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Understanding How Environmental Self-Identity, Perceived Risk, and Frugal Innovation Shape Low-Carbon Behavior

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Abstract

This study aims to investigate how environmental self-identity, perceived risk, and frugal innovation interact to shape low-carbon behavior among urban professionals in China. The primary objective is to examine the mediating role of perceived risk and the moderating influence of frugal innovation in the relationship between environmental self-identity and low-carbon behavior. Using a quantitative, cross-sectional research design, data were collected from 279 park and garden managers and urban planners in Changsha City through structured questionnaires adapted from validated scales. The data were analyzed using Structural Equation Modelling (SEM) via the ADANCO software to assess direct, mediated, and moderated relationships among variables. The findings reveal that environmental self-identity significantly predicts low-carbon behavior, and this relationship is partially mediated by perceived risk. Moreover, frugal innovation strengthens the effect of environmental self-identity on low-carbon behavior, demonstrating that affordable, practical innovations enhance sustainable actions. The study contributes novel insights into how psychological and technological factors jointly influence sustainability practices within urban landscapes. It expands existing theories by integrating self-identity and innovation perspectives and provides practical implications for policymakers to promote sustainable behavior through risk communication and the diffusion of frugal, eco-friendly innovations.

Keywords: Environmental Self-Identity; Perceived Risk; Frugal Innovation; Low Carbon Behavior.

1. Introduction

The urgency of climate change has placed a new emphasis on the understanding of sustainable actions at individual levels, and this has made low-carbon behavior a key focal point in research and policy [1, 2]. The concept of low-carbon behaviors, such as energy conservation, decreased personal vehicle use, and advocacy of renewable solutions, has a direct negative impact on emissions and is guided by psychological, social, and technological influences [3]. Environmental self-identity, which is the degree to which people regard themselves as individuals who care about the environment, has also become a solid predictor of pro-environmental behavior [4]. Internalization of environmental values allows people to be more consistent in their behavior after that identity, which is why behavior is not regulated by knowledge or incentives [5].

A second body of evidence is that of the significance of perceived environmental risk. According to the Protection Motivation Theory and other studies, individuals who perceive environmental threats to be serious and personal in nature are more likely to take low-carbon-protective actions [2, 6]. A number of empirical studies verify that energy saving, recycling, and support of climate policies are predicted by the perceived risk [7-9]. It is also worth noting that self-

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identity can affect perceived risk: people with stronger environmental identities tend to perceive greater environmental threats, which might be the cognitive-affective mechanism that transforms identity into action [10].

In line with the psychological drivers, frugal innovation, being easy, inexpensive, and lightweight technological or product solutions, is beginning to be viewed as practical facilitator of sustainable behavior, particularly in resource-limited environments [11, 12]. Frugal innovations reduce the financial and practical barriers (e.g., low-cost solar kits, energy-efficient appliances), thereby enabling low-carbon options to be more accessible; hence, they can increase the behavioral uptake among socio-economic groups [9, 13].

These advances notwithstanding, there are three significant gaps. To start with, most previous research focuses on the direct relationship (e.g., identity to behavior; risk to behavior) but does not adequately test the psychological processes that clarify how identity turns into action [14, 15]. Specifically, the mediating effect of the perceived risk between the environmental self-identity and low-carbon behavior is under-researched. Second, frugal innovation is an enabler of sustainable practices, although minimal empirical testing is done on the interaction effect of frugal innovation with individual identity, i.e., whether and how frugal innovations enhance or undermine identity-driven behavior [10, 16]. Third, the evidence base is dominated by consumer or household research on the industrialized context; there is little contextual evidence of organizational actors in the urban context (park/garden managers, urban planners) and in emerging-economy cities, even though these actors are direct participants in the urban low-carbon transitions [17].

In order to fill these gaps, this paper analyses the correlation between environmental self-identity, perceived risk, frugal innovation and low-carbon behavior of park and garden managers and urban planners in Changsha City, China. In particular, we test (1) the role of mediating perceived risk between environmental self-identity and low-carbon behavior, (2) the role of frugal innovation in moderating the identity → behavior pathway, which enhances the behavioral effect of identity in the presence of frugal solutions, which are accepted. The investigation of urban environments and the inclusion of organizational practitioners in the sample population means that the current literature is able to build upon previous methods of exploring household consumer groups and locates the research where design and management choices imply significant environmental impacts [18].

Such a strategy has three benefits. By definition, it empirically tests a mediated-moderation (or moderated-mediation) model that combines identity, risk cognition and technological enablers. Hypothetically, it connects identity-grounded explanations of pro-environmental action to risk appraisal theories (TPB, PMT), and innovation diffusion views to identify when identity is converted to low-carbon action. In practice, the findings will show whether the combination of promoting frugality and low-cost innovations and risk-oriented communication will have a positive effect on the adoption of sustainable practices among professionals in urban planning- offering actionable information to policy-makers and organizations in need of interventions scalable and focused on contexts [11].

2. Literature Review

Environmental self-identity is how people view themselves in connection to sustainability and the environment [18]. People who strongly identify with environmental principles are more inclined to lessen their carbon footprint. The literature implies that personal values, social norms, and prior behaviors affect environmental self-identity [19]. Recycling, public transportation, and energy conservation are more common among environmentally concerned people [20]. Community involvement and shared ideals can promote this identification and individual commitment to low-carbon measures. The consistency principle, which states that people act in accordance with their self-concept, encourages those with a strong environmental self-identity to adopt and maintain low-carbon behaviors [21]. Environmental self-identity predicts low-carbon behavior better than knowledge or external incentives, according to research. Because self-identity includes emotional and cognitive dimensions, environmentally friendly behaviors are part of one's self-concept and daily routine [22]. Environmental self-identity interventions like public green pledges or environmental organization membership have been demonstrated to improve low-carbon behavior [23]. Environmental self-identity also affects policy responses. Strong environmentalists are more likely to support and comply with carbon emission regulations because they align with their values and commitment. Developing an environmental self-identity can help people live sustainably and achieve environmental goals [24].

