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An Empirical Study on Carbon Literacy Among Graduate Students in Energy Sector Universities

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Abstract: Against the backdrop of global climate change and the deepening implementation of China's "Dual Carbon" goals, enhancing the carbon literacy of high-level talents has become crucial for driving the green transition. This study takes China University of Petroleum (Beijing) as a case and, through a questionnaire survey of 415 graduate students, employs a combination of descriptive statistics, cross-analysis, the LDA topic model, and an entropy weight-based TOPSIS evaluation model to deeply investigate the status, influencing factors, and group differences in carbon literacy among graduate students in energy sector universities. The findings indicate: (1) The overall carbon literacy of graduate students is at a medium to upper-medium level, but a significant attitude-behavior gap is evident; (2) Carbon literacy levels show a distinct disciplinary divide. Students from majors directly related to energy and chemical engineering (e.g., College of Petroleum Engineering, College of Carbon-Neutral Future Technology) performed significantly better than those from humanities and social sciences majors, indicating that professional education and academic environment are core factors shaping carbon literacy; (3) Regarding knowledge acquisition, online platforms, university campaigns, and formal coursework constitute the three main channels. Based on these conclusions, this study proposes implementing targeted education strategies, promoting university-wide curriculum coverage, and constructing an integrated cognition-practice-innovation cultivation cycle to provide a pathway for deepening the cultivation of green talents.

Keywords: Carbon literacy; Graduate education; "Dual Carbon" goals; Energy sector universities; Attitude-behavior gap

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1 Introduction

The pursuit of the carbon peak and carbon neutrality constitutes an extensive and profound systemic socioeconomic transformation. This transition, in turn, imposes new and critical requirements on the knowledge structures and comprehensive

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competencies of high-level talent. As the future backbone — or "energy leaders" — of China's energy system transition and green technology innovation, graduate students, particularly those in energy-sector universities, play a pivotal role. Consequently, their cognitive understanding, attitude, and behavioral intention toward carbon neutrality goals, which is collectively defined as carbon literacy (Howell, 2018), directly influence the efficacy of advancing the national Carbon Peak and Carbon Neutrality strategy, also commonly known as the "Dual Carbon" goals (MOE, 2022).

While studies on carbon literacy have largely concentrated on the general public (Sherry et al., 2023), primary and secondary school students (Xiao et al., 2012; Jiang et al., 2018), and practitioners in specific industries like tourism (Li et al., 2014), there has been little empirical attention paid to graduate students possessing specialized backgrounds and poised to enter core emission-intensive industries. It is therefore imperative to inquire into the defining characteristics of their carbon literacy, the contribution of expertise accumulation to its development, the potential disconnect between knowledge and action, and the optimization space within current cultivation frameworks. Resolving these questions is imperative for the precise optimization of green talent cultivation models.

Based on this rationale, the present study concentrates on energy-sector universities in China. Through a questionnaire survey administered to graduate students, it seeks to empirically investigate the current state of their carbon literacy, its key influencing factors, and the heterogeneity within this cohort. The findings are expected not only to bridge this research gap but also to offer data-driven insights for developing effective pathways for cultivating green talent.

2 Research Design and Methodology

2.1 Questionnaire Design

Drawing on established competency frameworks from information literacy, digital literacy, and AI literacy (Yang, 2025), as well as prior research on carbon literacy (Howell, 2018; Schleich et al., 2024), this study conceptualizes carbon literacy as a multidimensional construct measured across three core dimensions: cognitive, attitudinal, and behavioral intention. The cognitive dimension assesses awareness and understanding of the "Dual Carbon" goals, relevant technologies, and policies. The attitudinal dimension gauges levels of endorsement and sense of responsibility toward achieving these goals. The behavioral intention dimension captures willingness to adopt low-carbon practices in both academic research and daily life.

