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Sustainable human-environment interactions from scientific, technological, and psychological perspectives

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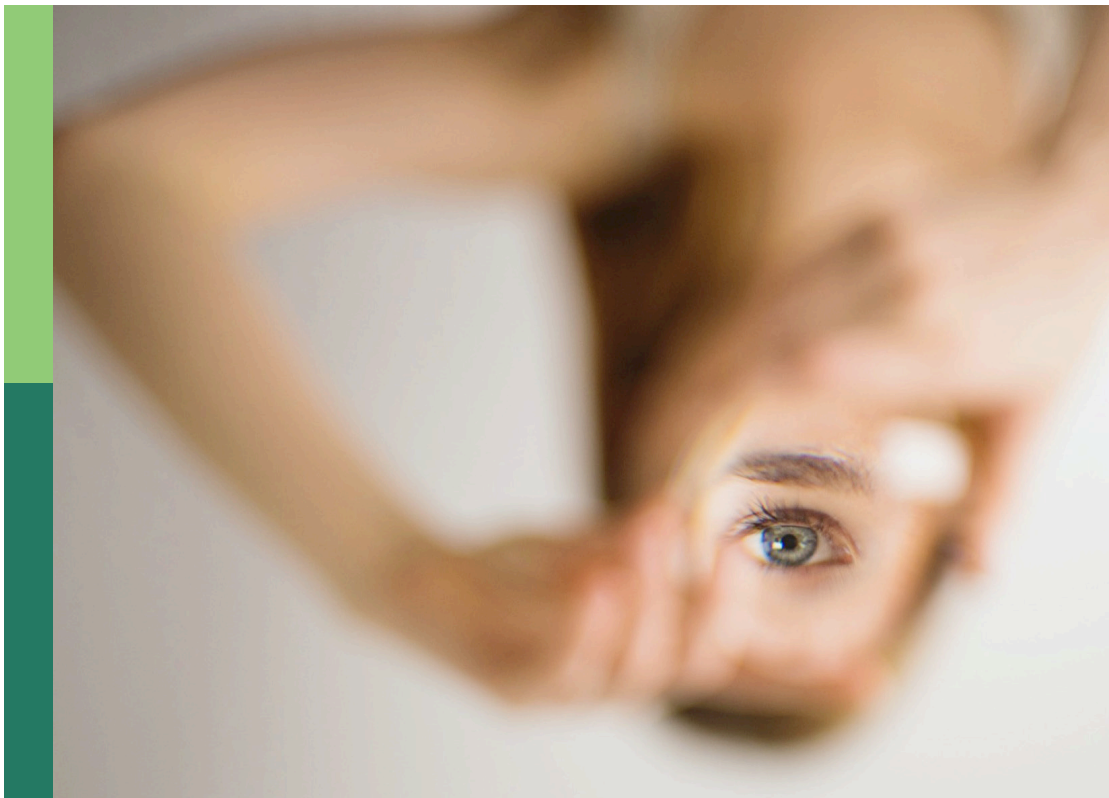

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Sustainable human-environment interactions from scientific, technological, and psychological perspectives

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Editorial: Sustainable human-environment interactions from scientific, technological, and psychological perspectives

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Editorial on the Research Topic
Sustainable human-environment interactions from scientific, technological, and psychological perspectives

The concept of Society 5.0, introduced by Japan in 2016, envisions a future where innovation and technology are harnessed to address societal challenges. This vision emphasizes problem-solving, value creation, interdisciplinary collaboration, resilience, and environmental harmony, aligning with the United Nations' 17 Sustainable Development Goals (SDGs). The United Kingdom's advocacy for "responsible science and technology" further underscores the need for balanced and sustainable approaches to technological advancements. In this context, this Research Topic sought to explore the intricate relationship between sustainable development, human-environment interactions, and the psychological dimensions that shape our responses to these challenges.

After a rigorous review process, these 11 papers were finally selected that fit the theme and made profound research contributions. Other papers that were not accepted, although valuable, were not selected due to various reasons. The Research Topic received 71 submissions, of which 11 were accepted, resulting in an acceptance rate of 15.5%. These accepted papers, representing the contributions of 63 authors, collectively delve into the multifaceted aspects of *Sustainable human-environment interactions from scientific, technological, and psychological perspectives*.

Sustainable development and human-environment interactions

Within this Research Topic, several papers delve into the interplay between sustainable development and human-environment interactions. Strappini et al. explore how the perception of material properties, affordances, and aesthetics can shape sustainable behaviors, emphasizing the impact of material design on user behavior and sustainability.

Zhang L. et al. investigate the influence of collectivist culture on pollution emissions in China, highlighting the importance of cultural factors in implementing environmental policies. Yin et al. utilize a socio-ecological model to understand why Chinese college students participate less in Earth Hour, shedding light on the disconnect between environmental beliefs and actions. Bapoğlu Dümenci et al. assess the impact of renewable energy education programs in museums on children's and parents' awareness of renewable energy and the environment, underlining the role of education in raising awareness. Hou et al. employ prospect theory and evolutionary game models to analyze how government subsidies can promote green supply chains, exploring how policy incentives influence corporate decisions.

These studies collectively emphasize that sustainable development is not solely a matter of technology and policy but is deeply influenced by cultural, psychological, and behavioral factors. Recognizing this interconnectedness is crucial for developing effective strategies to address environmental challenges. By understanding and incorporating cultural values, we can create solutions that resonate with people and foster genuine engagement. Acknowledging individual mindsets and behaviors helps us design interventions that motivate sustainable actions at a personal level. Ultimately, sustainable development is a holistic endeavor that requires us to consider the complex interplay of cultural, psychological, and societal factors to create lasting and meaningful change.

Technological innovations and sustainability

The role of technological innovations in promoting sustainability is another key focus of this Research Topic. Pol et al. investigate the psychosocial aspects of environmental communication, emphasizing the importance of effective information dissemination in fostering sustainable behaviors. This paper reveals that environmental communication, supported by information and communication technologies (ICT), can significantly influence public attitudes and behaviors toward sustainability. Effective communication strategies that leverage ICT can help mitigate the sense of learned helplessness and enhance public engagement in pro-environmental activities.

He et al. explore the complex relationship between urban built environments and public sentiment, highlighting how improvements in urban design can enhance wellbeing and promote positive emotions toward the environment. Their study underscores the significance of considering both macro and micro environmental factors in urban planning to foster a positive public sentiment and enhance the quality of life in urban settings. By integrating sentiment analysis with urban planning, policymakers can create urban environments that not only meet functional needs but also promote psychological wellbeing. Zhang J. et al. examine the impact of environmental management system certification on green innovation performance. Their research demonstrates that such certifications can significantly enhance corporate sustainability practices by promoting green innovations. The study highlights the importance of corporate social responsibility and the role of environmental certifications in driving green innovation. By adopting environmental management systems, companies can improve their sustainability performance and contribute to broader environmental goals.

Psychological factors and pro-environmental behavior

Understanding the psychological factors that influence pro-environmental behavior is essential for promoting sustainability. Liang et al. explore residents' preferences for lawns vs. spontaneous groundcovers in urban green spaces, revealing that aesthetic and ecological values significantly influence these preferences. Their findings suggest that promoting spontaneous groundcovers, perceived as more natural and ecologically valuable, can enhance urban biodiversity and sustainability. This research highlights the potential of integrating ecological aesthetics into urban planning to foster public support for sustainable landscaping practices.

Nowakowska and Rönnlund investigate the role of social value orientation and future time perspective in predicting pro-environmental behaviors, suggesting that highlighting future benefits can encourage sustainable practices. Their study shows that individuals with a future-oriented perspective and high social value orientation are more likely to engage in pro-environmental behaviors. This finding suggests that pro-environmental campaigns should emphasize the long-term benefits of sustainable actions to motivate individuals with different value orientations. Neurohr et al. develop a new scale to measure adolescents' interest in nature, finding that higher interest levels correlate with greater engagement in pro-environmental activities. Their research provides a valuable tool for assessing adolescents' interest in nature and suggests that fostering this interest can enhance their engagement in sustainability efforts. By incorporating nature-related activities into educational programs, educators can cultivate a generation that values and actively participates in environmental protection.

Future directions

The diverse contributions to this Research Topic underscore the complexity and interconnectedness of sustainable human-environment interactions. They highlight the need for interdisciplinary research that bridges the gap between scientific, technological, and psychological perspectives. Future research should continue to explore the psychological factors that influence pro-environmental behaviors, the role of technology in shaping our relationship with the environment, and the development of effective strategies for promoting sustainable development. By integrating insights from diverse fields, we can foster a deeper understanding of the challenges and opportunities that lie ahead in creating a more sustainable and harmonious future for both humanity and the planet.

Author contributions

T-CH: Data curation, Supervision, Writing – original draft, Writing – review & editing. T-KY: Supervision, Writing – review &

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Measuring adolescents' level of interest in nature: a promising psychological factor facilitating nature protection

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Studies indicate that young people are more prepared to engage in pro-environmental behavior if they are interested in nature and recognize it as worthy of protection. However, a reliable instrument to measure adolescents' interest in nature is still lacking. Therefore, we developed a new metric, the *Scale of Interest in Nature* (SIN). It consists of 18 items, is based on Item-Response-Theory and was validated using the known group approach (N=351 adolescents). Results indicate that adolescents' interest in nature correlates positively with their connection with nature, their intention to preserve nature and engagement in pro-environmental activities in their free time. Bivariate Pearson correlations between the SIN and the Connectedness to Nature Scale (INS), as well as the Environmental Values model (2-MEV) demonstrated the scale's construct validity. Hence, the SIN scale provides an economical way to measure adolescents' interest in nature in research contexts or environmental and sustainability education settings.

KEYWORDS

interest in nature, attitude measurements, environmental attitudes, adolescent attitudes, connection with nature, item response theory

1. Introduction

With the climate change and biodiversity crises, humanity is facing perhaps the most difficult challenges in its history. Reports about global warming (Al-Ghussain, 2019), sea-level rise (Nerem et al., 2018), permafrost gradation (Colucci and Guglielmin, 2019), glacier melting and retreat (Brighenti et al., 2019) as well as the dramatic loss of biodiversity (Eichenberg et al., 2021) are ubiquitous. Both, the IPBES (2019) as well as the (IPCC, 2021) reports confirm that human behavior and decisions are the main cause of these global effects. Changes are needed in political commitment, institutional frameworks, policies and instruments in order to set clear adaptation goals and define responsibilities and commitments (Pörtner et al., 2022). In addition, individual actions must also change. In regard to this important agenda, researchers worldwide highlight the great potential of the education sector to play an active role in fostering a just climate transition (Anderson, 2012; Lutz et al., 2014; Reimers, 2021; Winter et al., 2022). Otto I. M. et al. (2020) even identified the education system as a "social tipping element" within the "climate tipping elements," indicating the prominent role of education in helping to activate social dynamics that can stabilize the earth's climate by 2050 (Otto I. M. et al., 2020; Winter et al.,

2022). Here, Education for Sustainable Development (ESD) can respond to the urgent and dramatic challenges the planet faces and offers learners of all ages the knowledge, skills, values and attitudes needed to promote sustainable development and pro-environmental action. ESD is considered a lifelong learning process empowering people to make informed decisions and take individual and collective actions to address national and global challenges—such as climate change or biodiversity loss (UNESCO, 2020). Within this framework, research indicates that different influencing factors, such as environmental knowledge, interests, values, and attitudes, work to form a person's pro-environmental behavior (Kals et al., 1999; Roczen et al., 2014; Evans et al., 2018; Maurer and Bogner, 2020). These factors include affective, intellectual and behavioral components (Schwartz, 1992; Eagly and Chaiken, 1993; Fishbein, 2010; Kahneman, 2011). Interest, for example can be triggered either by intellectual or affective aspects (Hidi and Renninger, 2006).

Among the various factors influencing environmental behavior, interest in nature seems to play an important role in developing and maintaining environmental knowledge, values and attitudes (Uitto et al., 2011). Studies indicate that young people are more prepared to engage in pro-environmental behavior if they are interested in nature and recognize it as worthy of protection (Kals et al., 1999; Leske and Bögeholz, 2008; Uitto et al., 2011; Cheng and Monroe, 2012). Guiney (2009) demonstrated that the main reasons conservation volunteers actively engage in nature protection were interest in nature at a young age as well as nature-related activities and experiences in adolescence (Kals et al., 1999; Chawla, 2020). Such interest and experience leads to a comprehensive understanding of the natural world and humans' complex relationship with it, which in turn contributes to environmental awareness and willingness to act (Kals et al., 1999; Bogner, 2007).

Most research on interest in nature concentrates on its intellectual aspects (Kals et al., 1999; Kleespies et al., 2021). However, these intellectual factors (such as environmental knowledge) seem to have little to no influence on environmental behavior (Frick et al., 2004; Abrahamse et al., 2005; Otto and Pensini, 2017). Instead, it is more likely that the motivation to act is triggered by affective or motivational factors, such as personal values, goals, and self-efficacy beliefs, which play a crucial role in driving behavior. These factors can influence individuals' intentions, decision-making processes, and level of engagement in taking action (e.g., Ajzen, 1985; Deci and Ryan, 2000; Singh et al., 2006). Although interest's affective factors have not been thoroughly examined regarding their influence on pro-environmental behavior, it seems reasonable to assume that an interest in nature primarily driven by emotions could motivate individuals to actively engage in environmental protection. Therefore, the question arises as to how interest in nature develops over time and how it is related to other factors that influence pro-environmental behavior, such as environmental attitudes, and how it is ultimately affects behavior. Since we already know that most of the foundations for environmentally protective behavior is laid in childhood (Evans et al., 2018; Otto et al., 2019; Chawla, 2020), it can be assumed that formation of an affective interest in nature should also take place at an early age.

This study aims to validate a scale for measuring adolescents' interest in nature (*Scale of Interest in Nature*, SIN) in terms of its affective aspects—intrinsic, value and emotion-related—in order to provide an age-appropriate assessment instrument. We specifically chose adolescents as the target population because studies show that interest in nature drops with increasing age, especially when puberty hits (e.g., Leske and Bögeholz, 2008). Therefore, we believe it is of great importance to have an instrument at hand that reliably assesses interest in nature in this specific age group in research contexts as well as in environmental and sustainability education settings. Moreover, the newly introduced variable (SIN) could unveil additional attitude traits that affect pro-environmental behavior and enhance comprehension of the interrelations among these attitudes. Furthermore, by looking into existing measures of connectedness to and interest in nature (e.g., Kals et al., 1999; Schultz, 2002; Mayer and Frantz, 2004; Brügger et al., 2011), but also by their conceptualization, we expect interest in nature will most likely establish "only" as a specific but practically meaningful facet of attitude toward or connectedness to nature.

The scale developed for this purpose is based on the interest items by Schiefele et al. (1993) and was adapted to adolescents and to the topic of nature. In developing the items, we included (Markl's 1989) concept of nature and the biophilic values by Kellert (1993). For validation, we use the known groups approach and compare groups with different frequencies of experiences in nature. Based on former studies (e.g., Guiney, 2009) we hypothesize that adolescents who are more involved in nature-related activities in their free time feel more connected with nature and show a higher affective interest in it.

2. Theoretical framework

2.1. Environmental attitudes

Researchers emphasize the multidimensional nature of environmental attitudes and assume a framework of intellectual (facts, knowledge or understanding), affective (emotion and feeling) and conative (action and behavior) components (e.g., Fishbein and Ajzen, 1974; Gray, 1985). Educational programs have long provided the foundations of environmental awareness and concern about human impact, which shape the development of environmental behavior (Gigliotti, 1990; Hungerford and Volk, 1990; Bogner, 2004). Researchers have suggested that the most important determinant of behavior is attitude (Eagles and Demare, 1999). The construct of environmental attitudes commonly encompasses multiple components and can be defined as a "collection of beliefs, affect, and behavioral intentions a person holds regarding environmentally related activities or issues" (Schultz et al., 2004, p. 31). However, values might be at the broadest level and are conceptualized as important principles in life (Olson and Zanna, 1993; Schultz et al., 2004). Values function as an organizing system for attitudes and beliefs, and they are viewed as determinants of attitudes. Studies have further emphasized the importance of values in situational and personal interest (Hidi and Renninger, 2006). The term environmental values refers to values that are specifically related to nature or that have been found to correlate with specific environmental attitudes or concerns (Schultz et al., 2004).

Numerous approaches to operationalizing empirical scales have been proposed within the domain of environmental attitudes (Bogner and Wiseman, 2002), which captures attitudes at various levels of specificity, such as attitudes, worldviews, and values. In order to measure adolescents' environmental attitudes, Bogner and Wiseman (1999, 2002) developed the Environmental Scale (2-MEV). Their first

study revealed several subscales of environmental concern, including attitudes, verbal commitment, and actual behavior. Using higher-order factor analysis based on a large pool of items, they developed a model of ecological values (MEV) based upon one's position on two orthogonal dimensions: Utilization and Preservation. These two values allow a person both to endorse the protection of the environment on a biocentric dimension and to support the utilization of nature on an anthropocentric dimension. The theory of ecological attitudes (EA) posits that people who have strong Preservation (biocentric) attitudes do not necessarily have weak Utilization (anthropocentric) attitudes. This allows individuals to be placed in one of four quadrants rather than on either end of a continuum. The theory explicitly states that Preservation and Utilization are complementary and uncorrelated, not opposing values. Hence, a respondent's position on one dimension provides no information about his position on the other. At present, the 2-MEV scale's validity has been independently and repeatedly confirmed by different research groups and has been translated into 33 different languages. Additionally, several researchers have confirmed the bi-dimensional structure of EA, suggesting that Preservation and Utilization are two distinct constructs (Milfont and Duckitt, 2004; Johnson and Manoli, 2010). Therefore, Bogner and Wiseman (2006) offer an age-adjusted item battery for adolescents employing more rigorous psychometric techniques. By measuring environmental attitudes, they expect to obtain a valuable predictor of ecological behavior (Oerke and Bogner, 2013; Maurer and Bogner, 2020; Bogner and Suarez, 2022).

2.2. Connectedness with nature

Adolescents are increasingly disconnected from nature, a trend that has significant implications for the preservation of the biosphere (Louv, 2005; Charles et al., 2018; Chawla, 2020). Connectedness with nature is linked to ecological concern and is seen as a lever for societal change toward respect and care for nature (Ives et al., 2017; Otto and Pensini, 2017). This connectedness describes how people form a relationship with elements in the environment (Beery, 2013; Salazar et al., 2021). Numerous studies have identified experiences that create a sense of connection to nature and how this connection is linked to other aspects of life, such as happiness and support for environmental preservation (Tam, 2013; Zylstra et al., 2014; Restall and Conrad, 2015). Spending time in nature and focusing attention on it can enhance this connection (Richardson et al., 2020; Bezeljak et al., 2023).

Furthermore, studies have found that connection to nature is positively associated with pro-environmental behavior and can thus be seen as a significant predictor of it (Mayer and Frantz, 2004; Nisbet et al., 2009; Otto et al., 2014; Roczen et al., 2014; Zelenski et al., 2015; Whitburn et al., 2019, 2020). However, environmental values, attitudes, emotional involvement, social and cultural factors also play roles in explaining environmental behavior (Kollmuss and Agyeman, 2002; Eames et al., 2018). Young people with more access to and experience in nature express a stronger connectedness with it and are more likely to take action to care for nature, even into adulthood (Cheng and Monroe, 2012; Collado et al., 2013; Evans et al., 2018; Barrable and Booth, 2020; Chawla, 2020). Childhood is a crucial period for connecting with nature, but the level of connection tends to decrease to its lowest level in adolescence before slowly rising again in adulthood (Liefländer et al., 2013; Hughes et al., 2019; Richardson et al., 2019).

Regarding the terminology, various terms are employed to describe the concept of connectedness with nature, including affinity, biophilia, ecological self, and nature-relatedness, among others (Beery, 2013). One approach is presented by Schultz et al. (2004), who argue that an individual's beliefs about the extent to which they are part of the natural environment provides the foundation for the types of concerns they develop, and the types of situations that will motivate them to act. To analyze connectedness with nature, they used the Inclusion of Nature in Self Scale (INS; Schultz, 2002) which examines a person's relationship with nature. They found that connectedness correlates with biospheric concerns and with self-reported environmental behavior. Therefore, individuals who feel a link between themselves and the natural environment tend to have broader sets of concerns for environmental issues. In contrast, those who feel separate from nature only value nature when it benefits them individually.

2.3. Interest in nature

While connection with nature has been interpreted as an environmental attitude (Brügger et al., 2011), personal interest in nature can be seen as the basic factor underlying the development and maintenance of an internal motivation to study nature or act in a pro-environmental way (Uitto and Saloranta, 2010). According to the person-object theory by Krapp (2002), interest represents a specific relationship between a person and an object and encompasses intellectual and affective components (Hidi et al., 2004). Furthermore, he distinguishes between two levels of interest: a situational interest and individual interest (Krapp, 2002). Situational interest describes a motivational state of being interested during an actual activity and is necessary for the development of a sustained, individual interest (Krapp and Prenzel, 2011). Individual interest refers to a person's dispositional motivational state and is interpreted as a relatively stable tendency to engage with an object of interest without external pressure (Krapp and Prenzel, 2011). Through psychological processes like internalization and identification, the object of interest will be integrated into an individual's values and feelings and becomes a permanent part of their own identity (Krapp, 2007; Blankenburg and Scheersoi, 2018). Individuals with a well-developed individual interest not only act primarily out of their own motivation but have also developed a persistence to carry on despite failures or negative feelings (Renninger and Hidi, 2002). Therefore, in order to foster a successful development of interest and engagement in an object, individuals need to first identify with the object of interest and to integrate it into their self-concept (Blankenburg and Scheersoi, 2018).

Interest in nature can be considered a type of individual interest, describing the relationship between a person and the object of nature. This relationship is also described in Markl's (1989) understanding of nature: he advocates for a "biocentric" perspective in which humans recognize that they are part of a larger web of life rather than separate from it. This includes all aspects of the natural world, such as animals, plants and landscapes. In line with this, the biophilia hypothesis argues that humans have an innate interest in life and life-like processes (Wilson, 1984) and need nature for more than just physical survival. Studies support these theories and have shown that an (intellectual) interest in nature has a direct effect on the development of willingness to protect nature and could be therefore a predictor of

nature-protective behavior (Langeheine and Lehmann, 1986; Vining and Ebreo, 1992; Kals, 1996; Kals et al., 1999). However, existing studies have concentrated only on intellectual interest in nature, not on its affective character. Even though some researchers suggest that interest is a purely affective construct (Schiefele et al., 1993), it remains unclear what influence an affective interest in nature might have on pro-environmental behavior.

Schiefele et al. (1993) go further in describing affective interest and identify three different components: a value-related, an emotion-related, and an intrinsic component. Whereas the value-related component refers to matters that are personally meaningful to an individual, the emotional component of interest consists of matters that are associated with positive feelings such as pleasure. The intrinsic component involves direct emotional and value attributions to an object or action (Schiefele et al., 1993). Although these components are theoretically well-grounded, they do not separate well analytically in various studies and often load onto a common factor. Taking Schiefele et al.'s (1993) theoretical approach into account, Leske and Bögeholz (2008) examined the influence of interest in nature on the willingness to preserve biodiversity among student in grades 7–12. Their analysis identified the value-related and emotional components as influential predictors. However, they extended the concept of nature used by Kals et al. (1999) to include the terms "biodiversity" and "ecosystems." Both terms do not merely describe the natural environment, but also emphasize the importance of its conservation and preservation. Thus, the inclusion of these terms in the measurement of interest in nature implies not only a fascination or attraction to nature but also a recognition of the need to protect it for future generations (Miller, 2005). By including these terms, interest in nature does not describe an individual preference anymore, but also carries a sense of responsibility and concern for the well-being of the environment.

However, it remains unclear what influence interest in nature has on pro-environmental behavior and how it is related to other environmental attitudinal variables. Interest in nature could be an additional or rather more direct construct than environmental attitudes and behavior, possibly explaining why students develop greater pro-environmental competence through nature-based environmental education (Otto and Pensini, 2017). Moreover, interest in nature could be a motivation to develop environmental competency similar to a fascination with science, which is an important motivator for engaging in science and supports deeper learning (Otto S. et al., 2020).

Therefore, in this study we aim to develop and validate a comprehensive self-report instrument that accurately assesses adolescents' interest in nature: the Scale of Interest in Nature (SIN). We want to demonstrate the measure's reliability by confirming the internal consistency of the construct and by confirming unidimensionality. Assuming that attitudes toward nature and attitudes toward environmental protection represent different dimensions (Kaiser et al., 2013), we predict interest in nature to be on the same dimension as the inclusion of nature in self (Schultz, 2002), while preservation (Bogner and Wiseman, 2006) should be on a separate dimension. To ensure the construct validity of SIN, a known-group comparison was used. Using SIN, we hope to provide an assessment tool for adolescents' interest in nature, which can be helpful in research settings as well as in formal or informal education for sustainable development.

3. Methods

3.1. Participants and procedures

In 2017 and 2018, a sample of 351 adolescents (average age = 12.58 years, SD: 1.58, range: 10–15; 41.9% girls) were selected from different interest groups in Germany (Rhineland-Palatinate, North Rhine-Westphalia, and Saarland) and Austria (Vienna and Lower Austria). We employed the method of comparing of known groups as a validation criterion for the scale, as this approach has been previously utilized to assess pro-environmental and pro-social behavior (e.g., Neaman et al., 2021; Otto et al., 2021). Known-groups validity is demonstrated when a questionnaire can discriminate between two groups known to differ on the variable of interest. Based on previous research, we chose environmental organizations, humanitarian organizations, and sport clubs (i.e., Scarborough, 2013; Otto et al., 2021). This prior research has shown that connectedness to nature is higher in students enrolled in environmental studies compared to students enrolled in other courses, in park management students compared to sports management students, and in members of environmentalist groups compared to humanitarian groups. As interest in nature is theoretically related to attitudes and general ecological behavior, we expect that members of environmental groups spend more time outside, feel more responsible for nature and show a higher interest in nature and the environment than members of other interest groups. To test this hypothesis, we linked participants' interest in nature with their free time activities. Therefore, we divided the sample into three different interest groups:

1. Members of Sports Clubs ($N = 133$, e.g., football, handball or track and field), who were expected to express no specific interest in nature or nature protection. This group has chosen its hobby because of the physical activity involved. In personal conversations, the adolescents claimed that they chose football, for example, because of the sport itself and not as a way to spend more time outside;
2. Members of Socially Engaged Associations ($N = 112$, e.g., the Red Cross or other welfare organizations), who are engaged in voluntary work, but not with regard to nature or the environment; and
3. Active Members in Various Groups or Organizations for Nature Protection ($N = 106$, such as participants in Junior Ranger Programs or the youth associations of national nature conservation groups), who engage with protecting nature in their free time and also conduct nature protection activities as private individuals. To ensure that all participating groups are really focused on nature and its protection, we accompanied and observed them as they conducted weekly nature conservation activities. These activities include hanging birdhouses, building bat shelters, and planting trees.

We identified sport clubs, humanitarian and environmental organizations in the respective regions via the internet and then made individual appointments with the different groups to collect the data. The selected organizations were the same in Germany and Austria (e.g., the German and the Austrian Red Cross) in order to ensure that the organizations had equivalent aims. Participants completed the

questionnaire at their regular group meetings during their free time. To prevent overlap in interest groups, the questionnaires asked about participation in other organizations. Only 4.08% of participants demonstrated double engagement. Of the 360 participants who were provided with the paper-and pencil questionnaire, 351 completed it (response rate: 97.5%).

3.2. Measures

The 2 Major Environmental Values model scale (2-MEV, Wiseman and Bogner, 2003) comprises 18 statements addressing the constructs of Preservation and Utilization (see Supplementary material 1). The Preservation measure was derived from students' responses to 9 items, such as "I take care to save water and electricity." Utilization was also measured with 9 items, such as "Humans are more important than other living beings (e.g., animals and plants)." Participants gave their responses on a 5-point Likert scale from 0 (strongly disagree) to 4 (strongly agree). Conventional principal factors' extraction with varimax rotation confirmed the proposed two-factor solution. In total, the two-factor model accounted for 40.42% of the common variance in the data. Scores on the individual levels were calculated in accordance with convention as mean values for the 18 items using a Rasch-scale calibration. Although the 2-MEV was originally subject to a factor analysis, we believe a Rasch-based analysis provides numerous advantages. Even if participants do not respond to the exact same set of items, they can still be quantitatively compared as long as the scales have some core overlapping items (Kaiser et al., 2018). Because the estimation procedure is based on a maximum likelihood approach, attitude estimates can be attained even with incomplete data sets that contain missing values (Baierl et al., 2022). Further, Kaiser et al. (2018) propose that the Rasch model can assure a specific objectivity by ordering indicators transitively with respect to their difficulty. The type of indicator is not a defining feature of environmental attitudes, but the "numerical relations of magnitudes of psychological attributes incorporated in people" is (Kaiser et al., 2018, p. 141). The results of the analyses are in line with previous studies (Bogner and Wiseman, 2006) and revealed acceptable internal consistencies for both Preservation ($\alpha = 0.79$) and Utilization ($\alpha = 0.74$).

Inclusion of nature in self (INS) is the second scale used in this study. The INS is widely used as an assessment of nature connectedness and is based on only one item (Schultz, 2002). By means of a series of seven differentially overlapping circles (labeled "self" and "nature"), participants could choose the one that best described how connected they felt with nature. Compared to other multiple-item scales, the INS has been found to be very accurate for measuring individual connectedness with nature and correlates well with other connection with nature instruments (Brügger et al., 2011). Scores range from 0 to 6, with the circle with the least overlap receiving a score of 0 (complete separation from nature) and the most overlapping circle receiving a score of 6 (complete connection to nature) (see Schultz, 2002). Since this measure is a single-item measure, its reliability could not be estimated with our data. Nevertheless, its 4-week test-retest reliability is reported to be rtt = 0.84 (Schultz et al., 2004).

3.3. Development of the scale of interest in nature

Our newly developed scale of interest in nature (SIN) is a composite of 18 interest items (see Table 1), which were adapted from Schiefele et al. (1993). The item set was reduced statistically from initial 43 items via item response theory (see Supplementary material 2 for the initial set of 43 items). In contrast to other research groups (Prenzel et al., 1986; Kleespies et al., 2021), Schiefele et al. (1993) present a distinct perspective on the nature of interest. They conceptualize interest as a purely affective construct, separated from any intellectual or knowledge-related components. They propose indeed three components of affective interest: an emotion-related component, a value-related component, and an intrinsic component.

The emotion-related component involves positive emotional experiences and thoughts associated with the object of interest. The value-related component pertains to the personal significance or attributions linked to the object. Finally, the intrinsic component, which Schiefele et al. (1993) consider the most crucial, refers to self-intentionality. It represents a person's engagement with the object for its own sake, driven by internal motivation rather than external rewards or incentives. By emphasizing the intrinsic component, interest is distinguished from other forms of motivation that are externally driven. It describes then a self-determined and autonomous interest that arises from the inherent qualities of the object itself. This approach is consistent with former studies, which have suggested that intellectual variables have little or no effect on environmental behavior (Frick et al., 2004; Abrahamse et al., 2005; Barth et al., 2012; Otto and Pensini, 2017; Knutti, 2019).

To incorporate the idea of nature into our items, we utilized both Markl's (1989) concept of nature and Kellert's (1993) biophilic values. Both researchers emphasize the importance of understanding and valuing nature for the sake of environmental protection. Markl (1989) focuses more on the emotional aspects of human-nature relationships, underlining the importance of experiencing wonder in nature as part of one's spirituality. He suggests that humans should strive for a harmonious relationship with nature based on respect and humility. Similarly, Kellert's concept of biophilia emphasizes the innate human connection to nature and the importance of maintaining the connection for our well-being and the preservation of the natural world. However, unlike other studies (Kals et al., 1999; Leske and Bögeholz, 2008), we did not take into account resources, biodiversity and ecosystem in our items. These aspects encompass the idea of environmental preservation and thus express motivation rather than interest. We found support in this decision in Kaiser et al. (2013), who found that attitude toward nature and attitude toward nature protection represent two separate constructs. The items were formulated using age-appropriate language and considering the reality of adolescents' lives.

We measured interest in nature with 18 self-reported items on a 5-point Likert scale (0 = strongly disagree to 4 = strongly agree). To control for response style bias, the scale included 5 inverse items, which we recoded afterwards. In line with Kaiser and Wilson (2004), the answers to the polytomous items were recoded into a dichotomous format by collapsing strongly disagree, disagree and partially agree as indicators for a lack of interest in nature. The responses agree and strongly agree were combined to indicate an interest in nature. This dichotomization practice is an established precaution to guard against

TABLE 1 Item fit values of all the 18 items for the Scale of Interest in Nature (SIN) of the pilot and of the final study, adapted from Schiefele et al. (1993).

