enterprise innovation. However, there is some level of deficiency in these studies. For example, traditional relationship theory studies have not clarified how enterprise relationship networks can adapt to dynamic external environments after network embeddedness matches the levels of enterprise low-carbon innovation [10]. Although network embeddedness provides opportunities and convenience for organizations to access scarce resources, enterprises need to have certain levels of low-carbon dynamic capabilities to truly realize a low-carbon innovation culture [9]. Low-carbon dynamic capacity is considered as the unique ability of enterprises to adjust and adapt to changes of external environments by integrating and reorganizing internal and external low-carbon resources from low-carbon transformation initiatives [8]. However, low carbon dynamic capacities are not inherent in organizations. They are closely connected with specific natural and social environments. Therefore, Jiang et al. (2018) [5] believed that it is necessary to incorporate network embeddedness theory into organizational relationship management to promote low-carbon innovation initiatives of enterprises.

Environmental factors are important elements in the analysis of enterprise economic behavior decisions [11]. The role of dynamic ability on the choice of enterprise strategic behavior depends on some internal and external environmental factors. It has different expressive patterns from the perspective of environmental factors [8]. Low-carbon innovation activities of enterprises cannot produce an immediate effect. In this regard, external environmental regulation becomes indispensable [5]. In addition, the low-carbon behavior of enterprises is closely related to executives' low-carbon awareness and attention [3]. It is only when managers have a clear understanding of low carbon issues that they can invest their limited resources into low-carbon innovative activities [4]. Unfortunately, most of

the existing research focuses on the direct effect of low-carbon regulation and executives' low-carbon awareness on enterprises' low-carbon innovation. To this end, there are few studies on the indirect effects [3].

Based on the above literature, we found that existing studies have explored enterprises' low-carbon innovation behaviors from both internal and external perspectives [12]. However, we found the following research gaps: (1) From the external perspective of the organization, there is a lack of research that explores enterprises' low-carbon innovation from the perspective of network embeddedness [5]. At present, studies mainly analyze the impact of enterprises' low-carbon innovation based on government behavior, banking policies, environmental regulations, etc. The existing literature on external perspectives considers the impact of individual influencing factors on enterprises' low-carbon innovation. However, these studies have not explained the impact of relational networks on the level of enterprises' low-carbon innovation [1]. (2) From the perspective of organizations, there is a lack of research on corporate low-carbon innovation from the perspective of executives' low-carbon cognition. Intuitively, the low-carbon innovation of enterprises cannot be separated from the executives' low-carbon strategic thinking [3]. The formation of this kind of thinking depends on senior executives' low-carbon cognitive behaviors. However, the existing literature has not uncovered the black box of how executives' low-carbon cognition affects corporate low-carbon innovation. (3) There is a lack of studies that explore enterprises' low-carbon innovative behaviors from the perspective of dynamic abilities. With the emerging trend of low-carbon development, some enterprises with weak dynamic abilities are unable to implement low-carbon innovation in a timely manner. Therefore, they lose their competitive advantage due to excessive carbon emissions [13]. On the contrary, some enterprises with strong dynamic abilities continue to improve their competitiveness. However, the question on how low-carbon dynamic abilities affect enterprises' low-carbon innovation has not been addressed in the existent literature.

Therefore, the present study uses network theory, dynamic ability theory and cognitive theory to explore the impact of external network embeddedness and internal low-carbon dynamic ability on enterprises' low-carbon innovation. Furthermore, we introduce executives' low-carbon cognition as a variable to explore its moderating role in low-carbon dynamic capacity and low-carbon innovation aspirations of enterprises. Against this background, the present study demonstrates the impact of organizational dynamic capabilities on enterprises' low-carbon innovation under different schemes of network embeddedness. We hope that this study will clearly showcase the antecedents of low-carbon innovation initiative among enterprises and provide a solid theoretical basis for enterprises to effectively carry out low-carbon innovation.

Compared to prior research, the contribution of this study is mainly reflected in the following: (1) This study adds a great deal of wealth to the debate on network embeddedness, dynamic abilities and cognitive theories. Previous research has not addressed the key factors driving low-carbon innovation decision-making in enterprises [2]. To this end, this study focuses on the two key influencing factors of low-carbon innovation in enterprises' structural embeddedness and relational embeddedness. In addition, most of the prior literature on this subject matter lacks in-depth exploration of executives' low-carbon cognition [2]. To address this, the present study examines the impact of network embedding on enterprises' low-carbon innovation. The study also incorporates low-carbon dynamic abilities as a variable to extensively explore the mechanism of enterprises' low-carbon innovation. (2) A theoretical model for low-carbon innovation in enterprises has been proposed from both internal and external perspectives. In particular, the study provides theoretical support for the promotion of low-carbon innovation in enterprises. (3) Based on the findings of the study, relevant policy recommendations and decision support have been provided to shape the course of managerial and governmental actions.

2. Theoretical and Hypotheses Development

2.1. Network Embeddedness Theory

The concept of "embeddedness" was proposed by Polanyi (1944) [14] and gradually formed embedding theory. In detail, Polanyi believed that the economy is not a separate field, but is rather highly interconnected. For instance, pre-industrial society was characterized as being deep-rooted in social, religious and other systems. With the evolvement of research on network embedding, existing studies classify network embeddedness from different perspectives. For instance, Granovetter (1985) [15] proposed that corporate innovation activities are limited by social structures and relationships. These social structure and relationships determine the form and outcome of innovation activities. This means that the potential opportunities that a company may gain mainly depend on its type of network.