Guided by this theoretical framework, a structured questionnaire comprising 32 items was developed. The questionnaire is organized into five sections: (A) demographic information (gender, educational level, school/department); (B) knowledge of the "Dual Carbon" goals (16 items); (C) low-carbon behavioral intention (6 items); (D) perception of national emission reduction strategies (5 items); and (E) open-ended suggestion (2 items). Most items employ a five-point Likert scale to ensure data quantifiability and comparability.

2.2 Sample Characteristics

The survey targeted master's and doctoral students at China University of Petroleum, Beijing. To maximize response diversity, the questionnaire was distributed through official university channels, departmental advisors, and social media platforms. Participation was anonymous to ensure data authenticity and protect respondent privacy. A total of 415 valid responses were collected, exceeding the recommended minimum sample size of 10 times the number of measurement items and thus meeting robust statistical analysis requirements (Li et al., 2014).

As illustrated in Figure 1, the sample comprised a 2:1 male-to-female ratio (68% male, 32% female). Master's students constituted 77% of respondents, while doctoral students accounted for 8%. Participants were drawn from key schools, including Mechanical and Transportation Engineering (MTE), Chemical Engineering and Environment (CEE), Economics and Management (EM), Petroleum Engineering (PE), and Geosciences (DEOS), ensuring disciplinary diversity.

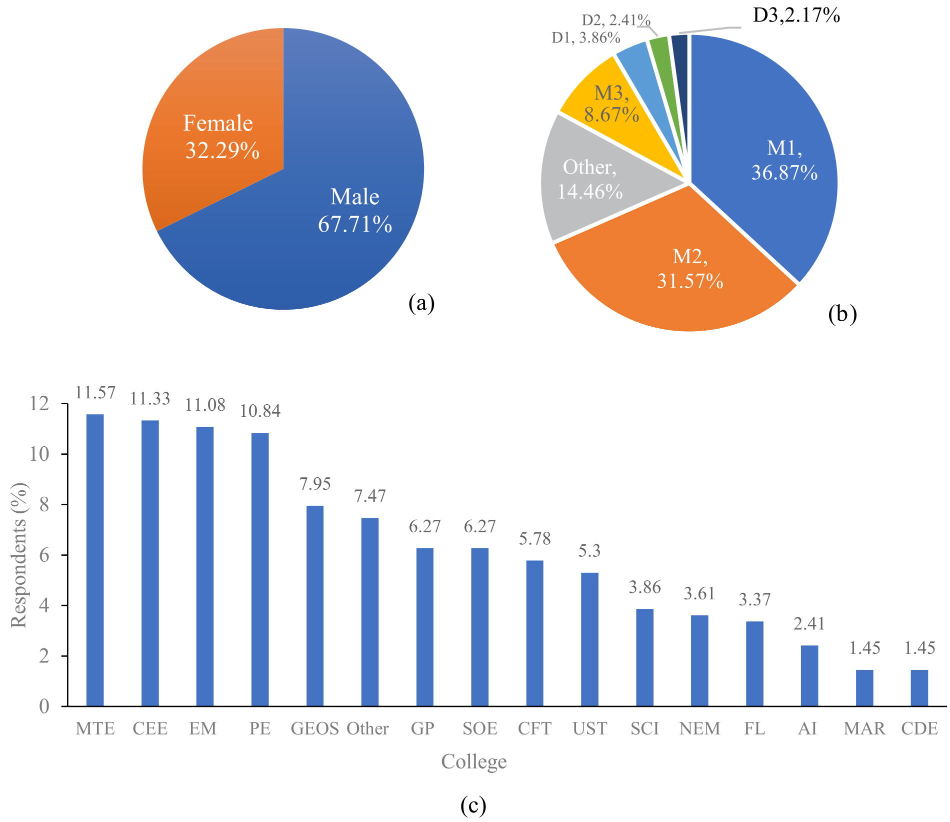

Figure 1 Composition of the Sample (a. Gender; b. Grade Level; c. College)

Note: (1) College name abbreviations: SOE, College of Safety and Ocean Engineering; GEOS, College of Geosciences; GP, College of Geophysics; UST, Unconventional Science and Technology Research Institute; CEE, College of Chemical Engineering and Environment; MTE, College of Mechanical and Transportation Engineering; EM, College of Economics and Management; SCI, College of Sciences; MAR, School of Marxism; AI, School of Artificial Intelligence; PE, College of Petroleum Engineering; CDE, College of Carbon-Neutral Demonstration Energy; CFT, College of Carbon-Neutral Future Technology; FL, College of Foreign Languages; NEM, College of New Energy and Materials. (2) Academic year abbreviations: M1, first-year master's student; M2, second-year master's student; M3, third-year master's student; D1, first-year PhD student; D2, second-year PhD student; D3, third-year PhD student.