POI dimension	Original item (Schiefele et al.), translated	Items in the final questionnaire		MNSQ pilot study (*N*=256)	MNSQ final study (*N*=351)
		#	Item		
Emotion-related valences	Working with the subject matter and problems of my major is not really among my favorite activities	IN 27	I enjoy discovering nature with my friends more than playing computer games or video games with them	1.16	0.94
	I do not like to talk much about the subject matter related to my studies	IN 5i	Plants are boring	1.15	0.98
		IN 37	It is exciting to examine bees or other insects with a magnifying glass	0.88	0.93
	I prefer to talk about my hobbies rather than about my major	IN 13i	I prefer talking about new movies and music, rather than animals	0.83	1.11
	When I am in a library or bookstore, I like to browse through magazines or books with topics related to my major	IN 15	In libraries, I like reading nature books (for example on animals or plants)	0.64	0.91
	A reference book as a birthday present would not give me any particular pleasure	IN 3	In my opinion, documentaries and movies on nature are interesting	0.83	1.00
		IN 16	I would be happy to receive a calendar with nature pictures (for example animals or landscapes) for my birthday	0.92	0.95
	Many areas within my major do not mean anything to me	IN 17i	I do not really mind the fact that humans destroy nature	0.70	1.10
Value-related valences	It was of great personal importance to be to be able to study this particular subject	IN 24	It is important to me to know the names of local animals and plants	0.67	0.92
		IN 26	Personally, I find it important to know the role of humans in nature	0.68	1.06
	To be absolutely honest, I feel sometimes rather indifferent toward my major	IN 22i	If I am being completely honest, I do not care about animals and plants at all	1.05	0.99
	Compared to other things that are of great importance to me (e.g., hobbies, social life), my studies are of markedly less significance to me	IN 7i	I have no personal interest in what happens in nature	0.60	1.12
	I cannot imagine pursuing the content of my studies as a hobby*	IN 28	I could imagine collecting feathers, leaves or other things as a hobby	1.10	0.86
Intrinsic orientation	If I had enough time, I would work more intensively with certain aspects of my studies, even if they had nothing to do with any course requirements	IN 21	In my spare time I take pictures of flowers, animals and landscapes	1.08	1.12
	In my free time, I am unwilling to deal with problems in my field of study*	IN 34	In my spare time I examine plants and conduct small experiments with them (e.g., poking them gently, blowing at them)	1.11	0.96
		IN 30	In my spare time I participate in projects on preserving nature	0.86	1.06
	Even before coming to college I voluntarily spent time thinking about the subject matter of my major (e.g., read books, went to lectures, had conversation with others)	IN 36	Outside of school, I seek out information about animals and plants (for example on the internet or in books)	0.81	0.70
	I chose my major primarily because of the interesting subject matter involved	IN 42	I purposely chose hobbies that allow me to spend a lot of time in nature (e.g., riding, fishing, geocaching)	1.25	1.16

*own translation due to missing translation by the author, "*i*" indicates an inverted item.

excessive measurement error, particularly in attitude research (DeCoster et al., 2009; for supporting evidence, see, e.g., Kaiser and Wilson, 2004; Byrka et al., 2016). For all items, "Not applicable" was an alternative response when an answer was not possible: such responses were treated as missing values. Rasch model calibrations and therefore person score estimations can be gained even with incomplete data records, as this estimation is based on a maximum probability procedure (Embretson and Reise, 2000; Linacre, 2002; Kaiser et al., 2007; Boone et al., 2014). In addition, we collected socioeconomic data from the adolescents such as age, gender, grade, type of school and the native language.

Using the methodology of parceling (Little et al., 2002), the items of the SIN scale were reduced statistically from 43 to 18 items via item response theory (see Supplementary material 2 for the 43 initial items). This method involves grouping multiple observed variables together into smaller parcels, which are then used as indicators of latent variables. It is mostly used in structural equation modeling (SEM) to create composite variables or parcels from observed indicators. Parceling aims to improve the efficiency and stability of the analysis by reducing the number of observed variables and increasing the reliability of the parcels. We reviewed Item Infits (MS Infit <1.3; Wright et al., 1994) and the difficulty distribution on a Wright map (person-item map). A Wright map is a graphical representation of a Rasch model that visually displays the performance of items and persons on a single scale, demonstrating the fit between items and persons and providing information about any patterns or anomalies in the data (Linacre, 2021). It is a useful tool for evaluating the performance of a questionnaire and can be used to identify problematic items. Items that are on the same level on the Wright Map cover the same degree of interest in nature. In order to reduce the number of items and ensure that all levels of interest were covered, we removed items that were located on the same level in the Wright Map. As a result of this reduction, we lessened disturbance variants, minimized scattering and errors, and enabled a normal distribution (Bandalos and Finney, 2001). This adaptation was justified by two pilot studies (first pilot: $N = 79$; second pilot: $N = 177$) in grades 5–8 (10–15 years old) in German schools (Rhineland-Palatinate) using the original scale (item rel.: 0.96, person-rel.: 0.92 and MNSQ Infit: 0.62–1.45). The indices for item reliability, person reliability, construct validity, normal distribution and model fit were checked, which attested to the test quality (e.g., Linacre, 2009; Boone et al., 2014). Mean-Infit MS-Values (MNSQ) up to 1.3 suggest a reasonable fit of the data to the model (Wright et al., 1994).

3.4. Statistical analysis

The Rasch model was used to analyze the measurement data (Linacre, 2002). This model can obtain specifically objective (i.e., item and person-independent) test results. Specific objectivity in this context means that two persons can be quantitatively compared with each other regarding a latent attribute (e.g., environmental attitudes) even if different measurement instruments have been used to assess the attribute (for more details, see Kaiser et al., 2018). Therefore, the specific objectivity can be seen as a formal validation criterion. To test if the developed test items fit the Rasch model, we analyzed the model fit indices. To further evaluate the test quality, reliability indices such as person reliability, person separation and item reliability were also checked (Bond et al., 2020). Person separation was used to classify individuals and ensure that the instrument can effectively differentiate between high and low performers. Item separation was employed to validate the item difficulty hierarchy, which demonstrated the construct validity of the instrument (Boone et al., 2014; Boone and Staver, 2020). Malec et al. (2007) suggests the following critical values: item reliability of 0.90, person reliability of 0.80, person separation of 2.0, and item separation of 4.0. Due to the relatively large sample size, we relied on the mean square values (MS Infits) in the assessment of item fit, where values lower than 1.3 indicate an acceptable fit (O'Connor et al., 2016; Linacre, 2021).

The discriminant and convergent construct validity of the newly developed scale were evaluated with two well-established environmental attitude instruments (INS: Schultz, 2002; 2-MEV: Bogner and Wiseman, 1999). To demonstrate that the instrument is unidimensional and internally consistent, we conducted a principal-axis factor (PAF) analysis based on the theoretical factors established in the instrument design process. Analyses were done with a varimax rotation. The inclusion of nature in self scale (INS) is designed to measure the degree to which people include nature in their self-concept (Schultz, 2001). Since both the INS scale and interest in nature measure individuals' psychological connection and affinity with the natural world, comparing the scores on these two measures can provide evidence of convergent validity. To show discriminant validity, the Preservation items by Bogner and Wiseman (1999) were used. Kaiser et al. (2013) postulates a two-dimensional attitude model, which distinguishes between appreciation for nature (which we measure with SIN) and appreciation for environmental protection (which can be called preservation).

To ensure construct validity, we compared groups with different frequencies of experiences in nature (known-groups) using an analysis of variance (ANOVA). Following the known groups approach, we assume that members of an environmental organization, respectively, show a higher-than-average pro-environmental motivation (Otto et al., 2021). Data analysis was conducted with the Rasch software Winsteps (Linacre, 2015) and SPSS 26 for further calculations.

4. Results

The present findings are reported in two parts. First, we describe the calibration of the proposed SIN scale using the partial-credit Rasch model in order to evaluate the construct validity with the 2-MEV (Wiseman and Bogner, 2003) and INS (Schultz, 2002). Here, we present the test quality indices. Second, we also present the comparison of the known groups to demonstrate the construct validation of the newly developed scale.

4.1. Psychometric quality of the scale of interest in nature

To assess the construct validity of the three instruments used, we performed a principal-axis factor analysis (PAF) with a varimax rotation, extracting three factors. The objective was to confirm that the

items representing the constructs of Interest in Nature, Preservation, and Utilization loaded significantly on their respective factors. The PAF was employed to establish the unidimensionality and internal consistency of each of the three above mentioned constructs, based on the underlying theoretical framework. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.81, above the commonly recommended value of 0.5, and Bartlett's test of sphericity was significant ($p < 0.001$), indicating that correlations between items were sufficiently large to perform a PAF. Examination of Kaiser's criteria and the scree plot yielded empirical justification for retaining three factors with eigenvalues exceeding 1, which accounted for 31.94% of the total variance.

Based on the theoretical framework, we assumed three factors to be examined: Interest in Nature, Preservation and Utilization. The analyses indicated that most of the items' factor loadings resembled the theoretical structure (see Table 2). Some unexpected cross-loadings were found between the value-related interest in nature items and the preservation items. However, this can be explained with reference to the theoretical derivation of the two constructs. Only if a person considers nature to be valuable will he or she also commit themselves to it and protect it. For this reason, the Preservation construct already contains value-related tendencies. If the SIN is used together with the 2-MEV, the 5 value-related items could be cut (Table 1), since these are already reflected in the preservation items (in the following "SIN re" refers to the reduced version of the scale consisting of 13 items). The internal consistency of the reduced SIN scale and bivariate correlations can be found in Table 3 (see variable SIN re). However, since the aim was to create a stand-alone instrument, these items remain included in the further analyses, and the results presented below pertain to the entire SIN scale (with 18 items).

Using a Rasch analysis, we found that all item statistics lay within a valid range and indicated a good test quality for the developed SIN scale (Item-Rel.: 0.99, MNSQ Infit mean: 0.99). All 18 items fitted the model prediction with reasonable MS-values between 0.70 and 1.16. None of the items fell outside the tolerable range of fit (i.e., $MS < 1.3$; *cf.* Wright et al., 1994; Linacre, 2009; Boone et al., 2014). The Rasch-model based person reliability of our developed scale was thus also found to be good with person rel. = 0.81 ($N = 351$).

The convergent validity of interest in nature was derived from the pattern of correlations between interest in nature and inclusion of nature in self. In addition to its intellectual dimension, inclusion of nature in self contains an affective dimension which describes the feeling of a connection to and desire to care for nature (Schultz, 2002). Thus, an emotional affinity can arise between a person and nature (Kals et al., 1999). These emotion-and value-related aspects can also be found in the construct of interest in nature. As expected, the measurement-error-attenuation-corrected Pearson correlation between the two instruments showed that they substantially overlap (i.e., $r_{corr} = 0.61$; see Table 3).

Discriminant validity was inferred by the correlations between the interest in nature and the two environmental attitudes - Preservation and Utilization. Kaiser et al. (2013) present a two-dimensional attitude model, distinguishing between appreciation for environmental protection and appreciation for nature. We therefore assume that interest in nature reflects a different dimension than Preservation and Utilization. This idea is also supported by the preceding PAF, where items from these scales loaded on different factors. Both measures exhibit only a small to moderate correlation with interest in nature ($0.16 < r_{corr} < -0.29$), which shows the measured constructs to be unrelated or only slightly related.

TABLE 2 Standardized loadings on the dimensions emotion-related, value-related and intrinsic interest in nature (SIN) as well as Preservation (PRE) and Utilization (UTL) for the sample of adolescents (10–15years old) (N=351).

Item		SIN	PRE	UTL
Emotion-related				
IN3[a]		0.52		
IN5i[a]		0.38		
IN13i[a]		0.47		
IN15[a]		0.55		
IN16[a]		0.43		
IN17i[a]			0.43	
IN27[a]		0.38	0.39	
IN37[a]		0.55		
Value-related				
IN7i[a]			0.34	
IN22i[a]			0.42	−0.31
IN24[a]		0.49		
IN26[a]		0.35	0.39	
IN28[a]		0.68		
Intrinsic				
IN21[a]		0.46		
IN30[a]		0.47		
IN34[a]		0.53		
IN36[a]		0.74		
IN42[a]		0.39		
UTL1[b]				0.49
UTL2[b]				0.49
UTL3[b]				0.41
UTL4[b]			−0.33	0.50
UTL5[b]				0.48
UTL6[b]				0.42
UTL7[b]			−0.34	0.63
UTL9[b]			−0.44	0.46
UTL10[b]				0.55
PRE1[b]			0.55	
PRE2[b]		0.36	0.62	
PRE3[b]			0.49	
PRE4[b]				−0.50
PRE5[b]		0.31	0.51	
PRE7[b]			0.65	
PRE8[b]		0.58	0.46	
PRE9[b]			0.48	
PRE10[b]				−0.56

Inverse items are marked with an *i* (for inverted); loadings under 0.3 were suppressed.
Item (s) source:
[a]Modified from Schiefele et al. (1993).
[b]Modified from Bogner and Wiseman (2006).

TABLE 3 Descriptive statistics and bivariate correlations of attitudes toward nature (Preservation and Utilization), Inclusion of nature in self (INS) and interest in nature (total and reduced).

	M	SD	*N*	SIN	SIN re	PRE	UTL	INS
Interest in nature (SIN)	−0.34	1.68	351	0.99	0.98	0.16	−0.29	0.61
Interest in nature (SIN, reduced)	−0.66	1.76	351	0.96**	0.99	0.15	−0.20	0.61
Preservation (PRE)	0.63	0.80	351	0.16**	0.15**	0.96	−0.14	0.18
Utilization (UTL)	−0.61	0.91	351	- 0.28**	−0.20**	- 0.14*	0.98	−0.23
Inclusion of nature in self (INS)	4.41	1.53	335	0.56**	0.56**	0.16**	- 0.21**	0.84

The reduced version of the SIN does not include the 5 value-related items and thus comprises only 13 items.

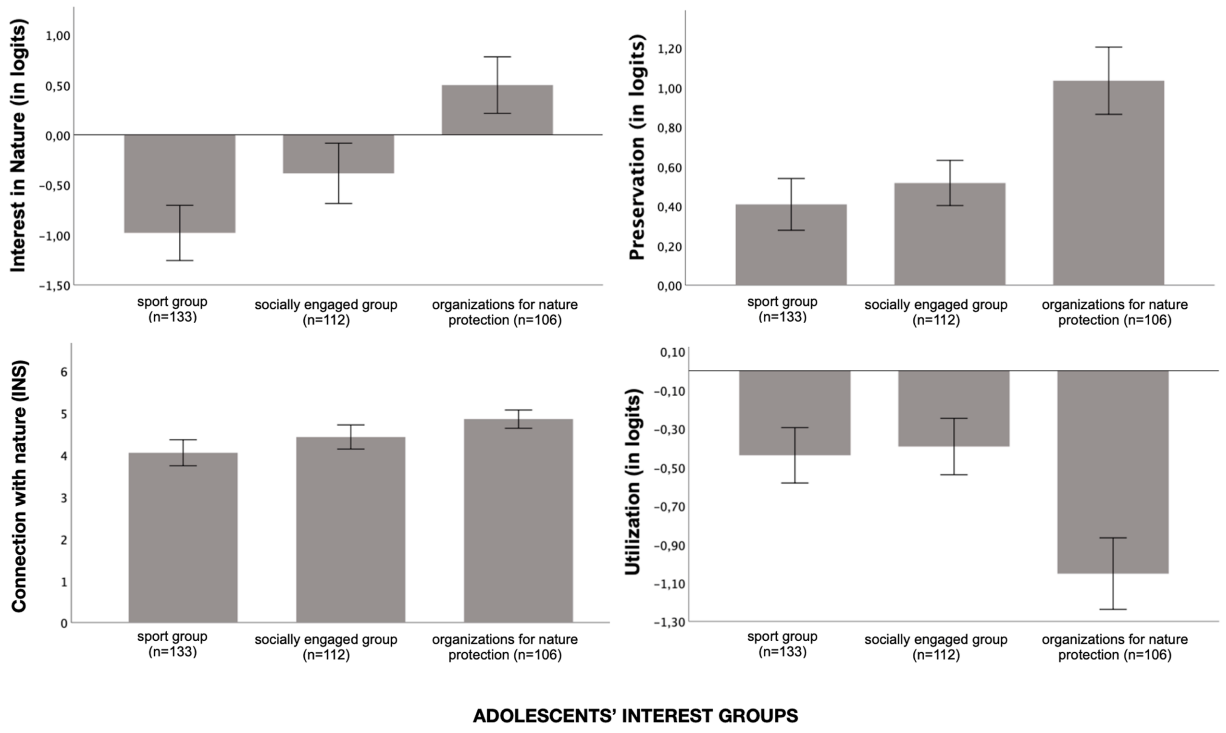

FIGURE 1
Differences in self-reported Interest in Nature (SIN), Preservation (PRE), and Utilization (UTL), as part of the 2-MEV, and self-reported Connection with nature (measured by the Inclusion of Nature in Self scale, INS) among the three interest groups: sport group, socially engaged group and group involved in organizations for nature protection; mean values and 95% confidence intervals.

4.2. Known groups comparison

The known-group comparison is based on the assumption that participants who are less involved with nature or its protection in their free time will also show little interest in nature. To test this hypothesis, we linked participants' interest in nature with their free time activities. Our results indicated that this was the case. Specifically, we defined three different interest groups: a sports group, a socially engaged group and a group demonstrating an active commitment to nature and environmental protection.

A first analysis of variance (ANOVA) indicated a significant difference between groups in interest in nature: $F(2, 348) = 26.28$, $p < 0.001$, $d = 0.94$ (see Figure 1). For theoretical reasons, we expected that the assumed stronger attitudes in favor of environmental protection among members of a nature conservation organization would be linked to a higher interest in nature. Accordingly, we discovered that participants in nature conservation groups held a more pronounced interest in nature ($M = 0.50$, SD = 1.47) than participants in socially engaged groups ($M = -0.38$, SD = 1.61) or sports groups ($M = -0.98$, SD = 1.61). To examine the construct validity of the interest in nature scale, we compared the three different interest groups. *Post hoc* comparisons using t-tests with Bonferroni correction indicated highly significant differences (sports group and socially engaged group, $t(243) = -2.89$, $p = 0.01$, $d = -0.37$; sports group and nature protection organization, $t(237) = -7.33$, $p < 0.001$, $d = -0.96$; socially engaged group and nature protection organization, $t(216) = -4.22$, $p < 0.001$, $d = -0.58$). Overall, we discovered a continuum of interest from the sports group to the social group to the nature group.

Additionally, we were able to show that the three interest groups have different preferences for environmental preservation (Figure 1). Nature group participants' preservation level ($M = 1.03$, SD = 0.88) significantly surpassed that of both the socially engaged group ($M = 0.52$, SD = 0.61, $t(216) = -5.06$, $p < 0.001$, $d = -0.67$) and the

sports group ($M = 0.41$, SD = 0.76, $t(237) = -5.87$, $p < 0.001$, $d = -0.76$). By contrast, there was no evidence for a significant difference between sports group participants and participants in socially engaged groups ($t(243) = -1.21$, $p = 0.23$).

In terms of Connection to Nature and Utilization, no significant difference emerged between participants in sport groups (INS: $M = 4.05$, SD = 1.74; UTL: $M = -0.44$, SD = 0.84) and socially engaged groups (INS: $M = 4.42$, SD = 1.52; UTL: $M = -0.39$, SD = 0.78). However, if we compare participants in both the sport group and the socially engaged group with environmental organization members (INS: $M = 4.85$, SD = 1.10; UTL: $M = -1.05$, SD = 0.96), significant differences can be seen ($p < 0.001$, see Figure 1). Cohen's d values show small effects ($0.158 < d < 0.353$).

5. Discussion

Interest in nature seems to have an influence on willingness to preserve nature (Kals et al., 1999), but it remains unclear how it is related to environmental attitudes and behavior. Interest in nature might be a construct and motive explaining why adolescents develop greater pro-environmental behavior (Otto and Pensini, 2017; Otto S. et al., 2020). To analyze these relationships better, a comprehensive instrument to measure interest in nature is needed. To this end, the aim of this study was to develop a valid instrument to assess adolescents' interest in nature.

We therefore developed an age-appropriate scale for measuring adolescents' interest in nature, the SIN. Using Wright Maps and already established scales for measuring environmental attitudes we were able to establish construct validity (convergent and divergent). In addition, the results from known group comparisons support the construct validity of our instrument. Unless stated otherwise, the results presented for the SIN scale pertain to the overall scale consisting of 18 items.

Both the principal-axis factor analysis, and the Rasch-model analysis support the assertion that the SIN has a one-factor structure. The different items seem to measure different parts of one latent construct. As in the underlying scale (Schiefele et al., 1993), this study confirmed that the theoretically postulated interest components—namely emotion-related and value-related valences as well as the intrinsic character of interest—cannot be conceived as independent (orthogonal) factors. Even though the interest components represent covarying aspects of the interest construct, we nevertheless consider their analytic distinction useful and necessary (Krapp, 2002, 2007).

The factor analysis confirms that the constructs Preservation and Utilization do not load onto the same factor as the SIN scale. These data align with Kaiser et al. (2013), who find that attitude toward nature and attitude toward environmental protection are two separate but correlated constructs. However, the factor analysis of the SIN and 2-MEV items together showed that some value-related items not only loaded onto the respective factor of SIN, but also cross-loaded on the Preservation factor of the 2-MEV. The 2-MEV measures environmental values and includes various subscales of environmental concern. Thus, it is to be expected that the items also contain a value-related tendency, which is thus related to some of the SIN items. In any case, SIN provides more detailed information on the emotion-related and intrinsic components of interest in nature.

Furthermore, the analysis confirmed that the newly developed measure is an instrument with reasonable psychometric quality, namely good item fit, reliability, and internal consistency. In terms of convergent validity, the SIN correlated strongly with the INS scale (inclusion of nature in self, Schultz, 2002) and thus should be seen as a more specific dimension within the construct of nature connectedness, but with high practical usefulness. While connection to nature encompasses a broader concept that includes emotional, cognitive, and behavioral components, interest in nature specifically focuses on the level of attraction, curiosity, and engagement individuals have toward the natural world. Regarding discriminant validity, we found low correlations between the SIN scale and the environmental attitude scales Preservation and Utilization (MEV-2 model, Bogner and Wiseman, 2006). By excluding items related to interest in nature preservation from our instrument, our scale will be fully distinct from these aspects and the 2-MEV. Unlike previous studies (e.g., Kals et al., 1999; Leske and Bögeholz, 2008), we did not include measures referencing resources, ecosystem and biodiversity in our item set.

The results show that connection to nature is not only related to interest in nature, but also slightly related to environmental attitudes, in this case Preservation and Utilization. Thus, even though the two scales (INS and 2-MEV) represent two different constructs, the data shows a relationship between them. This suggests that the degree to which a person associates themselves with nature is related to their attitude toward nature protection. Therefore, a person with a stronger connection to nature is more concerned about environmental issues. This is consistent with previous studies showing that nature connectedness and environmental attitudes are substantially related (Schultz et al., 2004; Sellmann and Bogner, 2013; Otto and Pensini, 2017). Moreover, Roczen et al. (2014) integrated nature connectedness into their environmental competence model and considered it an important factor influencing individual environmental behavior. In our study, the strongest level of connection to nature was found among members of environmental organizations. We assume that frequent (positive) experiences with nature increased their individual connection to nature. Even though positive changes in connection are already apparent after one-day environmental education programs, a long-term connection to nature can only be achieved after longer, repeated nature experiences (Stern et al., 2008; Kossack and Bogner, 2012; Sellmann and Bogner, 2013; Möller, 2021). We also identify a trend across the various interest groups in interest in nature. We find the strongest connection to nature in the nature groups, which often spend longer periods of time in nature and deal with topics related to nature conservation (i.e., planting trees, installing nest boxes for birds etc.).

The SIN measure discriminates well between the three interest groups. In the present sample, the higher the SIN, the more likely that one is a member of an environmental organization, that aims to motivate and guide adolescents toward more environmentally friendly behavior. Within the study samples, drawn in Germany and Austria, we also found that adolescents' self-reported interest in nature was significantly related to the kind of activities they engage in in their free time. We found that members of environmental organizations reported a stronger interest in nature than did members of sports groups or socially engaged groups. We also found the same effect for the connection to nature (INS) and the

environmental attitude scales Preservation and Utilization of nature (2-MEV). Our hypothesis suggests that frequent interactions with nature enhance the level of personal engagement among adolescents actively involved in environmental organizations, ultimately leading to a greater interest in nature. Only those who identify with the object of interest will develop an individual interest (Krapp, 2002). The result of individual interest is an experience of positive emotions, increased appreciation, and a consolidation of knowledge about the subject matter (Renninger and Hidi, 2002). We assume that adolescents involved in environmental organizations have developed an individual interest in environmental issues due to their positive experiences in nature and that they have integrated nature as an important aspect of their identity. They have rather low values regarding utilization of nature in this study, which indicates that they do not place humans above nature and therefore do not believe that people should exploit nature for their own needs, which also fits well with their high values on the Preservation-scale.

The results of the known-group comparison align with previous studies highlighting the significance of prosocial propensity in the ecological domain (e.g., Otto et al., 2021). Prosocial propensity refers to an individual's inclination to engage in actions that benefit others or society as a whole. Within the ecological domain, this propensity is reflected in a willingness to participate in behaviors that protect and conserve the environment, such as recycling, reducing energy consumption, and supporting conservation initiatives (Neaman et al., 2021). By cultivating a strong prosocial propensity, individuals are more likely to take actions that benefit the environment, promote sustainability, and yield positive outcomes such as a reduced ecological footprint, increased involvement in environmental initiatives, and the formation of collective efforts to address environmental challenges. Prosocial propensity in the ecological domain plays a crucial role in fostering a sense of responsibility, empathy, and collective action toward environmental protection, ultimately contributing to a more sustainable and harmonious relationship between humans and the natural world (Otto et al., 2021). In our study, adolescents engaged in social activities also demonstrate a stronger connection to nature and a higher level of interest in the natural world. While their environmental attitudes may not be as pronounced as those of adolescents involved in environmental organizations, they still fall within a higher range compared to members of sports groups.

A limitation of our study is that pro-environmental behaviors and time spent in nature were not directly assessed, but rather assumed based on membership in environmental organizations. However, the examined groups were carefully selected according to strict criteria. It was crucial for us that the meetings of the environmental groups took place outdoors in natural settings and involved activities related to nature and environmental conservation, such as hanging bird houses or planting trees. This approach aimed to ensure that the adolescents not only regularly spent time in nature but also actively participated in nature conservation activities. To ensure the groups' suitability and adherence to these criteria, we accompanied them on-site. However, in order to make statistically robust statements about the causal relationship between engagement in various leisure activities, time spent in nature, and pro-environmental behavior, future studies should measure these constructs using self-reported variables, such as the General Ecological Behavior scale (Kaiser and Wilson, 2004). Based on the present study, we cannot make any causal statement. This could be addressed in future studies.

Another limitation is the composition of the three interest groups. Not only do they differ in sample size, but they were also collected at different locations. This was due to the challenge of finding enough adolescents in the respective groups willing to participate in the study. In addition, in this age group, it was particularly difficult to find young people who are institutionally involved in nature conservation in their free time. Because of this, we expanded the sample acquisition geographically (in the authors' home countries of Germany and Austria). This condition may limit the generalizability of the conclusions. The latter would require a representative sample. Another limitation of the present study involves the possibility of participants engaging in multiple groups. We tried to avoid overlaps by also asking all participants about their participation in all three types of organizations (e.g., nature conservation organizations or welfare associations). Only 4.08% of participants demonstrated double engagement, mainly between the socially engaged group and members of nature protection organizations. For participants with double engagement, we can assume a higher tendency toward pro-environmental behavior, as this is driven by prosocial propensity (Otto et al., 2021). Note, however, that such double engagement would have deflated rather than increased the differences between groups in terms of interest in nature, connection with nature and preservation and utilization of it.

6. Conclusion

The empirical findings presented in this study suggest that the SIN is a reliable and valid instrument that can be used to measure adolescents' level of interest in nature as a specific and practically meaningful facet of attitude toward or connectedness to nature. Furthermore, the results of the comparison between members and non-members of environmental organizations indicate a significant difference in the level of interest. Therefore, to promote interest in nature, a stronger engagement with nature should be encouraged (Otto and Pensini, 2017). Additionally, our data suggests a correlation between interest in nature and other environmental attitudes, which may contribute to a deeper understanding of the underlying mechanisms underlying pro-environmental behavior. For example, our scale could help model the interconnections between as well as the prerequisites for environmental attitudes. With the SIN, we provide researchers and educators with an instrument to empirically assess interest in nature as an important component of a more sustainable future. This is of great importance, as the ecological domain seems to be related to the prosocial domain of sustainable development, at least on the individual level (Otto et al., 2021). Prosocial propensity stems from a feeling of connection to a relevant domain. In our case, it is connectedness to nature which serves as a motive for acting on one's prosocial propensity within the ecological domain and generating further pro-environmental behavior (Otto et al., 2021). Knowing that environmental education interventions foster connectedness to nature as well as pro-environmental behavior, it is important to investigate any recursive effect on prosocial propensity. Only by understanding the interrelatedness of these constructs can we make recommendations on the most effective ESD or environmental education programs (Otto

et al., 2021). Here, our scale could supplement even broad existing outcome measures of ESD (e.g., Günther et al., 2022) by contributing a measure of a potential driver of individual sustainable behavior. With the SIN, we can not only investigate the relationship between interest in nature and other environmental variables in more detail, but also find out more about its influence on pro-environmental behavior. It can also be used by practitioners in formal or non-formal ESD settings alike to evaluate their programs, exploring whether they are able to increase adolescents' interest in nature and thus pave the way for more pro-environmental behavior.

Data availability statement

The original contributions presented in the study are publicly available. This data can be found at: https://osf.io/w2epc/.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

A-LN contributed to the conceptualization, methodology, data collection, validation, formal analysis, writing the original draft, visualization, and project administration. NP contributed to the conceptualization and methodology. SO contributed to the validation, formal analysis, reviewing, and editing the manuscript. AM contributed to the conceptualization, methodology, validation, formal analysis, reviewing, and editing the manuscript, resources, project administration, funding acquisition and supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1186557/full#supplementary-material

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Improving the greenness of enterprise supply chains by designing government subsidy mechanisms: based on prospect theory and evolutionary games

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Fostering sustainable development through green supply chains is of paramount significance. Government subsidies emerge as a successful strategy for motivating businesses to actively participate in such eco-friendly practices. This study employs prospect theory and an evolutionary game model to analyze the transition toward carbon peaking and neutrality while promoting the expansion of highly sustainable businesses. By exploring the decision-making processes of businesses and governments regarding sustainability, we develop an evolutionary game-based decision model to assess the impact of government subsidies on businesses engaged in green supply chains. Through numerical simulation obtained via MATLAB, we examine various factors influencing the evolution of the game system between green supply chain businesses and the government. Additionally, we investigate how government incentives impact the decision-making behavior of green supply chain businesses. Our findings indicate that governmental fines can effectively encourage the adoption of green supply chains. Furthermore, moderate government subsidies incentivize enterprises to opt for sustainable supply chains, benefiting both the government and businesses. However, providing hefty government subsidies not only fails to encourage the adoption of green supply chains but also incurs costs for the government, without yielding any positive change in the businesses' approach. By incorporating evolutionary game theory and prospect theory, this study contributes to the body of knowledge on government-supported green supply chains, offering incentive programs tailored to the real-world conditions faced by businesses while demonstrating practical application values.

KEYWORDS

green supply chain, government subsidies, prospect theory, evolutionary game, reward and punishment mechanisms

1. Introduction

As global climate change intensifies, most countries have realized the need to shift from traditional economic growth models to green development paths. Carbon dioxide emissions are the leading cause of global warming. More than 20% of the world's greenhouse gas (GHG) emissions come from the 2,500 largest multinational corporations' supply chains (World Bank,

2022). Numerous organizations have incorporated environmental factors into the project governance of their supply chains as a result of increased awareness, visibility, and stakeholder pressure (Song J. et al., 2022a). Supply chain corporations have played a significant role in these endeavors by executing investment decisions that are less detrimental to the environment than their existing equivalents (Tian et al., 2022). Such a strategy effectively mitigates environmental impacts throughout the entire supply chain process. And it is possible lowering environmental stress via sustainable supply chains. Therefore, green supply chains hold the potential to significantly alleviate or even reverse the environmental impact caused by human activities. In the face of intense international market competition, growing uncertainty in economic demand, and continuous technological innovation, green supply chains have become essential for supply chain enterprises.

Government subsidy mechanisms play a critical role in fostering enterprise involvement in green supply chains (Wang and Zhang, 2023). Stakeholders within green supply chain enterprises exhibit bounded rationality, and such enterprises adapt their strategies in response to government subsidy actions, which is more consistent with the actual behavioral characteristics of the players (Zhu et al., 2022). Therefore, the government can facilitate the development of a green economy, industrial transformation, and green supply chains through policy guidance and financial support. Currently, due to the defects in market mechanisms and constraints of individual business interests, the development of green supply chains faces numerous obstacles. For instance, small rural retailers in developing countries face challenges related to supply chain reform and technology management (Guo et al., 2022b). In this context, decision-making for green supply chain enterprises involves various complexities, such as cost reduction, interlinking interests, and adapting to dynamic market environments.