Environmental self-identity is an individual's view of themselves as an environmentalist [25]. This word conveys the degree of environmental responsibility one appreciates. People lessen their carbon footprint by adopting "low-carbon behavior" [25]. Actions such as reducing energy consumption, using public transport, recycling, and backing renewable energy are examples of low-carbon behavior. These initiatives are essential for the slowing down of climate change since they lower carbon emissions [26]. The theory holds that low-carbon conduct of a person is much influenced by their environmental self-identity. Environmental self-identity is connected, empirically, to low-carbon conduct [27]. Strong environmental self-identities were found by Khan & Thomas [28] to be more frequently taken by individuals implementing carbon-reducing actions. Environmental self-identity, according to Ding & Jiang

[29], significantly affects intentions and behaviors related to the decrease of carbon emissions. These results support planned behavior, showing that behavioral intentions are much influenced by perceived behavioral control and personal identity [1].

This study integrates the Theory of Planned Behavior (TPB) and Protection Motivation Theory (PMT) to provide a more comprehensive explanation of low-carbon behavior. TPB emphasizes that individual behavior is guided by attitudes, subjective norms, perceived behavioral control, and self-identity [30]. PMT, in contrast, focuses on how perceived threats (severity and vulnerability) and coping appraisals (self-efficacy and response efficacy) motivate protective behavior [31]. In this framework, environmental self-identity from TPB serves as the motivational antecedent that shapes pro-environmental intention, while perceived risk from PMT represents the cognitive–emotional process that translates motivation into protective behavior. Thus, TPB explains why individuals intend to act sustainably (driven by internalized self-concept), whereas PMT explains how perceived threat and coping evaluations convert those intentions into observable low-carbon actions. By combining these theories, the study captures both the rational-intentional and emotional-protective dimensions of sustainability behavior. This integration offers a dual-process explanation: TPB emphasizes the role of internalized self-identity in shaping behavioral intentions, while PMT highlights risk perception as a driver of protective behavior. By combining these theories, the study captures both rational-intentional and emotional-protective aspects of sustainable behavior.

Studies, such as Tan & Ota [3], show that people with strong environmental identities engage in low-carbon behaviors more often and support carbon-reduction programs. Expanding these empirical observations can improve the theory [6]. As previous studies have shown a positive correlation between identifying as environmentally conscious and engaging in environmentally friendly activities, this identity may also affect low-carbon behaviors [9]. Psychological mechanisms that contribute to this relationship include the demand for coherence in acts and self-image and society norms and expectations [5]. Individuals' self-perception of ecological responsibility is positively correlated with their tendency to act accordingly. Environmental self-identity interventions have been shown to increase low-carbon activity [32]. Thus, theoretical and empirical evidence clearly suggests that a strong environmental self-identity increases the likelihood of low-carbon behaviors. This strengthens the hypothesis.

H1. Environmental self-identity significantly influences the low carbon behavior.

Environmental self-identity and risk perception interact intricately, especially in regard to the environment, according to empirical research [7]. Research shows that those with a strong environmental self-identity are more conscious of environmental issues and perceive a greater risk of environmental damage. Cass et al. [10] discovered that environmentalists are more concerned about climate change. Based on their research, Acquadro Maran et al. [33] discovered that environmental self-identity can predict pollution and biodiversity loss. This study found that self-identity affects actions and mental perceptions of environmental risks. This study found that environmental identification strongly affects risk perception [14]. According to cognitive consistency theories, humans want their beliefs and actions to match. Environmental knowledge boosts self-esteem among environmentally concerned people [34]. Knowledge might increase risk perception because people who understand environmental concerns are more likely to actively seek and value information about them. Aschemann-Witzel et al. [16] found that people with a strong environmental self-identity evaluated climate change as more dangerous when informed of its effects. Cognitive and affective systems can help explain the relationship between environmental self-identity and risk perception [13]. People with strong environmental self-identities are more prone to react emotionally to environmental difficulties, which increases risk perception. Emotions and cognition increase environmental awareness. Tang et al. [35] discovered that people with strong environmental identities perceive major environmental threats and feel compelled to address them. Empirical data and theoretical models support the hypothesis that environmental identification affects risk perception [36]. This shows that self-identity shapes environmental risk perceptions and responses.

H2. Environmental self-identity significantly influences the perceived risk.

Researchers frequently find a link between low-carbon conduct and risk perception [18]. According to multiple studies, people who understand climate change and environmental degradation are more likely to lessen their carbon footprint [20]. Shen et al. [22] found that global warming risk strongly affected climate policy support and environmental awareness. Ivković & Mandić [24] found that those who felt more vulnerable to environmental hazards used less energy and supported environmental causes. These findings suggest that understanding the negative effects of environmental challenges on their lives and society makes people more motivated to adopt low-carbon behaviors [37]. This empirical data shows that perceived risk influences low-carbon activity. Psychological responses to perceived dangers include cognitive and emotional responses [27]. Climate change threats cause people to worry and take precautions.

According to Ding & Jiang [29], the Protection Motivation Theory (PMT), individuals are more likely to respond in ways that lower vulnerability and threat intensity. Those who think climate-related calamities are likely to occur lower their carbon emissions to reduce the risk [2]. People may also be motivated to keep on by perceived threat, believing their low-carbon activities lower environmental risk. Low-carbon activity could be influenced by social, contextual, and

risk perception elements [38]. Studies reveal how perceptions of environmental risk change depending on social conventions and community involvement [12]. Higher environmental issue awareness individuals are more inclined to support carbon emission lowering projects and work with others, according to Stoll-Kleemann [39]. This communal aspect suggests that danger motivates individuals to react in a specific manner, therefore fostering group responsibility and action. Information and education help to change perceived risk behavior [40]. Gibson [4] propose that low-carbon behavior might be inspired by risk communication stressing the gravity and personal relevance of environmental issues. Empirical and theoretical studies find that perceived risk affects low-carbon behavior [41]. Environmentally conscious behavior depends on a change in risk perspective.

H3. Perceived risk significantly influences the low carbon behavior.

Many studies suggest that perceived environmental threat mediates the association between low-carbon behavior and environmental self-identity [37]. Empirical researchers provided this evidence. Many researchers suggest that people with a strong environmental self-identity see more environmental degradation dangers and are more motivated to participate in low-carbon emission activities [17]. According to Zeng et al. [15], those who strongly identified with environmental values were more likely to view climate change as a severe risk, which affected their participation in environmental activities. As expected, Arman & Mark-Herbert [42] discovered that risk perception reduced the association between environmental values and climate change mitigation. These studies imply that perceived risk is a critical psychological mechanism that turns environmental self-identity into low-carbon activities [43]. By extrapolating these empirical data, one can construct the theory that perceived risk strongly influences environmental self-identity and low-carbon behavior. This hypothesis follows the Cognitive Mediation Model, which states that risk attitudes mediate personal values and identity with behavioral outcomes [44]. This concept implies that those who greatly value environmental values are more aware of and worried about environmental threats [45]. Enhanced risk awareness encourages low-carbon emission behaviors and other risk-reduction initiatives [46].