Network embeddedness is the organizational form of economic activities of enterprises with certain network relationships. The embedded relationship can be generally divided into relational embeddedness and structural embeddedness [15]. Among them, structural embeddedness is used to describe the structural characteristics of social networks and the impact of enterprise network location on economic activities. It is generally measured by three indicators: network size, centrality and heterogeneity [16]. On the other hand, relational embeddedness is used to describe the relationship between enterprises in a social network. It is usually measured by relationship strength and quality [8]. According to the embedded theory, a network is an open system, and the members embedded in it constantly have complicated relations with other subjects. Embedded enterprises can access and mobilize scarce resources through the network and obtain more resources than the external entities of the network [15]. Enterprises in the center of the network can access the information flow of other enterprises in the network. This implies that they can access unique resources and opportunities [17]. In addition, close ties between enterprises have a positive impact on acquiring new knowledge and accelerating information flow. They will also maximize the role of existing resources [8]. These studies provide a theoretical basis for understanding how network embeddedness affects the resource acquisition of network entities.

At present, most of the research on network embeddedness focuses on the organizational level. These include but are not limited to the relationships between organizational network embeddedness and knowledge sharing; network embeddedness and enterprise performance; and organizational climate and organizational performance [17]. Some scholars have explored the impact of network embeddedness on individual behaviors. However, in general, research on enterprise innovation from the perspective of network embeddedness is rare. Through network embeddedness, organizations can establish a good relational network to obtain diversified resources for enterprise innovation. Therefore, it is imperative to study organizational low-carbon innovation from the perspective of network embeddedness [5]. With this in mind, the present study analyzes the impact of network embeddedness on organizational low-carbon innovation from structure embeddedness and relationship embeddedness.

2.2. Network Embeddedness and Enterprise Low-Carbon Innovation

The relationship between structural embeddedness and enterprise low-carbon innovation can be analyzed from three aspects: network scale, network heterogeneity and network centrality [16]. First, large cooperation network embeddedness means that enterprises will have more opportunities to establish contacts with external organizations for mutual gains. This makes it easier for organizations to obtain strategic low-carbon and scarce resource support. This helps them to expand innovative ideas and stimulate innovative inspirations [8]. Second, from the perspective of network heterogeneity, enterprises can effectively meet consumers' low-carbon needs by maintaining a good corporate relationship with customers. By maintaining a good corporate relationship with suppliers, enterprises will in turn obtain the latest information on the market to develop new low-carbon products [16].

Third, the higher the centrality of the enterprise network, the closer the enterprise connects with other network members [8]. In general, enterprises at the center of the network have a strong influence and a stronger voice. This helps enterprises to have more access to external low-carbon knowledge resources [16].

In addition, relationship embeddedness may also affect enterprises' low-carbon innovation [18]. From the angle of relationship strength, the degree of connection between enterprises and stakeholders affects the acquisition of external knowledge resources of enterprises. Strong network connectivity can effectively alleviate vicious competition among individuals. It can also help organizations to focus on solving important problems. By collaborating with partners, multiple enterprises can jointly design new products and technologies. This type of collaboration significantly reduces the difficulty and challenges of technological innovation [8]. Furthermore, strong linkage can reduce the transaction cost and uncertainty of enterprises and help to promote the flow of knowledge and information. The higher the embeddedness of enterprise relations, the more accurate low-carbon policies are controlled. On the other hand, the more accurate the positioning of external resources, the more likely it is to launch low-carbon products [5]. From a relationship quality trajectory, high-quality network relationships have the propensity to increase communication and cooperation among different organizations. In the long run, it creates a culture of harmonious environments among organizations by reducing communication barriers among members to boost information exchange between interested parties. The more the trust and closer the relationships between network members, the higher the cost of violating network conventions, and the more conducive it will be to establish mutually beneficial norms between enterprises. At this point, enterprises are more willing to actively share key information and carry out high-quality cooperation networks in order to materialize their low-carbon knowledge transfer ambitions [8]. Moreover, relationship embeddedness can also reduce the cost of knowledge exchange between enterprises, remove barriers to cross-functional communication and promote low-carbon innovation of enterprises [5]. Accordingly, the following hypotheses are proposed in this paper:

Hypothesis 1a (H1a). *Structural embeddedness has a significant positive impact on enterprises' low-carbon innovation.*

Hypothesis 1b (H1b). *Relational embeddedness has a significant positive impact on enterprises' low-carbon innovation.*

2.3. Mediation Effect of Low-Carbon Dynamic Capacity

Teece (2014) [19] first proposed the concept of dynamic abilities. He contended that enterprises must have the ability to update and restructure internal and external resources to flexibly respond to turbulent and unforgiving market environments. Dynamic abilities continuously coordinate the existing associated resources of enterprises for dynamic combination and innovation. This engenders enterprises to form unique resources that cannot be replaced by the organization [2]. Scholars have successively proposed the concept of low-carbon dynamic ability based on the research results of dynamic ability [8].

The low-carbon dynamic ability describes the special ability of enterprises to integrate and restructure low-carbon resources, internally and externally, to cope with changes in the external environment, with the objective to achieve low-carbon developmental goals [3]. Extensive resource searches will accrue more heterogeneous information to enterprises. In the end, it will help enterprises to understand and grasp the dynamics of market changes, leveraging it as an important way for enterprises to improve their innovation capabilities [8]. The larger the scale of network embeddedness, the closer the connectivity of networks between partners. Research shows that the establishment of cooperative relations among enterprises births a conducive atmosphere for the transmission and diffusion of low-carbon information. The degree of opportunities available for enterprises to obtain low-carbon information determines their level of low-carbon dynamic capacity [20]. In

comparison with competitors, enterprises at the center of cooperation networks have the laxity to prioritize information and increase opportunities for knowledge exchange with network members. This provides convenient conditions for the integration of organizational resources. It also enables an environment for research and development (R&D), which in turn leads to improvements in the low-carbon innovative capabilities of enterprises. Moreover, diversified network relationships can equip enterprises to adopt diversified low-carbon knowledge in the process of communicating with individual members of the network. This further improves the dynamic low-carbon capacity of enterprises [18]. Based on the above analyses, we propose that

Hypothesis 2a (H2a). *Structural embeddedness has a significant positive impact on enterprises' low-carbon dynamic ability.*