2.3 Analytical Methods

A mixed-methods approach combining quantitative and qualitative techniques was employed for comprehensive data analysis, utilizing SPSS software. Analytical strategies included descriptive statistics, cross-tabulation analysis, and thematic modeling. To quantitatively assess respondents' carbon literacy levels, a comprehensive evaluation model integrating the entropy weight method and the TOPSIS model was constructed (Chen &Wang, 2003).

(1) Descriptive Statistics and Cross-Tabulation Analysis. These methods were used to summarize sample characteristics and overall performance across the carbon literacy dimensions. Cross-tabulation examined variations in carbon literacy across gender, educational level, and disciplinary background.

(2) Thematic Modeling Analysis. Latent Dirichlet Allocation (LDA) was applied to the open-ended responses to identify predominant themes and suggestion categories, providing qualitative insights that complement the quantitative findings.

(3) Comprehensive Carbon Literacy Evaluation Model. Questionnaire responses were first scored and aggregated into three primary indicators: Cognition, Attitude and Behavior. The entropy weight method was then used to objectively assign weights to each indicator. Finally, the TOPSIS model calculated a composite carbon literacy score for each respondent, who was subsequently classified into one of five performance levels: High, Moderately High (Mod-High), Moderate (Mod), Low, and Very Low (V-Low).

3 Findings and Discussion

3.1 Evidence of a Persistent Attitude-Behavior Gap

Using the TOPSIS comprehensive evaluation model, this study quantified the carbon literacy of graduate students. Results indicate that while the overall carbon literacy level falls in the moderately high range, its internal structure is imbalanced. Among the 415 respondents, only 13 individuals (3.13%) were rated as High level, the elite group; 31.32% as Mod-High level; and 49.64% as Mod level. Collectively, these three categories account for over 80% of the sample (see Figure 2). This suggests that the vast majority of graduate students possess a foundational level of carbon literacy; however, the notably small elite group highlights substantial room for overall improvement.

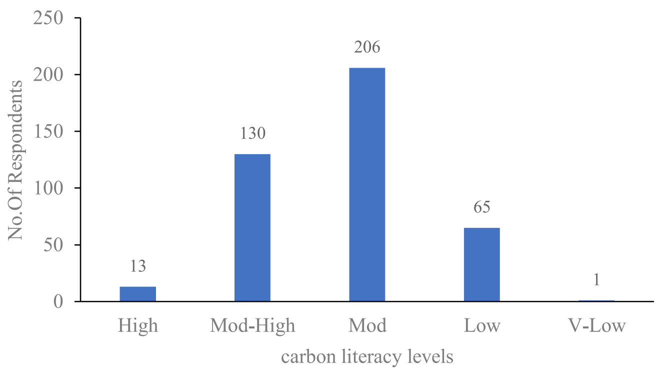

Figure 2 Distribution of Graduates' Carbon Literacy Level

A comparative analysis across the cognitive, attitudinal, and behavioral dimensions reveals a significant Attitude-Behavior Gap (Kollmuss & Agyeman, 2002) in the students' carbon literacy. Specifically, performance is positive in the cognitive and attitudinal dimensions but lags notably in behavioral practices.

Over 91% of respondents accurately understood the core concept of carbon neutrality, and 75.18% believed that achieving the "Dual Carbon" goals is "highly significant". When describing the perceived importance of these goals, more than 80% selected positive descriptors such as "ushering in a new era of ecological civilization" "improving air quality", and "achieving green, low-carbon, sustainable development". This reflects a strong theoretical endorsement and positive emotional inclination among graduate students toward the national carbon neutrality strategy.