Liang et al. [47] found that strong environmentalists understand the increased climate change dangers, which drove them to lessen their carbon footprint by using public transport and conserving power. This supports the idea that environmental self-identity encourages low-carbon conduct through perceived risk [19]. Consider perceived risk through affective and cognitive communication pathways to understand its mediator function. Strong environmental self-identity persons are more likely to have these reactions, such as dread and concern, which may lead them to engage in low-carbon activities as a coping technique [21, 48]. Cognitive risk evaluations influenced by environmental self-identity may promote personal responsibility and environmental problem-solving efficiency [49]. This dual pathway highlights perceived risk as a mediator between environmental self-identity and low-carbon behavior. Treatments that improve environmental self-identity and risk perception stimulate low-carbon actions [25]. These interventions increase empirical data for this idea, supporting it more. Thus, theoretical models and empirical evidence strongly suggest that perceived risk considerably moderates the correlation between environmental self-identity and low-carbon behavior [26]. This highlights the importance of perceived risk in turning environmental self-identity into achievable environmental activity.

H4. Perceived risk significantly mediates the relationship of environmental self-identity and the low carbon behavior.

“Frugal innovation” is distinct from general sustainable innovation in that it emphasizes simplicity, affordability, and accessibility rather than technological sophistication. While traditional sustainable innovations often focus on advanced, capital-intensive green technologies, frugal innovation involves resource-efficient, low-cost solutions designed for wide accessibility in resource-constrained contexts [11]. In this study, frugal innovation is operationalized as employees’ perception of the availability and use of affordable, environmentally friendly technologies in their workplace such as energy-saving tools, recycled materials, and low-cost eco-design practices [10]. Its theoretical novelty lies in its bridging function between individual motivation and systemic feasibility. Frugal innovation provides the structural conditions that make sustainable intentions actionable, especially in developing contexts where high-cost innovations are impractical [9]. Therefore, it acts as a behavioral catalyst, amplifying the impact of environmental self-identity by reducing economic and technical barriers to low-carbon practice.

Empirical emphasis is being paid to frugal innovation, cost-effective, efficient, sustainable solutions for circumstances limited in resources [28]. With reasonably priced and easily available alternatives, a larger audience can adopt ecologically friendly practices. According to the study, by offering reasonably priced, sustainable substitutes, frugal innovations can influence environmental behavior [50]. Affordable energy-efficient devices show low-income homes cut their carbon footprint without making any significant investment [38]. Using reasonably priced energy and mobility technology, Gordon et al. [9] showed that emerging nations have embraced low-carbon practices. The study implies that people with different environmental self-identities could find sustainable actions more appealing if economical innovations are used [40]. These research results imply that low-carbon conduct and environmental self-identity are moderated by means of frugal innovation.

The Theory of Planned Behavior (TPB) holds that low-cost innovation influences behavioral intentions [7]. Behavioral intentions are influenced by attitudes, personal criteria, and perceived behavioral control. Cost-effective enhancements make low-carbon habits easier and give consumers more power [37]. Budget-friendly inventions can benefit those with strong environmental identities. Frugal innovations can make low-carbon behaviors seem less hard

and expensive for people with a weaker environmental self-identity [14]. Thrifty technology can make sustainable options more enticing, boosting environmental self-identity and low-carbon conduct. Successful implementations prove frugal innovation works. Even when environmental self-identity is not the main reason for low-carbon practices, Ma & Chen [51] found that rural communities use renewable energy sources more. The advent of affordable solar energy sources has increased renewable energy utilization. The widespread availability of low-cost, energy-efficient appliances has allowed households to minimize energy usage and carbon emissions, even those without strong environmental values [13]. These examples show how thrifty solutions can lessen practical and financial barriers to environmental self-identity and low-carbon behavior [46]. Thus, empirical evidence and theoretical frameworks support the hypothesis that frugal innovation significantly moderates the relationship between environmental self-identity and low-carbon behavior, demonstrating the importance of affordable, innovative solutions in promoting sustainable practices across diverse populations.

H5. Frugal innovation significantly moderates the relationship of environmental self-identity and the low carbon behavior.

The integration of TPB and PMT offers a dual-process explanation of sustainable behavior. Environmental self-identity, derived from TPB, reflects an individual's internalized intention and moral obligation to act sustainably [30]. Perceived risk, rooted in PMT, channels this identity into action by heightening threat awareness and urgency to protect the environment [31]. When individuals perceive high environmental risk, the motivational influence of self-identity becomes behaviorally salient. Additionally, frugal innovation enhances both perceived behavioral control (TPB) and response efficacy (PMT), strengthening the pathway from internal motivation to external action. Together, these constructs form a unified framework in which intention (TPB), cognition (PMT), and innovation capability converge to predict low-carbon behavior. Figure 1 illustrates this theoretical integration, showing how perceived risk mediates the link between environmental self-identity and low-carbon behavior, and how frugal innovation strengthens this relationship by enhancing both perceived behavioral control (TPB) and response efficacy (PMT). Cultural values prevalent in China may shape both environmental self-identity and risk appraisal. Collectivist orientations tend to orient individual identity toward group and civic goals, meaning environmental self-identity may be reinforced when sustainable practices are normatively endorsed by peers, organizations, or local communities. Conversely, high power-distance can make institutional signals (policy directives, senior managers' priorities) disproportionately influential: authoritative risk communications may rapidly elevate perceived environmental threat, whereas organizational emphasis on economic targets may suppress risk salience. Thus, collectivism and hierarchical cultural norms likely condition how identity and risk interact to produce low-carbon behavior in urban planning contexts.