The strong connection of the cooperative network can enable members to leverage available opportunities. This will improve the efficiency of information identification and search. This condition results in the sharing of knowledge. It also encourages individual members to obtain some valuable information from the network partners [20]. Moreover, a strong network relationship can promote interactions between members of the organization and reduce barriers to information. This can promote in-depth communication among partners and, thus, improve the ability of enterprise resources acquisition and integration [8]. This can promote exchange of information among network members and foster the dynamic capabilities of enterprises [18]. Therefore, mutually beneficial and high-quality network relations can enhance the quality of cooperation and communication of low-carbon knowledge. Given this background, we hypothesize that

Hypothesis 2b (H2b). *Relationship embeddedness has a significant positive impact on enterprises' low-carbon dynamic ability.*

The low-carbon dynamic capacity affects the quantity and quality of low-carbon resources externally obtained by organizations. Essentially, having this capacity is deemed as a guarantee for enterprises to be able to carry out environmental innovation [18]. Strong low-carbon dynamic capabilities make it easier for enterprises to carry out extensive information searches and help them quickly capture and acquire advanced technical knowledge. It also helps them to better understand the potential needs of consumers and the future development direction of the industry. This arrangement in turn creates a congenial environment for the smooth development of enterprises' low-carbon innovation activities [20]. Specifically, information obtained from the cooperation network helps enterprises to better appreciate future development trends of the industry in a timely manner and, as such, helps to improve the probability of success of enterprises' low-carbon innovative plans [8]. Specifically, valuable information can be obtained from the enterprises in the cooperation network, which may be instrumental in the holistic understanding of future development trends in the industry [8]. In addition, information on national macro-control objectives, tax incentives and financial support can be obtained from the government, industry associations, banks and other political networks which play indispensable roles in promoting enterprises' low-carbon innovation [10]. For these reasons, enterprises with abundant resources are more likely to generate new ideas, acquire low-carbon new technologies and develop new markets to effectively reduce innovation risks and costs [8]. It also implies that enterprises with strong low-carbon dynamic capabilities can effectively share, allocate and reorganize the information and knowledge obtained externally among different business departments to effectively promote a low-carbon innovative agenda [10]. Based on the above illustration, we propose that

Hypothesis 3 (H3). *A low-carbon dynamic ability has a significant positive influence on enterprise low-carbon innovation.*

In order to maintain a good cooperative relationship between enterprises, network embeddedness is required. A good network relationship can provide a convenient environment for enterprises to use heterogeneous resources. However, the mere possession of such static resources cannot effectively promote enterprises' low-carbon innovation activities. To this end, enterprises also need to have certain dynamic capabilities [8]. It is only through this approach that new external technologies can be obtained to achieve an optimal level of low-carbon innovation. When the external environment renders the existing capabilities of enterprises weak, enterprises, as a matter of urgency, should reconstruct the resource base and innovation management system [18]. This requires organizations to have a high dynamic ability and adjust the thinking mode and action plan of solving problems in time. External network embeddedness affects the low-carbon dynamic ability of enterprises. It enables enterprises to capture external business opportunities in time, while equipping them with the resources to execute novel low-carbon activities [5]. To sum up, low-carbon dynamic ability plays an intermediary role between network embeddedness and enterprise low-carbon innovation. Following the above assertion, we hypothesize that

Hypothesis 4a (H4a). *A low-carbon dynamic ability plays an intermediary role between structural embeddedness and enterprise low-carbon innovation.*

Hypothesis 4b (H4b). *A low-carbon dynamic ability plays an intermediary role between relational embeddedness and enterprise low-carbon innovation.*

2.4. The Moderation Effect of Executives' Low-Carbon Cognition

The cognitive model, from a strategic management point of view, has received massive currency in recent years [21]. The model explains what strategic formation process means within the scope of cognitive science. By constructing the subjective cognition behaviors of managers, the prior literature has cogently made a case on the strategic decision-making process of top managers [22]. This provides a theoretical basis for promoting specific strategic behaviors of companies.

The cognitive behavior of corporate executives has an important impact on organizational decision-making and the related economic benefits [23]. The way that managers identify and interpret the opportunities and challenges of the external environment is a reflection of their behavioral dispositions. Invariably, the cognitive paradigm of senior executives intervenes to determine the behavioral choices of enterprises [24]. Previous studies have analyzed executives' low-carbon cognition as the internal driving factor of enterprises' low-carbon innovation. These studies, however, mostly focus on the direct impact of low-carbon innovation and ignores the moderating role of executives' low-carbon cognitive initiative [3].

Research indicates that enterprises with strong low-carbon dynamic ability mostly have the capacity to initiate and carry out independent low-carbon innovative plans [25]. This is because managers with strong low-carbon cognitive capabilities actively pay attention to low carbon policies, regulations and the latest developments of the industry. Their accessibility to rich information equips them with the right information to deepen their drive for low-carbon initiatives. The narrative presupposes that the managers will be more positive and optimistic about marketing low-carbon initiatives and confidently link them with long-term developmental goals and the prevailing opportunities available to the enterprise. When senior managers have positive attitudes toward low-carbon concepts, enterprises with strong low-carbon dynamic capabilities are more likely to carry out environmental innovation [3]. Based on the above illustration, the following hypothesis was developed:

Hypothesis 5 (H5). *Executives' low-carbon cognition has a moderating role in the association between low-carbon dynamic ability and enterprise low-carbon innovation.*

This research demonstrates the interplay of network embeddedness (i.e., structural embeddedness and relational embeddedness) on enterprise low-carbon innovation. Accordingly, the study advances the idea that network embeddedness affects enterprise low-carbon innovation through the intermediary role of the low-carbon dynamic ability. Moreover, we posit that the effect of low-carbon dynamic ability on enterprise low-carbon innovation varies under different conditions of executives' low-carbon awareness. The theoretical model involving the constructs of this study is shown in Figure 1.