Considering the increasing complexities in logistics and supply chains in the current global business climate, understanding decision-making intricacies becomes imperative. Consequently, adopting more suitable methods for making green supply chain decisions has become increasingly vital. In the green supply chain, the decision-making behavior of government management and enterprise operation is often affected by subjective judgment and value perception (Hu et al., 2023). Prospect theory, recognized as a well-established framework for depicting risky decision-making, emerges as a mature decision theory (Tversky and Kahneman, 1992). This theory deviates from expected utility theory in two crucial aspects. First, utility under Prospect theory is assigned to gains and losses considering a reference point and not the final acquisition. This feature is known as reference dependence. Second, losses "loom larger" than gains of the same size, and this phenomenon is referred to as loss aversion. Prospect theory argues that decision-makers value gains and losses distinctively, with emphasis on perceived gains than on perceived losses (Aydogan, 2021). This theory acknowledges the crucial role of emotional states and rational capabilities within the intricate framework of green supply chain decision-making, thereby equipping enterprise decision-makers to make more astute choices (Heutel, 2019). Prospect theory emerges as an essential tool in promoting and guiding business and government entities through complex decision-making scenarios (Cai et al., 2023). By considering the decision-making processes of both sectors, it provides profound insights into diverse decision environments and significantly promotes the advancement of green practices in corporations.

Furthermore, integrating prospect theory with evolutionary games can optimize its application and provide a more comprehensive representation of the risky decision process. Some scholars have integrated evolutionary game and prospect theory to study human behavior in diverse fields (Golrezaei et al., 2021). Evolutionary games, an essential aspect of game theory, facilitate the comprehension of complex systems and cooperative behavior evolution (Killingback and Doebeli, 1996). This aspect renders them highly potent in modeling real-world economic issues and supporting decision-making processes undertaken by economists and policymakers (Schwerter, 2023). The versatility of evolutionary games extends to various domains, such as economics, management, political science, and social and biological evolution, addressing problems such as pricing wars between businesses, government-business cooperation, market volatility, and competition (He and Strub, 2022). The prospect theory was integrated into an evolutionary game framework to scrutinize the decision-making processes of businesses and governments within the realm of a green supply chain. The objective of this study, which combines evolutionary game theory and prospect theory, revolves around examining the decision-making process concerning government subsidies and green supply chains. It seeks to empower businesses and governments in enhancing their sustainability efforts within the context of green supply chains. This study analyzes government policies in diverse scenarios and their impact on business decisions, presenting the perspectives of both the government and businesses. By leveraging prospect theory and evolutionary gaming, effective decision-making support can be provided to meet market demands amid the increasingly complex supply chain environment.

This paper employs evolutionary game theory and mathematical modeling to explore the effects of two decisions (subsidization and penalties) based on their choice of green supply chains. The goal is to better address the challenges faced by green supply chain enterprises and the government in their decision-making processes. We explore the effect of irrational psychology on decision-making entities within green supply chain enterprises operating in collaboration with the government. This study contributes in three ways by integrating prospect theory, evolutionary game, and a review of the existing literature. First, our study broadens the theoretical understanding of green supply chains by introducing the perspective of psychological and behavioral factors. Second, our research has improved the design of government subsidy mechanisms by advancing the field of game theory research in the evolution of green supply chain subsidies. Third, we demonstrate the interactive relationship between green supply chain decisions and governmental subsidies and identify the specific factors of green supply chain practices that are favourable to sustainability. Our research contributes to the formulation of effective government subsidy strategies by aligning them with the varied strengths of subsidies and associated punitive measures. The central theme focuses on government's strategies to incentivize businesses to adopt eco-friendly, green supply chains.

2. Literature review

2.1. Prospect theory

Prospect theory, a descriptive decision model rooted in psychology and behavior, finds application in various domains such

as economics, political science, and psychology. It serves as a guiding framework for decision-making involving risks, ranging from personal choices to financial matters and policy welfare (Ruggeri et al., 2020). The influence of prospect theory on political science and decision-making in international relations has been subject to investigation. Its usefulness in political science has been confirmed, and further in-depth studies are being pursued. Additionally, researchers have analyzed the relative significance of prospect theory components in economic decision-making by aggregating research over four decades (Cheng and Cheng, 2023). Outside the laboratory, prospect theory finds relevance in settings where attitudes toward risk play a pivotal role. Consequently, an increasing number of scholars are applying prospect theory as a psychological and behavior-based descriptive model for research in various economic fields, with implications for decisions involving risk (Uppari and Hasija, 2019). Furthermore, prospect theory plays a vital role in diverse contexts, including agriculture and business negotiations. For instance, research has shown a significant connection between farmers' risk preferences, risk perceptions, and observed risk behavior in the context of climate change. Farmers who align with the prospect theory hypothesis are more likely to perceive higher risks associated with climate change (Villacis et al., 2021). In the realm of commercial negotiations, the impact of loss aversion on renegotiation has been studied through mathematical models based on prospect theory. These studies reveal that loss aversion leads to sticky and inefficient renegotiation outcomes (Trivella et al., 2021).

Moreover, prospect theory is employed in logistics decision-making, particularly in emergency logistics. The SF-GRA multi-attribute group decision-making method, based on cumulative effect theory, has been applied to the selection of emergency material suppliers (Katok and Villa, 2022). This approach evaluates supplier scores on multiple attributes using the SF-GRA method, converts them into utility values through cumulative effect theory, and then ranks the suppliers using the TOPSIS method to select the optimal supplier (Zhang et al., 2022).

2.2. Evolutionary game

The evolutionary game is a mathematical model that elucidates the evolution of individual behavior in society (Jung and Kouvelis, 2022). It is built upon the principles of Mendelian genetics and draws upon the evolutionary theory in ecology, enabling the study of strategy selection regularity and the evolution of group behavior among participants in the game process (Long et al., 2021). At the heart of the evolutionary game lies the concept of an "evolutionary stable strategy." This strategy, after several rounds of the game, becomes widely adopted and cannot be easily replaced by alternative strategies, making it evolutionarily stable. The theory of evolutionary games describes the interaction of individuals within a group, asserting that individual behavior is influenced by the behavior of others in the group, and follows certain evolutionary laws (Kwon, 2022). In this context, individuals may exhibit cooperative or non-cooperative behaviors, with different consequences for individual and group payoffs (Li X. et al., 2020). As an essential interdisciplinary research field, evolutionary game theory has garnered significant attention from scholars. It holds substantial importance for comprehending the evolutionary mechanisms of complex systems and cooperative behavior. Furthermore, evolutionary game theory has been applied to investigate dynamic reward and punishment schemes in green building development incentives, revealing that in competitive construction markets, such schemes can encourage the adoption of more environmentally friendly and sustainable building designs, enhancing their market competitiveness (Meng et al., 2021b).

Intra-enterprise collusion has also been studied through the lens of the tripartite evolutionary game of railroad safety regulation (Birge et al., 2023). These studies show that intra-enterprise collusion can erode trust between regulators and railroad enterprises, thereby affecting the effectiveness of railroad safety regulation (Tang et al., 2021). Additionally, researchers have reviewed the application of game theory in green supply chain management (Agi et al., 2021). Long et al. (2021) utilized evolutionary game theory to analyze the behavior of green-sensitive parties in green supply chains, considering interactions among green suppliers, green buyers, and non-green buyers.

2.3. Green supply chain

A supply chain is a network structure established by a core enterprise, encompassing related manufacturing, assembly, distribution, and retail enterprises interconnected through information flow, material flow, and capital flow. Through this network, enterprises transform raw materials into products, which are then sold to end-users (Song S. et al., 2022). A green supply chain integrates the concepts of green manufacturing, product life cycle, and extended producer responsibility into the business process of enterprises based on the traditional supply chain (Stumpf et al., 2023). This integration aligns the economic benefits of enterprises with resource conservation, environmental protection, and human health and safety requirements (Birge et al., 2023). Implementing green supply chain management is an effective strategy for enhancing the competitiveness of enterprises and achieving green and sustainable development (Zhou et al., 2021).

Green supply chain management is a management approach emphasizing environmental and social responsibility, which has garnered significant attention from researchers over the past 30 years (Nematollahi and Tajbakhsh, 2020; Roemer et al., 2023). A review of the literature on decision theory in sustainable supply chain management suggests that enterprises are increasingly adopting prospect theory in green supply chain decision-making to enhance its effectiveness (Zhu et al., 2022). Green supply chains incorporate environmental considerations into various supply chain practices, including product design and development, procurement, manufacturing, logistics, and end-of-life management (Li G. et al., 2020). The ultimate goal of green supply chains is to minimize environmental impact while simultaneously reducing costs, improving efficiency, and enhancing customer satisfaction (Song et al., 2023).

Recent research on green supply chains has focused on the trade-offs between different cost factors and environmental impacts in green supply chains to design greener and sustainable supply chain networks. Some researchers delved into the incentives and shared responsibility for emissions in supply chains, arguing that considering emission responsibility is crucial for achieving global environmental goals. Adopting incentive mechanisms can motivate supply chain participants to reduce emissions (Gopalakrishnan et al., 2021). To

promote green product process innovation, an approach based on closed-loop supply chains and remanufacturing has been proposed by some researchers. This approach optimizes product design, production, and remanufacturing processes to maximize resource utilization and environmental protection while improving the enterprise's economic efficiency (Park et al., 2022). Scholars also discuss key challenges and responses related to supply chain collaboration, technological innovation, and policy support. Future research directions include an in-depth study of supply chain synergy effects and remanufacturing process optimization to further sustainable development goals (Chai et al., 2021). Researcher integrated green supply chain operations and hospital environmental performance were examined in relation to the effects of big data analytics and artificial intelligence. According to the study, big data analytics and artificial intelligence applications may considerably boost the effectiveness and quality of green supply chains while also assisting in the reduction of resource waste and environmental degradation (Benzidia et al., 2021).

2.4. Government subsidies for green supply chains

Researchers are increasingly focusing on the role and impact of government subsidies in green supply chains. Some have examined the important interaction between subsidies and regulations in the market and presented key findings. The effectiveness of these measures depends on market circumstances (Wang et al., 2021). Subsidies and regulations are essential to correct market failures, but caution is needed when competition exists to avoid negative impacts on it (Zhang et al., 2023). Thus, the government must carefully consider the interplay between subsidies and regulations and select appropriate policies based on market conditions to maximize societal benefits (Wang and Zhang, 2023). From the perspective of carbon taxes, studies have explored the environmental and economic performance of closed-loop supply chains. Others have investigated the impact of the emissions intensity of new and remanufactured products on the overall emissions (Dou and Cao, 2020). These results highlight the importance of government involvement and promotion of green practices in organizations, as well as the significant role of environmental awareness in society for building a strong green supply chain management framework.

Scholars have provided effective green supply chain management strategies for enterprises and policymakers (Lo et al., 2022). They have discussed green subsidy models and pricing strategies in capital-limited supply chains. The concept and types of green subsidies are introduced, followed by an exploration of their impact on various supply chain participants (Gopalakrishnan et al., 2021). Additionally, the significance of pricing strategies for green supply chains is discussed, including the influencing factors and decision-making process (Huang et al., 2020). Studies have also examined the impact of government involvement, enterprise green investment, and consumer green preferences on supply chain coordination for the oil supply chain. Research has demonstrated that government encouragement of enterprise green investment and consumer advocacy of green products contributes to improved supply chain coordination (Zhang and Yousaf, 2020). Regarding taxation, scholars have explored environmental governance strategies for supply chains in the context of tax and subsidy interactions and found that flexible tax and subsidy strategies should be adopted by governments to address the varying needs of different enterprises and consumers, ultimately achieving sustainable development goals (Li Y. et al., 2020).

Researchers have also explored the incorporation of government subsidies into optimization models for redesigning optimal trauma care networks (Liu et al., 2023). Additionally, they have used evolutionary game models of green innovation stakeholders and simulation methods to analyze them. The findings emphasize the significant impact of stakeholder behavior and decisions on sustainable development in the field of green innovation (Guo et al., 2022a). To promote sustainable development, positive actions should encourage stakeholders to adopt cooperative strategies (Aydinliyim et al., 2022). Government intervention and regulation play a crucial role in fostering green innovation and sustainable development (Zhou et al., 2022).

3. Construction of the evolutionary game model

In this study, we combine evolutionary game theory with prospect theory and expand upon the evolutionary game model of governmental and green supply chain businesses. First, we applied prospect theory to analyze the perceived prospect value of enterprises and governments under different decisions. The model analyzes and calculates the perceived prospect value of each strategy for the government and enterprises, considering the two stages of prospect theory. Subsequently, we conducted an evolutionary game analysis based on the prospect value for each decision subject. Figure 1 illustrates the analysis process of the model in this paper.

3.1. Description of evolutionary game problem

The government subsidizing the green supply chain involves two key decision-makers: the government itself and the enterprises. These two players can be viewed as participants in a game, wherein neither acts rationally. Initially, each business must determine whether to adopt a "high green" or "low green" approach, with the chosen strategy significantly impacting the costs and benefits of the firm. Simultaneously, the government faces the decision of either imposing restrictions or offering incentives to influence behavior. The strategic decisions taken by the government significantly influence not only its own cost–benefit dynamics but also the choices pursued by businesses. The interaction between these strategic decisions from both the government and the enterprise creates a game process.

For the government and the enterprise to achieve a desirable outcome, they must strive to reach a Nash equilibrium point. In this equilibrium, neither party can unilaterally modify its plan to gain greater rewards, leading to a balanced and mutually beneficial arrangement. The model depicts the game between the enterprises and the government as a repeated game. This means that they engage in multiple rounds of decision-making. In each round, they base their new decisions on the results of the previous round. As the number of rounds increases, the strategies employed by both parties gradually stabilize, eventually leading to a dynamic equilibrium state.

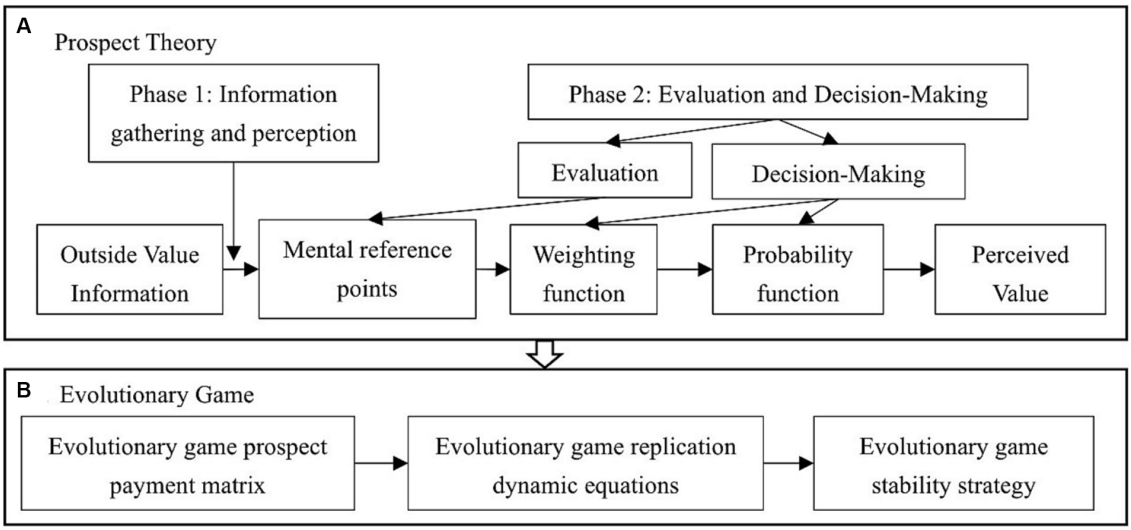

FIGURE 1
Game analysis process of government and green supply chain enterprises.

TABLE 1 Variables and explanation (Assumption 1).

Symbols	Variable description	Symbols	Variable description
R_1	The benefits for enterprise when they adopt a "high green" strategy	G_1	The benefits to the government when it adopts incentive policy
C_1	The costs for enterprise when they adopt a "high green" strategy	K_1	The cost to the government when it adopts incentive policy
R_2	The benefits for enterprise when they adopt a "low green" strategy	G_2	The benefits to the government when it adopts regulatory policies
C_2	The costs for enterprise when they adopt a "low green" strategy	K_2	The cost to the government when it adopts regulatory policies
G	Actual amount of government subsidies to high green businesses when using incentives	P	The actual fines levied on low green businesses when the government implements regulatory policies
U	The prospective value of environmental benefits to the government when enterprise implement "high green" strategies		

3.2. Basic model assumptions

3.2.1. Assumption 1

There are two decision makers, namely enterprise x and government y, both of whom are not fully rational when considering whether to subsidize green supply chains. Within the green supply chain, there are two types of enterprise strategies: the "high green" strategy and the "low green" strategy. The government has two policy options: the incentive policy and the regulatory policy. The incentive policy involves the government providing incentives and subsidies to environmentally friendly enterprises, while the regulatory policy entails the government enforcing environmental protection supervision and imposing penalties on non-compliant enterprises. Initially, the proportions of the two strategies are represented by p and $1-p$, while the proportions of the two policy options are represented by q and $1-q$. When an enterprise adopts the "high green" strategy, it incurs a benefit of R_1 and a cost of C_1. Conversely, when an enterprise adopts the "low green" strategy, it incurs a benefit of R_2 and a cost of C_2. When the government adopts the incentive policy, it offers a subsidy of G to high green enterprises. In contrast, when the government adopts the regulatory policy, it imposes a penalty of P on low green enterprises, it experiences a benefit of G_1 and a cost of K_1 for the incentive policy, and a benefit of G_2 and a cost of K_2 for the regulatory policy. The prospective value of environmental benefits to the government after enterprises implement the "high green" strategy is represented by U, listed in Table 1.

3.2.2. Assumption 2

The strategy sets of enterprise x and government y are $S_e\{s_e^g, s_e^n\}$ and $S_g\{s_g^a, s_g^b\}$, respectively, where s_e^g indicates that the green supply chain enterprise decides to impose more stringent green requirements on upstream enterprises on top of environmental compliance, i.e., the "high green" strategy, and s_e^n indicates that the green supply chain enterprise decides to maintain environmental compliance, i.e., the "low green" strategy. Furthermore, s_g^a indicates that the government adopts an incentive policy and s_g^b indicates that the government adopts a regulatory policy. Based on the risk perception characteristics of decision makers, the prospect theory and cumulative prospect theory models can be composed as follows:

$$V(x,p) = w(p)\cdot v(x), \tag{1}$$

$$v(x) = \begin{cases} v^+(x) = x^\alpha, & x \geq 0; \\ v^-(x) = -\lambda_1(-x)^\beta, & x < 0; \end{cases} \tag{2}$$

and

$$w(x)=\begin{cases} w^{+}(p)=\dfrac{p^{\lambda}}{\left[P^{\lambda}+\left(1-P^{\lambda}\right)\right]^{\frac{1}{\lambda}}} & x\geq 0 \\ w^{-}(p)=\dfrac{p^{\delta}}{\left[P^{\delta}+\left(1-P^{\delta}\right)\right]^{\frac{1}{\delta}}} & x<0 \end{cases} \quad (3)$$

where α and β is the coefficient of risk appetite, λ_1 is the coefficient of loss aversion, λ is the gain perception probability coefficient, δ is the loss perception probability coefficient, p is the actual probability of an event occurring, $w(p)$ is the subjective weight probability, and x is the amount of change in the value identified by the decision maker relative to the reference point. Generally, $\alpha=\beta=0.88$, $\lambda_1=2.25$, $\lambda=0.61$, and $\delta=0.69$ are based on information acquired through previous experiments (Kahneman and Tversky, 1979).

Furthermore, $V_e\{\pi_e^g, \pi_e^n\}$ and $V_g\{\pi_g^g, \pi_g^n\}$ are the sets of projected revenue functions for the enterprise and government, respectively. The likelihood of having π_e^g profit is p_g for "high green" enterprises, and the probability of having zero profits is 1 – p_g. The probability of having π_e^n profit is p_n for "low green" enterprises, and the probability of having zero profits is 1−p_n. Accordingly, "high green" enterprises have a revenue prospect function of $\pi_e^g=V\left(s_e^g,p_g\right)$, while "low green" enterprises have a revenue prospect function of $\pi_e^n=\left(s_e^n,p_n\right)$:

$$\begin{aligned}\pi_e^g &= V\left(s_e^g,p_g\right)=w^{+}\left(p_g\right)v^{+}\left(R_1-C_1\right)+w^{-}(0)\mathrm{v}^{-}(0)\\ &= w^{+}\left(p_g\right)v^{+}\left(R_1-C_1\right)\end{aligned} \quad (4)$$

and

$$\begin{aligned}\pi_e^n &= V\left(s_e^n,p_n\right)=w^{+}\left(p_n\right)v^{+}\left(R_2-C_2\right)+w^{-}(0)\mathrm{v}^{-}(0)\\ &= w^{+}\left(p_n\right)v^{+}\left(R_2-C_2\right)\end{aligned} \quad (5)$$

The probability of a zero return is $1-q_a$, such that the prospect function for the government implementing an incentive strategy is $\pi_g^a=V\left(s_g^g,q_a\right)$. The probability of a zero return is $1-q_b$. Finally, $\pi_g^b=V\left(s_g^n,q_b\right)$ represents the prospect function for the government to enact a regulatory policy:

$$\begin{aligned}\pi_g^a &= V\left(s_e^g,q_a\right)=w^{+}\left(q_a\right)v^{+}\left(G_1-K_1\right)+w^{-}(0)\mathrm{v}^{-}(0)\\ &= w^{+}\left(q_a\right)v^{+}\left(G_1-K_1\right)\end{aligned} \quad (6)$$

and

$$\begin{aligned}\pi_g^b &= V\left(s_g^n,q_b\right)=w^{+}\left(q_b\right)v^{+}\left(G_2-K_2\right)+w^{-}(0)\mathrm{v}^{-}(0)\\ &= w^{+}\left(q_b\right)v^{+}\left(G_2-K_2\right)\end{aligned} \quad (7)$$

The firm's perceived value of the actual government subsidy, G, is G'. The firm's perceived value of the actual government penalty, P, is P', as follows:

$$G'=V(G,1)=w^{+}(1)v^{+}(G)+w^{-}(0)v^{-}(0)=v^{+}(G) \quad (8)$$

and

$$P'=V(P,1)=w^{+}(0)v^{+}(0)+w^{-}(1)v^{-}(P)=v^{-}(P) \quad (9)$$

The government's perceived value of the real government subsidy, G, is G_g, which is as follows:

$$G_g=V(G,1)=w^{+}(0)v^{+}(0)+w^{-}(0)v^{-}(G)=v^{-}(G) \quad (10)$$

Table 2 lists the above variables and provides an explanation. The following presumptions were used based on this information:

(1) Firm X and government Y independently select their strategies at each time point and reap the corresponding benefits.
(2) The perceived benefits for both the firm and government are determined by the sum of the prospect value and the subsidy-related amount.
(3) The evolution of the firm's strategy is influenced by the strategies of neighboring enterprises and the government.
(4) Similarly, the evolution of the government's strategy is influenced by the firm's strategy.

3.3. Game benefit matrix

According to previous assumptions, the evolutionary game model for the enterprise and government can be expressed by the following game matrix, when the measurement strategy is $\{s_e^g, s_g^a\}$. According to the assumption that the enterprise selects "high green," and the government selects the incentive policy, the perceived benefit of the enterprise is π_e^g+G' and the perceived benefit of the government is π_g^a+U-G'. When the strategy scenario is $\{s_e^g, s_g^b\}$, where the firm selects "high green," and the government selects the regulatory policy, the government's perceived gain is π_g^b+U. The firm's perceived benefit in this case is π_e^g. The perceived benefits of the enterprise and government are π_e^n and π_g^a, respectively. When the strategy is $\{s_e^n, s_g^a\}$, the corporation selects "low green," and the government selects the incentive policy. When the strategy is $\{s_e^n, s_g^b\}$, the government selects the regulatory policy and the perceived benefit is π_g^b, whereas when the enterprise selects "low green," the perceived benefit is π_e^n-P'. Table 3 lists the prospective payment matrix for each decision scenario.

4. Model analysis

4.1. Replicated dynamic equation

The game analysis was performed by replicating the dynamics based on the prospect payment matrix calculated based on the prospect theory and the assumptions above. When the enterprise implements the "high green" strategy, s_e^g, the prospect gain is u_g; when the enterprise implements the "low green" strategy, s_e^n, the prospect gain is u_n:

TABLE 2 Variables and explanation (Assumption 2).

Symbols	Variable description	Symbols	Variable description
π_e^g	Perceived value when enterprise adopt a "high green" strategy	π_g^a	Perceived value when the government adopts incentive policies
π_e^n	Perceived value when enterprise adopt a "low green" strategy	π_g^b	Perceived value when the government adopts regulatory policies
p_g	The probability that a "high green" firm with return π_e^g	q_a	When the government adopts an incentive policy, the probability that the government gains π_g^a
p_n	The probability that a "low green" firm with return π_e^n	q_b	When the government adopts a regulatory policy, the probability that the government gains π_g^b
G'	The perceived value of government subsidies to businesses	P'	The perceived value of government penalties to business and government
G_g	The perceived value of government subsidies to the government		

TABLE 3 Game payment matrix for the government and enterprise.

	High green (g)		Low green (n)	
	Enterprise (x)	Government (y)	Enterprise (x)	Government (y)
Incentive policies (a)	$\pi_e^g + G'$	$\pi_g^a + U - G_g$	π_e^n	π_g^a
Regulatory policy (b)	π_e^g	$\pi_g^b + U$	$\pi_e^n - P'$	π_g^b

$$u_g = q\left(\pi_e^g + G'\right) + (1-q)\pi_e^g \tag{11}$$

and

$$u_n = q\pi_e^n + (1-q)(\pi_e^n - P') \tag{12}$$

The average prospective gain for enterprise is $\overline{u_e}$:

$$\overline{u_e} = pu_g + (1-p)u_n \tag{13}$$

As a result, the firm's replicated dynamic equation can be calculated as follows:

$$\begin{aligned} F(p) &= \frac{dp}{dt} \\ &= p(1-p)\left(u_g - \overline{u_e}\right) \\ &= p(1-p)\left(u_g - u_n\right) \\ &= p(1-p)\begin{pmatrix}\left(q\left(\pi_e^g + G'\right) + (1-q)\pi_e^g\right) \\ -\left(q\pi_e^n + (1-q)(\pi_e^n - P')\right)\end{pmatrix} \\ &= p(1-p)\left((G'-P')q + \pi_e^g - \pi_e^n + P'\right) \end{aligned} \tag{14}$$

The prospective gain is u_a when the government implements an incentive policy and u_b when the government implements a regulatory policy:

$$u_a = p\left(\pi_g^a + U - G\right) + (1-p)\pi_g^a \tag{15}$$

and

$$u_b = p\left(\pi_g^b + U\right) + (1-p)\pi_g^b \tag{16}$$

The average prospective gain for the government is $\overline{u_g}$:

$$\overline{u_g} = qu_g + (1-q)u_n \tag{17}$$

Based on this, the replication dynamics equation for the government can be obtained as follows:

$$\begin{aligned} G(q) &= \frac{dq}{dt} \\ &= q(1-q)\left(u_a - \overline{u}_g\right) \\ &= q(1-q)\left(u_a - u_b\right) \\ &= q(q-1)\begin{pmatrix}p\left(\pi_g^a + U - G_g\right) + (1-p)\pi_g^a \\ -\left(p\left(\pi_g^b + U\right) + (1-p)\pi_g^b\right)\end{pmatrix} \\ &= q(1-q)\left(G_g p + \pi_g^b - \pi_g^a\right) \end{aligned} \tag{18}$$

The two replicated dynamic Eqs 14, 18 were combined to obtain a 2-D dynamic system of firm and government decisions as follows:

$$\begin{cases} F(p) = \dfrac{dp}{dt} = p(1-p)\left((G'-P')q + \pi_e^g - \pi_e^n + P'\right) \\ G(q) = \dfrac{dq}{dt} = q(1-q)\left(G_g p + \pi_g^b - \pi_g^a\right) \end{cases} \tag{19}$$

4.2. Analysis of evolutionary stability strategy

According to the aforementioned model, the proportion of businesses adopting a "high green" approach is partially stable when

$p=0$, $p=1$, or $q=\frac{\pi_e^n-\pi_e^g-P'}{G'-P'}\left(G'\neq P'\right)$; the proportion of governments selecting an incentive policy is similarly partially stable when $q=0$, $q=1$, or $p=\frac{\pi_g^a-\pi_g^b}{G_g}$.When $q=\frac{\pi_e^n-\pi_e^g-P'}{G'-P'}\left(G'\neq P'\right)$, p takes any value, which is the evolutionary stability strategy (ESS) of the system; if $q\neq\frac{\pi_e^n-\pi_e^g-P'}{G'-P'}$ or $G'=P'$, $p=0$, and $p=1$ are the two ESSs of the system; when$G'\neq P'$, $P'<G'$and $G'-P'\leq\pi_e^n-\pi_e^g$, then $p=1$ is the ESS of the system; and if $G'\neq P'$, $P'>G'$ and $G'-P'\geq\pi_e^n-\pi_e^g$, then $p=1$ is the ESS of the system.

When $p=\frac{\pi_g^a-\pi_g^b}{G_g}$, q is the system's ESS regardless of its value; if $p\neq\frac{\pi_g^a-\pi_g^b}{G_g}$, $q=0$ and $q=1$ are the system's two ESSs; and when $\pi_g^a-\pi_g^b\leq G_g$, $q=1$ is the system's ESS.

The 2-D decision dynamics system of the firm and the government, as reported above, has five local stability points, which are (1,1), (0,0), (1,0), (0,1) and $\left(\frac{\pi_e^n-\pi_e^g-P'}{G'-P'},\frac{\pi_g^a-\pi_g^b}{G_g}\right)$.

Figure 2 reveals four local stability points in the two-dimensional dynamical system involving the corporation and government. Each equilibrium point corresponds to an evolutionary game strategy that holds practical significance.

The point (1,1) indicates that all enterprises in the system adopt a "high green" strategy, and the government provides incentives to each enterprise. This scenario leads to positive development for both the enterprise and the government, facilitating the achievement of green goals.

The point (0,0) signifies that all enterprises in the system adopt "high green" strategies, and the government takes punitive measures against each enterprise. As a result, all enterprises adopt the "high green" strategy, which causes a decrease in their revenue. However, the government gains revenue from the firm's green strategy, leading to an increase in the firm's risk.

The point (1,0) implies that all enterprises in the system adopt a "low green" strategy, while the government continues to provide incentives to each firm. In this case, the government incurs higher costs, and the enterprises receive subsidies but are unable to achieve their green goals.

The point (0,1) indicates that all enterprises in the system adopt a "low green" strategy and the government takes punitive measures against each firm. In this case, there is no additional risk for both the government and enterprise, but no further greening is achieved. These findings shed light on the practical implications of the different equilibrium points in the system, highlighting the dynamics between the corporation and government in pursuing environmentally friendly strategies.

5. Simulation

5.1. Simulation analysis data

In summary, several factors affect the stability of this evolutionary game system. From the replicated dynamic equation system, π_e^g, π_e^n, π_g^a, π_g^b, G, P, and other factors can affect this evolutionary game system; furthermore, p_g, p_n, q_a, and q_b influence π_e^g, π_e^n, π_g^a, π_g^b, and other factors. We used MATLAB to simulate the components, examined the development of business and governmental strategy under various parameter modifications, and better understood the impact of each aspect on the evolutionary game system. Considering current circumstances, the initial values of each parameter were established in Table 4.

We assumed that the "high green" firm had benefit R_1 and cost C_1; the "low green" firm had benefit R_2 and cost C_2; the incentive policy had benefit G_1 and cost K_1; and the regulatory policy had benefit G_2 and cost K_2, where the expected probability of occurrence of each prospect was $p_g=0.65$, $p_n=0.7$, $q_a=0.70$, and $q_b=0.88$.

We conducted calculations and produced the prospect values of enterprises and governments under various strategies based on the prospect theory model utilized in the preceding section, which were $\pi_e^g=0.77$, $\pi_e^n=2.3155$, $\pi_g^a=0.3856$, and $\pi_g^b=1.0675$.

According to the survey research, assuming an initial value of 0.4 for p and 0.6 for q, in the current social context (He et al., 2021), the proportion of "high green" supply chain enterprises was relatively low while the proportion of government incentives for "high green" environmentally friendly enterprises was significant.