In stark contrast to this high cognitive recognition, the adoption of low-carbon practices in both research and daily life remains noticeably inadequate. For instance, in research contexts, only 62.17% reported "assessing the carbon emissions of their research activities", and 58.07% "prioritizing the selection of low-carbon equipment". More advanced practices, such as "implementing carbon management strategies" and "publishing findings in low-carbon journals" were less frequent, at 42.89% and 31.81%, respectively. In daily life, non-low-carbon behaviors were prevalent, including "leaving chargers plugged in after devices are fully charged" (51.81%), "frequently ordering takeout" (44.34%), and "not sorting garbage" (42.17%).

This observed disconnection between knowledge and action aligns with findings from global environmental behavior studies, such as those by Kollmuss et al. (2002), indicating that translating knowledge into sustained action requires overcoming additional motivational and contextual barriers. Within the specific context of energy-sector universities, this gap may stem from multiple factors: the contextual constraints, the dominance of habit and convenience, and the externalization of emission reduction responsibility to governments and corporations.

For example, in research activities, the energy demands of experimental equipment and computational resources often act as contextual constraints. Even with low-carbon awareness, individuals may struggle to prioritize low-carbon options without systemic support, such as lab carbon accounting tools or green procurement standards. The high prevalence of behaviors like “leaving chargers plugged in” and “frequently ordering takeout” in daily life suggests that, in the absence of professional guidance and immediate feedback mechanisms, ingrained habits and convenience can override abstract environmental principles. This observation supports the view of scholars like Schleich et al. (2024) that enhancing carbon literacy requires overcoming inherent behavioral inertia. Furthermore, some students may perceive the primary responsibility for carbon reduction to lie with governments and enterprises, thereby underestimating the cumulative impact of individual actions and potentially weakening their personal motivation to act.

3.2 Impact of Disciplinary Background

Cross-tabulation analysis reveals that disciplinary background serves as a key differentiator in carbon literacy levels (Chi-square test, $p < 0.05$), whereas factors such as gender and educational level show no statistically significant influence.

(1) Strong Association between Discipline and Carbon Literacy

Graduate students from disciplines directly aligned with the “Dual Carbon” field demonstrated significantly higher levels of carbon literacy. For instance, the College of Petroleum Engineering (PE) had the highest proportion of students (53.3%) rated at the Mod-High level or above, followed by the Unconventional Science and Technology Research Institute (UST) and the College of Carbon-Neutral Future Technology (CFT), both at 40.9%. In contrast, schools with a stronger humanities and social sciences focus exhibited notably lower overall carbon literacy (see Figure 3). As an illustration, none of the respondents from the School of Marxism (MAR) were rated above the Mod level, while only 14.3% of those from the College of Foreign Languages (FL) achieved a Mod-High level or higher.