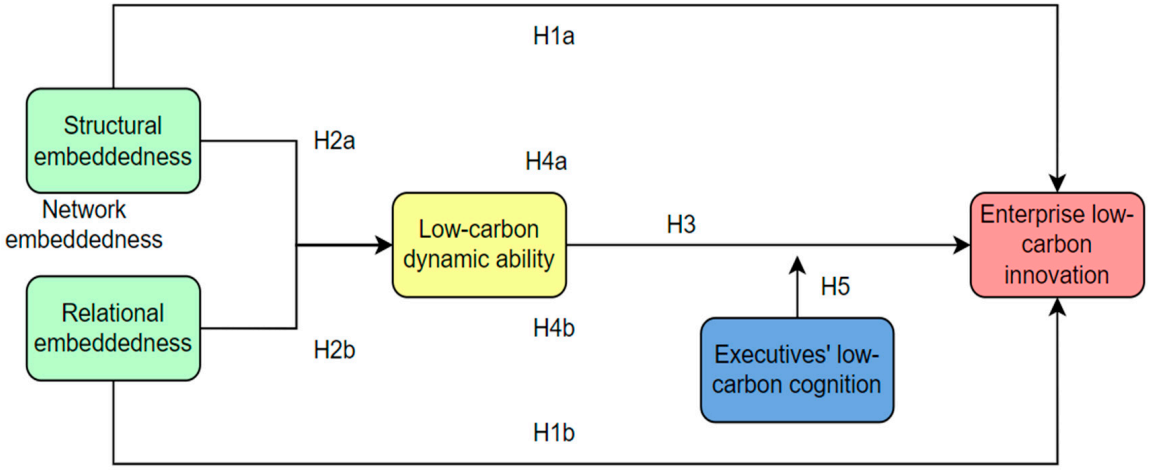

Figure 1. The research model.

3. Methodology

3.1. Measurement Tools

Because the variables involved in this study are difficult to obtain using secondary data, a survey instrument was used to acquire the necessary data. In order to ensure the reliability and validity of the questionnaire, we chose the authoritative maturity scale as the measuring tool. Moreover, before the execution of the actual survey, a preliminary survey was conducted in some selected enterprises in Sichuan province and Chongqing city to test the items of the study. As a matter of necessity, the questionnaire was appropriately revised based on the opinions of senior academics and professionals with a deep knowledge on the subject matter. All of the items were measured on a five-point Likert scale, ranging from 1 = very disagree to 5 = very agree.

We used the scales of Fu and Zeng (2008) [26] and Tian et al. (2021) [27] to measure the 10 items of structural embeddedness. Similarly, the scales of Rong et al. (2011) [28] and Rui et al. (2020) [29] were used to measure the 6 items of relational embeddedness.

Moreover, the 10 items on low-carbon dynamic capacity were adapted based on the scales of Teece et al. (1999) [30] and Li (2014) [31].

Following the scales of Xie et al. (2019) [32], Chang (2011) [33] and Delmas and Toffel (2008) [34], 6 items were developed to cover the three dimensions of low-carbon product innovation, production process innovation and low-carbon management innovation.

Four items were developed to measure executives' low-carbon cognition following Jiang et al. (2022) [3] and He et al. (2013) [35].

Control variables: In this study, the number of years, scale, nature and industry of the sample enterprises are listed as the control variables. The unit of years of establishment is one year. Enterprise size is expressed as the quantity of enterprises in logarithmic form. The industry to which the enterprises belong is divided into the manufacturing and service industries. The nature of enterprises is divided into state-owned enterprises, private enterprises and foreign-funded enterprises. Moreover, this study divides the nature of enterprises into three dummy variables for analysis. The main variables are listed in Table 1.

Table 1. The researched variables.

Variable	Measurement Index	Literature Resources
Structural embeddedness	SE1: The cooperation between the company and its partners is strong. SE2: The company and its important partners can trust each other. SE3: The company agrees with the strategy of important partners very much. SE4: The company's partners have provided a lot of help to the development of the company. SE5: The company works with a large number of organizations outside the industry. SE6: The company maintains partnerships with a large number of non-corporate organizations. SE7: The company has a cooperative relationship with enterprises or organizations outside the cluster. SE8: The company has great influence on other enterprises or organizations. SE9: Most enterprises and companies in the cluster have cooperative behaviors. SE10: Companies can quickly obtain information through other enterprises or organizations in the cluster.	Fu and Zeng (2008) [26]; Tian et al. (2021) [27]
Relational embeddedness	RE1: Compared with major competitors, enterprises have a closer relationship with other enterprises or institutions. RE2: Compared with major competitors, enterprises have more frequent exchanges and cooperation with other enterprises or institutions. RE3: Compared with the main competitors, the enterprise has a longer cooperation relationship with other enterprises or institutions. RE4: The company can trust each other with other enterprises or institutions. RE5: The cooperation between the company and other enterprises or institutions is a win–win relationship. RE6: The company keeps its promise with other enterprises or institutions.	Rong et al. (2011) [28]; Rui et al. (2020) [29].
Low-carbon dynamic capacity	LDA1: Enterprises have carried out low-carbon innovation and obtained a lot of external resources. LDA2: Enterprises use resources to complete cross-department tasks. LDA3: Enterprises use the integrated resources to improve their work efficiency. LDA4: Enterprises continue to learn through strategic alliance cooperation. LDA5: Enterprises have realized the sharing of low-carbon knowledge. LDA6: Enterprises have processed and utilized new low-carbon knowledge. LDA7: Enterprises can establish effective low-carbon working relationships with external partners through formal or informal channels. LDA8: Enterprises should understand and grasp the government's policies related to low-carbon regulation in a timely manner. LDA9: Enterprises should understand the changes of low-carbon technologies in the industry and take corresponding measures in a timely manner. LDA10: Enterprises clearly understand consumers' low-carbon needs to adapt to market changes.	Teece et al. (1999) [30]; Li, X. (2014) [31].
Enterprise low-carbon innovation	ELI1: Enterprises often develop recyclable products. ELI2: Enterprises often develop low-carbon products. ELI3: Enterprises often optimize the production process to ensure compliance with low-carbon regulations. ELI4: Enterprises often introduce new low-carbon equipment for production. ELI5: In order to meet the needs of low-carbon management, enterprises have reshaped their organizational structure. ELI6: Enterprises actively introduce low-carbon management techniques to comply with the development trend of low-carbon economy.	Xie et al. (2019) [32]; Chang (2011) [33]; Delmas and Toffel (2008) [34].
Executives' low-carbon cognition	ELC1: The company executives believe that low-carbon competitiveness can be advantageous to enterprises. ELC2: The company executives believe that reducing carbon emissions is the social responsibility of enterprises. ELC3: The company executives believe that low-carbon consumption is the way to go. ELC4: The company executives believe that enterprises are to comply with various low-carbon policies.	Jiang et al. (2022) [3]; He et al. (2013) [35].