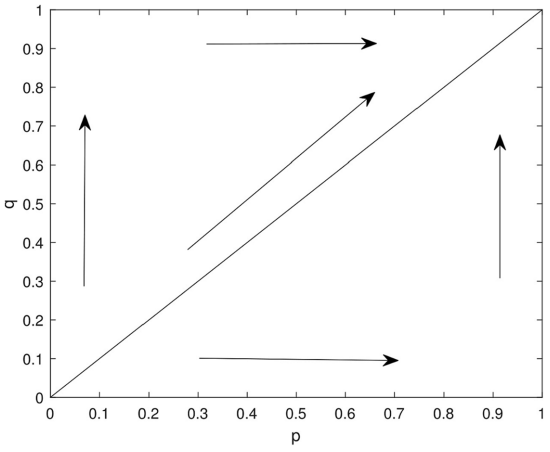

FIGURE 2
Dynamic evolution phase diagram of the enterprise and government game.

5.2. Simulation analysis of factors affecting evolution

To simulate the evolutionary game model in MATLAB, we set the value of the government subsidy, $G=8$, and the value of the government penalty, $p=3$, for "low green" enterprises. This resulted in Figure 3, which is consistent with the phase diagram change in the equilibrium point analysis mentioned above.

Figure 4 illustrates the progression of the "high green" strategy as depicted in the simulation. Over time, there was a convergence toward a ratio of 1 between businesses adopting the "high green" strategy and governments implementing incentive policies. Similarly, the ratio of businesses choosing the "high green" strategy and the ratio of

TABLE 4 Benefits and costs for businesses and governments.

Enterprise benefits		Enterprise costs		Government benefits		Government costs	
R_1	25.2425	C_1	22.2001	G_1	28.8945	K_1	27.6055
R_2	29.7946	C_2	21.0868	G_2	31.0399	K_2	27.9461

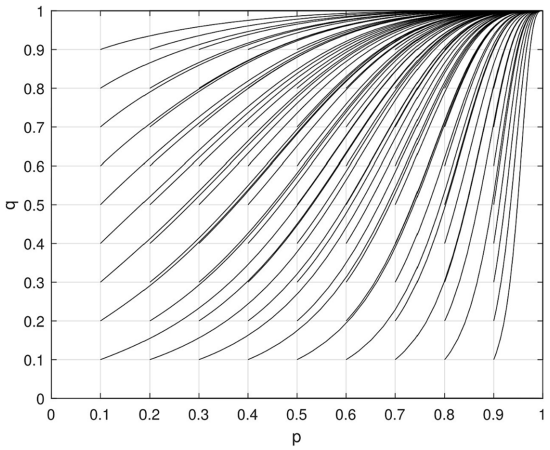

FIGURE 3
ESS of the enterprise and government evolutionary game simulation.

governments opting for incentive policies also converged to 1. Remarkably, the government's incentive policy (reward) continued to rise until it reached a ratio of 1 before the businesses' choice of the "high green" approach. This clearly demonstrates the significant role of the government in directing environmental protection efforts.

As depicted in Figures 5, 6, when the perceived value G' of government subsidies increases, enterprises begin to develop in the direction of high environmental sustainability, and the government becomes more inclined to provide subsidies to them. In other words, as the perceived prospect of subsidies grows, enterprises are more willing to adopt the "high green" strategy, leading to a stable game system. This outcome arises from the fact that the enterprises' perception of increased government subsidies motivates them to engage more actively in environmental protection activities.

According to Figure 7, when $p > 0$, the government penalizes low green enterprises, and their behavior initially moves in the direction of becoming more environmentally friendly. However, as the magnitude of G (government penalties) increases beyond a certain threshold, these enterprises begin to shift back toward low green decisions. In other words, businesses are more likely to adopt a "high green" approach and the game system achieves stability when the government offers fewer subsidies to businesses. Nevertheless, the percentage of businesses choosing the "high green" strategy starts to decline once the number of subsidies reaches a particular threshold. Simply stated, government incentives can partially encourage businesses to engage in green practices, but excessive incentives might lead businesses to become overly reliant on them, resulting in reduced environmental investment or even the use of environmentally destructive methods to boost profits. For instance, the Canadian government decided to give Germany's Volkswagen a $13 billion subsidy. Governments' green product incentives could backfire (He et al., 2021), when formulating policies; the government must carefully

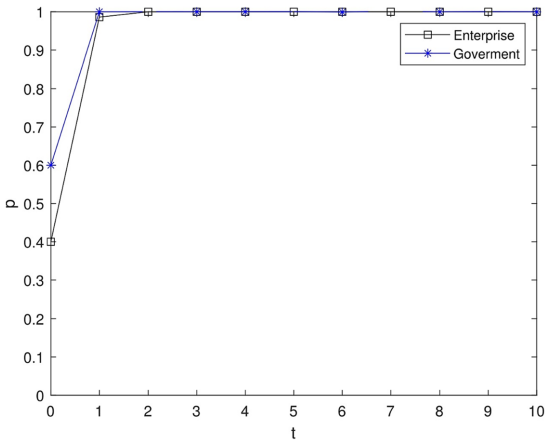

FIGURE 4
Evolutionary path of government and enterprise strategy.

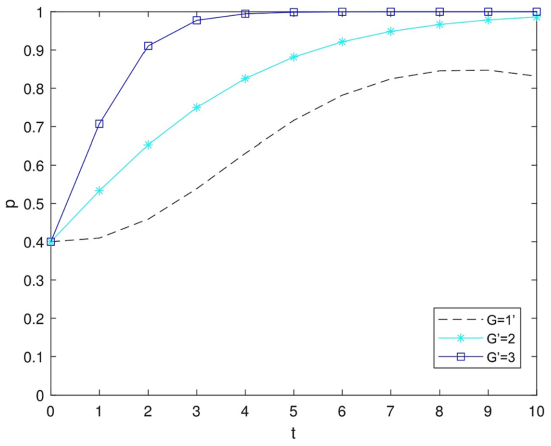

FIGURE 5
Impact of G' on enterprise decision making.

consider the amount and timing of subsidies to prevent negative impacts on enterprise environmental behavior.

Figure 8 illustrates that when $p \leq 0$ the government decides not to fine the enterprises, or, in cases where there are no penalties, enterprises are less inclined to pursue high green supply chain plans. The time required for the system to reach a steady state increases as the actual subsidy amount, G, from the government to the firm rises. Clearly, government penalties for businesses can effectively encourage them to opt for green supply chains; sanctions against businesses with inadequate environmental standards can lead to the more successful adoption of greener practices compared to simple subsidies.

6. Discussion

6.1. Main findings

This study obtained three main findings. First, attaining an optimal balance between corporate conduct and government policies proves to be a considerable challenge within the actual functioning of supply chain businesses. Businesses often tend to produce only in line

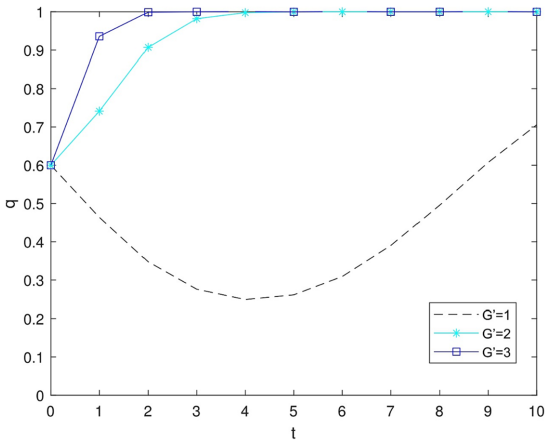

FIGURE 6
Impact of G' on government decision making.

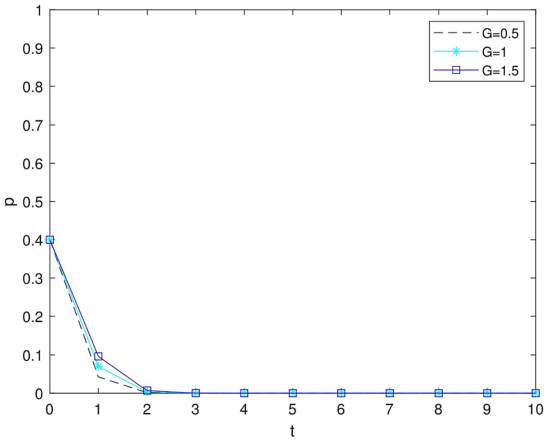

FIGURE 8
Impact of perceived value of government subsidies on enterprises' decisions at $p = -1$.

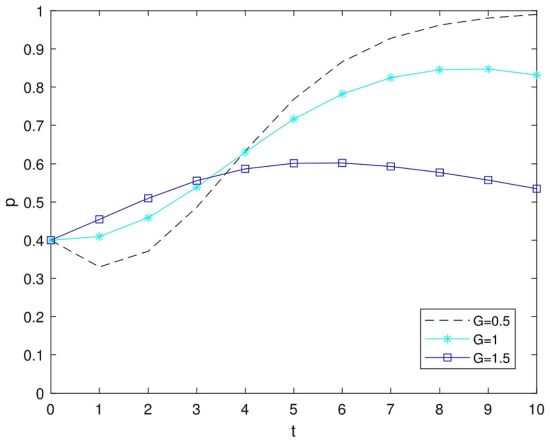

FIGURE 7
Impact of perceived value of government subsidies on enterprises' decisions at $p = 1$.

with the minimum green criteria. Four ideal limitations that can lead to the supply chain enterprise evolving to its best form are revealed by the mathematical modeling analysis: when P' is less than G' and G' minus P' is greater than π_e^n minus π_e^g; when P' is greater than G' and G' minus P' is less than the difference of π_e^n minus π_e^g, p is equal to the value of π_g^a minus π_g^b divided by G_g; and when P' is not equal to G', and q is equal to π_e^n minus π_e^g minus P' divided by G' minus P'. However, in reality, the business environment of supply chain enterprises and the strategic environment of the government are highly complicated. The government's reward and punishment mechanism are not yet perfect, and decision makers in enterprises may exhibit various behavioral biases because of overconfidence or cognitive biases. Considering the reflection effect in prospect theory, it becomes challenging for all these factors to align simultaneously. Moreover, relying solely on government subsidies proves insufficient to achieve the best outcomes.

Second, our research identified the main factors influencing the government's decision to provide subsidies to green supply chain businesses. Due to the complex and uncertain nature of the game system between green supply chain enterprises and the government, we identified six key influencing factors that affect the effectiveness of subsidies. These factors were examined from the perspectives of both enterprises and the government: π_e^g, π_e^n, π_g^a, π_g^b, G and P, respectively. The simulation revealed that increasing the prospective value of the "high green" strategy, reducing the prospective value of the "low green" strategy, boosting government subsidies, and imposing higher penalties for "low green" enterprises can indeed partially encourage the adoption of the "high green" strategy. However, it is crucial to recognize that there are specific thresholds for the impact of G and P on the adoption of environmental protection strategies. Only by making rational decisions based on these criteria can we effectively accelerate and promote the transformation of green supply chain enterprises.

Last but not least, both governmental fines and moderate subsidies have demonstrated effectiveness in promoting the adoption of green supply chains. However, the provision of substantial government subsidies falls short in incentivizing businesses to opt for sustainable supply chains. The model's results demonstrate that the penalty system is a valuable tool for the government to encourage businesses to opt for green supply chains. A win-win situation for the government and enterprises can be attained through modest government subsidies. Conversely, excessive subsidies may not only fail to achieve the desired effect of promoting enterprises' green supply chains but also lead to losses for both the enterprises and government. In other words, government green subsidies to businesses should be capped and primarily utilized to penalize environmentally damaging businesses.

6.2. Theoretical implications

This study notably enhances the existing literature on public support for sustainable supply chains through several significant contributions. First, our study broadens the theoretical understanding of green supply chains by introducing the perspective of psychological and behavioral factors. Previous studies mainly focused on the cost-effectiveness of green supply chains and variables influencing businesses' environmental behavior, such as competitive pricing and

green supply chain strategies, but largely missed behavioral decision-making (Knemeyer and Naylor, 2011; Barman et al., 2021). In this context, we transfer the research focus to psychological and behavioral factors, and investigate how these factors impact the dynamics within a green supply chain. We then use an innovative approach that combines the prospect theory with evolutionary game theory to construct an evolutionary game model for both businesses and governments involved in a green supply chain. Existing research on green supply chain decision models typically considers elements such as profit, cost, benefit, and government subsidies for energy-efficient products (Xue et al., 2019), but often overlooks the influence of firm behavior on subsidy results. To fill this gap, we integrate prospect theory and evolutionary game theory to provide a more comprehensive analysis involving both government and firm behavior. This combined perspective paves the way for new insights and methodologies for devising green supply chain policies. A key assumption underpinning our study is that every decision-maker operates with finite rationality, exhibits loss aversion, and is sensitive to psychological effects. Moreover, it is expected that these decision-makers will choose the most advantageous course of action, based on the perceived value of their prospects.

Second, our research substantially extends the prevailing theoretical work on green supply chains, offering fresh insights into government subsidy mechanism design. By utilizing prospect theory in conjunction with an evolutionary game model, we pushed forward the field of evolutionary game research concerning government subsidies for green supply chains. Historically, studies have primarily concentrated on how government subsidies affect businesses or stressed aspects of collaboration, negotiation, and equity issues within green supply chains (Adhikari and Bisi, 2020; Ye et al., 2022). To address these real-world concerns more effectively, our study harmonizes prospect theory and evolutionary game theory from the synergistic perspectives of both businesses and governments. We crafted an evolutionary game model encapsulating the dynamics between green supply chain enterprises and governments. This model scrutinizes how businesses negotiate decisions regarding government subsidies, along with assessing the sway of government incentives and regulations over the adoption of green practices. In scenarios where government subsidies are not factored in, enterprises may lean towards a "high green" strategy only when they perceive the prospects of this choice outweighing a "low green" approach. However, firm decisions are subject to influence by government conduct when considering its impact on supply chain enterprises. The model we have developed demonstrates that government policies significantly shape businesses' propensity to adopt "high green" strategies. Government subsidies can inspire businesses to select "high green" methods, and escalating fines for "low green" firms under regulatory policies can stimulate the embrace of greener production models.

Finally, we delve deeper into the intricacies of the connection between green supply chain decisions and governmental subsidies. Our research contributes to the formulation of effective government subsidy strategies by aligning them with varied strengths of subsidies and associated punitive measures. The central theme focuses on how governments can more effectively incentivize businesses to adopt eco-friendly, green supply chains. Building upon previous research, it is evident that government subsidies pave the way for businesses to embrace green production techniques, concurrently reducing consumer costs (Meng et al., 2021a). In our study, we scrutinize the potential future benefits for both businesses and governments using the lens of prospect theory, leveraging these insights to develop an evolutionary game model tailored for green supply chain enterprises and governments. However, our findings also indicate a paradox; large government subsidies often fail to motivate businesses toward green supply chains, resulting in losses for both parties. Therefore, this paper delivers theoretical frameworks for governments to stimulate the transformation of green supply chain businesses into sustainable, environmentally conscious organizations, thus aiding their transition. In summary, our research provides crucial insights into behavioral decision-making within subsidized green supply chains, while underscoring the significance of incorporating prospect theory and evolutionary game theory when assessing the efficacy of government subsidies.

6.3. Practical implications

6.3.1. Providing appropriate subsidy

According to the status of supply chain enterprises, the government should provide appropriate subsidies. Offering small government subsidies can encourage businesses to adopt green supply chains, leading to a significant increase in both government and businesses' earnings. This benefits not only the growth of businesses but also advances both social and economic development. For enterprises that meet the requirements, the government may extend financial assistance in the form of tax breaks, preferential loan terms, and capital subsidies. These efforts aim to enhance their competitiveness and foster growth momentum. Additionally, the government should focus on developing more detailed environmental policy measures, enabling businesses to execute them more effectively. This will create a conducive environment for supply chain enterprises to thrive safely and orderly. Simultaneously, the government should actively expand its support and oversight of businesses to foster sustainable development. This approach will enable supply chain businesses to address challenges effectively and achieve long-term growth.

6.3.2. Penalizing non-environmental enterprises

By imposing fines on enterprises with low or no environmental standards, the government should encourage corporations to take their environmental obligations more seriously. Enforcing sanctions on businesses that do not prioritize environmental protection or lack eco-friendly practices will also compel such enterprises to pay greater attention to environmental issues. For instance, the government can employ administrative sanctions, such as fines and the cancellation of enterprise licenses, to penalize businesses that disobey environmental laws. These measures will hold businesses accountable for their transgressions and foster a heightened awareness of the importance of environmental preservation. This approach creates a positive feedback loop between the economy, environment, and society, while simultaneously promoting the sustainable development of businesses.

6.3.3. Enhancing communication and environmental awareness

Prospect theory suggests that the perception of business revenue under environmentally friendly techniques is influenced by enterprise culture, as decision-makers often exhibit non-fully rational

characteristics. To achieve sustainable development, the enterprise should increase their environmental consciousness, actively invest in environmental protection, and adopt eco-friendly techniques. Moreover, businesses should be mindful of and positively respond to the government's environmental regulations to achieve better win-win outcomes.

To promote environmental protection, the government and businesses must improve communication and exchange ideas, engaging in collaborative debates on environmental policies. Cooperation and coordination should serve as the foundation for supporting the growth of the environmental protection industry. Additionally, the government must enhance its oversight to ensure that businesses comply with environmental protection laws, thus contributing to the healthy development of the environmental protection sector.

In conclusion, government subsidies play a significant role in encouraging enterprises to transition to sustainable supply chains. However, such subsidies must be carefully implemented, considering factors including the environment, economics, and policy implications. Proper regulation and evaluation are essential for their effectiveness.

6.4. Limitations and future research

There are several limitations to this study. First, this study lacks a discussion on how internal green supply chain enterprise procedures influence enterprise decision-making. Factors such as enterprise culture and staff understanding have a significant impact on how businesses manage their green supply chains. Hence, it is imperative to incorporate these elements into the research scope and develop a more comprehensive model of green supply chain management (Han et al., 2022; Huo et al., 2023). Second, the discussion of government subsidies in this paper is relatively brief and fails to delve into the specific forms, criteria, and implementation methods of these subsidies. To comprehend the effects of government subsidies on green supply chain businesses and suggest more sustainable incentive programs, additional empirical research is required. Finally, this study overlooks critical aspects of model-building, such as regional disparities and social network connections between specific businesses, which may limit the model's applicability. Therefore, it is essential to consider more factors in the model-building process and expand the research horizon to enhance the applicability and prediction accuracy of the model.

To address the aforementioned issues and gain a deeper understanding of green supply chains, a future study can be conducted on the mechanisms of cooperation between businesses and governments in the context of green supply chains as per the current situation. This investigation should further explore the form, level, substance, and process of cooperation between businesses and the government to develop a more comprehensive model of green supply chain management. Moreover, the sustainability of government subsidies must be considered to ensure their long-term impact on green supply chain businesses. To develop a more realistic subsidy model, it is essential to analyze the actual effects of various forms, standards, and implementation techniques on businesses.

Furthermore, the effects of government subsidies on different types of enterprises, sizes, geographic regions, and other factors should be studied to determine more effective subsidy policies. When building a green supply chain management model, several factors, including the internal mechanisms of enterprises, should be considered. For example, social network relationships, organizational structure, management mode within the enterprise, geographical factors, and the policy environment can all contribute to improving the applicability and prediction accuracy of the model. To comprehensively analyze the effectiveness and feasibility of green supply chain management models, a variety of methods and techniques, including statistical analysis, case studies, and simulations, should be employed. This approach will enable a more robust assessment of these models. By addressing these issues and adopting a comprehensive research approach, we can enhance our understanding of green supply chains and contribute to the development of sustainable practices in the supply chain industry.

7. Conclusion

This study utilized prospect theory and evolutionary games to examine the impact of government subsidies on the behavior of green supply chain businesses and the government. We have considered behavioral and psychological factors and examined whether its potential an impact on decision-making behavior between governments and businesses in green supply chain practices. We have obtained the following results based on the analysis.

First, we observed that achieving an optimal balance between corporate conduct and government policies proves to be a considerable challenge within the practical operation of supply chain businesses, which is consistent with the finding of Stekelorum et al. (2022). This finding implies that the government's reward and penalty mechanisms are not yet well-developed, and corporate decision-makers might exhibit various behavioral deviations owing to overconfidence or cognitive biases. Consequently, businesses might frequently align their production only with the minimum green criteria.

Second, our research identified that the perceived benefits of enterprises, the magnitude of government subsidies to enterprises, and the penalties imposed by government to enterprises, are the primary factors influencing the government's decision to grant subsidies to green supply chain businesses. These factors have a huge impact on how complex and uncertain the game between green supply chain enterprises and the government is. Therefore, the Chinese government can develop relevant policies to guide and provide proper incentives to improve enterprises' green supply chain practices.

Third, both governmental fines and moderate subsidies have been emerged as having a positive correlation with promoting the adoption of green supply chains. Interestingly, the provision of substantial government subsidies falls short of incentivizing businesses to opt for sustainable supply chains. The model's results demonstrate that the penalty system is a valuable tool for the government to encourage businesses to opt for green supply chains. This finding indicates that a win-win situation for government and enterprises can be attained through modest government subsidies. Conversely, excessive subsidies may not only fail to have the intended impact of boosting green supply chains but also have losses for both the enterprises and the government.

In conclusion, the research results indicate that government behavior can not only affect whether enterprises adopt green supply chains, but also effectively enhance the benefits for both the

government and the enterprises. Thus, we propose incentive policies that better align with the actual circumstances faced by businesses, thus holding significant practical application potential. The incentive programs presented here offer practical applications that are better suited to the real-world challenges encountered by businesses.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

LH: Supervision, Conceptualization, Methodology, Writing – original draft. YZ: Methodology, Writing – original draft. CW: Supervision, Writing – review & editing. JS: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Lawn or spontaneous groundcover? Residents' perceptions of and preferences for alternative lawns in Xianyang, China

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Within urban green spaces, spontaneous groundcovers, as potential alternatives for traditional lawns, have garnered attention due to their ecological adaptability. However, little attention has been paid to whether spontaneous groundcovers can serve as suitable replacements for lawns in terms of the aesthetic values and human preferences for each. Based on questionnaires accompanied by photo elicitation, this study explored the perceptions of and preferences for seven kinds of lawns and six kinds of spontaneous groundcovers in China. The effects of social backgrounds on people's perceptions of and preferences for ground covers were also analyzed. The results indicated a general equivalence in preferences for the lawn and spontaneous groundcover. The *Taraxacum mongolicum* – *Cynodon dactylon* – *Conyza canadensis* community was significantly preferred most among all of the selected ground covers. Spontaneous groundcovers were regarded as more natural, wild, variable, and species-richer compared to lawns, while lawns were perceived as better kept than spontaneous groundcovers. Ground covers were preferred which were perceived to have high ecological aesthetic value and low wildness. Industry and attention to herbaceous plants mostly affected human perceptions and preferences among the social background factors, and gender, age, education level, and occupation also had significant effects. The results thus provide the support for the application of spontaneous groundcovers in moderately developed cities, but such application should consider the comprehensive development of ecological aesthetic value and the applicability of different groups of residents.

KEYWORDS

landscape perception, landscape preference, spontaneous vegetation, urban lawn, social background

1. Introduction

Historically, lawns have stood as prominent symbols in cities globally (Ignatieva and Hedblom, 2018). Lawn is fine-textured turf of grass that is kept mowed (The Editors of Encyclopaedia Britannica, 2013), originally composed of a mixture wild grasses and mowing tolerant wildflowers native to the relatively moist and mild maritime climate of Northwest Europe (Smith and Fellowes, 2015). In China, the term "lawn" encompasses a broader connotation that it is a surface made up of herbaceous plants, established and managed artificially and offering both aesthetic and recreational values (Xia and Zhao, 2000). Lawns provide positive ecosystem services like reducing runoff, increasing infiltration, purifying water from sediments and pollutants, controlling erosion, improving soil quality and providing wildlife habitat (Monteiro, 2017). Notably, the visual appeal of lawns underscores their importance, with many cultures valuing the neatness and order they bring (Monteiro, 2017; Ignatieva and Hedblom, 2018).

However, the overall use of lawns has caused concerns. Lawns worsen problems brought on by population increase and climate change, such as rising greenhouse gas emissions and declining urban biodiversity (Ignatieva and Hedblom, 2018). Lawn irrigation consumes a huge amount of water every year (Milesi et al., 2005). The frequent use of fertilizer and pesticide due to intensive management causes environment pollution – lawn chemicals have been found in 99% of urban rainwater samples in the United States (Cheng et al., 2008; Alumai et al., 2009). In addition, the positive effect of soil carbon sequestration on the climate footprint of intensively managed lawns was found to be negated by greenhouse gas emissions from management operations such as mowing, irrigation, and fertilization (Tidåker et al., 2017). From an aesthetic perspective, tidily trimmed lawns are not always familiar to residents in different geographical contexts. While prevalent in western countries, lawns were historically absent from traditional Chinese gardens, their current ubiquity stemming from Western influences (Yang et al., 2019a). Consequently, research has pivoted toward exploring lawn alternatives like grass-free lawns, flowering lawns, and urban meadows that offer advantages in maintenance, aesthetics, and biodiversity (Smith and Fellowes, 2015; Ramer et al., 2019).

Urban spontaneous vegetation refers to the vegetation that grows naturally and spontaneously in urban sites (Li et al., 2019b). Normally, it was not intentionally planted and cultivated by humans (Cervelli et al., 2013) and was often referred to as "weeds," which are indicators of mess and are thus removed from parks and gardens (Li et al., 2019b). As people have begun to pay attention to sustainable alternatives to urban lawns, the spontaneous vegetation has been gradually noticed due to its obvious benefits including supporting biodiversity (Villasenor et al., 2020), increasing carbon sequestration and organic carbon content (Chamizo et al., 2017), restoration of the soil environment (Boechat et al., 2016), etc.

While the ecological superiority of spontaneous vegetation is evident, its acceptability as a lawn substitute among urban dwellers remains ambiguous. Studies in Sweden, Singapore and the United Kingdom showed city dwellers appreciated natural diverse grassland and wild flowerbeds over monotonous lawns (Ignatieva, 2017; Southon et al., 2017; Hwang et al., 2019). Yet still, the wild look of spontaneous vegetation is often regarded as messy, dangerous and brings about the thought of a place being abandoned (Hands and Brown, 2002; Lyytimäki et al., 2008), potentially deterring its adoption. Li et al. (2019b) found that Chinese residents favored short-cut lawns and traditional flowerbeds, while spontaneous vegetation with specific features was only preferred by people with more exposure to nature and higher levels of education, and who are gardeners, landscape architects, and professional students. Given the divergent findings across various studies and contexts, there is an imperative for systematic comparisons to derive meaningful conclusions for urban design.

The public's perception of lawns and spontaneous groundcovers may be the motivation of human preference and utilization of such. Yang et al. (2019b) found lawns were valued for their ecological and aesthetical values but least appreciated as important for recreational activities in Xi'an, China. The respondents in a similar study (Teixeira et al., 2022) realized the benefits of spontaneous plants in resisting climate change and enriching biodiversity, but also showed desire for some care and maintenance, which led to their preference for combinations of cultivated and spontaneous plants. Social background including gender, age, education level, occupation, living environment, income, and especially the possession of ecological knowledge, were also proved to have effects on urban ground cover perception and preference (Lindemann-Matthies et al., 2010; Jiang and Yuan, 2017; Fischer et al., 2018; Li et al., 2019a). Thus, to understand people's preference, it is necessary to analyze individual perceptions and social background factors.

A series of case studies have centered on developed areas such as Europe and North America, and highly urbanized cities in China like Beijing and Xi'an (e.g. Mathey et al., 2018; Li et al., 2019b; Yang et al., 2019b; Phillips and Lindquist, 2021). Many underdeveloped Chinese cities such as Xianyang with medium to low economic and education levels, have prominent contradictions between socio-economic growth and ecological conditions (Shi et al., 2020; Xiao et al., 2022), and therefore should also be considered. In addition, these cities are facing intense environmental changes including habitat fragmentation and the increase of non-native plants due to rapid urban expansion and large population growth (Zhao et al., 2010), with the additional burden of increasing recreational needs of urban residents at the same time. With these circumstances in mind, this study investigated people's perceptions and preferences regarding the common spontaneous groundcovers and lawns in Xianyang, China, and explored the social background factors that affect people's attitudes in order to inform urban design strategies. Since the definition of lawn in China has not been unified (Yang et al., 2019a) and usually includes other cultivated groundcovers, the lawn in this study mainly includes conventional short-cut lawn and a few common monoculture groundcover that artificially planted in the local area. The spontaneous groundcover refers to the low spontaneous plant community that can serve as a groundcover in green spaces. This study aims to address the following questions:

(1) How do the residents perceive spontaneous groundcovers and lawns?
(2) How do the residents like spontaneous groundcovers and lawns (what are their preferences)?
(3) What is the relationship between people's perceptions of and preferences for different ground covers?

(4) To what extent do people's social background factors affect perceptions of and preferences for different ground covers?

2. Materials and methods

2.1. Study site and ground cover selection

The study site was conducted in Xianyang city, China, characterized by a warm temperate zone in East Asia with a semi-humid and semi-arid continental monsoon climate. It is cold and dry in winter with temperatures dipping to around −6°C in January, and hot and rainy in summer, peaking at around 32°C in July. By 2020, the per capita GDP of Xianyang city was USD 7,665.75, below the national average of USD 10,000.80. Its urbanization rate (proportion of urban population to total population) was 55.44%, which is also lower than the national average of 63.89% (Xianyang Statistics Bureau, 2021). As in most Chinese cities, lawns in Xianyang became popular at the end of the 20th century and the beginning of the 21st century (Yang et al., 2019a). Largely due to the nation's garden city construction program and the region's climate constraints, the lawns (mostly cool-season lawns) covered a large area of urban green space.

A pre-investigation spanning 2019–2021 was conducted for ground cover selection, focusing on five types of urban green spaces (park, protective green space, plaza, attached green space, and regional green space) in Xianyang according to the latest national standard for classification of urban green space in China (CJJ/T85-2017) (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2018). Additional field surveys extended to surrounding rural areas, wastelands and Qinling mountain, a vital place of surrounding plant resources. The lawns appeared in all the five types of urban green spaces, and the spontaneous groundcovers were usually distributed in informal urban green spaces, abandoned grasslands, and urban-rural junctions. Consultations with local seedling companies and lawn experts further informed our selection. Finally, six kinds of spontaneous groundcover communities were selected which appeared frequently and grew stably, and seven kinds of lawns were also confirmed which were used most commonly in urban green spaces in the semi-humid and semi-arid climate zone (**Table 1**).

In order to avoid the participants' perceptions and preferences being influenced by varying contexts, all ground covers were planted in 39 planting units (2 m × 2 m each) on the study site with every kind of ground cover repeatedly planted in three units in May 2021. The lawns were constructed by turf or seedlings bought from the local nursery. The spontaneous groundcovers were transplanted from initial habitats, which were nearby vacant lands and abandoned lawns, to every unit (**Figure 1**). The underground part of the selected spontaneous groundcover communities was cut into squares with a length of 40 cm, a width of 20 cm and a depth of 30 cm, and transplanted and spliced in the sample units. All the spontaneous groundcovers were combinations of native and non-native plants. As for the lawns, the *Oxalis corymbosa* lawn and *Poa pratensis* lawn were both native plants, and the other lawns were composed of non-native plants.

2.2. Ground cover maintenance and observation

Proper maintenance is pivotal for both lawn and spontaneous ground covers to ensure health growth and prevent excessive flourishing in urban landscape. According to the watering principle adopted by Lilly et al. (2015), combined with the empirical value of local lawn watering quantity, a best practice method was chosen which was to irrigate every unit twice a week, 1.5 cm a time, including any natural rainfall. This method has been acknowledged in several studies (e.g. Taylor, 1998; Goatly, 2009). The spontaneous groundcovers were only watered when the blades were yellow or wilting, and the water amount was 3 cm each unit at a time.

In order to maintain adequate ornamental characteristics that are normal for ground covers and encourage them to grow well, the mowing height of spontaneous groundcovers and lawns was determined according to the experiences of local daily management coupled with the mowing method adopted by Lilly et al. (2015). The plots were checked weekly in the growing season and mowing was conducted once the vegetation attained a predetermined height. Spontaneous groundcovers were cut to 15 cm once they reached a height of 20 cm. The lawns were cut to different heights, based upon kind: T was cut to 12 cm at 18 cm; C was cut to 5 cm at 8 cm; FPL was cut to 10 cm at 15 cm and P was cut to 8 cm at 12 cm. Lawn kinds O and DH were not mowed because their heights did not exceed 8 cm across all growing seasons. Every 10 days, the seedlings of woody plants and lianas found in the experimental plots were removed to avoid their interference to the normal succession of the groundcover communities. During the experiment, some vines were found in the spontaneous communities, such as *Calystegia hederacea*, *Humulus scandens*, and *Cayratia japonica*, along with some woody seedlings such as *Ligustrum lucidum* and *Triadica sebifera*. For lawns, all plants except for the lawn itself were removed. All of the planting, management, and maintenance was completed by professional gardeners.

In order to understand the growth and development of the ground covers over time, the number of plant species in every ground cover community was observed and calculated, based on which the dominant species was also determined (**Table 2**). The species in the lawns were maintained as consistent with the original planting.