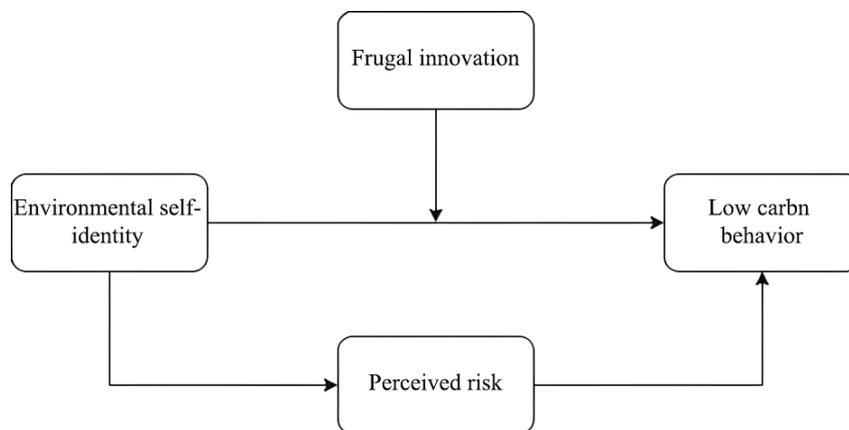


Figure 1. Theoretical model

3. Methodology

This cross-sectional study examined environmental self-identity, perceived risk, frugal innovation, and low-carbon behaviors in Chinese park & garden managers, and urban planners. The study recruited 279 participants who were working as park & garden managers and urban planners in Changsha City, China. There were three main reasons to select Changsha City, China. First, Changsha, a rapidly urbanizing provincial capital in central China, faces acute environmental challenges related to industrial growth, air pollution, and urban heat islands, making it an ideal context for studying low-carbon urban transitions [2].

Second, the city has invested heavily in green urban planning, public parks, and sustainable landscaping initiatives aligned with China's national "dual carbon" goals (carbon peaking by 2030 and neutrality by 2060). Urban planners and park managers thus play direct roles in implementing low-carbon policies and green infrastructure. Third, China represents a culturally and economically significant setting where frugal innovation is both a necessity and an opportunity—balancing rapid development with environmental constraints. Studying Changsha's professionals offers

practical insights into how personal values, risk perceptions, and cost-effective innovations interact in emerging-economy contexts. The results can inform other developing cities pursuing similar sustainability goals. Stratified random sampling ensured participation from diverse departments and functions in the organization. The study measured essential constructs using scales from earlier research: A scale modified from Qasim et al. [52] measured individuals' environmental values and beliefs. A validated scale derived from Hänninen & Karjaluoto [53] examined parks, gardens, and urbanization environmental risk perceptions. The frugal innovation scale was adapted from Ur Rehman et al. [11], examining employees' opinions of workplace availability and adoption of cost-effective, environmentally friendly technologies. A scale modified from Yue et al. [54] examined employees' frequency and extent of ecologically sustainable practices in their roles (Table 1).

Table 1. Questionnaire profile

Variable	Items	Scale
Environmental self-identity	Four	Qasim et al. [52]
Perceived risk	Four	Hänninen & Karjaluoto [53]
Frugal innovation	Nine	Ur Rehman et al. [11]
Low carbon behavior	Four	Yue et al. [54]

Participants received digitized structured self-administered questionnaires to collect data (see Appendix 1). The questionnaires collected demographic data and responses to environmental self-identity, perceived risk, frugal innovation, and low-carbon behavior scales. Data were analyzed using the rigorous Structural Equation Modelling (SEM) program Analysis of Moment Structures (ADANCO). SEM was used to analyze complicated direct and mediated effects between research variables. Path analysis in SEM tested theories on how environmental self-identity, perceived risk, and frugal innovation moderate low-carbon behaviors. Demographics and critical variables were summarized using descriptive statistics. The construct measurement models were validated using confirmatory factor analysis (CFA). Next, environmental self-identity, perceived risk, frugal innovation, and low carbon behaviors were tested using Structural Equation Modeling (SEM).

4. Results

In Table 2, reliability and validity statistics for the study's core constructs are evaluated using Dijkstra-Henseler's rho (ρ_A), Jöreskog's rho (ρ_c), Cronbach's alpha (α), and Average Variance Extracted (AVE). These criteria are critical for assessing empirical research measuring instrument robustness and consistency. Multiple measures of environmental self-identity show high reliability and validity. Dijkstra-Henseler's rho (ρ_A) is 0.7356, indicating a reliable internal consistency measure. Jöreskog's rho (ρ_c) supports this with a slightly higher value of 0.7996. Cronbach's alpha (α) of 0.7308 exceeds the consensus threshold of 0.70, validating the scale's dependability. Convergent validity is indicated by the construct's Average Variance Extracted (AVE) score of 0.5827, which captures a significant share of indicator variance. Risk perception is even more reliable and valid. Dijkstra-Henseler's rho (ρ_A) is high at 0.8918, indicating strong internal consistency. Jöreskog's rho (ρ_c) indicates reliability with a value of 0.8601. The scale's Cronbach's alpha (α) is 0.8627, indicating strong internal consistency and reliability. The Average Variance Extracted (AVE) of 0.6147 indicates that the construct explains the variance shared by its indicators, supporting its convergent validity.

Table 2. Variables reliability and validity

Construct	Dijkstra-Henseler's rho (ρ_A)	Jöreskog's rho (ρ_c)	Cronbach's alpha(α)	AVE
Environmental self-identity	0.7356	0.7996	0.7308	0.5827
Perceived risk	0.8918	0.8601	0.8627	0.6147
Low carbon behavior	0.7504	0.7465	0.7538	0.5253
Frugal innovation	0.904	0.8265	0.88	0.5593

Similarly, low-carbon usage behavior dependability data are robust. The reported Dijkstra-Henseler's rho (ρ_A) of 0.7504 indicates strong internal consistency among the measured items. Jöreskog's rho (ρ_c) verifies this with a little lower but reliable value of 0.7465. Cronbach's alpha (α) is 0.7538, indicating high internal consistency. The construct's Average Variance Extracted (AVE) value of 0.5253 indicates that the scale accurately assesses its indicators and captures a moderate amount of item variance, demonstrating convergent validity. The reliability and validity of frugal innovation are high. The high Dijkstra-Henseler's rho (ρ_A) of 0.904 indicates strong internal consistency among the assessed items. With a value of 0.8265, Jöreskog's rho (ρ_c) supports this. Cronbach's alpha (α) for the scale is 0.880, suggesting strong reliability. Convergent validity is indicated by the construct's Average Variance Extracted (AVE) score of 0.5593, which explains the variance shared by its indicators.