3.2. Collection of Data

To improve the representativeness of the sample, we selected enterprises from Sichuan, Guizhou, Shandong and Chongqing. The primary consideration for the selection of these provinces stems from both economic and geographic perspectives. The study settings cover both the economically developed and less developed areas in China. Geographically, they span across the east, central and western regions of China and, thus, demonstrate strong representativeness. These enterprises come from different industries. Since top managers are often endowed with deeper understandings of the low-carbon strategy and

operation of enterprises, we selected senior managers of the enterprises as the respondents to the questionnaire. The senior executives used in the study include the chairman, general manager, deputy general manager, assistant general manager, environmental protection department manager or environmental project leader, etc. The questionnaire distribution was performed through direct door-to-door surveys, letters and e-mails. In order to increase the response rate and also to attain statistical power, three methods, telephone, on-site and online surveys, were adopted. For the on-site survey, we engaged 12 trained research assistants to conduct the interviews at the targeted companies. For online surveys, we mainly used WeChat, QQ, Questionnaire Star and email. The participants in the study were assured of utmost confidentiality and anonymity. The duration of the survey was from 1 January 2022 to 31 March 2022.

In this study, a total of 495 enterprises were selected. However, 386 valid questionnaires were finally obtained. The effective recovery rate was 77.98%. After obtaining the data, we carried out a detailed analysis of years of establishment, corporate size, enterprise type and industry type. The results are shown in Table 2.

Table 2. Characteristics of the samples.

Items	Categories	Frequency (N = 386)	Percent (%)
Years of establishment (YE)	Less than 10 years (Including 10 years)	124	32.12%
	11–20 years	193	50.00%
	More than 20 years	69	17.88%
Corporate size	Under 100	92	23.83%
	101–1000	86	22.28%
	1001–5000	147	38.08%
	More than 5000	61	15.80%
Enterprise type (ET)	State-owned enterprise	187	48.45%
	Private enterprise	167	43.26%
	Foreign-funded venture	32	8.29%
Industry type (IT)	Manufacturing industry	214	55.44%
	Service industry	172	44.56%

4. Results

4.1. Homologous Deviation Test and Confirmatory Factor Analysis

It was envisaged that study data may have a common method bias. In order to ensure the validity of the data, the Harman single-factor variance analysis method was employed. The test results showed that the unrotated maximum factor in this study can only explain 36.84% of the total variance, which was less than the recommended threshold of 50%. An additional check on the preliminary analysis indicated that the common method bias in the data was not serious, and as such, further analysis could be carried out.

In this study, confirmatory factor analysis (CFA) was used to test the discriminate validity of the variables. The results are shown in Table 3. In particular, the fitting effect of the five-factor model attained good statistics ($\chi^2(149) = 272.35$, RMSEA = 0.054, CFI = 0.961, TLI = 0.972, IFI = 0.962), as compared with other factor models. This indicated that the five variables above had a good discriminate validity with no significant common method bias.

Table 3. Analysis of discriminant validity among variables.

Measurement Model	df	χ^2	χ^2/df	TLI	CFI	IFI	RSMEA
Five-factor model (SE, RE, LDA, ELC, ELI)	149	272.35	1.828	0.972	0.961	0.962	0.054
Four-factor model (RE + LDA, SE + ELC + ELI)	155	462.15	2.982	0.924	0.935	0.921	0.065
Four-factor model (SE + LDA, RE + ELC + ELI)	155	521.94	3.367	0.903	0.927	0.923	0.047
Four-factor model (SE + RE + ELC, LDA + ELI)	155	443.68	2.862	0.921	0.934	0.927	0.063
Four-factor model (SE + RE + LDA, ELC + ELI)	155	423.47	2.732	0.932	0.945	0.935	0.054
Single-factor model (SE + RE + LDA + ELC + ELI)	164	954.26	5.819	0.775	0.817	0.832	0.115

4.2. Correlation Analysis

The correlation coefficient and descriptive statistical results of each variable are shown in Table 4. From the results, relational embeddedness (RE) and low-carbon dynamic ability (LDA) were found to be significantly positively correlated (r = 0.675, $p < 0.01$); structural embeddedness (SE) and low-carbon dynamic ability (LDA) were found to be positively correlated (r = 0.564, $p < 0.05$); relationship embeddedness (RE) and enterprise low-carbon innovation (ELI) were found to be positively correlated (r = 0.538, $p < 0.01$); structural embeddedness (SE) and enterprise low-carbon innovation (ELI) were found to be positively correlated (r = 0.586, $p < 0.05$); and low-carbon dynamic ability (LDA) and enterprise low-carbon innovation (ELI) were also found to be positively correlated (r = 0.639, $p < 0.01$).

Table 4. Descriptive statistics and correlation coefficients.