2.3. Photograph and questionnaire

In December 2021 and March 2022, three unaltered photographs of each kind of ground cover were taken. The first and second photographs were taken at a height of 1.5 m, from the parallel perspective and angulation perspective, respectively. The third photograph was taken at a height of 0.3 m, representing the details of the communities (**Figure 2**). Since the ground covers varied in spring, four detailed photos were taken to show the varying appearances of the communities and were then compiled into one photograph in March. The photographs were printed in high resolution at the size of 297 mm × 180 mm for use in subsequent interviews.

TABLE 1 Types of ground covers in the field.

Type	Kind	Abbreviation of name	Planting process
Spontaneous groundcover	*Trigonotis peduncularis – Cynodon dactylon – Bromus catharticus*	TCB	Transplanting
	Gueldenstaedtia verna – Cynodon dactylon – Cerastium glomeratum	GCC	Transplanting
	Medicago lupulina – Cynodon dactylon – Capsella bursa-pastoris	MCC	Transplanting
	Coronilla varia – Veronica persica – Cynodon dactylon	CVC	Transplanting
	Taraxacum mongolicum – Cynodon dactylon – Conyza canadensis	TCC	Transplanting
	Duchesnea indica	D	Transplanting
Lawn	*Cynodon dactylon* × *C. transvaalensis*	C	Turfing
	Poa pratensis	P	Turfing
	Oxalis corymbosa	O	Planting
	Festuca elata – Poa pratensis	FP	Turfing
	Festuca elata – Poa pratensis – Lolium perenne	FPL	Turfing
	Trifolium repens	T	Planting
	Dianthus deltoides × *hybrida*	DH	Planting

The groundcover names are displayed in order of dominant species.

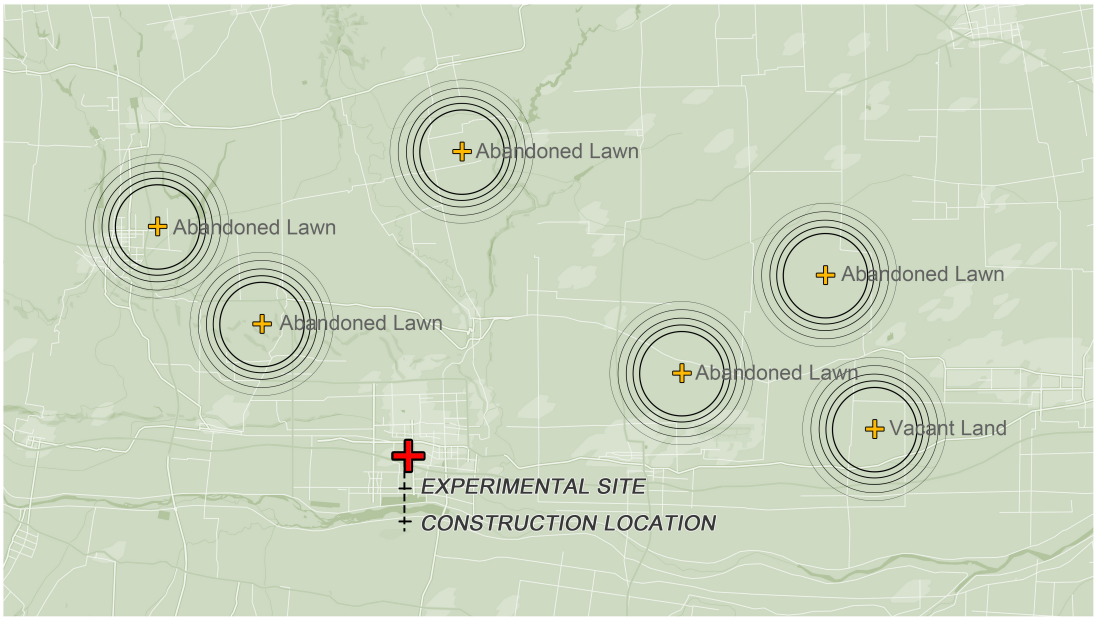

FIGURE 1
The distribution of initial habitats of the spontaneous groundcovers.

The questionnaire consisted of two parts. The first part focused on residents' perceptions of and preference for the ground covers showcased in the photos. Drawing from established literature on ground cover perceptions (Gyllin and Grahn, 2005; Ode et al., 2009; Brun et al., 2018), eight pairs of antithetical semantic attributes to evaluate the perceptions of ground covers were incorporated, including "artificial/natural," "domesticated/wild," "boring/interesting," "ugly/beautiful," "neglected/well kept," "monotonous/varied," "non-ecological/ecological," and "with few species/with rich species." Participants were asked to rate their perceptions and preferences using five-point Likert scales. For example, for attributes "artificial/natural", 1 = very artificial, 2 = a little artificial, 3 = neutral, 4 = a little natural, 5 = very natural. Preference was assessed through the question "How do you like these photos?" on a continuous five-point scale (1 = very dislike, 5 = very like). Participants were probed on the reasons behind the choices. The second part of the questionnaire contained the personal information of the participants, including gender, age, education level, occupation, monthly income, industry, living environment, and attention to herbaceous plants. Participants' attention to herbaceous plants were assessed through the question "Have you ever paid attention to the herbaceous plants around you in your everyday life?"

10.3389/fpsyg.2023.1259920

TABLE 2 The plant species in ground covers in winter and spring.

Type	Kind	Plant species in winter	Plant species in spring
Spontaneous groundcover	TCB	***Cynodon dactylon***, *Artemisia lavandulaefolia, Bromus japonicus, Geranium wilfordii, Ixeris polycephala, Veronica persica*	***Cynodon dactylon***, *Artemisia lavandulaefolia, Bromus japonicus, Veronica persica, Cerastium glomeratum, Trigonotis peduncularis, Capsella bursa-pastoris, Sonchus oleraceus, Sonchus asper*
	GCC	***Veronica persica***, *Cynodon dactylon, Artemisia lavandulaefolia, Gueldenstaedtia verna, Geranium wilfordii, Carex tristachya, Ixeris polycephala, Trifolium repens, Rumex acetosa, Taraxacum mongolicum*	***Cynodon dactylon***, *Artemisia lavandulaefolia, Veronica persica, Gueldenstaedtia verna, Trifolium repens, Cerastium glomeratum, Medicago lupulina, Taraxacum mongolicum, Rumex acetosa*
	MCC	***Cynodon dactylon***, *Ixeris polycephala, Veronica persica, Medicago lupulina, Sonchus oleraceus, Rumex acetosa, Oxalis corymbosa, Althaea rosea*	***Medicago lupulina***, *Capsella bursa-pastoris, Cynodon dactylon, Veronica persica, Sonchus oleraceus, Oxalis corymbosa, Rumex acetosa, Althaea rosea, Ixeris polycephala, Bromus japonicus, Stellaria media, Euphorbia helioscopia*
	CVC	***Coronilla varia***, *Veronica persica, Bromus japonicus*	***Veronica persica***, *Coronilla varia, Capsella bursa-pastoris, Sonchus asper, Bromus japonicus, Geranium wilfordii, Cerastium glomeratum*
	TCC	***Cynodon dactylon***, *Coronilla varia, Poa pratensis, Veronica persica, Duchesnea indica*	***Cynodon dactylon***, *Coronilla varia, Poa pratensis, Veronica persica, Capsella bursa-pastoris, Carex tristachya, Cerastium glomeratum, Ixeris polycephala, Lolium perenne, Viola philippica, Inula japonica, Oxalis corymbosa, Taraxacum mongolicum, Erigeron annuus*
	D	***Duchesnea indica***, *Inula japonica, Digitaria sanguinalis*	***Duchesnea indica***, *Inula japonica, Poa pratensis, Veronica persica, Euphorbia helioscopia*
Lawn	C	***Cynodon dactylon* × *C. transvaalensis***	***Cynodon dactylon* × *C. transvaalensis***
	P	***Poa pratensis***	***Poa pratensis***
	O	***Oxalis corymbosa***	***Oxalis corymbosa***
	FP	***Festuca elata***, *Poa pratensis*	***Festuca elata***, *Poa pratensis*
	FPL	***Festuca elata***, *Poa pratensis, Lolium perenne*	***Festuca elata***, *Poa pratensis, Lolium perenne*
	T	***Trifolium repens***	***Trifolium repens***
	DH	***Dianthus deltoides* × *hybrida***	***Dianthus deltoides* × *hybrida***

Bold words indicate dominant species.

2.4. Survey process

The surveys were conducted in Xianyang in December, 2021 and March, 2022. People in public outdoor spaces like parks, plazas, and roadsides were randomly invited to participate in the survey. Each participant was asked to look at the three photos of one kind of ground cover and complete the questionnaire. An initial total of 4,150 people were recruited for the survey and 12 were excluded due to incomplete questionnaires. Finally, a total of 4,138 participants were included.

2.5. Data analysis

All statistical analyses were carried out using SPSS 20.0 software. The two sample *T*-test and one-way ANOVA were used to explore the differences in residents' perceptions of and preferences for spontaneous ground covers and lawns, and the 13 kinds of ground covers. A principal component analysis (PCA) was executed to extract prominent factors for the semantic attributes of perception. A multiple linear regression analysis was conducted to explore the effects of perceptions on preferences. To explore the effects of social backgrounds on perceptions and preferences, a generalized liner model was used. The significant level used was 0.05 in this study.

3. Results

Out of all the participants, 1,858 (44.90%) were male. The age of participants was mostly distributed across the range of 18–40 (47.17%). Most participants (51.09%) held a bachelor's degree or other college degree. Students occupied the largest number across all occupations (29.89%), spanning primary to tertiary education levels. A considerable majority (78.64%) were not affiliated with industries related to agriculture, forestry, ecology, or landscape architecture, and quite a few participants (63.65%) said that they only paid attention to herbaceous plants occasionally in their lives (**Figure 3** and **Supplementary Table 1**).

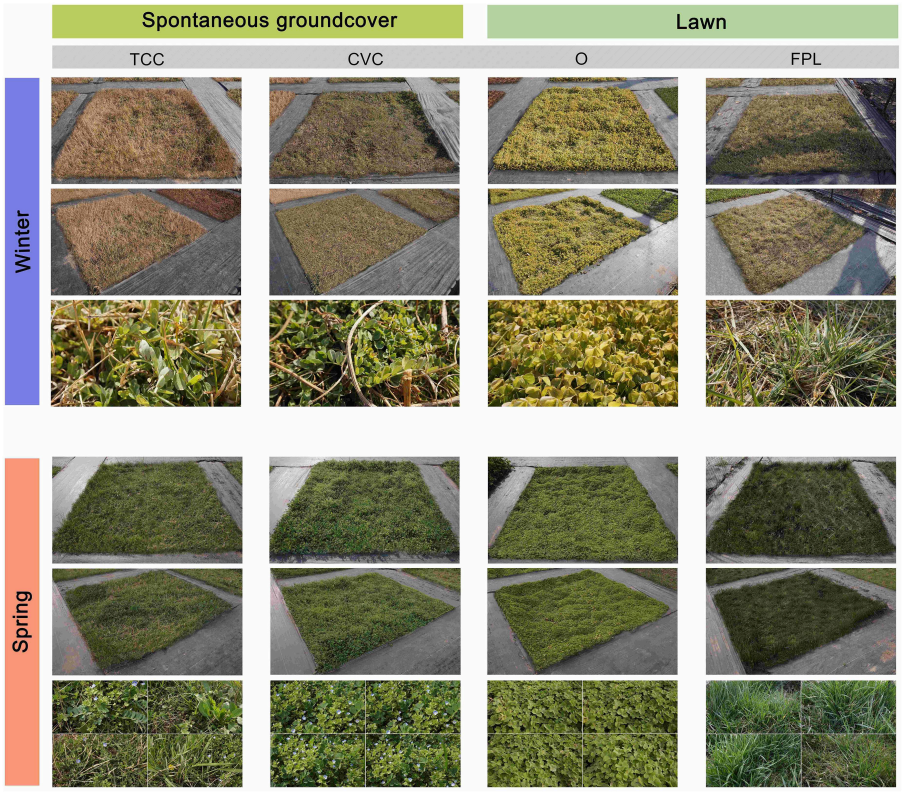

FIGURE 2
Examples of photo materials of ground covers taken from three angles.

3.1. Residents' perceptions of spontaneous groundcovers and lawns

Residents' perceptions of spontaneous groundcovers and lawns were found to have significant differences in five dimensions (Table 3): artificial/natural ($p < 0.01$), domesticated/wild ($p < 0.01$), neglected/well kept ($p < 0.01$), monotonous/varied ($p < 0.01$) and with few species/with rich species ($p < 0.01$). Spontaneous groundcovers were regarded as more natural, wild, varied, and species-richer than lawns, whereas lawns were viewed as better kept than spontaneous groundcovers. There was no significant difference in the categorizations of boring/interesting, ugly/beautiful, or non-ecological/ecological.

3.2. Residents' preferences for spontaneous groundcovers and lawns

The result of the one-way ANOVA indicated that residents' perceptions were significantly different among the 13 ground cover sites (Table 4). Spontaneous groundcover kind *T. mongolicum* – *C. dactylon* – *C. canadensis* (TCC) received the highest scores in almost all of the perception attributes (Figure 4). Kinds *O. corymbosa* (O) and *Trifolium repens* (T) also earned high scores among lawns in attributes except for domesticated/wild, monotonous/varied, and with few species/with rich species. FPL received fairly low scores in most attributes and MCC received lower scores than other spontaneous groundcovers except for perceptions of artificial/natural and domesticated/wild attributes. Generally, among all the attributes, people gave the highest scores to perceptions of non-ecological/ecological, followed by ugly/beautiful and boring/interesting, while the mean value of perceptions of monotonous/varied, with few species/with rich species, and domesticated/wild were much lower than other attributes (Figure 4).

The result of the *T*-test showed that there was no significant difference in residents' preferences between spontaneous groundcovers and lawns ($t = 0.616$, $p = 0.538$). The result of a one-way ANOVA showed that there was a significant difference in preferences among the 13 sites ($F = 3.217$, $p < 0.01$). TCC received the highest preference score, followed by GCC, O, T, P, C, DH, D, and TCB. Specifically, the score for TCC was significantly higher than those measured for CVC, MCC, FPL, and FP (Figure 5).

3.3. The relationship between perceptions of and preferences for ground covers

The results of the Kaiser–Meyer–Olkin test (KMO = 0.831) and Bartlett's Test of Sphericity ($p = 0.000$) showed that PCA could be used to extract prominent dimensions for the perception-related semantic attributes. The explained variance of each component is reported in Supplementary Table 2 and the first

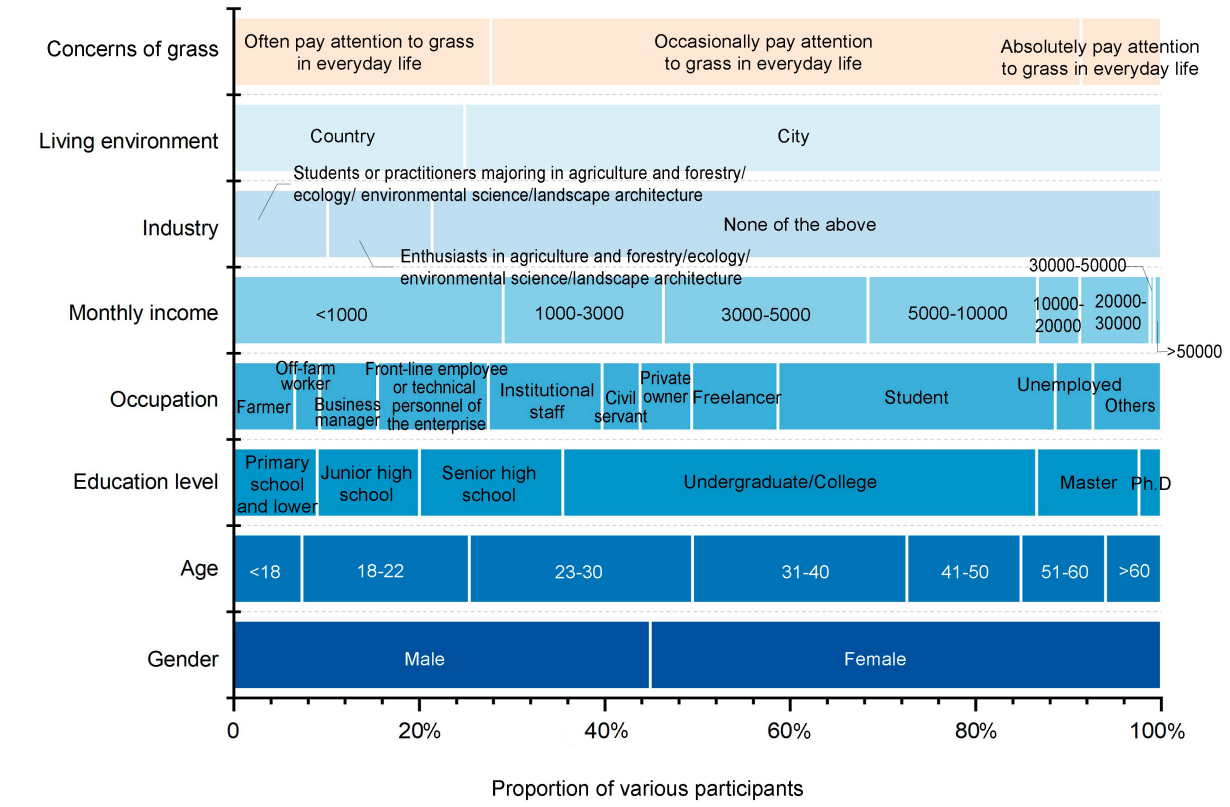

FIGURE 3
Social background characteristics of the participants.

TABLE 3 Perceptions of spontaneous groundcovers and lawns.

	F	*t*	df	Sig.
Artificial/natural	6.30	5.02	4,133.78	<**0.01**
Domesticated/wild	0.15	8.78	4,136.00	<**0.01**
Boring/interesting	4.98	−0.23	4,134.58	0.82
Ugly/beautiful	7.02	−1.89	4,135.99	0.06
Neglected/well kept	0.15	−6.80	4,136.00	**0.01**
Monotonous/varied	0.28	2.58	4,136.00	**0.01**
Non-ecological/ecological	5.35	0.05	4,135.30	0.96
With few species/with rich species	2.45	6.91	4,136.00	<**0.01**

Bold type indicates significant differences.

TABLE 4 The effects of the groundcover types on eight perception attributes through one-way ANOVA.

Attributes	Sum of squares	Mean square	*F*	Sig.
Artificial/natural	145.890	12.158	6.759	**0.000**
Domesticated/wild	176.187	14.682	9.270	**0.000**
Boring/interesting	65.773	5.481	4.144	**0.000**
Ugly/beautiful	105.163	8.764	7.305	**0.000**
Neglected/well kept	274.845	22.904	16.152	**0.000**
Monotonous/varied	90.808	7.567	4.923	**0.000**
Non-ecological/ecological	54.605	4.550	4.247	**0.000**
With few species/with rich species	196.984	16.145	10.105	**0.000**

Bold values indicate significant differences.

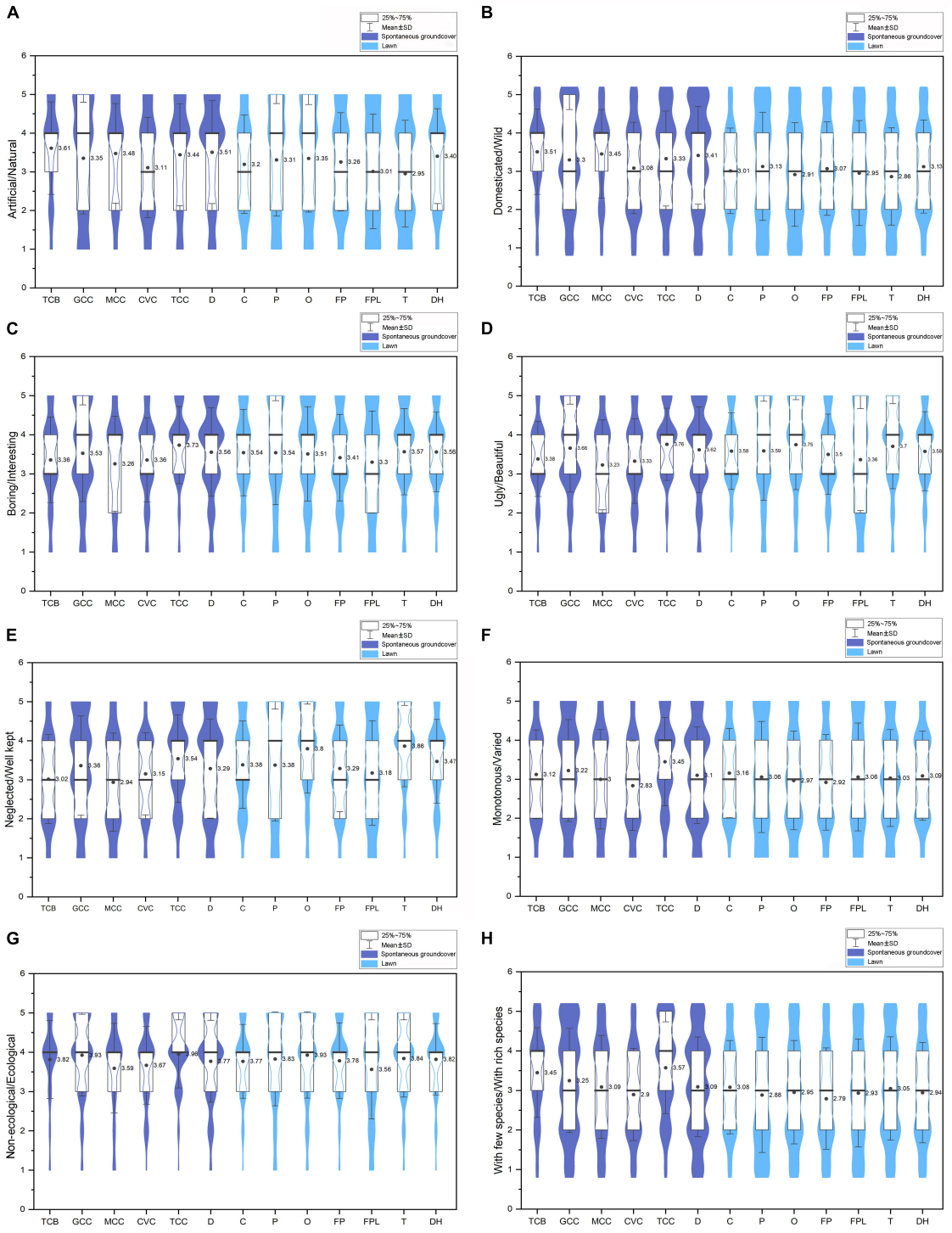

FIGURE 4
Perceptions of 13 ground covers about eight attributes. **(A)** artificial/natural, **(B)** domestic/wild, **(C)** boring/interesting, **(D)** ugly/beautiful, **(E)** neglected/well kept, **(F)** monotonous/varied, **(G)** non-ecological/ecological, and **(H)** with few species/with rich species.

two components were retained, with total explanatory power of 60.942%. Component 1 exhibited 41.106% explanatory power and included "boring/interesting," "ugly/beautiful," "monotonous/varied," "non-ecological/ecological," "with few species/with rich species," and "neglected/well kept," and was therefore labeled ecological aesthetics. Component 2 exhibited 19.837% explanatory power and included "artificial/natural" and "domesticated/wild," and was therefore labeled wildness (Figure 6).

Of the two components used in the multiple linear regression, the results showed that perception on ecological aesthetics had a significant positive effect on preference and the effect was relatively strong (p = 0.000, B = 0.679). The perception on wildness had a

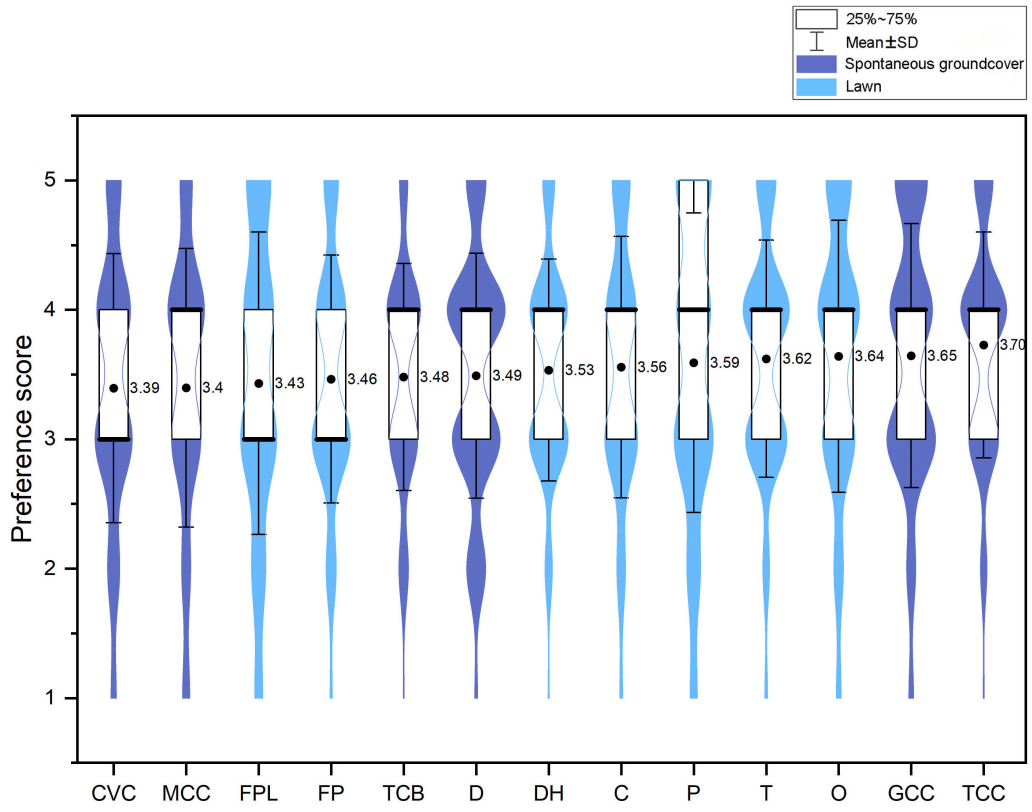

FIGURE 5
Preference scores for 13 ground covers. Groups with different letters were significantly different.

significant negative effect, although the effect was weak ($p = 0.000$, $B = -0.115$) (Table 5).

3.4. The effect of social background on perceptions of and preferences for ground covers

The results of the generalized liner model showed that education level, industry and attention to herbaceous plants had significant effects on ecological aesthetics, while gender, age, occupation, monthly income, and living environment had no significant effect (Table 6). People who had obtained a master's degree, who had engaged in ecology-related industries and those who hardly paid attention to herbaceous plants in daily life tended to appreciate less ecological aesthetics (Supplementary Table 3). Gender, age, occupation, industry, and attention to herbaceous plants had significant effects on perceived wildness, while education level, monthly income, and living environment had no significant effect (Table 6). Women, people under 18 years old and farmers perceived a significantly higher degree of wildness than other participant groups in general. Men, the elderly, enthusiasts about ecology and people who often paid attention to herbaceous plants showed lower perceptions of wildness (Supplementary Table 4).

As for preference for ground covers, gender, age, education level, occupation, industry, and attention to herbaceous plants had significant effects on preference, while monthly income and living environment had no significant effect (Table 6). People with senior high school education, those engaged in other occupations (mostly housewives), and participants who often paid attention to herbaceous plants showed significantly higher preferences. People with junior high school education or with a master's degree, off-farm workers, unemployed participants, students, and practitioners majoring in agriculture and forestry/ecology/environmental science/landscape architecture and people who never paid attention to herbaceous plants were found to have significantly lower preferences than others (Figure 7 and Supplementary Table 5).

4. Discussion

4.1. How do the residents perceive spontaneous groundcovers and lawns?

Compared to lawns, the participants discerned spontaneous groundcovers as more natural, wilder, more neglected, more varied and with richer species, indicating residents' perceptions were in correspondence with reality. Given the pervasive presence of urban short-cut lawns throughout the region, residents are well-acquainted with them and can readily differentiate them from spontaneous groundcovers based on their wild appearance and maintenance standards, especially lawns which were trimmed neatly and mainly composed of grasses.

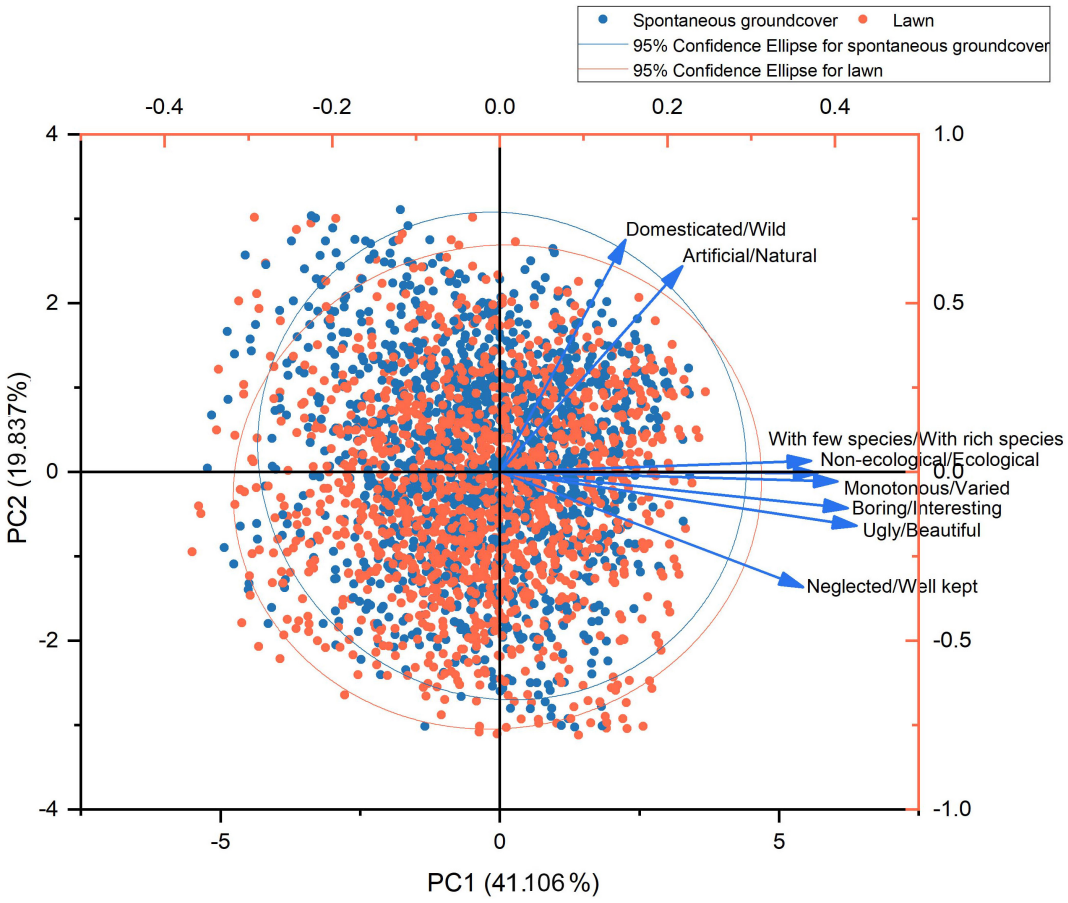

FIGURE 6
The variance of eight pairs of attributes explained by component 1 and component 2 through PCA.

TABLE 5 The effects of perceptions on preferences for ground cover through multiple linear regression.

Model	*B*	SE	*t*	Sig.	Tolerance	VIF
(Constant)	3.543	0.011	313.963	0.000		
Ecological aesthetics	0.679	0.011	60.133	**0.000**	1.000	1.000
Wildness	−0.115	0.011	−10.222	**0.000**	1.000	1.000

Bold type indicates significant differences (adjusted R^2 = 0.473).

Interestingly, there were no significant differences in terms of the aesthetic feature, attraction, and ecological traits between the two types of ground covers. Although there is evidence that higher naturalness contributes to higher aesthetic values in urban green spaces (Ode Sang et al., 2016), excessive wildness and messy appearances of ground covers will also reduce aesthetic perceptions. Prior studies have showed the aesthetic appreciation was related to vegetation structure (Wang et al., 2017) and colors (Hoyle et al., 2018) in urban green spaces. In this study, given that the showcased ground covers are local, possess homogenous structures, and lack pronounced color differences, the ground covers seemed to be aesthetically similar.

Participants' perceptions of the ecology feature were also much the same, with the ecology feature receiving the highest scores across perception metrics. During the survey, most people thought that compared with the built area, all plants inherently bolster the environment, thus classifying them as "ecological." Clergeau et al. (2001) found that the city residents often lacked the experience and skills necessary to identify plants and appreciate biodiversity. Therefore, they tended to think the ground covers were ecologically beneficial without distinguish their differences.