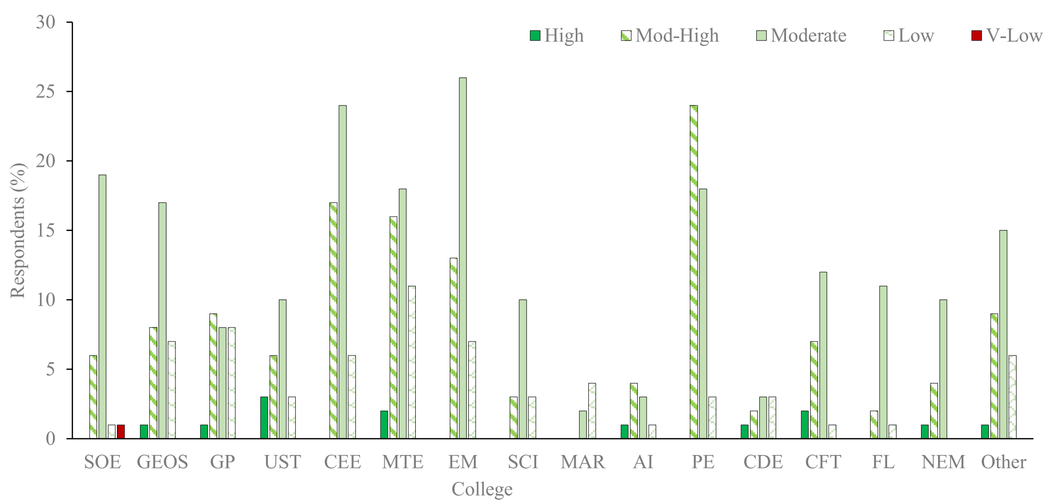

Figure 3 Discipline-Specific Distribution of Graduates’ Carbon Literacy Level

Note: School name abbreviations are the same as in Figure 1.

These findings underscore the pivotal role of specialized education, academic environment, and research practice in shaping carbon literacy. This phenomenon transcends mere differences in knowledge reserves and illuminates, at a deeper level, that carbon literacy is a competency profoundly molded by disciplinary culture and professional habits. In disciplines like energy and chemical engineering, low-carbon development is integral to the academic discourse, research paradigms, and professional ethics; consequently, carbon literacy becomes internalized as a form of disciplinary thinking (Li et al., 2022). Through this immersion, carbon literacy evolves beyond simple knowledge into what can be termed an internalized professional habitus, that is, a deeply ingrained professional disposition and value orientation. Conversely, in non-aligned disciplines, carbon issues may be perceived merely as distant, external topics, struggling to integrate into the core cognitive schemata of students.

This finding extends the definition of carbon literacy proposed by scholars like Rachel Howell (2018), emphasizing that it is not solely an individual capability but also a construct shaped within specific social fields, such as disciplinary communities. This insight also serves as a critical reminder for educators. If carbon literacy education fails to integrate effectively with students' professional identity and cognitive frameworks, it risks being relegated to superficial general knowledge.

(2) Limited Impact of Gender and Educational Level

No statistically significant differences in carbon literacy scores were observed across gender or year of study. A noteworthy, though non-significant, trend emerged among doctoral students, who demonstrated a higher proportion of Mod-High level literacy compared to master's students. This pattern may be attributed to their more advanced research training and broader knowledge base, yet the difference did not reach statistical significance.

3.3 Insufficiency in Systematic and Collaborative Carbon Literacy Education

Analysis of knowledge acquisition channels indicates that online platforms, university campaigns, and formal oral constitute the three primary avenues through which graduate students access information on the "Dual Carbon" goals (see Figure 4). This pattern underscores the characteristics of information dissemination in the digital age while affirming the central role of higher education institutions. However, enterprise outreach and community initiatives are significantly underutilized, accounting for only 11.81% and 8.67% of knowledge sources, respectively. This reveals notable gaps in the current ecosystem for carbon literacy education, particularly in terms of industry-academia collaboration and broader societal engagement.