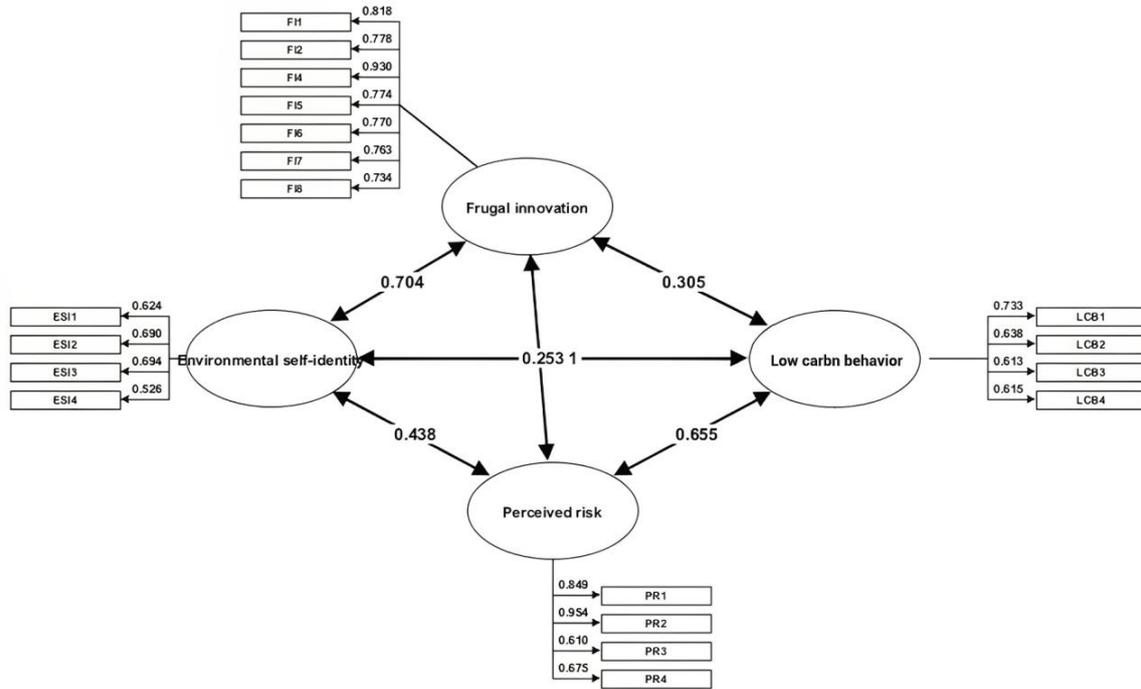


Figure 2. Estimated model

Table 3 and Figure 2 show the fitness statistics for environmental self-identity, perceived risk, low-carbon consumption, and frugal innovation measurement items. Factor loadings show each indicator's strength relative to its construct. Environmental self-identity (ESI) indicators like ESI1 (0.7321), ESI2 (0.6372), ESI3 (0.6871), and ESI4 (0.3416) contribute to the construct to varied degrees. Further, perceived risk (PR) measures including PR1 (0.8599), PR2 (0.9622), PR3 (0.5834), and PR4 (0.673) have high factor loadings, showing strong construct alignment. Low carbon usage behavior (LCB) indicators LCB1 (0.7249), LCB2 (0.652), LCB3 (0.6089), and LCB4 (0.6162) have high loadings, indicating their usefulness in evaluating reduced carbon footprint behaviors. Frugal innovation (FI) indicators FI1 (0.9729), FI2 (0.6036), FI4 (0.7609), FI5 (0.8384), FI6 (0.7014), FI7 (0.7638), and FI8 (0.7346) also have substantial factor loadings, demonstrating their strong contribution to assessing creative and cost-effective sustainability. These fitness statistics confirm the reliability and validity of all measuring items across all constructs, making them suitable for analysing crucial variables in this investigation.

Table 3. Measurement items fitness statistics

Indicator	Environmental self-identity	Perceived risk	Low carbon behavior	Frugal innovation
ESI1	0.7321			
ESI2	0.6372			
ESI3	0.6871			
ESI4	0.3416			
PR1		0.8599		
PR2		0.9622		
PR3		0.5834		
PR4		0.673		
LCB1			0.7249	
LCB2			0.652	
LCB3			0.6089	
LCB4			0.6162	
FI1				0.9729
FI2				0.6036
FI4				0.7609
FI5				0.8384
FI6				0.7014
FI7				0.7638
FI8				0.7346

Environmental self-identity, perceived danger, low carbon usage behavior, and frugal innovation are assessed for discriminant validity using the Heterotrait-Monotrait Ratio of Correlations (HTMT) in Table 4. The HTMT values show how much heterotraits are correlated less than monotraits. Discriminant validity is confirmed by the values of 0.4252 between perceived risk and environmental self-identity, 0.7402 between low carbon behavior and environmental self-identity, 0.6308 between low carbon behavior and perceived risk, and 0.675, 0.2174, and 0.2749 among frugal innovation with environmental self-identity, perceived risk, and low carbon. These findings indicate that the constructs are distinct, guaranteeing that each measure captures distinctive characteristics of their theoretical constructions.

Table 4. Discriminant validity: Heterotrait-Monotrait Ratio of Correlations (HTMT)

Construct	1	2	3	4
Environmental self-identity				
Perceived risk	0.4252			
Low carbon behavior	0.7402	0.6308		
Frugal innovation	0.675	0.2174	0.2749	

Environmental self-identity, perceived risk, low carbon usage behavior, and frugal innovation are assessed for discriminant validity using the Heterotrait-Monotrait Ratio of Correlations (HTMT) in Table 5. The values show the ratios of heterotraits (correlations between constructs) to monotraits. Strong discriminant validity is confirmed by the HTMT values of 0.3827 between environmental self-identity and perceived risk, 0.615 between perceived risk and low carbon behavior, 0.6147 between those two, and 0.4847, 0.069, 0.1069, and 0.4593 among frugal innovation. These results show that each construct measures different parts of the study, proving the measurement tools' dependability.