4.2. How do the residents like spontaneous groundcovers and lawns (what are their preferences)?

Participants exhibited comparable preferences for both spontaneous groundcovers and traditional lawns, which shows that people's acceptance of native ground cover parallels that of lawn. After the housing reform and the "National Garden City" program in the 1990s, the 2008 Beijing Olympic Games

TABLE 6 The effects of social background on perceptions of and preference for ground covers through a generalized linear model.

Origin	Ecological aesthetics			Wildness			Preference		
	Wald χ^2	df	Sig.	Wald χ^2	df	Sig.	Wald χ^2	df	Sig.
(Intercept)	4.303	1	0.038	2.291	1	0.130	4415.419	1	0.000
Gender	0.023	1	0.879	16.203	1	**0.000**	6.523	1	**0.011**
Age	10.663	6	0.099	19.503	6	**0.003**	12.924	7	**0.044**
Education level	11.372	5	**0.044**	7.365	5	0.195	17.333	5	**0.004**
Occupation	16.786	10	0.079	22.670	10	**0.012**	18.361	10	**0.049**
Monthly income	7.111	7	0.417	11.115	7	0.134	9.984	7	0.190
Industry	11.695	2	**0.003**	6.520	2	**0.038**	17.541	2	**0.000**
Living environment	0.248	1	0.619	0.867	1	0.352	0.189	1	0.664
Attention to herbaceous plants	124.273	2	**0.000**	9.302	2	**0.010**	133.409	2	**0.000**
Ground cover kind	83.436	12	**0.000**	182.092	12	**0.000**	37.767	12	**0.000**

Bold type indicates significant differences.

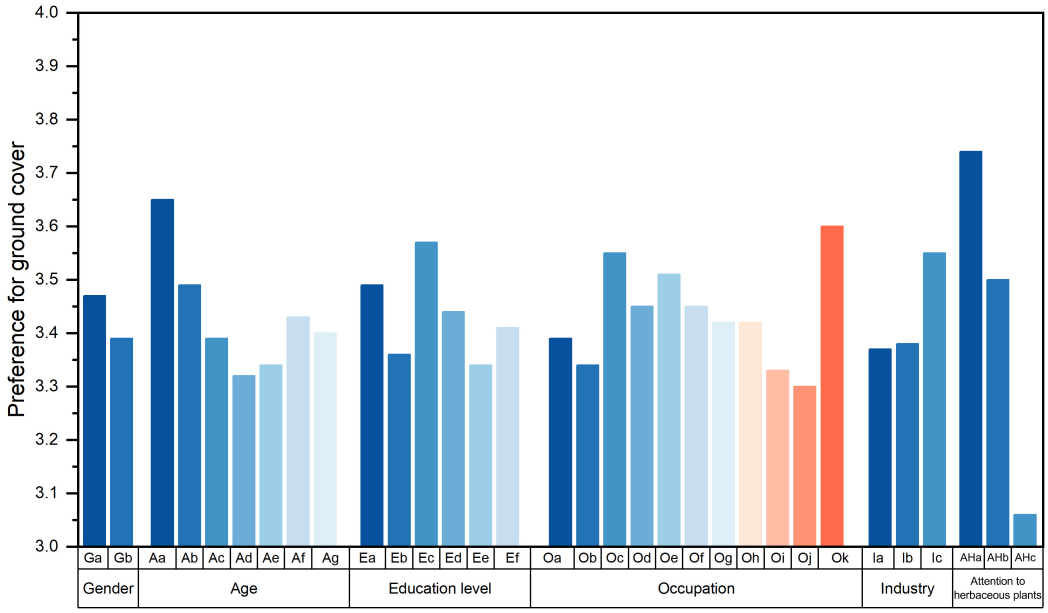

FIGURE 7
Participants' preferences with different social backgrounds. Only social backgrounds with significant differences are shown. Detailed information concerning the model can be seen in **Supplementary Table 5**. The variables represented by the letters are: Ga – male, Gb – female; Aa – below 18, Ab – 18~22, Ac – 23~30, Ad – 31~40, Ae – 41~50, Af – 51~60, Ag – over 60; Ea – primary school and lower, Eb – junior high school, Ec – senior high school, Ed – undergraduate/college, Ee – master, Ef – Ph.D.; Oa – farmer, Ob – off-farm worker, Oc – business manager, Od – front-line employee or technical personnel of the enterprise, Oe – institutional staff, Of – civil servant, Og – private owner, Oh – freelancer, Oi – student, Oj – unemployed, Ok – others; Ia – students or practitioners majoring in agriculture and forestry/ecology/environmental science/landscape architecture, Ib – enthusiasts in agriculture and forestry/ecology/environmental science/landscape architecture, Ic – none of the above; Aha – often pays attention to herbaceous plants in everyday life, Ahb – occasionally pays attention to herbaceous plants in everyday life, Ahc – absolutely pays attention to herbaceous plants in everyday life.

and other construction projects, the residential areas and urban public green spaces in China were quickly covered by lawns. These lawns, while offering rapid urban greening, also symbolize a western lifestyle, which, given China's economic trajectory at the time, held significant appeal (Yang et al., 2019a). However, as urbanization has proliferated, the once-unique allure of lawns has waned, replaced by an increasing societal inclination toward natural settings. Research in China has underscored a preference for natural grasslands over traditional manicured lawns (Jiang and Yuan, 2017), and the intrinsic value of spontaneous vegetation has gained recognition among professionals (Li et al., 2019b; Yang et al., 2019b). Given the economic and urbanization level of Xianyang, which sit below the national averages, there may be no obvious difference in residents' preference for spontaneous groundcovers and lawns. However, as the city evolves, the widespread adoption of lawns may not align with evolving resident

needs, positioning spontaneous groundcovers as a potentially popular alternative.

The most popular spontaneous groundcover was the *T. mongolicum* – *C. dactylon* – *C. canadensis* community, which received the highest perceptions across almost all the attributes. Oppositely, the spontaneous groundcovers *Coronilla varia* – *Veronica persica* – *C. dactylon* and *Medicago lupulina* – *C. dactylon* – *Capsella bursa-pastoris*, and the lawns *Festuca elata* – *P. pratensis* – *Lolium perenne* and *F. elata* – *P. pratensis* received the lowest preferences and also earned relatively lower perceptions across most attributes. These findings mean the preference for ground cover type is not absolute and instead is related to the performance of specific communities. Spontaneous groundcover kind TCC was composed of richer species and was perceived as being ecological, natural, beautiful and well kept, while kinds CVC and MCC, also spontaneous groundcovers, contained fewer species and were perceived as being more neglected, monotonous, ugly and boring. The differences among the spontaneous groundcovers led to the differences in terms of coherence and complexity of landscape. In Kaplan and Kaplan's (1989) landscape preference matrix, the term coherence represents an orderly and organized setting with limited and repeating themes, and complexity represents the richness of a setting. Kuper (2017) found that landscape preference did correlate with evaluations of complexity. There were abundant species with different morphological features (e.g., leaf shape, flower shape, and color) in TCC in spring (**Figure 2**), with the highest score measured in species richness perception. Species diversity also proved to be related to human preference (Lindemann-Matthies et al., 2010; Southon et al., 2017). By contrast, FPL and FP, both composed of grass, showed highly homogeneous looks and low complexity, and thus were disliked.

Although there were also many plant species found in kinds CVC and MCC, the plant morphology found within them showed a bad order, especially in winter. For instance, the leaves of *C. varia*, the dominant species of CVC, fall off in winter, leaving messy yellow stems (**Figure 2**). Zhang et al. (2021) reported people prefer a landscape with high richness when the landscape keeps a good sense of order, which is one aspect of coherence. In addition, order to some extent represents "being cared for" in landscapes, and thus is perceived in landscapes which are valued (Nassauer, 2011).

Generally, results indicate that the spontaneous groundcovers have the potential to replace or even surpass the lawns in respect to gaining people's appreciation due to the richness of their components, but the groundcover kind should be selected cautiously to exhibit good order. These findings provide solid evidence in favor of rewilding practices. Rewilding, which originated in Germany and was primarily focused on wilderness areas like national parks and nature reserves, has since evolved into a new technique for ecological restoration that aims to minimize human intervention, emphasize the importance of natural restoration in the process and mechanism of ecosystem self-maintenance and self-regulation, place a strong emphasis on extensive native species restoration, appropriately reintroduce key species of ecosystems, and restore ecosystem function (Lorimer et al., 2015; Kowarik, 2018). As products and important tools in the process of rewilding, the spontaneous plants have evolved into a practical design strategy that enhances urban landscapes (Kühn, 2006), used in worldwide projects like Jiang Yang Fan Eco-Park in China, Landscape Park Duisburg-Nord in Germany, Carl-Alexander Park in the United States, and High Line Park in New York.

4.3. What is the relationship between people's perceptions of and preferences for different ground covers?

The results indicate that people tended to prefer ecological, good-looking, and less wild ground covers. The term "ecology" resonated positively among participants, often being equated with environmental benefits. As such, there was a discernible inclination toward ground covers perceived as ecologically vibrant and species-rich.

Yet, people still attached importance to the aesthetic value, which is not always consistent with ecological quality (Gobster et al., 2007). Although people showed great interest in approaching more natural and biologically rich environments (Carrus et al., 2015; Hwang et al., 2019), they value the order and neatness over pure wildness. Wildness often conjures images of disorder, potentially invoking feelings of unease or perceived danger (Nassauer, 1995; Mathey et al., 2018; Li et al., 2019b). Therefore, the positive ecological aesthetic preference can be seen as an expectation for urban ground covers but not reflective of the reality for the quality of ground covers. In order to maintain adequate ecological and aesthetical values and avoid wildness, the application of the spontaneous groundcover requires the introduction of human stewardship, which was termed as "cues to care" (Nassauer, 1995, 2011), into daily management. Moreover, enhanced ecological knowledge might change the public's response to the groundcovers (Gobster et al., 2007) and should be introduced more to help glean greater information about ground cover preference.

In general, the preference for ground covers is a composite reflection of considering various perceptions of attributes which results in the balance of ecological and aesthetic values. The results imply that ground cover, with no distinction for lawns or spontaneous groundcovers, with attractive appeal, better ecological functions and a touch of human stewardship, should be adopted in urban green spaces.

4.4. To what extent did people's social background factors affect perceptions of and preferences for different ground covers?

Professional experience and attention to herbaceous plants emerged as significant determinants of ground cover perceptions among the demographic characteristics. Previous studies in multi-scales showed that differences appeared in how green experts vs. laymen assess urban greenery (Muratet et al., 2015; Fischer et al., 2018). The results of the present study indicated that people who were engaged in ecology-related industries tended to appreciate less ecological aesthetics, but still showed a higher preference for them. Li et al. (2019b) reported that professionals could better recognize and preferred the value of spontaneous vegetation than traditional

plantings. In this study, due to the experimental design that each participant only assessed one kind of ground cover, the ground cover seemed to be identified as less functional and less aesthetically pleasing, because diverse plant communities containing rich plant diversity and diverse vegetation structures are generally preferred (Qiu et al., 2013; Giergiczny et al., 2015; Gao et al., 2019). The results also showed that ecology enthusiasts showed lower perceptions of wilderness. Chances are that these people have enough knowledge and experience in observing nature and plants, but are short of professional knowledge, leading to their tolerance to wilder groundcovers but low consciousness of wilderness. Nevertheless, the present study expands existing knowledge in the comparison between experts and laymen, showing the similar preference results as found in previous studies, but revealing differences in perception under a pure single evaluation.

It has been shown that when residents have stronger ties to nature, they value plant species richness more (Lindemann-Matthies and Bose, 2007). In this study, people who usually paid attention to herbaceous plants in daily life recognized higher ecological aesthetics and wildness value, and also held higher preferences for them. Results of the questionnaire indicated this group was easily pleased with all kinds of ground covers, because they provided greenery and increased the chances for people to get close to nature, no matter which kinds they were.

Gender, age, education level and occupation were all significantly related to one of the two perception dimensions and preference. Gender was usually thought to influence safety (Jansson et al., 2013), and women potentially seek more security, use less green space (Jim and Shan, 2013; Liu et al., 2022) and may feel a greater sense of wildness and less safety than men when faced with the same ground cover type. In addition, the elderly population was thought to care less about security which may originate from their childhood experiences – in the early years when urbanization was not yet developed, their childhood had more contact with nature (Jim and Shan, 2013). Thus, the elderly population may have felt less wild than participants of other age groups, especially teenagers under 18 who mainly rely on urban parks for exposure to nature. As opposed to previous reports that people who are better educated preferred natural landscape such as spontaneous vegetation (Zheng et al., 2011), the participants who had obtained a master's degree perceived a lower ecological aesthetic value and showed lower preferences, as well as participants with junior high school education. Furthermore, people engaged in other occupations (mostly housewives looking after children) showed a higher preference. These results implied people with higher education levels may occupy higher demands for ground covers in ecology and aesthetic attributes, while "average," or ordinary people find it easier to meet their personal requirements for ground covers. Thus, in order to approve the utilization of spontaneous groundcover in urban green spaces, it is necessary to reflect the ecological aesthetic value of the spontaneous groundcover for highly educated residents and professionals, and to provide enough exposure opportunities for ordinary, or "average," people.

While monthly income and living environments did not exhibit significant influence on ground cover perceptions in our study, previous studies showed that higher economic status may contribute to the priority to obtain more social space due to their higher private car ownership rate (Zhang et al., 2019; Tao et al., 2020), which then results in a difference in green space use pattern and perception. In this study, since Xianyang is a city with a moderate economic level, the green spaces there were distributed fairly homogeneously. Thus, the inhabitants with different incomes do not obtain green spaces with extreme differences.

Living environment was demonstrated not to affect preference for vegetated landscape (Wang and Zhao, 2017). The increase of population mobility between urban and rural areas and the homogenization of urban and rural landscape can be seen to promote the familiarity and perception of people in different living environments concerning spontaneous groundcovers and lawns.

4.5. Limitations and further study recommendations

Even though different ground covers were selected in winter and spring to show the most obvious seasonal appearance of ground covers, it may not have been enough for participants to recognize them. Evidences have proved that preference is significantly related to seasonality (Southon et al., 2017; Xiang et al., 2021). To glean a more comprehensive understanding of perceptions and preferences, future research should contemplate evaluating ground covers across all seasons.

Considering that only photographs of quadrats sized 2 m × 2 m were used in the questionnaire survey, it may have been a challenge for the participants to experience the actual ground covers. Although the context was controlled in the experimental photos, more technology (like virtual reality) could be used to assist in building the same and living contexts, in order to better explore humans' attitudes toward ground covers.

5. Conclusion

Due to the limitations of urban lawns, it is of great importance to explore the possibility of sustainable and enjoyable lawn alternatives. This study compared the perceptions and preferences concerning urban lawns and spontaneous ground covers and found there were no differences in preferences for the two types of ground cover. The *T. mongolicum* – *C. dactylon* – *C. canadensis* community was significantly preferred most among the 13 communities. Participants perceived spontaneous groundcovers as more natural, wild, varied, and species-richer compared to conventional lawns, while lawns were better kept than spontaneous ground covers. Industry and the degree of attention to herbaceous plants mostly affected the perception and preference among the social background factors measured. Gender, age, occupation, and education level also affected one of the perception dimensions and preference, whereas monthly income and living environment did not exert notable effects.

The results provide valuable insights for groundcover selection from the perspective of the acceptance of residents, showing that spontaneous groundcover has the potential to become a substitute for urban lawn usage in an undeveloped city but the type should be considered carefully. For landscape

design in Xianyang, the community with dominant species *T. mongolicum*, *C. dactylon*, and *C. canadensis* is particularly recommended in ground cover application. Landscape architects should strategically guide plant succession to foster communities enriched with these dominant species and diverse flora, enhancing their ecological and aesthetic appeal to residents. At the same time, people preferred ground covers with greater aesthetic and ecology values but less characteristics of wildness, indicating the spontaneous groundcover can be used in spaces loose in maintenance requirements.

Data availability statement

The original contributions presented in this study are included in this article/**Supplementary material**, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving humans were approved by the Ethics Committee of the College of Landscape Architecture and Arts, Northwest A&F University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

HL: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing — original draft. CL: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing — original draft. DX: Conceptualization, Data curation, Investigation, Writing — original draft. JL: Conceptualization, Data curation, Investigation, Writing — original draft. KJ: Conceptualization, Data curation, Investigation, Writing — original draft. YW: Conceptualization, Data curation, Investigation, Writing — original draft. DG: Conceptualization, Data curation, Investigation, Writing — original draft. YC: Conceptualization, Data curation, Investigation, Writing — original draft. YL: Conceptualization, Project administration, Supervision, Writing — original draft. LQ: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Writing — review and editing. TG: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Writing — review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1259920/full#supplementary-material

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Non-depleting energy in the museum

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The present study aimed to uncover whether the renewable energy education carried out in a museum has an impact on awareness of renewable energy and the environment among children and their parents. The study was carried out with two groups of 65 children aged 6 years and their parents ($n = 47$). The findings revealed significant differences between the pretest and posttest in favor of the pretest and between pretest and follow-up test in favor of follow-up test, but there was no significant difference between posttest and follow-up test. We determined It was observed that the children had a considerable willingness to participate in the sessions and used the names of renewable energy sources in their follow-up drawings or their remarks on the drawings. Moreover, given the parents' statements, we discovered that the children acquired considerable awareness of the environment and efficient energy consumption and became acting more consciously toward renewable energy sources.

KEYWORDS

early childhood, renewable energy sources, museum education, environment, family

Introduction

Energy may be a noteworthy starting point for achieving the objectives of environmental protection, one of the three fundamental components of sustainable development (Öymen, 2020). Due to being both complex and broad, sustainability has several goals to achieve. Increasing the demand for renewable energy, reducing carbon intensity, and ensuring green growth may be the most striking among these goals (Lu et al., 2023). The aim of promoting educational principles and priorities behind sustainable development and a better and multifaceted understanding of the problems in our increasingly global world needs to be embedded in education systems (Ocetkiewicz et al., 2017). In this respect, despite being a necessary means for the functioning of technological tools and one's survival, wasting energy and insufficient environmental awareness have adversely affected habitats and sustainability in nature (Çukurçayır and Sağır, 2008; Korkmaz and Develi, 2012; Çetin et al., 2016; Esen and Esen, 2018). Therefore, regular and conscious use of renewable energy sources is considered essential, particularly for humans, to alleviate such adverse impacts (Karabağ et al., 2021).

In general, environmentally friendly energy sources come to mind regarding renewable energy. In general, renewable energy is associated with environmentally friendly energy sources.

These sources already exist in nature; in other words, no harm is brought to nature when used. The energy generated from such sources interestingly meets contemporary needs to a great extent and can be recycled again (Koç and Kaya, 2015), which emphasizes the importance of consciously benefitting renewable energy sources (e.g., solar, wind, hydropower, geothermal, and biomass) (Karagöl and Kavaz, 2017). These sources are more or less available in every geographical region and seem totally nature friendly. Although Türkiye is geographically rich in renewable energy sources (Yılmaz, 2012), it is prudent to claim that social awareness of these sources has not yet been established. Similarly, the previous research highlights limited national and global awareness of the importance of renewable energy sources and how they are found and utilized (Tortop, 2012; Bilen et al., 2013; Saraç and Bedir, 2014; Çolak et al., 2015; Keramitsoglou et al., 2016; Cebesoy and Karışan, 2017; Çelikler et al., 2017; Cirit, 2017; Eren et al., 2017; Ali et al., 2019; Karaeva et al., 2019; Wojuola and Alant, 2019; Yıldırım et al., 2019; Ilias et al., 2020; Özyurt and Yalman, 2020; Szakaly et al., 2021). Hence, it may be claimed that awareness-raising activities on renewable energy sources should be provided from early childhood to contribute to awareness of renewable energy and protect nature.

Early childhood can be conceived of as invaluable years of human life. As a matter of fact, all kinds of habits to be taught to children in this period would also contribute to their personality traits and maintaining what they have acquired as a lifelong habit (Aral et al., 2002; Karaca et al., 2011; Ihmediah and Oliemat, 2015). Yet, despite being keen on learning, the children in this period may also need to have concrete experiences and "learning by doing" to successfully interpret and rely on their learning (Andiema, 2016; Ülker Erdem et al., 2017; Yıldırım and Özyılmaz Akmaca, 2017). In this sense, museums have recently attracted attention as educational environments where children can learn by doing. In museums, children not only have the opportunity to learn through their own experiences but also internalize what they have learned and turn it into behaviors and attitudes (Lopez Alcarria et al., 2014; Akman et al., 2015; Akgün et al., 2017; Guardino et al., 2019). The previous research also confirmed this idea and suggested that children would make the knowledge acquired through museum visits permanent (Dağal and Bayındır, 2016; Rönkkö et al., 2016; Aktın, 2017; Karakaş and Eğitmen, 2017; Dilli et al., 2018; Gong et al., 2020). In this context, it may be more convenient to introduce the abstract concept of renewable energy to children in early childhood in a practical and joyful way in a museum setting. Yet, the literature hosts a limited number of studies on teaching renewable energy to children in a natural environment in early childhood. Among these studies, Ardoin and Bowers (2020) carried out research to introduce renewable energy sources to children in forest schools and suggested that children in early childhood would develop an awareness of the sun, water, and renewable energy in natural environments. At the same time, they emphasized that children would develop environmental awareness thanks to such by the help of/via activities. In Türkiye, Dilli et al. (2018) carried out a study to introduce renewable energy sources to children aged 6 years in a museum setting and concluded that the participating children developed an awareness of renewable energy sources and the conscious use of the environment.

Parents are known to be an integral part of supporting positive developments in children in early childhood. The behaviors of parents, their children's utmost role models in early childhood, occupy a substantial place in forming and developing their children's habits and attitudes. Since children learn by observing their parents' behaviors, offering programs about learning in early childhood to families is considered to be important (Ekinci-Vural and Kocabaş, 2016; Hayakawa et al., 2016; Kınık et al., 2016; Özel and Zelyurt, 2016; Boz et al., 2018; Marti et al., 2018; Puccioni et al., 2020). However, the relevant literature seems to have missed education/programs on renewable energy sources for parents, which, in turn, contributes to the importance of increasing social awareness of renewable energy sources. Given these considerations, the present study attempted to reveal whether the renewable energy education carried out in a museum and parent-oriented training have an impact on awareness of renewable energy and attitudes toward the environment among (six-year-old) children and their parents.

Methods

Research design and participants

We carried out this mixed-design research with children aged between 60 and 72 months, attending kindergartens and daycare centers affiliated with Mamak and Altindag municipalities, and their parents. We resorted to the opinions of teachers and administrators who knew the potential participants very well and selected the sample considering the criteria of students' socioeconomic status (SES), special needs status, how long they had been enrolled in preschool education, and previous visits to the museum where the project would be implemented. Accordingly, we recruited a total of 112 participants in the study: 65 socio-culturally disadvantaged preschool children (35 girls, 30 boys) without any health problems who had been attending preschool education for at least 6 months and had not visited the museum before and 47 parents providing their informed consent to participate in the study with their children.

Data collection tools

In the quantitative phase of the research, we utilized the "**Children's Attitude toward the Environment Scale: Preschool Version (CATES-PV)**" to reveal the participating children's attitudes toward the environment before and after the implementation of renewable energy-related activities. Moreover, we readministered the instrument 3 weeks after the implementation to determine any changes to their attitudes. The **CATES-PV** was developed by Musser and Diamond (1999)and adapted into Turkish by Gülay (2011). The scale consists of 15 items and is scored on a four-point Likert-type scale. One may obtain 60 as the highest score and 15 last the lowest score on the scale, and higher scores indicate a higher attitude toward the environment.

In the qualitative phase of the research, we deployed the "drawing," "observation," "portfolio," "diary keeping," and "photograph taking" techniques to uncover the children's achievements in renewable energy. In addition, we recruited the participating parents for face-to-face interviews (a semi-structured interview form) before and after implementing the renewable energy-related activities to reveal the impacts of learning about renewable energy on their children's lives. The form inquires the parents about environmental education, the way

they use energy sources in everyday life, their children's attitudes toward the environment, renewable energy sources, and the children's knowledge of renewable energy sources. The form was finalized relying on the suggestion of field experts (two child development specialists, two preschool education specialists, and one measurement and evaluation specialist).

In the study, we designed renewable energy-oriented activities as educational events to be implemented for five full days (10.00–14.30). The training for parents was planned in three sessions, two face-to-face and one online. While preparing the mentioned educational activities and training, we considered the relevant literature and achievements and indicators in the Ministry of National Education (MoNE) 2013 Preschool Curriculum. The project team often rallied together online or face to face during the study and reviewed/updated the activities prepared for the parents and children when needed. Activities and parent training sessions were first submitted to expert opinion (specialists in child development, preschool education, parent education, energy, and curriculum and instruction) and then finalized in line with their views. We included games, language skills, STEM, and drama activities and experiments in the educational activities and utilized different methods and techniques to ensure the active participation of the children. Parent training also covered educational activities, lecturing, discussions, and demonstrations that allowed the parents' active engagement.

Procedure

The Scientific Research and Publication Ethics Committee of Tarsus University granted ethical approval to our study (2021/33 dated 07.28.2021). Next, we held online meetings with all team members to design the project logo and launch the website where project details and announcements would be posted. Next, we opened Twitter and Instagram accounts for the projects and shared them on the website. Then, we engaged in arrangements and took measures to prevent the distraction of the children in the project site - the General Directorate of Mineral Research and Exploration, Sehit Mehmet Alan Energy Museum.

The mission of the Sehit Mehmet Alan Energy Museum, affiliated with the MTA general directorate, is to contribute to the welfare of the country by producing knowledge in the field of earth sciences. In this regard, it is the first energy museum that introduces natural energy resources such as water, sun and wind, as well as mineral assets and helps understand their use in daily life. The exhibition areas in the energy museum include sections of renewable energy sources (wind, solar, geothermal and hydroelectric energy stands) as well as mining stands (boron, coal, etc.).

In line with the cooperation with Mamak and Altindag municipalities, we set a series of meetings with administrators and teachers through the municipality officials responsible for the nurseries and daycare centers affiliated with the municipalities. We informed the administrators and teachers about our research, obtained their verbal permission to reach the parents, and carried out some preliminary activities with children upon their parents' written consent. Then, we took pretest measurements from the children with the CATES-PV on May 16–20, 2022 and conducted face-to-face interviews with the parents on the days of the first training session (Group 1 on May 23, 2022 and Group 2 on May 30, 2022).

As part of the project, we coordinated the safe transportation of the children to the project site with a series of meetings with the management of the mentioned educational institutions. Then, we performed the pre-determined educational activities on May 23–27, 2022 for the first group of children and on May 30–June 3, 2022 for the second group between 10.00–14.30 for five consecutive days. Meanwhile, the parents were recruited for face-to-face (2) and online (1) sessions in two groups (Group 1 on May 23, 25, 27, 2022 between 13.30–14.15; Group 2 on May 30–June 1, 3, 2022 between 13.30–14.15). Immediately after finalizing the activities for the children (Group 1 on May 27, 2022 between 13.30–14.30; Group 2 on June 3, 2022 between 13.30–14.30), we took the posttest measurements from the children in the project site and reinvited the parents to face-to-face interviews at the end of the third session of their training.

We considered precautions against the pandemic during the activities with children and parents, although its impacts turned out to perish. The project site was always disinfected using professional devices during lunch breaks. Moreover, all security and safety measures were taken within the project site. The project implementation was concluded with the help of security guards and guides in the museum. Then, we took follow-up measurements 3 weeks after the project (June 19–23, 2022) in the children's classrooms to assess the permanence of knowledge they acquired during the project.

Data analysis

We initially checked the normality of distribution considering skewness-kurtosis values and the results of the Kolmogorov–Smirnov test. We decided on non-parametric analyses after discovering the data to show a non-normal distribution. Accordingly, the data were subjected to the Wilcoxon signed-rank test to explore the differences between the children's pretest, posttest, and follow-up CATES-PV scores. We performed the analysis on the SPSS program and accepted a *value of p* <0.05 as statistically significant (Figure 1).

When it comes to the qualitative data, we subjected the children's drawings, our observations, portfolios, diaries, and photographs during the project and interviews with the parents to content analysis (Figure 2).

Findings

The findings of the study, performed to uncover whether renewable energy-related activities have an impact on children's attitudes toward the environment and awareness of renewable energy, are presented below separately for the participating children and their parents (Figure 3).

Quantitative findings for children

The findings showed the mean pretest, posttest, and follow-up CATES-PV scores to be 49.70 ± 4.88, 51.52 ± 5, 82, and 52.71 ± 4.60, respectively. Below are the results of the Wilcoxon signed-rank test to determine the differences between the children's CATES-PV scores (Table 1).

As in Table 2, there was a significant difference between the participants' mean pretest and posttest CATES-PV scores ($z = -2.896$,

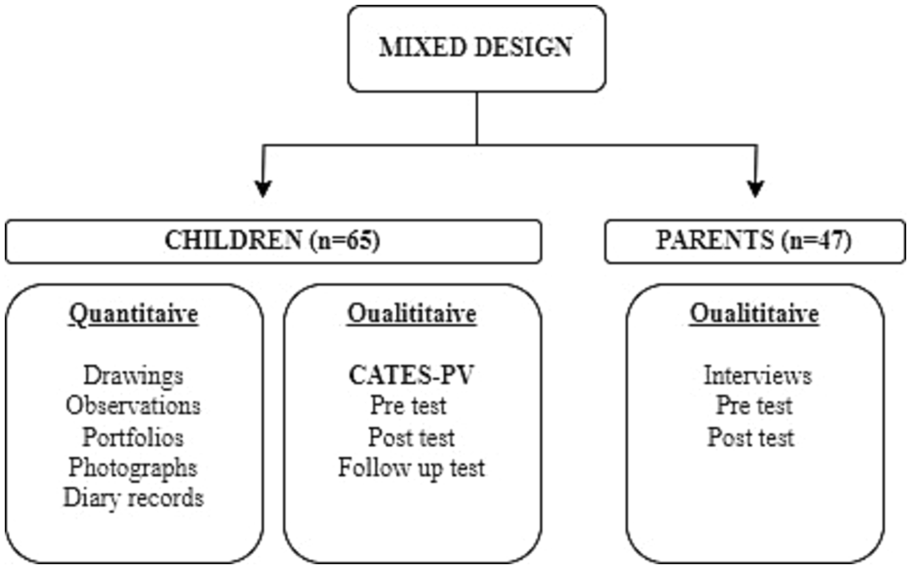

FIGURE 1
Study design.

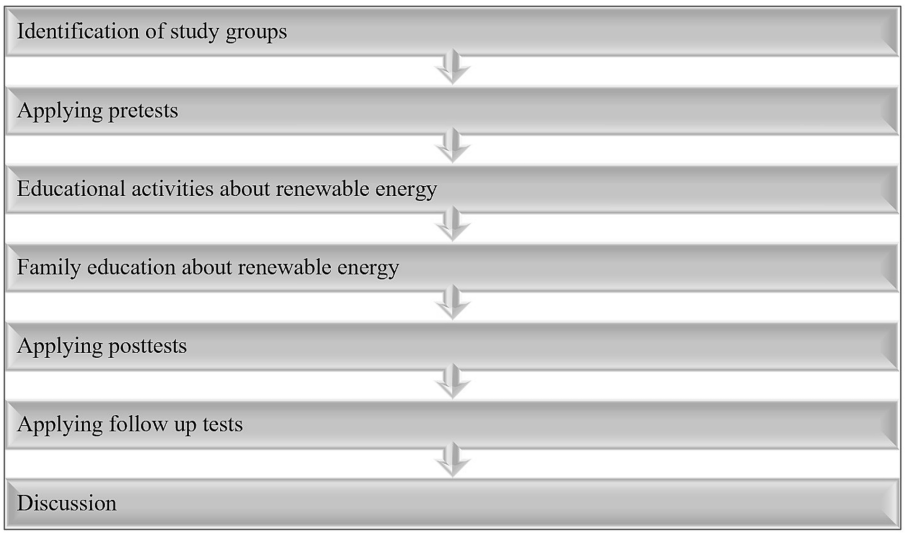

FIGURE 2
Data collection procedure.

$p < 0.05$). The children's mean CATES-PV score in the posttest ($M = 51.52$) was found to be higher than in the pretest ($M = 49.70$). To put it another way, there was a significant increase in the children's attitudes toward the environment and awareness of renewable energy at the end of the project.

We discovered a significant difference between the children's pretest and follow-up mean CATES-PV scores ($z = -4.226$, $p < 0.05$; Table 3) and that this difference was in favor of the follow-up test. The mean CATES-PV score in the follow-up test ($M = 52.71$) was significantly higher than in the pretest ($M = 49.70$). In other words, the children maintained their awareness of the environment and renewable energy 3 weeks after the project.

Yet, our findings revealed no significant difference between the children's posttest and follow-up mean CATES-PV scores ($z = -1.799$, $p > 0.05$). Accordingly, although the follow-up score ($M = 52.71$) seemed higher than the posttest score ($M = 51.52$), the difference was not significant, which implies that the project outcomes continued after the project. Therefore, we may assert that the children had similar levels of awareness of the environment and renewable energy even 3 weeks after the project (Table 4).