Variable	1	2	3	4	5	6	7	8	9	10	11
Years established	1										
Corporate size	0.467 **	1									
State-owned enterprise	0.496 **	0.416 **	1								
Private enterprise	−0.417 *	−0.419 **	−0.715 **	1							
Foreign-funded venture	0.015	0.158 **	−0.236 **	−0.423 **	1						
Industry type	−0.234 **	−0.182 **	0.171 **	−0.075	−0.124 **	1					
RE	−0.059	−0.035	−0.156 **	0.136 **	0.036	−0.145 **	(0.776)				
SE	0.038	0.054	−0.148 **	0.072	0.074	−0.175	0.765	(0.895)			
LDA	−0.135 *	−0.026	−0.253 **	0.169 **	0.039	−0.132 **	0.675 **	0.564 *	(0.846)		
ELC	0.043	0.011	−0.219 **	0.154 **	0.063	−0.238 **	0.367 **	0.527 **	0.435 *	(0.768)	
ELI	−0.078	0.058	−0.413 **	0.183 **	0.136 **	−0.315 **	0.538 **	0.586 *	0.614 **	0.639 **	(0.821)
Mean	19.542	2.753	0.214	0.654	0.154	1.352	3.541	3.647	3.638	3.679	3.547
Standard deviation	15.459	0.765	0.526	0.518	0.478	0.524	0.594	0.675	0.476	0.794	0.634

N = 386; ** shows significance at the level of 0.01; * shows significance at the level of 0.05; The value in diagonal brackets is the arithmetic square root of the extracted mean variance of the variable.

4.3. Hypothesis Test

In this study, hierarchical regression analysis was used to test the hypotheses. First, we tested the variance inflation factor (VIF) of all the models. The results showed that the VIFs of all the models were between 0 and 10, excluding the influence of multicollinearity. Second, we analyzed the residual terms of all the regression models. The results showed that there were no serious problems of heteroscedasticity. Finally, the Durbin–Watson (DW) statistics of all the regression models were close to two, indicating that there were no serious series autocorrelations in the data.

4.3.1. Main Effect and Mediating Effect

The findings of the main effect and mediating effect are shown in Table 5. From the results, structural embeddedness (β = 0.417, $p < 0.01$) and relational embeddedness (β = 0.248, $p < 0.01$) had a significant positive impact on enterprise low-carbon innovation. Therefore, H1a and H1b were verified. Both relational embeddedness (β = 0.641, $p < 0.01$) and structural embeddedness (β = 0.215, $p < 0.01$) had significant positive effects on low-carbon dynamic ability. Accordingly, H2a and H2b were verified. The low-carbon dynamic ability had a significant positive effect on enterprise low-carbon innovation (β = 0.612, $p < 0.01$) and, thus, supported the verification of H3.

After adding low-carbon dynamic ability as an intermediary variable, the outcome could positively predict enterprise low-carbon innovation (β = 0.436, $p < 0.01$). However, the relationship between relational embeddedness and enterprise low-carbon innovation (β = −0.127) was no longer significant. Moreover, we found that there is a positive relationship between structural embeddedness and enterprises' low-carbon innovation (β = 0.316, $p < 0.01$). Therefore, low-carbon dynamic ability was found to play a complete intermediary role in the relationship between relational embeddedness and enterprise low-carbon innovation. It, however, played a partial intermediary role in the relationship between structural embeddedness and enterprise low-carbon innovation. Thus, H4a was found to be partially true, while H4b was found to be completely true.

Table 5. Hierarchical regression analysis.

Variable	Low-Carbon Dynamic Ability				Enterprise Low-Carbon Innovation			
Control variable								
Years established	−0.038	−0.036	−0.075	−0.124 *	−0.058	−0.072	−0.135 **	−0.121 **
Corporate size	0.046	0.031	0.128 *	0.124 *	0.138	0.047 *	0.107 *	0.131
State-owned enterprise	−0.231 *	−0.124	−0.317	−0.232 **	−0.187 *	−0.164 **	−0.135 *	−0.124 *
Private enterprise	0.012	0.024	−0.065	−0.057	−0.074	−0.054	−0.064	−0.065
Foreign-funded venture	−0.078	0.012	−0.285 **	−0.232 **	−0.223 **	−0.235 **	−0.124 **	−0.154 **
Independent variable								
SE		0.215 **		0.417 **		0.316 **	0.257 **	0.235 **
RE		0.641 **		0.248 **		−0.127	−0.135	−0.175
Intermediary variable								
LDA					0.612 **	0.436 **	0.375 **	0.416 **
Moderating variables								
ELC							0.274 **	0.365 **
Interactive items								
LDA*ELC								0.135 *
R^2	0.056	0.332	0.515	0.418	0.456	0.536	0.715	0.468
Adjusted R^2	0.051	0.423	0.109	0.327	0.413	0.124	0.105	0.021
F	6.024 **	52.011 *	18.016 **	51.357 **	67.357 **	64.218 **	8.357	6.217 **

** shows significance at the level of 0.01; * shows significance at the level of 0.05.

This study used the PRODCLIN procedure to further examine the mediation role of low-carbon dynamic capacity. The results showed that (1) The 99.50% confidence interval of the mediating role of low-carbon dynamic capacity between structural embeddedness and enterprise low-carbon innovation was found to be [0.164, 0.431], excluding 0. Therefore, the intermediary effect of low-carbon dynamic ability in this study was verified. (2) The 99.50% confidence interval of the mediating role of low-carbon dynamic ability in relational embeddedness and enterprise low-carbon innovation was found to be [0.265, 0.512], excluding 0. Therefore, the intermediary effect of low-carbon dynamic ability in the study was verified.

4.3.2. Moderating Effect

In order to eliminate the possible problem of multicollinearity, the study used the standardized low-carbon dynamic ability and executives' low-carbon cognition to create the interactive item of moderating effect. The results of the moderating effect are shown in Table 4. It can be seen that given the control variables, structural embeddedness and relational embeddedness, the interaction between low-carbon dynamic ability and executives' low-carbon cognition could positively predict enterprise low-carbon innovation. This indicates that the greater the executives' low-carbon cognition, the greater the effect of low-carbon dynamic ability on enterprise low-carbon innovation.