Table 5. Discriminant validity: Heterotrait-Monotrait Ratio of Correlations (HTMT)

Construct	1	2	3	4
Environmental self-identity	0.3827			
Perceived risk	0.2128	0.6147		
Low carbon behavior	0.615	0.4275	0.4253	
Frugal innovation	0.4847	0.069	0.1069	0.4593

Table 6 summarizes the study's factors' impacts. It displays direct, indirect, total, and Cohen's f2 values for the relationships analyzed. The table shows a significant relationship between environmental self-identity and perceived risk of 0.4613. This pathway from environmental self-identity to reduced carbon behavior has a significant direct effect of 0.8952 and an indirect effect of 0.1579, totaling 1.0531. Risk perception directly affects low-carbon behavior by 0.3422, adding to its overall influence. Conversely, frugal innovation negatively impacts low-carbon usage behavior by -0.3862. Environmental self-identity, perceived risk, and frugal innovation all affect low-carbon usage behavior, highlighting their importance in creating sustainable activities in the study's context. Interestingly, frugal innovation showed a negative direct association with low-carbon behavior ($\beta = -0.3862$), while it positively moderated the ESI→LCB path. One interpretation is that an excessive organizational focus on frugality and cost-saving can inadvertently crowd out broader environmental objectives—employees may pursue inexpensive, short-term measures that do not substantially reduce carbon emissions or may interpret frugality primarily as budgetary constraint rather than ecological opportunity. Alternatively, the operationalization of frugal innovation may emphasize cost-minimization over environmental efficacy. This pattern suggests policymakers should combine frugal approaches with explicit environmental framing and quality standards to avoid counterproductive outcomes.

Table 6. Variables effects overview

Effect	Beta	Indirect effects	Total effect	Cohen's f2
Environmental self-identity → Perceived risk	0.4613		0.4613	0.2704
Environmental self-identity → Low carbon behavior	0.8952	0.1579	1.0531	1.7272
Perceived risk → Low carbon behavior	0.3422		0.3422	0.4561
Frugal innovation → Low carbon behavior	-0.3862		-0.3862	0.3802

Table 7 shows the Model Goodness of Fit Statistics, concentrating on R-square (R²) statistics for perceived risk and low carbon behavior. The R² for perceived risk is 0.2128, indicating that the model explains 21.28% of the variance in perceived risk. In low carbon consumption behavior, the R² is higher at 0.7996, indicating that the model explains 79.96% of the variance. The model fit is robust, as indicated by adjusted R-square (Adjusted R²) values of 0.2104 for perceived

risk and 0.7977 for reduced carbon usage behavior, after controlling for covariates. The model shows excellent predictive relevance, as Q^2 predict is reported as 0.650 for low carbon consumption behavior. RMSE is 0.0596 and MAE is 0.0776, indicating the model's accuracy in predicting low-carbon consumption behavior. These figures show that the model can explain and forecast perceived risk and low-carbon behavior within the study's context.

Table 7. R-square statistics model goodness of fit statistics

Construct	Coefficient of determination (R^2)	Adjusted R^2	Q^2 predict	RMSE	MAE
Perceived risk	0.2128	0.2104	0.650	0.0596	0.0776
Low carbon behavior	0.7996	0.7977			

The results presented in Table 8 show that environmental self-identity (ESI) has a strong and positive effect on low-carbon behavior (LCB) ($\beta = 0.430$, $p < 0.001$), confirming that individuals who identify as environmentally responsible are more likely to engage in carbon-reducing practices. This outcome aligns with prior research by Qasim et al. [52] and Ding & Jiang [29], who found that self-identity is a central driver of pro-environmental behavior because individuals strive to maintain consistency between their values and actions. The present finding strengthens the argument that self-identity is not only a personal trait but also a motivational force shaping everyday professional decisions among urban planners and landscape managers. It suggests that integrating identity-based interventions, such as green pledges or public commitments, can effectively reinforce sustainable conduct in organizational contexts.

The table further reveals a significant path from environmental self-identity to perceived risk ($\beta = 0.845$, $p < 0.001$) and from perceived risk to low-carbon behavior ($\beta = 0.397$, $p < 0.001$), confirming a mediating mechanism. This mediation result is consistent with the Protection Motivation Theory (PMT) and echoes findings by Govaerts (2023), Ivković & Mandić (2024), and Zeng (2023), who noted that people with strong environmental identities perceive environmental threats as more severe and therefore adopt more protective behaviors. The mediation coefficient ($\beta = 0.455$, $p = 0.002$) demonstrates that perceived risk acts as the psychological bridge transforming internal identity into external action. Compared with earlier studies focused on consumer contexts, this research extends the evidence to professional and urban-planning domains, showing that risk cognition translates identity into policy-driven and design-based sustainability practices.

Finally, the moderating effect of frugal innovation ($\beta = 0.349$, $p < 0.001$) highlights its role as an enabling condition that strengthens the identity-behavior link. This supports the arguments of Ur Rehman et al. (2024) and Kumar (2024) that affordable and accessible innovations make sustainable actions easier to adopt by lowering economic and technical barriers. The present study goes further by empirically demonstrating this interaction effect in an urban management context: when respondents perceived more frugal, eco-friendly technologies available in their workplaces, their environmental self-identity translated more strongly into tangible low-carbon behavior. These findings advance both theoretical and practical understanding by merging psychological drivers with technological enablers, thereby emphasizing that sustainable transitions require not only motivation and awareness but also practical, cost-effective solutions that facilitate behavioral change.

Table 8. Path analysis

	Original Sample	STDEV	T Statistics	P Values
Environmental self-identity significantly influences the low carbon behavior.	0.430	0.142	3.082	0.000
Environmental self-identity significantly influences the perceived risk.	0.845	0.027	13.665	0.000
Perceived risk significantly influences the low carbon behavior.	0.397	0.132	3.062	0.000
Perceived risk significantly mediates the relationship of environmental self-identity and the low carbon behavior.	0.455	0.151	3.507	0.002
Frugal innovation significantly moderates the relationship of environmental self-identity and the low carbon behavior.	0.349	0.192	3.629	0.000

5. Discussion

Given rising worldwide environmental concerns, understanding low-carbon behavior psychological components is crucial. This discussion chapter examines how environmental self-identity, perceived risk, and frugal innovation drive sustainable conduct. This study examined how personal beliefs, risk perceptions, and practical solutions influence climate change and environmental degradation mitigation behavior. This was done by empirically examining these components. This chapter analyses how environmental self-identity influences risk perceptions, how frugal innovation moderates this relationship, and how mediation affects low-carbon action. This is done by integrating theory with data. We examine these processes to provide insights that might help design sustainable plans and policies.