Qualitative findings for children

We resorted to drawings, observations, portfolios, photographs, and diary records to present the qualitative findings for the participating children. During the implementation, the children were

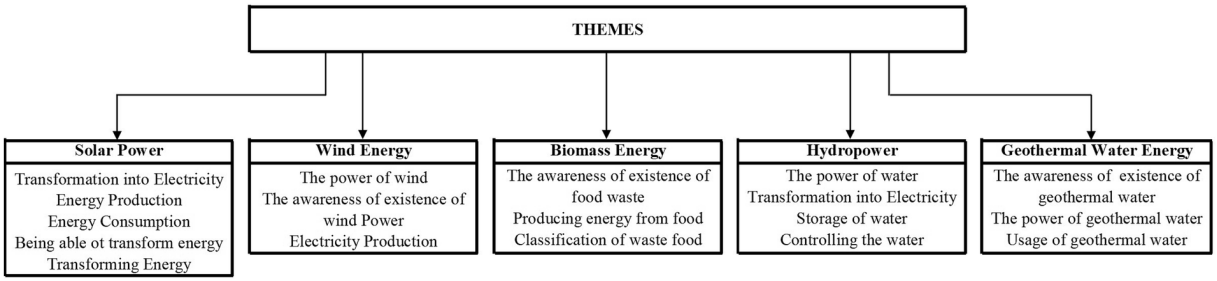

FIGURE 3
Themes of drawing analysis.

TABLE 1 Programme flowchart.

Day 1	Day 2	Day 3	Day 4	Day 5
Grabbing attention-A letter came from the postman	Expert opinion	Expert opinion	Expert opinion	Expert opinion
Expert opinion	The power of the wind	Playing a game "Biomass"	Playing a game "Fishing net"	Playing a game "Water transport"
The power of the sun	A trip to wind turbines	Trip to the biomass section	Building a water mill	Steam experiment
Scientific trip to solar panels	Listening to the wind	STEM organic food waste recycling machine	Trip to the hydropower section	Trip to the geothermal water section
Lunch time	Lunch Time	Lunch time	Lunch Time	Lunch time
Family education-1	STEM Boat	Learning biomass energy	Learning hydropower	Energy sources via drama
Observing the sun	Story Time Windy Day	Family education 2 online	Hydropower via drama	Family Eduation
What if the sun never set?	Kite making	Biomass collage art	Evaluation of the day	Predict, observe, explain
Evaluation of the day	Evaluation of the day	Evaluation of the day		Evaluation of the day
				Exhibition – Final Evaluation

asked to draw pictures to describe them following the educational activities, and we noted down what the children uttered for their drawings. At the same time, we observed and kept observation notes for the children during the implementation. Along with the mentioned data, we presented findings from the portfolios, diaries, and photographs of the children below.

Findings of drawing analysis

In the study, we held many activities related to renewable energy sources such as solar, wind, geothermal, biomass, and hydropower. We present the children's drawings and remarks for renewable energy sources and some examples of their drawing remarks.

Solar power

The children's drawings about solar energy and their remarks on their drawings may be considered important in revealing their perspectives on how solar energy is generated from renewable energy sources (Figures 4–6). Some children put the following remarks under their drawings about solar energy: "*I drew the time we stand next to a solar panel. The thing by it transfers electricity*" (C5); "*I drew solar panels and people sunbathing*" (C43), "*The purple cable is connected to the solar panel. This draws electricity and transfers it to black one. And, therefore, we can charge our phones and tablets*" (C56); "*There are trees and solar panels. There are also a TV and remote. The sun turns the TV o.*" (C31); "*One of the flowers is a rose, and the other is a daisy. Under the solar panel is a blue chair (experimental materials)*" (C9). These sample statements may imply that the children successfully reflected their awareness of solar energy in their drawings.

Wind energy

It seems significant that the children placed wind turbines in their drawings, and they could explain that wind turbines help generate energy with which vehicles operate and other digital transactions are carried out. The sample remarks in the children's drawings are presented below. "*The wind makes it (wind turbine) blow. It then generates electricity. I color the sun blue because it supplies the electricity*" (C11); "*I first drew a wind turbine. For electricity…*" (C13); "*I drew a wind turbine. It spins with the wind. Phones work thanks to it*" (C57); "*The wind is coming, and a wind turbine is spinning. Warm air replaces cold air, and the wind stops*" (C41); "*When the wind comes, electricity is produced. Cars are running, the traffic lights become on*" (C38); "*Since we have learned what wind turbine is today, I drew hearts and balloons. I drew clouds and grass, too*" (C13). Their remarks and reflections imply that the children may have internalized awareness of wind energy.

Biomass energy

Biomass is an abstract concept among renewable energy sources that may be challenging to convey to children. However, considering their drawings and remarks, the children seemed to understand what

TABLE 2 Results of the Wilcoxon signed-rank test for the children's pretest and posttest CATES-PV scores ($n = 65$).

Pretest – Posttest	*n*	Mean Rank	Sum of Ranks	*z*	*p*
Negative rank	20	27.13	542.50	−2.896	0.004
Positive rank	41	32.89	1348.50		
Ties	4				
Total	65				

TABLE 3 Results of the Wilcoxon signed-rank test for the children's pretest and follow-up CATES-PV scores ($n = 65$).

Pretest – follow-up	*n*	Mean rank	Sum of ranks	*z*	*p*
Negative rank	19	20.58	391.00	−4.226	0,000
Positive rank	44	36.93	1625.00		
Ties	2				
Total	65				

TABLE 4 Results of the Wilcoxon signed-rank test for the children's posttest and follow-up CATES-PV scores ($n = 65$).

Posttest – Follow-up	*n*	Mean rank	Sum of ranks	*z*	*p*
Negative rank	22	35.07	771.50	−1.799	0.072
Positive rank	42	31.15	1308.50		
Ties	1				
Total	65				

biomass energy is. The sample remarks in their drawings are: "*If we do not throw our foods into nature and save them, we can produce electricity with these foods. No electricity means no telephone or computer. Animals may not understand how it becomes morning*" (C40); "*Dried food shells pass through a pipe and are ground*" (C12); "*I drew a television. I drew the cage in the energy room. I drew flowers and a tree, too. Also, things made of biomass…*" (C19); "*I drew daisies and sunflowers. I also drew a machine that transforms garbage*" (C3); "*Biomass is important. There are sunflowers and other materials*" (C43). These remarks indicate that the children relatively acquired and internalized the awareness of biomass energy.

Hydropower

We found out that the children used the concepts of rain, dam, tribune, and energy and explained what hydroelectric energy is and how it is obtained in their drawings. "*It is raining while the girl is eating a carrot. Then, electricity is generated from rain*" (C2); "*I drew a dam. Then, I drew a mill and rain. And then, I let the dam fill. When it was full, I drew a heart on the dam*" (C51); "*There are clouds. It is raining into the dam. Then, the light is on over the world*" (C19); "*I drew a dam. The water is flowing. There is something black there…tribunes*" (C37); "*I first drew rain. When hitting the ground, it becomes a pool. It then becomes a fountain and a dam later on*" (C5); "*I drew a dam. There is an anthill inside. Water comes out of the fountain to the flowers. The evaporated water is replenished with rain*" (C8).

Geothermal energy

The children's drawings and their remarks on the concepts in their drawings revealed how they understood and explained geothermal energy. "*Water goes through this pipe. The sun warms it; therefore, people obtain hot water. Then, we can cook*" (C11); "*I put an egg in hot water. Then, the water becomes evaporated*" (C16); "*In my drawing, I pour hot water into the bottom of the pit to cook the egg*" (C29); "*I fill the box with hot water and cover it with a glass lid. The water has evaporated, forming drops*" (C30); "*We experimented it before. There was hot water and pots. Steam was coming out of water. Those vapors went up and became a cloud. Then, it rained*" (C44). These remarks also imply that the children relatively acquired and internalized the awareness of geothermal energy.

To sum up, we discovered that the children successfully reflected their achievements in renewable energy in their drawings, as evident in their remarks. Presenting the concept of renewable energy - an abstract topic for early childhood - with its concrete examples in the museum - an environment for children to learn by doing and experiencing - is believed to contribute to their achievements. Moreover, their changing attitudes continued even 3 weeks after the project implementation.

Findings of observations

In the research, we maintained observations for children throughout the activities and shared our observation notes with the project team under the leadership of the project coordinator at the end of each day. Accordingly, we deduced from the observations that educational activities significantly contributed to the participating children's specific development areas, particularly early literacy. In the study, carrying out different activities (e.g., experiments and scientific trips) with the children allowed us to observe them in different environments. As a result of the observations, we found that the children showed a high level of participation in the activities, were not distracted during the activities, were able to solve the scientific problems raised, and were not influenced by other children visiting the museum. In addition, the children completed all activities without getting bored, and the participation rate was the highest in group work. As a result of the activities, we noticed in the children's reflections on their drawings, their questions, and their answers to the questions raised that they got achievements in their creativity and problem-solving skills and scientific knowledge of renewable energy sources through hands-on experiences. Besides, the children's asking what the next day's activities would be and ability to work in harmony with their peers were among the significant outcomes of the project.

Findings of portfolios

As mentioned before, we resorted to different techniques to evaluate the data from the children. In this context, we also utilized portfolios generated for children. The children's products created during the activities in the museum, including group work, were collected considering their preferences for 5 days. At the end of the fifth day, the children's products were exhibited in a convenient venue in the museum. The children examined both their own work and the work of their friends and told their families and peers about their work, which may have contributed to their social skills. Meanwhile, by identifying the elements having attracted the children's attention during the activities, we caught some clues about their interests and

FIGURE 4
Renewable energy sources such as solar, wind, geothermal, biomass an hydropower.

allowed them to perceive how they integrated their skills and reflected on their achievements. Besides, we discovered that one of the children created products beyond the level of development expected from their age group. Accordingly, we suggested the teachers perform detailed assessments of the child's products.

Findings of diaries

We referred to the children's drawing skills in their diaries. In this context, we adopted the 'draw and tell' technique, given the children's limited motor skills, and asked them to describe their drawings. At the end of each day, the children were given drawing notebooks and asked to draw something about the activities of the day and to describe these drawings (Figure 7). Then, the project team noted down what the children uttered about their drawings and, thus, created their diaries. Below are the sample quotes from the children's descriptions of their drawings in their diaries: "Teacher Selim is loudly telling me about solar panels. I asked a question about two flowerpots under the sun and in the shade (experimental materials)" (C19); "When the wind comes, electricity is produced. Cars are running, the traffic lights become on" (C7); "I drew a biomass machine and its buttons. There are the heart and charge icons" (C59); "The water mill in the dam generates electricity. Water is colored blue" (C35); "They put the boiling water in the can and covered it with a plate. Then, raindrops appeared on the plate" (C27); "We learned about wind energy, hydropower, geothermal energy, solar energy, and biomass energy. I drew all the energy sources that I learned" (C53). These remarks reveal that the children were able to display the achievements they got throughout the project, which may have brought significant contributions to their areas of development.

Findings of photographs

Since the participating children were preschool-aged, we also utilized the photography technique among qualitative research techniques. In this regard, we analyzed the photographs of children taken during the activities throughout the project. The findings implied that the materials and scientific trip sites in the project led the children to feel surprised, happy, curious, and excited. Considering that they felt multiple emotions simultaneously, we can confidently assert the children had high learning motivation. In addition, the inclusion of game-based activities in the program entertained the children; thus, they could keep their attention on practices during the project. Implementing the program designed by field experts in a museum may suggest the effectiveness of the project on children.

Findings for the parents

In the semi-structured interviews held with the parents to explore their and their children's awareness of renewable energy (Figure 5). We asked the parents before and after the project about what they understand from environmental education, how they and their children utilize energy sources in daily life, what their children do about protecting the environment, and what their children know about renewable energy (Table 5).

FIGURE 5
Presentation about the renewable energy sources for parents.

We found that the parents' responses to the first question (What do you understand from environmental education?) included common expressions, such as "**keeping the environment clean**" and "**protecting the environment**," in the pretest and posttest. However, the posttest responses differed from the pretest responses with the expressions "**charming appearance**," "**energy sources**," "**the least harm to the environment**," and "**proper use of sources**."

The parents were also asked how their children behave toward those polluting the environment. The parents' pretest responses to this question included the expressions "throwing the garbage away," "getting angry," "verbally reacting to the agent," "taking it for recycling," "getting upset," and "trying not to pollute the environment." Yet, their posttest responses did not significantly differ from their pretest responses.

The third question asked to the parents was about how they use energy sources in their daily lives. It was found out that their pretest and posttest responses shared the following expressions: "turning on the taps less," "turning off unnecessary lights," and "conscious consumption." Besides, different from the pretest, their posttest responses included the expressions "placing the dishes in the dishwasher without rinsing them" and "taking care of energy-consuming needs quickly."

Another question asked to the parents was about how their children use energy sources at home. In the pretest, parents' responses included the expressions "turning off the taps," "avoiding unnecessary electricity consumption," "having sufficient awareness of consumption and acting responsibly," "turning off the TV," "trying not to harm the nature," and "keeping bath time short." In the posttest, in addition to their pretest responses, the parents mentioned that their children wanted to water the flowers with wastewater and suggested some opinions on how to manage waste.

We also asked the parents what their children knew about renewable energy sources. In the pretest, most of the parents ($n = 20$) reported that their children did not know about renewable energy sources. In the posttest, however, 19 parents suggested that their children learned and knew about renewable energy sources. Sample responses to the question are as follows: "*He sees windmills on the way back to the hometown. Now, we have told him about what they serve for. He knows it anymore* from now on (P36); "*After the project, s/he has explained solar, wind, and hydro energy at home*" (P21); "*S/he now knows about solar energy panels and the types of energy generated from hydropower and wind*" (P18); "*S/he has found the project very useful and liked it. S/he has loved the activities about watermill*" (P7); "*Thanks to this project, s/he has learned the types of renewable energy sources and can now distinguish them*" (P13); "*This project has helped my child and me. S/he can distinguish between renewable and non-renewable energy sources*" (P23); "*Actually, s/he did not know about renewable energy. S/he has learned it in this project*" (P41); "*Following the project, s/he has become even more conscious, and her/his awareness increased. S/he has learned how energy is generated and how wind, sun, water, and mines help generate energy. It has been rather useful, and I have been very satisfied with it. Thank you very much*" (P46); "*Until the last five days, s/he did not know much about renewable energy, but now s/he has learned partially about energy sources and their benefits*" (P38); "*The activities in this project have helped her/him gain knowledge about renewable*

FIGURE 6
Solar power and wind energy presentation at museum.

energy. S/he has also kept us informed" (P16); "*I think the project has been effective. Children have learned about water, wind, and electrical energy. I think the examples and experiments in the project would be permanent in their minds*" (P5).

We could imply from the parents' responses that their children had an increased awareness of renewable energy, transferred the knowledge they acquired in the project to their daily lives, and shared their knowledge of renewable energy sources with others.

Discussion

In this study, we aimed to explore whether the educational activities implemented in a museum for children and their parents have an impact on the children's attitudes toward the environment and awareness of renewable energy. The findings revealed significant differences between the measurements taken from the children before and after the project. The significant differences in the posttest measurements were also recognized in the children's behaviors, drawings/remarks, portfolio products, and diaries, our observations, and the interviews with their parents throughout the project. It is expected that children in early childhood may have difficulties acquiring abstract concepts. Therefore, for such children to enjoy a learning environment and internalize their learning, it may be essential to create educational settings that appeal to their multiple senses and where they are entirely active. Children assume the responsibility of learning in such environments that stimulate their inner sense of curiosity, which, in turn, contributes to their motivation (Önal and Sarıbaş, 2019). Since children are involved in educational activities in such environments where teachers act as guides, they both enjoy and internalize quite abstract concepts (Çiftçi and Uyanık, 2017). The previous research consistently highlighted the significance of using diverse methods in teaching abstract concepts to children in early childhood and reported that teachers are better to utilize experimental and drama techniques for children in this period (Gerde et al., 2013; Yalçın and Tekbıyık, 2013; İnan and İnan, 2015; Guo et al., 2016; Mavilidi et al., 2017; Tippett and Milford, 2017; Akgündüz and Akpınar, 2018). In our research, we can assert that the children's visits to energy panels in the museum and the experiments under the guidance of educators contributed to their awareness of renewable energy sources. Their increased awareness was revealed in our observations as well as in their drawings about renewable energy sources. Based on our observations, we determined that the children actively participated in the educational activities, were excited during the experiments, and were highly motivated. In addition, the parents

FIGURE 7
Drawing on the experiences at the museum to the diaries.

TABLE 5 Themes of parents interviews.

Theme	Subtheme	Some sentences
Environmental education	Awareness Protection Conscious consumption	"*Following the project, s/he has become even more conscious, and her/his awareness increased. S/he has learned how energy is generated and how wind, sun, water, and mines help generate energy*
Child behavior	Knowledge Habits Behavior	"*S/he has found the project very useful and liked it. S/he has loved the activities about watermill*"
Consumption of energy (Parent)	Habits Behavior	"*Thanks to this project, s/he has learned the types of renewable energy sources and can now distinguish them*"
Consumption of energy (Child)	Habits Behavior	"*I think the project has been effective. Children have learned about water, wind, and electrical energy. I think the examples and experiments in the project would be permanent in their minds*"
Renewable energy sources	Knowledge Awareness	**"***He sees windmills on the way back to the hometown. Now, we have told him about what they serve for. He knows it anymore*" "*S/he now knows about solar energy panels and the types of energy generated from hydropower and wind*"

reported that the project was rather helpful in increasing their children's awareness of renewable energy. Similar to our findings, Dilli et al. (2018) reported that children successfully drew renewable energy sources following energy-related relevant activities in a museum and concluded a significant difference between pretest and posttest measurements regarding the participants' awareness of renewable energy. Besides, in the follow-up test 3 weeks after the project, we discovered that the children's scores were still significantly higher than their pretest scores. Despite a slight decrease, there was also no significant difference between their posttest and follow-up scores. In other words, children's attitudes toward and awareness of renewable energy continued even 3 weeks after the project, which implies that the children may have internalized what they learned in the educational activities in the museum and utilized them in their daily lives.

When learning any subject, children in early childhood may need to be able to internalize and transfer it to different domains of their lives (Breiner et al., 2012). The knowledge and skills that children would acquire in this period are likely to follow them in the long run and shape their entire behavioral repertoire (Aral et al., 2002; Hensch, 2016; Turhan and Özbay, 2016). The ability of children to internalize knowledge and behaviors without only imitating them can also be attributed to teaching methods and techniques. As a matter of fact, we can assert that the children internalized the knowledge about renewable energy during the project, where they were all active under the guidance of their teachers and were able to use it 3 weeks after the project. There are various limitations in the study. One of the limitations is that only renewable energy sources were examined in museum education. Another limitation of the study is that it was carried out only with preschool children and

their parents. In addition, it is limited to the data obtained from socially disadvantaged children and families living in Ankara city centre.

Conclusion and recommendations

Overall, our findings revealed a significant difference between the children's pretest and posttest CATES-PV scores (in favor of the posttest) but no difference between the posttest and follow-up scores. It was also determined that the children successfully drew renewable energy sources and actively participated in the educational activities in the museum and that the parents highlighted their children's increased awareness of renewable energy and attitudes toward the environment following the project. Based on our findings, we may recommend:

- Implementing renewable energy education to samples composed of different children in early childhood,
- Carrying out longitudinal studies to uncover the long-term impacts of the project implemented for the children, and
- Recruiting teachers for educational activities on renewable energy.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Scientific Research and Publication Ethics Committee of Tarsus University (2021/33 dated 07.28.2021). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

SB: Methodology, Resources, Supervision, Writing – original draft. NA: Funding acquisition, Investigation, Methodology, Writing – review & editing. FG: Data curation, Investigation, Project administration, Resources, Supervision, Writing – review & editing. ED: Data curation, Funding acquisition, Methodology, Supervision, Writing – review & editing. GK: Methodology, Resources, Writing – review & editing. ST: Project administration, Validation, Writing – review & editing. NÖ: Resources, Visualization, Writing – review & editing. GH: Data curation, Writing – review & editing. CT: Data curation, Investigation, Writing – review & editing. ŞÇ: Data curation, Investigation, Writing – review & editing. MG: Data curation, Investigation, Writing – review & editing. ÖY: Resources, Validation, Visualization, Writing – review & editing. SH: Resources, Validation, Visualization, Writing – review & editing. EY: Formal analysis, Investigation, Writing – review & editing. YÇ: Formal analysis, Investigation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Future of nature, our future. A preregistered report on future time perspective, social value orientation, and pro-environmental outcomes based on data from Poland and Sweden

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Introduction: The objective of the study was to examine the role of social value orientation and future time perspective to account for individual differences in pro-environmental behaviors, intentions, and opinions about the link between pro-environmental action and pandemic threat (three separate models) in Polish and Swedish samples expected to differ in rate of pro-environmental behaviors (higher in Sweden). We hypothesized that for Poland, future time perspective would be linked to pro-environmental outcomes only when social value orientation is average or high. In contrast, for Sweden, we expected a significant link between these variables regardless of social value orientation.

Methods: In total, 301 (150 Polish, 151 Swedish) participants completed online surveys via Prolific.co research panel. We controlled for individualizing/binding moral foundations, present time perspectives, and selected demographic variables in the analyses.

Results: In line with expectations, the individualizing moral foundations were a significant predictor across all three models. The data did not support our focal hypothesis regarding the interaction between future time perspective and social value orientation. For pro-environmental behaviors in the past 6 months, the future time perspective was a predictor only when social value orientation was low.

Discussion: The results suggest that when encouraging more competitive (compared to altruistic) people to behave in a green way, it might be crucial to underline the future consequences and benefits, consistent with the future time perspective. The pro-environmental campaigns could, therefore, highlight how green behavior may bring personal gains in the future, which are typically valued by individualistic people, such as savings or social status.

KEYWORDS

future time perspective, moral foundations, pandemic threat, pro-environmental behaviors, social value orientation

Introduction

The world faces a climate change crisis (Romanello et al., 2022). Without taking action, humanity is threatened with many adverse effects, such as diseases (Khraishah et al., 2022; Semenza et al., 2022), crop failure (Kogo et al., 2022), extreme temperatures, and hazardous weather conditions (Clarke et al., 2022). Furthermore, due to the emergence of

the COVID-19 pandemic, research was conducted regarding the relationships between the environmental state and the risk of spreading viruses. A study from Germany indicated that not only temperature but also the presence of PM2.5, O_3, and NO_2 was associated with the spread of COVID-19, whereas PM10, humidity, and environmental quality index were significantly related to the number of active COVID-19 cases (Bilal et al., 2020). Another study from California showed that PM2.5, PM10, NO_2, CO, and SO_2 were significantly associated with COVID-19 cases (Bashir et al., 2020). It provides preliminary data on how pollutants bring a risk of spreading viruses and how they might contribute to pandemics.

Success in combatting climate change relies on governmental and individual actions (Maiella et al., 2020). Therefore, exploring the individual characteristics that promote pro-environmental behaviors, intentions, and beliefs regarding the link between pro-environmental attitudes and pandemics' emergence is crucial. Without effort and consideration of the future consequences of the present actions by individual persons (Ho et al., 2020), any large-scale pro-environmental policy cannot be successfully implemented.

Based on the social norm activation model by Schwartz (1970) and later literature taking temporal and social aspects in prosocial behaviors into account (Joireman et al., 2001), the purpose of the current study is to identify individual difference variable responsible for considering the long-term consequences of actions (future time perspective) and the welfare of other people (social value orientation). We also aim to test whether their interaction accounts for (1) pro-environmental behaviors during the last 6 months, (2) pro-environmental behavior intentions in the following 6 months, and (3) opinion about the linkage between pro-environmental attitude and the threat of pandemics.

Given the difference in Polish and Swedish policies and the pro-environmental culture (Mikuła et al., 2021), we chose these two countries to additionally check if the participant's country of residence modifies this interaction mechanism. Although future time perspective is regarded as a trait-like and relatively stable factor (Kairys and Liniauskaite, 2015), how it links to behaviors may differ depending on what is valued in a particular culture as having long-term positive consequences. For instance, pro-environmental behavior might be seen as a waste of money when it is deemed costly, and the public needs to be convinced about its long-term benefits or investment when its positive results are precise. A future-oriented person might choose what they find beneficial, and the appraisal of behavior as such depends on general beliefs in their social circle (e.g., in their own country).

The inclusion of moral foundations and present time perspectives as covariates will enable us to determine whether the future time perspective effect is noticeable over more general moral attitudes of caring for other people and caring for the present over the future. We will also test the potential effects of sociodemographic variables: age, gender, socioeconomic status, and education.

By our study, we aim to address theoretical gaps regarding (1) the intercultural differences between countries of low (Poland) and high (Sweden) pro-environmental behaviors in society; (2) testing the norm activation model (Schwartz, 1970) in the pro-environmental context, taking into account present time perspectives (which complement the understanding of future time perspective and have been recently proven to be essential for prosocial outcomes; Maki et al., 2016; Nowakowska, 2023, including pro-environmental ones, Wittmann and Sircova, 2018), moral foundations (which describe not only caring for the welfare of others does social value orientation but also the moral reasons for behaviors and the underpinnings of politics-related convictions; Graham et al., 2009), and sociodemographic covariates.

Our analysis is expected to broaden knowledge about the norm activation model and test whether time perspectives, recently gaining attention in the field of pro-environmental behaviors (Hoffmann et al., 2022; Olsen et al., 2023), remain significant predictors of such activities, when controlling for the propensity to care for others and morality. Our results might also prove vital for pro-environmental education and campaigns, for instance, how to shape attitudes and behaviors—what aspects we should target (e.g., future orientation, cooperation tendencies, or morality). To our knowledge, no such intercultural comparison has been made regarding pro-environmental behaviors and intentions based on our theoretical basis and this set of covariates.

Literature review

People are often supposed to choose between long-term and short-term interests—for themselves, society, or interaction partners (Milfont and Gouveia, 2006). The norm activation model (Schwartz, 1970) states that personal norms (with altruistic values highlighted) influence behaviors only when a person thinks that their action has consequences for another's wellbeing (as other people are the main objects valued by altruists) and when an individual believes in their responsibility in doing these actions. Personal norms are forming a feeling of moral obligation to either undertake or refrain from particular actions (Schwartz and Howard, 1981). Stern et al. (1993) and Stern (2000), in his value-belief norm model, suggested an expansion of Schwartz's model. Value orientation, according to this conceptualization, describes the principle that guides the desirable states or outcomes and is hypothesized to influence the way how people formulate and structure their beliefs regarding the environment (Stern, 2000).

Pro-environmental behaviors are considered one of the most important in terms of their consequences for society. Utilizing resources as much as possible can bring short-term benefits for an individual but harm society, whereas sparing these resources can bring long-term benefits to society. Joireman et al. (2001) present pro-environmental behavior through the norm activation model as a social dilemma embedded in two dimensions—the social dilemma (conflict between interests of the self and others) and the temporal one (immediate and delayed consequences of action). Based on available data, we propose that social value orientation in solving the social dimension of the social dilemma of undertaking pro-environmental behavior and the future time perspective can be critical in solving the temporal dimension (Joireman et al., 2001; Maki et al., 2016). Moreover, we suggest that it is important to control for moral foundations, as pro-environmental behaviors can be linked to moral norms and resulting political orientations (Chan and Bishop, 2013; Vainio and Mäkiniemi, 2016; Milfont et al., 2019).

Pro-environmental behaviors in Poland and Sweden

Countries, even those close geographically, differ significantly in the level of pro-environmental behaviors the citizens display. It is due to historical, socioeconomic, and mentality-related aspects. Poland and Sweden are interesting examples of such a difference. Poland is a country with <20,000 USD gross domestic product per capita. It has <10% usage of renewable energy sources (Iwińska et al., 2023). Poland is also still developing regarding environmental protection and resists the shift from conventional energy sources (Zuk, 2022). The country was the only one to reject the Green Deal, which aimed to introduce the rules of a climate-neutral economy by 2050. In 2017, decisions were made regarding logging the Bialowieza Forest—a unique natural treasure of the Polish territory—resulting in worldwide protests (Cislak et al., 2021). It is also one of Europe's countries with the lowest rates of pro-environmental behaviors (Mikuła et al., 2021); however, during the COVID-19 pandemic, it was ranked as showing higher rates of pro-environmental behaviors than Sweden (Iwińska et al., 2023). By contrast, Sweden is a relatively rich European country with over 50,000 USD in gross domestic product per capita. It has over 40% usage of renewable energy sources (Iwińska et al., 2023). Sweden is at the top of the green policies in Europe (D'Adamo et al., 2020). It showed the highest rates of pro-environmental behaviors in Europe (Mikuła et al., 2021), but during COVID-19—had the rate of pro-environmental behaviors lower than Poland (Iwińska et al., 2023). Nevertheless, Sweden is considered a leader in green regulations and actions (Berck et al., 2011).

According to a study by Mikusiński et al. (2023), value orientations are one of the most important factors associated with human-nature connectedness (related to pro-environmental attitudes; Klaniecki et al., 2018). However, a study by De Groot and Steg (2007) showed that value orientations were strongly related to personal norms and awareness of consequences only in the case of Sweden (and not in the case of four other investigated countries: the Netherlands, Italy, Austria, and the Czech Republic). On the contrary, in a study by Caniëls et al. (2021), altruistic value orientation was unrelated to pro-environmental behaviors in the case of Poland. This suggests that both countries may also differ in the case of the role of individual differences in pro-environmental behaviors.

The social dilemma of pro-environmental behaviors: social value orientation

The individual endorsement of social norms describing the preferred consequences of one's own actions may be operationalized with social value orientation (Joireman et al., 2001). Social value orientation is a personal trait (Messick and McClintock, 1968), which describes the preference for self or other's outcomes in social interactions (Van Lange, 2000). It may be considered a continuum regarding the individual's tendency for rivalry or altruism in sharing resources with others (Murphy et al., 2011). Generally, higher social value orientation, i.e., altruism, facilitates cooperation in social dilemmas (a meta-analysis by Pletzer et al., 2018). A pro-environmental behavior is a social dilemma (Bogaert et al., 2008). It has been proven that the higher the altruistic value orientation, the higher the pro-environmental self-determination (De Groot and Steg, 2010). Social value orientation has been used as an operationalization of the personal norms (altruistic concerns) within the norm activation model framework (Joireman et al., 2001).

Based on the literature review above, first, we hypothesized that:

(H1) Social value orientation is positively related to pro-environmental behaviors, intentions, and opinions about the pro-environmental behaviors-pandemic risk linkage (the latter referred to below as "pro-environmental opinions").

The temporal dilemma of pro-environmental behaviors: future time perspective

Time perspective is a dimension of the psychological time construal in humans. It is a result of cognitive processes which divide personal experiences into past, present and future temporal frames (Zimbardo and Boyd, 1999). Time perspectives describe to what extent people take into account their past, present, or future when making decisions (Zimbardo and Boyd, 2008). One of the traditionally distinguished time perspectives—the future time perspective -involves planning and being able to consider consequences that overcome the immediacy and the present (Zimbardo and Boyd, 1999). However, this perspective typically involves caring for oneself and one's own future, not the collective one (Zimbardo and Boyd, 2008). Despite this, future time perspective has been positively and consistently linked to pro-environmental behaviors, and the link was stronger for behaviors than attitudes (see meta-analysis by Milfont et al., 2012). Sustainable behaviors require anticipation of consequences and long-term orientation. Therefore, the relationship between future time perspective and sustainable behaviors exists, as future-oriented people are good at planning and meeting obligations in the long term (Corral-Verdugo and Pinheiro, 2006). Future-oriented people also have the ability to visualize their objectives, which has an impact on their present decisions (Keough et al., 1999), which supports them in undertaking pro-environmental behaviors (Corral-Verdugo et al., 2006).

Future time perspective can also facilitate solving the temporal dimension of the social dilemma in a way that promotes positive consequences for oneself or society (Arnocky et al., 2014). The motivation to act pro-environmental stems from the extent to which the consequences of pro-environmental action match the things people value (Stern et al., 1993). Based on the abovementioned data, the future time perspective, due to its relation to considering future consequences of actions, might be viewed as boosting the ability for consequence awareness, as conceptualized by Schwartz (1970). In our study, we propose that the effect of future time perspective on pro-environmental

behaviors/intentions/opinions depends on what consequences (benefits for oneself or others) the individual values.

We suppose that in the case of Poland, where the pro-environmental culture is not embedded, the future time perspective requires social value orientation to display behaviors that care for the collective (e.g., the pro-environmental ones). In the case of Sweden, where the green culture is more embedded in everyday life (as this country ranks very high in sustainability indices, e.g., Sustainable Development Report, 2021), we hypothesize that the simple effect of future time perspective and social value orientation will be present. However, future time perspective will be linked to pro-environmental behaviors, intentions, and opinions about the pandemic threat stemming from a lack of pro-environmental behaviors regardless of the level of social value orientation (thus, the interactive effect will not be found). In sum, we state two further hypotheses:

(H2) In the Polish sample, the future time perspective requires at least an average social value orientation to be related to pro-environmental behaviors/intentions/opinions.