In order to further clarify the moderating effect of executives' low-carbon cognition (ELC), the study followed Bollen and Stine (1993) [36], taking one standard deviation plus or minus the mean as the benchmark. This was performed in order to analyze the difference of influence in terms of the low-carbon dynamic ability on enterprise low-carbon innovation under different conditions of executives' low-carbon cognition. The result is shown in Figure 2. It can be observed that executives' low-carbon cognition strengthened the influence of low-carbon dynamic ability on enterprises' low-carbon innovation. In other words, when executives' low-carbon cognition is high, low-carbon dynamic ability experiences a stronger positive effect on enterprises' low-carbon innovation. Hence, H5 was verified.

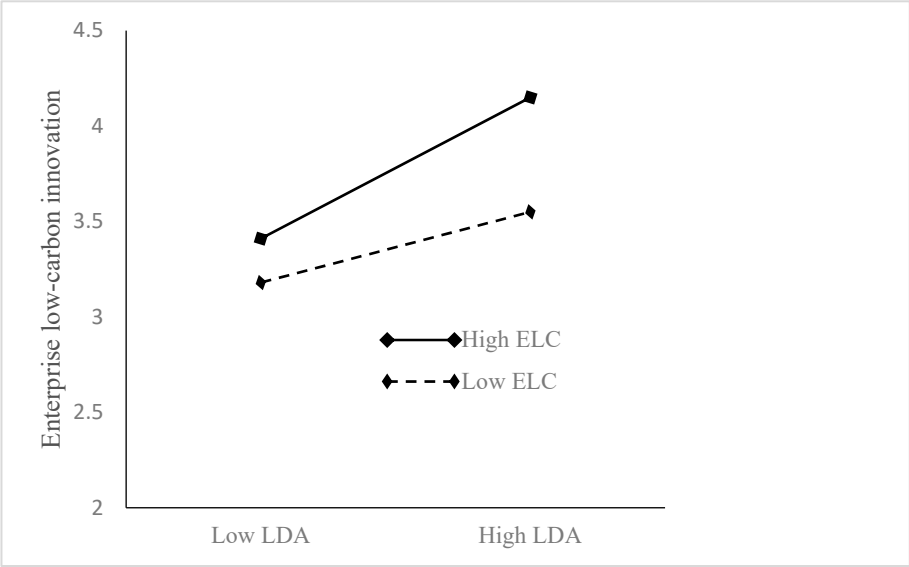

Figure 2. The interaction between LDA and ELC.

5. Discussion and Implications

In the context of the low-carbon environment, enterprise low-carbon innovation is an important way to enhance low-carbon competitiveness. Previous studies rarely analyze the impact of network embeddedness on enterprise low-carbon innovation. This study introduces two variables, namely low-carbon dynamic ability and executives' low-carbon cognition, to explore the antecedent effect of network embeddedness on enterprise low-carbon innovation. This extends the knowledge cut-off point of research on innovation management, showing that low-carbon behavior is diverse, based on the following findings of the study.

First, both relational embeddedness and network structural embeddedness had significant positive effects on enterprise low-carbon innovation. Their regression coefficients are 0.248 and 0.417, respectively, with $p < 0.01$. This finding of this study supports an earlier study conducted by Xing et al. (2022) [8], which showed that network embeddedness had a significant positive impact on enterprise low-carbon innovation. It also indicated that there was no significant difference between the effect of relational embeddedness and structural embeddedness on enterprise low-carbon innovation. Therefore, we believe that the pivotal and dominant position of enterprises in the knowledge network has a similar impact on improving their low-carbon innovation ability. In the context of the low-carbon environment, enterprises should pay full attention to network embeddedness by widely absorbing and utilizing the surrounding low-carbon knowledge. This is the only guarantee for enterprises to achieve a significant feat in the low-carbon innovation agenda.

Second, relational embeddedness and structural embeddedness had significant positive effects on low-carbon dynamic ability, with regression coefficients 0.641 and 0.215, respectively, at $p < 0.01$. This result validates the study of Li et al. (2022) [37], which showed that knowledge network has a positive effect on enterprises' low-carbon dynamic ability. This implies that a good cooperation network can enable enterprises to search and obtain substantial information on low-carbon technology, knowledge and other heterogeneous resources. It will also stimulate the innovative thinking of enterprises, facilitate the reorganization of enterprise resources, and play an important role in promoting the improvement of the low-carbon dynamic ability of organizations. Furthermore, a close cooperation network creates a conducive environment for deep communication among the organizations. This, in turn, improves the efficiency of knowledge acquisition and learning. In addition, a mutual trust atmosphere has the propensity to reduce the barriers to communication and cooperation among partners. This further helps to cultivate the culture of low-carbon dynamic capabilities among enterprises [38].

Third, low-carbon dynamic ability played a mediating role between structural embeddedness and enterprise low-carbon innovation. It also mediated between relational embeddedness and enterprise low-carbon innovation. But the two scenarios above were different. Specifically, dynamic ability only partially mediated between structural embeddedness and enterprise low-carbon innovation. This indicates that structural embeddedness cannot only promote the development of enterprise low-carbon innovation, but also indirectly promotes enterprise low-carbon innovation plans through the mediating effect of dynamic abilities. On the other hand, low-carbon dynamic ability completely mediates the influence of relational embeddedness on enterprise low-carbon innovation. This is an indication that relational embeddedness could promote enterprise low-carbon innovation only through the linkage effect of the low-carbon dynamic ability. As found by Xing et al. (2022) [8], low-carbon dynamic ability was identified to be different as a mediating mechanism of structural embeddedness and relational embeddedness on enterprise low-carbon innovation.