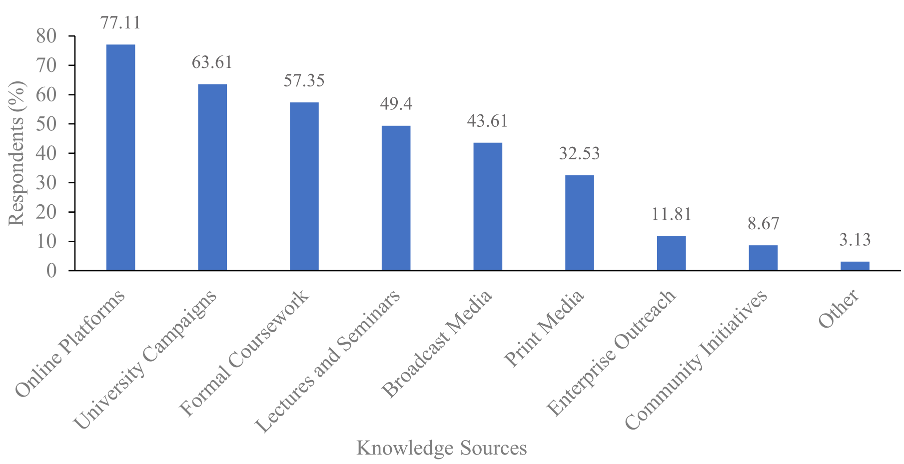

Figure 4 Distribution of "Dual Carbon" Knowledge Sources

This structure of knowledge acquisition calls for a re-evaluation of the role of higher education in fostering carbon literacy. Universities should transition from acting as the sole providers of knowledge to becoming the curators and guides of the information ecosystem. This shift requires educators not only to deliver systematic knowledge in traditional classrooms but also to actively engage with students' digital information environments. By recommending authoritative sources, creating high-quality online content, and cultivating students' ability to critically evaluate information, educators can empower students to autonomously construct a scientific and comprehensive understanding of carbon-related issues within a complex and multifaceted information landscape.

The open-ended question in the questionnaire invited respondents to propose suggestions for achieving the "Dual Carbon" goals. Using LDA topic modeling on the collected responses, eight distinct themes were identified and subsequently defined through auxiliary coding and word-frequency analysis as: Publicity and Education, Low-Carbon Transportation, New Energy, Technological Innovation, Legal Oversight, Policy Support, Corporate and Industrial Action, and Others. The frequency distribution of these themes is presented in Table 1. Among them, Publicity and Education were mentioned 57 times, Low-Carbon Transportation 33 times, New Energy and Technological Innovation 25 times each, and Legal Oversight and Policy Support 19 times each. This distribution indicates a prevailing recognition among respondents that achieving carbon neutrality is a systemic endeavor, requiring coordinated efforts across four key dimensions: awareness enhancement (education), behavioral guidance (transportation), technological advancement (innovation), and institutional safeguarding (policies and regulations). A portion of the responses did not distinctly align with any specific theme, potentially encompassing a variety of unique suggestions, which reflects the diversity and breadth of the respondents' perspectives on pathways to realize the "Dual Carbon" goals.

Table 1 Themes in Graduates' Suggestions for the "Dual Carbon" Goals

Themes	Word Frequency
Publicity and Education	57
Low-Carbon Transportation	33
Renewable Energy	25
Technological Innovation	25
Legal Oversight	19
Policy Support	19
Industry and Enterprises	9
Other	59

4 Conclusion and Implications

4.1 Research Conclusion

Based on a comprehensive questionnaire survey of 415 graduate students at China University of Petroleum, this study yields the following key findings.

(1) The overall carbon literacy of graduate students in energy-sector universities falls in the moderately high range; however, a significant attitude–behavior gap is observed. While the vast majority of students demonstrate high cognitive understanding and positive attitudes toward the "Dual Carbon" goals, their adoption of low-carbon behaviors in both research and daily life remains noticeably limited.

(2) Disciplinary background serves as a core factor influencing carbon literacy levels, with pronounced disparities

among students from different majors. Those in energy, chemical engineering, and carbon neutrality-related disciplines exhibit stronger carbon literacy, whereas students in humanities and social sciences tend to perform relatively poorly. This indicates that the existing disciplinary education system acts as a key site for shaping — yet also unevenly distributing — carbon literacy.

(3) Formal education channels such as university curricula and campus activities, together with online platforms, constitute the primary sources of carbon literacy knowledge. However, the potential for collaborative education among universities, industry, and society remains largely untapped.

(4) Graduate students have formed a systematic consensus on achieving China's "Dual Carbon" goals, recognizing that advancing carbon literacy education requires coordinated efforts across multiple dimensions — including awareness promotion, behavioral guidance, technological innovation, and institutional safeguards.

4.2 Policy and Educational Implications

To improve carbon literacy among graduate students in energy-sector and other universities and to cultivate green innovation talent aligned with the "Dual Carbon" strategy, the following implications are proposed.