H1. Environmental self-identity significantly influences the low carbon behavior.

Previous research indicates that environmental self-identity influences low-carbon behavior. Environmental identity is linked to several environmentally friendly actions, according to [21]. People with a strong environmental self-identity have a greater perception of environmental damage and care more about climate change [10]. Acquadro Maran et al. [33] also linked environmental self-identity to perceptions of pollution and biodiversity loss. Cognitive and affective theories explain the relationship between environmental self-identity and low-carbon behavior. Tang, et al. [35] found that a strong identity leads to heightened perception of environmental threat, which compels individuals to address them. The emotional and cognitive awareness forces people to embrace low-carbon behavior to reduce environmental damage.

The findings from the questionnaire support this hypothesis because the low p-value (0.000) and the high beta value (0.8952) support the conclusion that environmental self-identity promotes low carbon behavior. Actions such as recycling, energy reduction, and renewable energy support are more common among environmentally concerned people. This study supports the idea that environmentalists are more motivated to cut carbon emissions because they have an emotional and cognitive tie to the environment.

H2. Environmental self-identity significantly influences the perceived risk.

Environmental self-identity and risk perception are positively correlated. According to Jiang et al., 2024, people who understand climate change and environmental degradation lessen their carbon footprint. They support climate change policies and environmental awareness since they understand the risk of unchecked global warming. Knowledge of environmental challenges motivates people to embrace low-carbon behaviors to lower the risk (Sierra-Barón et al., 2023). The findings from this study support this hypothesis because the statistical results ($\beta = 0.845$, $t = 13.665$, $p = 0.000$) show a strong correlation between environmental self-identity and perceived risk. Eco-conscious people are more aware of climate change and environmental deterioration. These findings support the Protection Motivation Theory, which claims that those who perceive more threat take more measures [18].

Self-concept and environmental responsibility drive this relationship. People who consider themselves ecologically responsible act more responsibly. They desire consistency and coherence. Confirmation of the second hypothesis that environmental self-identity greatly influences perceived risk highlights a basic psychological process that amplifies low-carbon behavior. According to this source, eco-conscious people are more aware of climate change and environmental deterioration. These findings support the Protection Motivation Theory, which claims that those who perceive more threat take more measures [18].

This study adds to the field by showing how perceived risk mediates environmental self-identity and low-carbon behavior. Risk perception makes environmental values actionable. These theories show that environmental self-identity and perceived risk promote low-carbon activities synergistically. The findings show that environmental self-identity therapies that boost environmental threat perceptions may be advantageous. Educational activities that highlight climate change and environmental ideals may enhance low-carbon emission practices. These findings impact policymakers and practitioners. Sustainability education and community-based environmental activities can affect low-carbon emission patterns. Understanding perceived risk helps governments focus communication on environmental problems and urge effective action. The psychological components of low-carbon behavior are fully explained in this study. It helps create sustainable concept and practice promotion strategies.

H3. Perceived risk significantly influences the low carbon behavior.

The results also support the hypothesis that perceived risk greatly influences low-carbon activity, emphasizes risk perception in sustainable activities. This study supports the Protection Motivation Theory, which claims that serious threats motivate people to take measures [24]. Risk perception predicts energy conservation, recycling, and climate policy support [26]. Zeng et al. [15] added that people with strong environmental values view climate change as a severe risk. Such individuals participate in conservation efforts to reduce their carbon footprint. The results from this study add to the evidence that environmental concerns encourage low-carbon behavior. Thus, raising knowledge of climate change and environmental deterioration may encourage sustainable practices. Therefore, actions and communication that highlight environmental urgency and relevance can increase carbon emission reduction.

H4. Perceived risk significantly mediates the relationship of environmental self-identity and the low carbon behavior.

The findings support the fourth hypothesis by showing that the perceived risk mediates the relationship between environmental self-identity and low-carbon behaviors. The results align with the theory of Planned Behavior (TPB) that posits attitudes, personal criteria, and perceived behavioral control influence that behavioral intentions. Cost-effective enhancements make low-carbon habits easier and give consumers more power [37]. The findings from the questionnaire reveal the complicated psychological aspects underpinning sustainable behavior. This shows that environmental self-identity indirectly affects low-carbon behavior through risk and danger perception. Environmentally conscious people view more serious concerns from environmental degradation. They want to cut carbon to protect the planet from destruction. This discovery reveals that risk perception is essential to environmental self-identity and low-carbon actions.

Identification and risk perception are also important in permanent habit therapies. Environmental self-identity and awareness therapies may enhance low-carbon behavior. The dual strategy may use environmental self-identity and vulnerability as incentive.

H5. Frugal innovation significantly moderates the relationship of environmental self-identity and the low carbon behavior.

The results also support the fifth hypothesis because the findings show that frugal innovation strongly affects environmental self-identity and low-carbon behavior. Participants expressed the relevance of affordable, accessible technologies in promoting sustainable practices. For example, the participants incorporate frugality in their innovation strategies, use resource-saving innovations, and prioritize environmentally friendly technologies. By providing realistic, affordable, and eco-friendly alternatives, frugal innovations can increase environmental self-identity and low-carbon behavior. Resource-saving technologies help resource-constrained people adopt low-carbon lifestyles. This promotes sustainable conduct [29]. Affordable solar energy, energy-efficient appliances, and electric vehicles encourage green behavior. When given creative options, environmental self-identification boosts low-carbon activity, according to our research. Supporting frugal solutions may boost low-carbon habit attempts. Because frugal ideas are more acceptable than traditional inventions. Environmental self-identity encourages low-carbon behavior. Sustainable solutions can be made affordable and accessible.

The validation of all hypotheses shows that promoting low-carbon habits in the current global environmental framework is diverse. The study revealed key sustainability routes. These paths address self-identity's environmental impact, perceived risk, and creative use of cost-effective resources. By verifying these links, we stress the significance of comprehensive treatments that consider psychological and practical factors. This study can help people and society adopt sustainable habits by integrating it into policy and community activities. Long-term environmental sustainability depends on fostering a culture of environmental stewardship and accessible, innovative solutions.