Fourth, executives' low-carbon cognition was found to positively moderate the association between low-carbon dynamic ability and enterprise low-carbon innovation. It must be reechoed that existing studies have principally dwelt on the direct effect of managers' low-carbon cognition on enterprise environmental innovation, leaving a gap in the moderating effect component. Jiang et al. (2022) [3] only confirmed that executives' low-carbon cognition played a significant moderating role in the relationship between institutional pressure and enterprise low-carbon innovation; but they did not include organizational dynamic ability in their study. Therefore, this study makes a useful contribution to the literature in this regard. The findings of this study equips senior managers with full control over the allocation of organizational resources for optimal benefits (Neri et al., 2019) [23]. It presupposes that executives with a high level of low-carbon cognition can actively perceive and interpret low-carbon development opportunities in a market to enhance their competitiveness. From the narrative, they will pay more attention to low-carbon issues and actively search for relevant information. More so, they will be eager to invest more resources and energy into low-carbon projects. Therefore, enterprises with a strong low-carbon dynamic ability are more likely to implement low-carbon innovation.

The findings of this study provide some valuable direction for top managers' low-carbon innovation agenda.

(1) Enterprises should actively embed in the cooperation network and establish mutually beneficial relationships with network members in order to obtain more resource support. Within the framework of the open economy, enterprises need to obtain heterogeneous resources such as knowledge, capital and talents for low-carbon innovation through social networks and comprehensively improve their own low-carbon innovation ability through the allocation and integration of low-carbon resources. This arrangement will help them to achieve high-quality development through positive interactions with other network members. For this reason, it is incumbent on the enterprises to sufficiently utilize and mobilize network resources. They should also strive to collect and screen relevant information in order to stimulate their innovative thinking.

(2) The enterprises should regard the development and cultivation of low-carbon dynamic capabilities as a long-term strategic goal. By identifying the latest low-carbon policies of the government, enterprises can integrate and utilize internal and external knowledge resources effectively. Additionally, the enterprises should quickly update or restructure organizational resources based on the dynamics of the market and the technological environment. The application of this recommendation enables enterprises to adapt to the turbulent environment and gain new competitive advantages.

(3) The government, society and mainstream media should vigorously promote and publicize the concept of low-carbon development. This will serve as a reminder and keep enterprises in check. In addition, enterprises should pay more attention to the low-carbon demands of stakeholders, improve the low-carbon cognition level

of senior managers, and actively create a good low-carbon innovation atmospheres within the enterprises.

6. Conclusions and Limitations of the Study

Based on the analysis of 386 respondents, this study examines the impact of network embeddedness on enterprise low-carbon innovation. This study draws four important conclusions: (1) Both structural embeddedness and relational embeddedness can significantly promote enterprise low-carbon innovation; (2) Both structural embeddedness and relational embeddedness have significant positive effects on low-carbon dynamic ability; (3) Low-carbon dynamic ability partially mediates between structural embeddedness and enterprise low-carbon innovation; however, low-carbon dynamic ability completely mediates between relational embeddedness and enterprise low-carbon innovation. (4) Executives' low-carbon cognition moderates the link between low-carbon dynamic ability and enterprise low-carbon innovation. This implies that executives thinking about low-carbon initiatives will have a corresponding effect of increasing the low-carbon dynamic ability and low-carbon innovation plans of the enterprises.

According to the above conclusion, the theoretical contributions of this paper are mainly reflected in the following three aspects:

(1) This paper analyzes the positive impact of network embeddedness on enterprise low-carbon innovation from two aspects: structural embeddedness and relational embeddedness. This fills the gap of previous studies that only explored a single dimension of relational embeddedness or structural embeddedness. In addition, the study deepens the application of social network theory in innovation. Previous studies on enterprise low-carbon innovation mainly focused on technology or performance. At present, few studies have explored the antecedent variables of enterprise low-carbon innovation from the perspective of social networks.

(2) This study expands research on the antecedents of enterprise low-carbon innovation. Existing studies have explored the drivers of enterprise low-carbon innovation from the perspectives of alliance network, human capital and knowledge learning. However, studies on the impact of enterprise low-carbon innovation from the perspective of network embeddedness are rare. Therefore, this study explores the relationship between network embedment and enterprise low-carbon innovation, which is a useful addition to existing research.

(3) The study introduces two variables—executives' low-carbon cognition and the low-carbon dynamic ability of enterprises—in an attempt open the "black box" of enterprise low-carbon innovation. Theoretically, this study broadens research on the relationship between the upper echelon theory and the low-carbon development of enterprises. Moreover, the study helps to better understand the general mechanism of enterprise low-carbon innovation from executives. The study also promotes the streams of research on the impact of structural embeddedness on enterprises' low-carbon innovation.

Although this study makes valuable contributions to knowledge, there are some limitations which ought to be acknowledged. First, the enterprises used in the study are distributed in different provinces. Although it is beneficial to control for regional factors and improve internal validity, it also weakens external validity to a certain extent. Therefore, in future research, samples from different regions or countries can be selected to further verify and expand the conclusion of this study to enhance the generalizability of the results. Second, this study solely used structured questionnaire to elicit the needed factual data. Future studies can therefore consider the incorporation of qualitative research methods such as semi-structured interviews, case studies, participatory action research, focus groups and observation for a holistic outcome. This will facilitate a panoramic view of low-carbon innovative practices of enterprises to mitigate potential subjective and bias responses. Third, this study only focused on the moderating role of executives' low-carbon cognition. As a result, it did not consider the impact of other factors such as executives'

low-carbon awareness, leadership type, etc. Other potential action paths can, therefore, be explored later. Finally, the data used in this study are static and cross-sectional in nature. Future research may consider the use of longitudinal data to verify the results.

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Abbreviations

Abbreviation and Notation	Full Term
SE	Structural embeddedness
RE	Relational embeddedness
LDA	Low-carbon dynamic ability
ELC	Executives' low-carbon cognition
ELI	Enterprise low-carbon innovation

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