(1) Implement precision education strategies to enable differentiated capacity building. Given the disciplinary variations in carbon literacy, educational interventions must shift from a "one-size-fits-all" approach to targeted interventions. Universities should establish dynamic assessment mechanisms to identify knowledge gaps and behavioral shortcomings across disciplines. Students in high-literacy engineering fields should be offered advanced courses focusing on frontier technologies, systemic innovation, and leadership development. Those in foundational disciplines such as the humanities and basic sciences may benefit more from universal, engaging, and life-relevant introductory modules designed to stimulate interest and responsibility. Such diagnostic-based differentiated teaching is essential for improving the cost-effectiveness of educational inputs.

(2) Promote cross-curricular integration of carbon literacy. Universities should move beyond confining carbon literacy to environmental or energy-related majors and integrate core carbon literacy modules into the curricula and training programs of all disciplines. By establishing interdisciplinary general education core courses and embedding carbon neutrality case studies into specialized courses, students across humanities, sciences, engineering, and management can acquire the necessary carbon literacy framework, thereby addressing disparities rooted in disciplinary divides.

(3) Establish an integrated cognition–practice–innovation model to close the attitude–behavior gap. Universities should strengthen practical teaching through initiatives such as low-carbon research grants, green technology innovation competitions, carbon footprint tracking activities, and green campus demonstration projects. Such measures create real-world scenarios where students can translate knowledge into action, bridging the gap between knowing and doing.

(4) Strengthen top-level design and foster an immersive low-carbon campus culture. Universities should formulate clear carbon literacy action plans and incorporate green and low-carbon concepts into campus governance, infrastructure, and cultural development. Meanwhile, they should leverage digital and new media platforms to build authoritative and engaging online carbon literacy education resources. Partnerships with enterprises and communities can further expand learning beyond the classroom, creating an immersive educational ecosystem that subtly shapes students' values and behavioral patterns.

(5) Energy-sector universities should assume a leading and industry-specific role. As incubators of future energy

professionals and "energy leaders", these institutions bear the responsibility to pilot innovative approaches. They should not only cultivate experts proficient in low-carbon technologies but also, through comprehensive carbon literacy education, equip all graduates with a deeply ingrained sustainability mindset and industry-specific sense of responsibility. In doing so, they can lead the green transition of the entire energy sector and serve as exemplars for related industries.

4.3 Research Limitations and Future Prospects

This study, while providing an initial empirical investigation into the carbon literacy of graduate students at energy sector universities, has several limitations that concurrently outline a clear agenda for future research. These limitations pertain primarily to the generalizability of findings, the research design, and the depth of mechanistic insight, each of which points directly to a valuable pathway for scholarly extension.

First, the singular sample source — a single energy-focused university — ensures internal consistency but limits the broader applicability of the conclusions. To address this, future work should employ a multi-institutional and cross-regional sampling strategy. Expanding the scope to include comprehensive universities and other types of engineering schools would test and enhance the external validity of the patterns observed here, determining whether they are distinctive to specialized energy institutions or more widespread across higher education.

Second, the cross-sectional and self-reported nature of our survey data constrains causal inference and may be susceptible to response biases. This methodological limitation naturally suggests the need for longitudinal and multi-method research designs. Future studies could track the same cohort over time — from admission through graduation and into early career stages — to map the dynamic trajectory of carbon literacy and better attribute changes to specific educational interventions. Complementing surveys with behavioral data, digital trace analysis, or experimental protocols would mitigate self-report biases and offer more objective measures of actual low-carbon behaviors.

Finally, while this study identifies the critical attitude-behavior gap and explores its plausible causes, it does not definitively quantify the pathways and relative strengths of the underlying influencing mechanisms. Building on this limitation, subsequent research should apply advanced analytical models, such as time series analysis or structural equation modeling, to rigorously test how factors like personal environmental identity, perceived social norms, and specific institutional contexts interact to either bridge or widen this gap. Furthermore, intervention studies that manipulate key variables — for instance, through designed mentorship programs, team-based challenges, or feedback systems — are essential to move from correlation to causation and to inform the design of truly effective educational and policy measures.

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