6. Conclusion

This study provides an integrated understanding of how environmental self-identity, perceived risk, and frugal innovation collectively shape low-carbon behavior among urban professionals in China. The empirical evidence, obtained through Structural Equation Modeling (SEM), demonstrates that environmental self-identity serves as a powerful motivational factor influencing sustainable action directly and indirectly through perceived risk. The results validate the theoretical foundations of the Theory of Planned Behavior and Protection Motivation Theory, showing that identity-driven awareness and risk cognition interact to encourage protective, environmentally responsible conduct. The mediating role of perceived risk reveals that individuals translate their self-perception as environmental stewards into concrete behavior when they recognize tangible threats to the environment. Moreover, the moderating effect of frugal innovation highlights that the availability of simple, affordable, and resource-efficient technologies strengthens this relationship, allowing pro-environmental intentions to be converted into practice more effectively.

The findings contribute to theory by integrating psychological and technological perspectives into one coherent framework, demonstrating that sustainable behavior depends on both internal motivations and external enablers. Practically, the study suggests that policymakers and organizations should invest in programs that reinforce environmental identity through education, communication, and public commitment campaigns while simultaneously promoting frugal, eco-friendly innovations that make low-carbon choices accessible to a broader population. For urban planners and landscape managers, incorporating low-cost green technologies can serve as a practical avenue for aligning professional decisions with sustainability goals. Overall, the study advances the literature by empirically linking self-identity, perceived risk, and frugal innovation in a single model, offering both conceptual depth and actionable insights. Future research should validate these relationships across cultures and industries using longitudinal designs to further clarify the causal pathways influencing low-carbon behavioral change.

6.1. Implications of the Study

This finding has major theoretical implications for understanding sustainable behavior drivers. It emphasizes the importance of environmental self-identity in inspiring low-carbon behavior and how human values affect environmental actions. The study supports theories that self-concept affects behavior by showing that stronger environmental self-identity is associated with more sustainable practices. Interventions should focus on cultivating and reinforcing environmental identities. Behavior modification theories are strengthened by the discovery that perceived risk mediates environmental self-identity and low-carbon behavior. Higher environmental risk perceptions enhance carbon footprint reduction efforts. This emphasizes the need for educational and communicative methods to improve environmental awareness and promote environmental action. The study also found that frugal innovation moderates the environmental self-identity-low carbon behavior relationship. The study highlights the importance of technological innovation in promoting sustainable habits by increasing the impact of environmental identification on behavior using affordable and accessible solutions. This understanding is needed by policymakers and innovators who want to design environmentally

friendly solutions and make sustainable practices more accessible. To operationalize frugal innovation for urban sustainability, municipalities should pursue a coordinated package of measures. First, targeted subsidies and green procurement rules can stimulate market supply of affordable, high-impact technologies for parks and public spaces. Second, public-private partnership models that combine municipal demand with local SME production can lower unit costs and support local industry. Third, capacity-building initiatives for park managers and planners—focused on selection, installation, and maintenance of frugal solutions—will enhance environmental efficacy and avoid low-quality, short-lived interventions. Fourth, pilot projects with rigorous monitoring and performance-linked scaling can identify the most effective low-cost interventions. Finally, aligning financial incentives with environmental performance (rather than cost-savings alone) ensures frugal innovation advances both affordability and genuine carbon reductions.

This study impacts sustainable behavior interventions and policy. Since environmental self-identity strongly encourages low-carbon conduct, programs should prioritize methods that promote environmental principles. Sustainable behaviors should be promoted through education, community involvement, and campaigns that highlight personal identity and environmental action. The discovery that perceived threat impacts environmental self-identity and conduct promotes communication and awareness-building. To promote sustainability, interventions should raise awareness of environmental threats and their effects. Connecting environmental concepts to real-world dangers and consequences might encourage sustainability. The study's insight into frugal innovation as a moderator proposes affordable and accessible technical solutions for sustainability. Environmentally friendly developments like energy-efficient technologies and sustainable products can be encouraged by policymakers and corporations. These technologies can make sustainable practices more appealing and viable for more people and communities by lowering barriers.

6.2. Limitations Future Research Directions

Although useful, this research has numerous drawbacks. First, the study used mostly self-reported data, which may involve response biases and social desirability effects. To verify self-reported behaviors, future research could include behavioral observations or ecological footprint evaluations. Second, the sample was mostly from one demographic or location, which may limit its applicability to populations with various socio-economic and cultural backgrounds. Comparing studies across areas and demographic groups could help explain how environmental self-identity and perceived risk affect low-carbon behavior. Furthermore, the cross-sectional study design limits causal conclusions. Longitudinal research could reveal how environmental self-identity, perceived risk, frugal innovation, and sustainable behaviors change over time. The study focused on individual characteristics, but future research might examine how organizational and social influences, such as business sustainability initiatives or government policies, affect sustainable behavior. Understanding these contextual elements may help explain environmental action drivers.

Future research could pursue various possible ways to advance this topic based on existing findings. First, examining how social norms and peer influence affect environmental behavior may indicate how social dynamics enhance sustainability. Social networks and community norms influence individual conduct, creating opportunities for collective sustainability solutions. Second, we may test behavioral nudges, financial incentives, and gamification to promote sustainable conduct. Policymakers and practitioners could benefit from comparative study on these methods' behavior modification effects across demographics and contexts. Psychological insights combined with economics, engineering, and urban planning may solve sustainability issues. Collaborative research could evaluate how technical and urban design advancements can increase individual environmental footprint reduction. Finally, enhancing sustainable behavior evaluation methodologies could address field restrictions. Mobile apps, sensors, and big data analytics could show real-time activity and environmental impacts. These developments may aid evidence-based policymaking and sustainability.

7. Declarations

7.1. Author Contributions

Conceptualization, B.W., M.S.M.N., and N.H.; methodology, B.W. and M.S.M.N.; software, B.W.; validation, B.W.; formal analysis, B.W.; investigation, B.W.; resources, B.W., M.S.M.N. and N.H.; data curation, B.W., M.S.M.N. and N.H.; writing—original draft preparation, B.W.; writing—review and editing, M.S.M.N. and N.H.; visualization, B.W.; supervision, M.S.M.N. and N.H.; project administration, M.S.M.N. and N.H. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Institutional Review Board Statement

Not applicable.

7.6. Informed Consent Statement

Not applicable.

7.7. Declaration of Competing Interest

The authors declare that there are no conflicts of interest concerning the publication of this manuscript. Furthermore, all ethical considerations, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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