(H3) In the Swedish sample, future time perspective is linked to pro-environmental behaviors/intentions/opinions regardless of the level of social value orientation (thus, the interactive effect will not be found).

Moral foundations as covariates of the social and temporal dilemma

As the norm activation model implies, moral norms may influence behaviors (Schwartz, 1970). Therefore, we plan to involve moral foundations as variables that should be controlled in the regression model. Moral foundations are constructs that are intuitively and unconsciously activated in any situation encountered by a person (Graham et al., 2011; Dickinson et al., 2016) and have an impact on judgment and behavior (Haidt and Graham, 2007). Moral foundations enable us to explore the behavioral orientation toward sharing with others (as does social value orientation, Van Lange et al., 2007; Murphy et al., 2011, but from an angle of moral appraisal, not a preference for own or other's outcomes in social interactions) and the underlying moral motivation of behavior, as described by Schwartz's theory (Schwartz, 1970). Moral foundations have been proven vital in predicting pro-environmental outcomes (Skalski-Bednarz et al., 2023). Moral foundations are classified into individualizing (harm avoidance and fairness/reciprocity) and binding (caring for ingroup loyalty, respect for authorities, and purity and sanctity; Graham et al., 2009). Typically, individualizing morality is considered the one that predicts a liberal orientation, and binding—predicts a conservative orientation (Van Leeuwen and Park, 2009). Individualizing morality and liberal attitudes promote pro-environmental attitudes (Vainio and Mäkiniemi, 2016; Milfont et al., 2019), whereas the binding morality and conservative worldview are linked to decreased level of pro-environmental choices (Vainio and Mäkiniemi, 2016). We suppose that:

(H4) Individualizing values may be positive. In contrast, the binding values are negatively linked to behaviors, intentions, and consideration of a pandemic as a threat reliant on the environment.

Present time perspectives and pro-environmental outcomes

We will also enter present time perspectives as covariates to our model to control for the effect of the endorsement of the present in pro-environmental behaviors (Arnocky et al., 2014; Valizadeh et al., 2018). Present-hedonistic time perspective relates to a preference for joy and seeking pleasure in present behavior (Zimbardo and Boyd, 1999). It is negatively related to pro-environmental behavior due to the impulsivity associated with it (Wittmann and Sircova, 2018). Impulsivity limits the capacity to plan and act for the sake of long-term consequences, and that is presumably why pro-environmental behaviors may be challenging for people with high levels of this trait. Moreover, at present, hedonism is linked to seeking pleasure, and sustainable behaviors might be linked to the devotion of own pleasure for positive results for the general public. The present-fatalistic time perspective may also encourage the use of natural resources here and now without concern for the future (Corral-Verdugo et al., 2006). Present fatalism is related to a conviction that an individual does not have the force to influence the course of life (Zimbardo and Boyd, 1999), which may lead to a decreased sense of responsibility for own behaviors and the environment.

Demographic variables and pro-environmental outcomes

Relevant demographic variables are as follows: age, gender, education, and socioeconomic status will also be controlled. In literature, minor effects of older age on sustainable behaviors are found (see meta-analysis by Wiernik et al., 2013). Studies have also shown women to be more likely to engage in pro-environmental behaviors. Higher socioeconomic status (measured as education and income level) facilitates such behaviors (Chen et al., 2011; Otto et al., 2016; Patel et al., 2017; Casaló and Escario, 2018). Education has also been described as increasing the propensity for environmentally friendly behavior, presumably due to higher concern for social welfare in educated people (Meyer, 2015).

Graphical summary of the hypothesized paths

Figure 1 shows a visualization of the hypothesized paths to be tested in three models predicting: ecological behaviors in the last 6 months, ecological behaviors' intentions for the following 6 months, and opinions about pro-environmental behavior and the pandemic threat risk.

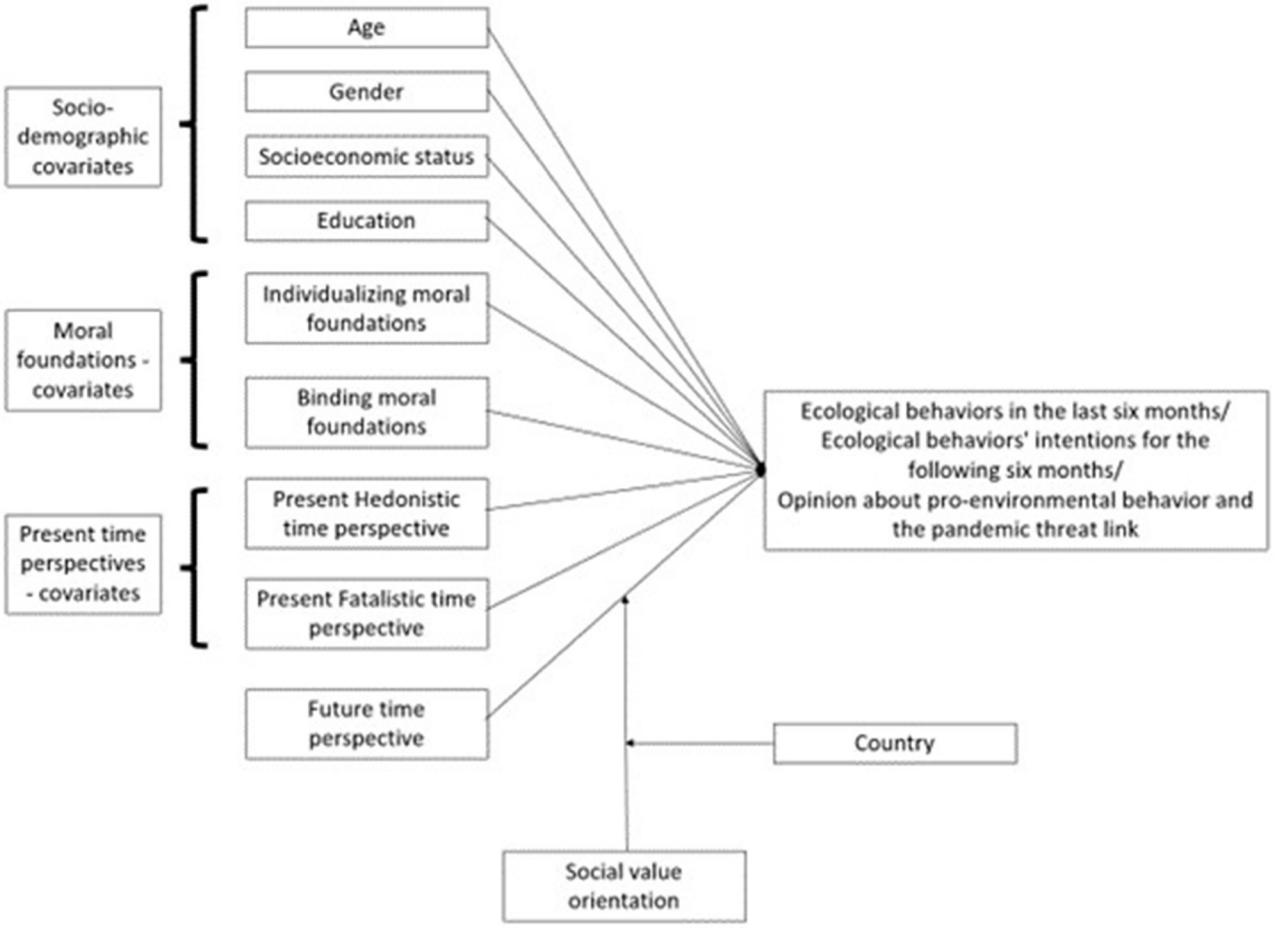

FIGURE 1
Visualization of the hypothesized paths to be tested in three models.

Materials and methods

Power analysis and preregistration-related demands

As indicated in our preregistration, we aimed to recruit $N = 150$ participants from Poland and $N = 150$ from Sweden (total $N = 300$). A power analysis conducted in G*Power 3.1.9.4 (Faul et al., 2009) suggested that such sample size will allow us to detect an effect of 0.10 with defined $\alpha = 0.05$ with a power of 0.95 in a regression analysis with 15 predictors. Our goal was to recruit participants from an age range of 18–65.

Participants

Polish sample

In total, 150 participants aged 18–57 ($M = 25.45$; SD = 7.55) participated in the study (74 women, 49.3%, 73 men, 48.7%, three of other gender/refusing to answer, 2.0%). A total of 86 (57.3%) were currently employed, and 64 (42.7%) were not. Concerning relationship status, 15 (10.0%) were married, 65 (43.3%) were in an informalized relationship, 64 (42.7%) were single, and 6 (4.0%) declared another status. For the place of residence, 24 (16.0%) lived in a village, 21 (14.0%) in a town with up to 50,000 inhabitants, 17 (11.3%) in a town with 50,000–100,000 inhabitants, 40 (26.7%) in a town with 100,000–500,000 inhabitants, and 48 (32.0%) in a town with 500,000 inhabitants or more. On a scale from 0 to 10, where 0 meant *I cannot afford basic expenses* and 10 = *I can afford whatever I want and can save money*, the answers ranged from 1 to 10 ($M = 5.81$; SD = 1.74). For education, the range of education (years spent on actual learning, parallel studying not included) was 11–21 ($M = 14.99$; SD = 2.13). A total of 133 participants were meat consumers (88.7%).

Swedish sample

A total of 151 participants aged 18–63 ($M = 31.32$; $SD = 9.81$) participated in the study (54 women, 35.8%, 96 men, 63.6%, 1 of other gender/refusing to answer, 0.7%). A total of 106 (70.2%) were employed, and 45 (29.8%) were not. For the relationship status, 27 (17.9%) were married, 42 (27.8%) were in an informalized relationship, 77 (51.0%) were single, and five (3.3%) declared another status. For the place of residence, 31 (20.5%) lived in a

village, 22 (14.6%) in a town with up to 50,000 inhabitants, 31 (20.5%) in a town with 50,000–100,000 inhabitants, 36 (23.8%) in a town with 100,000–500,000 inhabitants, and 31 (20.5%) in a town with 500,000 inhabitants or more. On a scale from 0 to 10, where 0 meant *I cannot afford basic expenses* and 10 *I can afford whatever I want and can save money*, the answers ranged from 0 to 10 ($M = 5.52$; $SD = 2.36$). For education, the range of education (years spent on actual learning, parallel studying not included) was 5–26 ($M = 14.84$; $SD = 2.99$). A total of 122 (80.8%) participants were meat consumers.

Procedure

The study was performed online and was fully questionnaire-based. All questions were multiple choice (no open-ended questions).

We used Qualtrics (Qualtrics, Provo, UT) for survey design. All data were collected using prolific.co (previously prolific.ac), a subject pool for online studies. Prolific is a reliable source of participants (Palan and Schitter, 2018). Its advantage is the availability to recruit people of different nationalities using the same rules of study inclusion and remuneration. All participants who finished the survey were remunerated through Prolific with a small financial reward (equal for all). As the study relied on convenience sampling, the sociodemographic structure was not representative of the whole population.

We started the data collection in Poland and Sweden simultaneously (end of June 2022). For Poland, the data collection ran till the end of June 2022; for Sweden, it finished in October 2022. We aimed to recruit the number of participants specified in our preregistration. The difference in the length of data collection was due to the smaller number of registered participants from Sweden than from Poland.

Measures

We used the same instruments for the Polish and Swedish samples. Except for the part on ecology and pandemic threat, which were prepared on our own, the measures were initially published in English and validated in Polish and Swedish.

Zimbardo Time Perspective Inventory

Zimbardo Time Perspective Inventory was used to measure time perspectives (original version: Zimbardo and Boyd, 1999; Polish version: Przepiórka, 2011; Swedish version: Carelli et al., 2011). It is a self-report measure consisting, in the Polish version, of five subscales: future, present-hedonistic, present-fatalistic, past-positive, and past-negative (56 items), and the Swedish version, six subscales: same as in the Polish version plus future-negative (64 items). For the current study, only future (e.g., *When I want to achieve something, I set goals and consider specific means for reaching those goals*), Present-Hedonistic (e.g., *I believe that getting together with one's friends to party is one of life's important pleasure*), and Present-Fatalistic (e.g., *Fate determines much in my life*) were the subscales of interest. The participants answered on a 5-point Likert scale, ranging from *very uncharacteristic of me* (coded as 1) to *very characteristic of me* (coded as 5). The general scores for the subscales of interest were computed as the mean of relevant items. For the Polish sample: for the future time perspective, Cronbach's $\alpha = 0.82$; for present-hedonistic time perspective $\alpha = 0.79$; for present-fatalistic time perspective $\alpha = 0.69$. For the Swedish sample: for future time perspective, Cronbach's $\alpha = 0.72$; for present-hedonistic time perspective, $\alpha = 0.83$; for present-fatalistic time perspective, $\alpha = 0.72$.

Social Value Orientation Slider Measure

Social Value Orientation Slider Measure was used to assess social value orientation (original version: Murphy et al., 2011; Polish and Swedish versions taken from the international project materials by Froehlich et al., 2021). Six basic items assessing the continuum of social value orientation were used. The participants are asked to imagine they need to allocate resources through money payoff between themselves and a stranger. The measure is a decomposed game; each item reflects specific payoff allocations. The results are called the social value orientation angle and can be computed using a syntax by Baumgartner (*n/d*). The angle can take values from −16.26 (extremely competitive) to 61.39 (extremely altruistic). The measure enables classifying each participant into a category of competitive, individualistic, prosocial, or altruistic player (based on angle cutoff points) and obtaining a continuous score for relevant computations. In the current samples, among Poles, none of the participants was competitive, 33 (22.0%) individualistic, 116 (77.3%) prosocial, 1 (0.7%) altruistic; among Swedes, 2 (1.3%) participants were competitive, 21 (13.9%) individualistic, 126 (83.4%) prosocial, 2 (1.3%) altruistic.

Moral Foundations Questionnaire

Moral foundations questionnaire was used to measure moral foundations (original version: Graham et al., 2011; Polish version: Jarmakowski-Kostrzanowski and Jarmakowska-Kostrzanowska, 2016; Swedish version: Nilsson and Erlandsson, 2015). The tool consists of 30 items and is a self-report measure. The participant's task is to assess the importance of five moral foundations for decision-making. The foundations are fairness/reciprocity, harm/care, authority/respect, ingroup/loyalty, and purity/sanctity. In the first part of the questionnaire (15 items), the respondents answer how relevant specific issues are in making a moral decision for them, for example, *Whether or not someone acted unfairly*. In this part, the participants answer on a six-point Likert scale ranging from 1 = not at all relevant (*This consideration has nothing to do with my judgments of right and wrong*) to 6 = extremely relevant (*This is one of the most important factors when I judge right and wrong*). In the second part (15 items), the participants agree or disagree with statements reflecting moral foundations; for example, *People should not do things that are disgusting, even if no one is harmed*. In this part, the participants answer on a six-point Likert scale ranging from 1 = *strongly disagree* to 6 = *strongly agree*. The five moral foundations are typically further classified into two groups as follows: individualizing (fairness/reciprocity, harm/care) and

binding (authority/respect, ingroup/loyalty, and purity/sanctity; Van Leeuwen and Park, 2009; Garvey and Ford, 2014). As this approach is more statistically efficient and specifically serves our hypotheses testing, we embraced it. We counted general scores for Individualizing and binding moral foundations by computing the mean of relevant items for both subscales. For the Polish sample: for individualizing moral foundations, Cronbach's $\alpha = 0.81$; for binding moral foundations, $\alpha = 0.85$; for the Swedish sample: for individualizing moral foundations, Cronbach's $\alpha = 0.74$; for binding moral foundations, $\alpha = 0.84$.

Ecological behaviors in the last 6 months

We used a survey of our construction, which was based on one question (*In the last 6 months, to what extent have you…*) with answer options ranging from 0 = not at all to 10 = totally, asked about seven behaviors: (1) limited food waste in your household, (2) limited water waste in your household, (3) limited energy consumption in your household, (4) limited buying new clothes, (5) chosen local products over imported ones, (6) limited unnecessary travel, and (7) limited meat consumption (preceded by a question about general meat consumption and asked only to meat consumers). The global score was computed as the mean of seven items. For the Polish sample, Cronbach's $\alpha = 0.68$; for the Swedish sample, $\alpha = 0.62$.

Pro-environmental behaviors' intentions for the following 6 months

We used a survey of our construction, which was based on one question (*To what extent are you ready to undertake the following behaviors in the next 6 months*) with answer options ranging from 0 = not at all to 10 = totally, asked about seven behaviors as follows: (1) limit food waste in your household, (2) limit water waste in your household, (3) limit energy consumption in your household, (4) limit buying new clothes, (5) choose local products over imported ones, (6) limit unnecessary travel, and (7) limit meat consumption (preceded by a question about meat consumption and asked only to meat consumers). The global score was computed as the mean of seven items. For the Polish sample, Cronbach's $\alpha = 0.75$; for the Swedish sample, $\alpha = 0.75$.

Opinion about pro-environmental behavior and the pandemic threat link

We used a survey of our construction based on the following three statements: (1) *The pandemic has shown me that we should care for the environment more*, (2) *I fear that if we do not care for the environment, another pandemic may come in the future*, and (3) *I think that the COVID-19 pandemic appeared because we did not care for the environment as much as we should*. The participants answered on a 5-point Likert scale ranging from 1 = *totally disagree* to 5 = *totally agree*. The global score was computed as the mean of the three items. For the Polish sample, Cronbach's $\alpha = 0.77$; for the Swedish sample, $\alpha = 0.73$.

Analytical tools

We performed all analyses using SPSS 28.0.1.0 for Windows (IBM Corp., 2021). For moderation analysis *post-hoc* tests, we also used PROCESS v4.0 for SPSS (Hayes, 2018).

Results

Open data note

The analysis has been preregistered (hypotheses H1–H3 and the set of covariates); the document is available from https://aspredicted.org/blind.php?x=GF6_4W3. Data underlying the project is available from Open Science Framework under the link https://osf.io/wcszy/.

Descriptive statistics and intergroup comparisons

In Table A1, we present an overview of the descriptive statistics (mean, standard deviations, skewness, and kurtosis) regarding the variables of interest, as well as the results of the *t*-test of differences between Polish and Swedish samples in terms of these variables.

Data from Table A1 suggest that Poles and Swedes differed significantly in terms of their age, with Swedes being older, $t_{(281.56)} = -5.82$; $p < 0.001$ (degrees of freedom different than in other cases due to heterogeneous variances detected in Levene's test); present-hedonistic time perspective, with Poles having this individual difference higher than Swedes, $t_{(299)} = 5.33$; $p < 0.001$; individualizing moral foundations, with Poles having them higher than Swedes, $t_{(299)} = 4.85$; $p < 0.001$; binding moral foundations, with Poles having them higher than Swedes, $t_{(299)} = 2.60$; $p < 0.01$; and pro-environmental intentions for the next 6 months, with Poles displaying them as higher than Swedes, $t_{(299)} = 2.09$; $p < 0.05$.

Next, we performed a bivariate correlation analysis to gain insight into the associations among the investigated variables. The results of these analyses are provided in Table 1. As shown in Table 1, for the pro-environmental behaviors in the last 6 months, significant bivariate correlates were as follows: age, social value orientation, and individualizing moral foundations. Significant correlates for the pro-environmental intentions for the following 6 months were as follows: country (Poland), age, female gender, education, social value orientation, future time perspective, individualizing moral foundations, and pro-environmental behaviors in the last 6 months. For the opinion about the link between pro-environmental behaviors and the pandemic, significant correlates were female gender, social value orientation, individualizing moral foundations, pro-environmental behaviors in the last 6 months, and pro-environmental intentions for the following 6 months.

Next, to perform the preregistered analysis, we ran three moderation models with bootstrapping ($N = 5{,}000$) for the following dependent variables: pro-environmental behaviors score for the last 6 months (Model 1), pro-environmental intentions score for the following 6 months (Model 2), and the opinion about the threat of pandemic related to environmental issues (Model

TABLE 1 Bivariate correlations and descriptive statistics between study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Country (0 = Poland, 1 = Sweden)	–													
2. Age	0.32***	–												
3. Gender (0 = female, 1 = male)	0.15*	−0.06	–											
4. Education	−0.03	0.29***	−0.03	–										
5. Socioeconomic status	−0.07	0.02	0.05	0.18**	–									
6. SVO	0.05	0.05	−0.11	−0.05	0.08	–								
7. Future TP	−0.11	0.04	−0.11	0.16**	0.16**	0.07	–							
8. Present-hedonistic TP	−0.30***	−0.15**	−0.03	−0.09	−0.03	−0.03	−0.23***	–						
9. Present-fatalistic TP	−0.07	−0.08	−0.02	−0.16**	−0.15**	−0.01	−0.36***	0.47***	–					
10. MFQ—individualizing	−0.27***	0.04	−0.31***	0.07	−0.04	0.31***	0.13*	0.17**	0.00	–				
11. MFQ—binding	−0.15**	−0.03	0.23***	−0.01	0.02	−0.09	0.19***	0.17**	0.06	0.03	–			
12. Pro-environmental behaviors—past 6 months	0.03	0.15**	−0.10	0.06	−0.05	0.15**	0.10	0.02	−0.06	0.18**	−0.07	–		
13. Pro-environmental intentions—next 6 months	−0.12*	0.14*	−0.20***	0.12*	−0.01	0.20***	0.16**	0.06	−0.08	0.31***	−0.08	0.74***	–	
14. Pandemic threat-pro-environmental behaviors link opinion	0.00	−0.03	−0.25***	−0.10	−0.02	0.12*	0.01	0.07	−0.01	0.25***	−0.06	0.26***	0.25***	–

***$p < 0.001$.
**$p < 0.01$.
*$p < 0.05$.

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3). The main aim of the preregistered moderation analysis was to test the significance of the social value orientation × future time perspective × country interaction. Given the results of the correlation analysis, only the preregistered covariates, which were significant correlates in our sample, were entered into the models. All variables were standardized before entering them into the models; interactions were computed on centered variables. The results of moderation analyses are presented in Tables 2–4.

According to Table 2, the overall regression was statistically significant, $F_{(9;291)} = 3.27$, $p < 0.001$, $R^2_{adj} = 0.064$. The statistically significant predictors of pro-environmental behaviors in the last 6 months were as follows: the interaction between future time perspective and social value orientation, $B = -0.10$; 95% CI (−0.20; −0.00), age, $B = 0.14$; 95% CI (0.02; 0.26) and individualizing moral foundations, $B = 0.14$; 95% CI (0.02; 0.27). Due to one significant interaction found in the analysis, we performed *a post-hoc* analysis. They indicated that the link between future time perspective and pro-environmental behaviors in the last 6 months was statistically significant only for low social value orientation, $B = 0.17$, 95% CI (0.02; 0.32), whereas it was insignificant for average, $B = 0.07$; 95% CI (−0.05; 0.18) and high, $B = -0.03$; 95% CI (−0.19; 0.12) social value orientation.

As indicated in Table 3, the overall regression was statistically significant, $F_{(11;285)} = 4.65$, $p < 0.001$, $R^2_{adj} = 0.120$. The statistically significant predictors of pro-environmental intentions for the following 6 months were as follows: age, $B = 0.13$; 95% CI (0.02; 0.25) and individualizing moral foundations, $B = 0.19$, 95% CI (0.07; 0.32).

Data in Table 4 suggest that the overall regression was statistically significant, $F_{(9;287)} = 4.05$, $p < 0.001$, $R^2_{adj} = 0.085$. The statistically significant predictors of the opinion about the link between the pandemic and pro-environmental behavior were as follows: female gender, $B = -0.20$; 95% CI (−0.32; −0.09) and individualizing moral foundations, $B = 0.21$, 95% CI (0.08; 0.32).

Discussion

In the current study, we aimed to investigate the role of future time perspective, social value orientation, and their interaction in predicting the following: (1) pro-environmental behaviors in the last 6 months, (2) pro-environmental behavior intentions in the following 6 months, and (3) opinion about the linkage between pro-environmental attitude and the threat of pandemics. We also intended to control for individualizing/binding moral foundations, present time perspectives, and demographic variables, including age, gender, education, and socioeconomic status, to determine whether the hypothesized interaction was significant above these variables.

As judged by the correlation analyses, the data supported H1 about the positive relationship between social value orientation and the outcome variables. A significant positive association was observed for pro-environmental behaviors, intentions, and opinions, which is consistent with prior research (De Groot and Steg, 2010), even though in none of the cases, this simple effect remained significant when controlling for other variables of interest. Similarly, the bivariate analyses revealed that future time perspective was positively associated with pro-environmental intentions, which aligns with prior research (Milfont et al., 2012). However, this simple effect was no longer observed in the multivariate analyses. Interactions hypothesized in H2 and H3 could explain the lack of simple effects.

H2 and H3 referred to the potential differences between Poland and Sweden regarding the future time perspective and social value orientation interaction in predicting pro-environmental behaviors/intentions/opinions. Our results were contrary to both hypotheses. The participants' country of origin did not play a moderating role in the models. As social value orientation and future time perspective are individual differences, present regardless of the culture, their interaction mechanisms may translate into similar outcomes. However, given that Poland and Sweden are part of the W.E.I.R.D. world (Henrich et al., 2010), further studies are needed to investigate whether the effects pertain to non-Western countries.

The lack of difference between Poland and Sweden may also stem from the lack of difference between our samples in terms of the levels of future time perspective, social value orientation, pro-environmental behaviors in the last 6 months, and the opinions about the link between pro-environmental behaviors and the pandemic threat. The specificity of online panel users might partially explain it. Such panels attract active users of the Internet, who, at the same time, wish to earn some small sums of money for their survey participation. It may be the reason for the similarity of samples in terms of the investigated mechanisms. However, the study revealed some interesting differences between our samples. First, Poles were younger and more Present-Hedonistic. These two characteristics are typically associated (Laureiro-Martinez et al., 2017), as younger people are more risk-taking and pleasure-oriented than older people.

Moreover, Poles were higher on both individualizing and binding morality. Poland might have a higher social desirability bias regarding morality-related statements, as it is a less secularized country than Sweden (Demerath, 2000). Detachment from religion in Sweden might encourage people to self-report their moral convictions more carefully. Moreover, as Poland is a more conservative society at large than Sweden, the integration between individualizing and binding morality might be higher in Polish society (Turner-Zwinkels et al., 2021).

Finally, Poles had greater pro-environmental intentions for the following 6 months than Swedes, which is in line with a recent study by Iwińska et al. (2023) about the pro-environmental behaviors during COVID-19 in Europe. It might be related to the economic concerns related to inflation, as in Poland, the harmonized inflation rate for 2022 was 13.15%. In contrast, in Sweden, it was 8.04% (Worldwide Inflation Data, 2023). Poles, therefore, might have thought more about ways to reduce their expenses in the nearest future, and the behaviors we asked about were one of the ways to do so.

A two-way future time perspective and social value orientation interaction were statistically significant for the past pro-environmental behaviors in the last 6 months' model. It was not observed for other models. The *post-hoc* tests indicated that the future time perspective activates only when social value orientation is low. Thus, the norm activation model (Schwartz, 1970) notions

TABLE 2 Results of moderation analysis predicting pro-environmental behaviors in the last 6 months.

Predictors	*B* (95% CI)	SE	*t*	*p*-value
Future time perspective	0.07 (−0.04; 0.19)	0.06	1.17	0.242
Social value orientation	0.09 (−0.03; 0.21)	0.06	1.47	0.144
Country (0 = Poland, 1 = Sweden)	0.03 (−0.09; 0.14)	0.06	0.40	0.687
Future time perspective × Social value orientation	−0.10 (−0.24; −0.01)	0.05	−1.97	0.050
Future time perspective × Country	−0.05 (−0.16; 0.06)	0.06	−0.95	0.342
Social value orientation × Country	0.06 (−0.04; 0.18)	0.06	1.13	0.262
Social value orientation × Future time perspective × Country	0.07 (−0.07; 0.17)	0.05	1.33	0.184
Age	0.14 (0.03; 0.25)	0.06	2.29	0.022
Individualizing moral foundations	0.14 (0.02; 0.26)	0.06	2.30	0.022
R^2_{adj}	0.064			
$F_{(9;291)}$	3.27			
p-value	<0.001			

TABLE 3 Results of moderation analysis predicting pro-environmental intentions for the next 6 months.

Predictors	*B* (95% CI)	SE	*t*	*p*-value
Future time perspective	0.08 (−0.02; 0.22)	0.06	1.45	0.148
Social value orientation	0.12 (0.01; 0.24)	0.06	1.93	0.054
Country (0 = Poland, 1 = Sweden)	−0.10 (−0.22; 0.02)	0.06	−1.59	0.113
Future time perspective × Social value orientation	−0.02 (−0.17; 0.08)	0.05	−0.40	0.691
Future time perspective × Country	−0.03 (−0.14; 0.09)	0.06	−0.57	0.571
Social value orientation × Country	0.03 (−0.09; 0.14)	0.06	0.45	0.653
Future time perspective × Social value orientation × Country	0.00 (−0.13; 0.11)	0.05	0.00	0.999
Age	0.13 (.02; 0.25)	0.06	2.17	0.031
Gender (0 = female, 1 = male)	−0.09 (−0.20; 0.02)	0.06	−1.58	0.115
Education	0.05 (−0.09; 0.20)	0.06	0.93	0.353
Individualizing moral foundations	0.19 (0.07; 0.31)	0.06	3.06	0.002
R^2_{adj}	0.120			
$F_{(11;285)}$	4.65			
p-value	<0.001			

were not fully confirmed. In our study, people low on social value orientation are focused on the benefits to self (Murphy and Ackermann, 2014). For these people, future time perspective can activate pro-environmental behaviors due to thinking about the positive consequences, for example, saving money (Rolison et al., 2017). It is because pro-environmental behaviors may be motivated by a desire to save money by cutting down expenses (e.g., by saving energy or water or avoiding meat consumption). Notably, 6 months before the study referred to a period of post-COVID and then the war in Ukraine-related inflation in Europe, which strongly encouraged people to save money and energy. It could translate into the effect observed in our study.

Consistent with H4, individualizing moral foundations positively predicted pro-environmental behaviors, intentions, and opinions; moreover, they seemed to be the strongest predictor of all investigated. It aligns with previous data (Vainio and Mäkiniemi, 2016; Milfont et al., 2019). However, contrary to the second part of H4, binding moral foundations were not significantly linked to any of the examined dependent variables. It suggests that rather than cooperation or ingroup, loyalty or sanctity valuing tendencies, the moral imperative of caring for other individuals can be universal in predicting environmental care and feeling threatened by pandemics. It is in line with previous research on environmental concerns and moral foundations by Milfont et al. (2019). It shows an interesting avenue for future research and formulating messages highlighting individual testimonies or individual-level consequences when promoting environmental actions.

TABLE 4 Results of moderation analysis predicting the opinion about the pandemic threat and pro-environmental behaviors' link.

Predictors	*B* (95% CI)	SE	*t*	*p*-value
Future time perspective	−0.04 (−0.17; 0.10)	0.06	−0.77	0.442
Social value orientation	0.02 (−0.10; 0.13)	0.06	0.36	0.721
Country (0 = Poland, 1 = Sweden)	0.08 (−0.04; 0.20)	0.06	1.33	0.185
Future time perspective × Social value orientation	−0.03 (−0.16; 0.08)	0.05	−0.54	0.593
Future time perspective × Country	0.05 (−0.08; 0.18)	0.06	0.83	0.410
Social value orientation × Country	−0.04 (−0.15; 0.07)	0.06	−0.71	0.481
Future time perspective × Social value orientation × Country	−0.06 (−0.20; 0.04)	0.05	−1.09	0.278
Gender (0 = female, 1 = male)	−0.20 (−0.32; −0.09)	0.06	−3.39	<0.001
Individualizing moral foundations	0.21 (0.08; 0.32)	0.06	3.27	0.001
R^2_{adj}	0.085			
$F_{(9;287)}$	4.05			
p-value	<0.001			

Regarding the demographic variables, the female gender was significantly associated with pro-environmental intentions for the next 6 months, and opinions about the pandemic threat and pro-environmental behaviors link. For the latter outcome variable, the gender association remained significant in models including the entire set of predictors. These findings are consistent with the evidence of stronger environmental attitudes and behaviors in females reported elsewhere (e.g., Zelezny et al., 2000). Research shows that women feel more threatened by the COVID-19 pandemic (Luo et al., 2021). Also, in our study, older age was a unique predictor of pro-environmental behaviors and intentions. This pattern aligns with meta-analytic evidence that older adults are slightly more likely than younger adults to engage in nature, avoid environmental harm, and conserve raw materials (Wiernik et al., 2013). However, no significant effect was observed in bivariate analyses for sociodemographic status and no effect in multivariate analyses for education. The reason behind this could be the recruitment strategy—Prolific.co panelists may be specific regarding their sociodemographic characteristics, and they do not constitute a representative sample. However, given that pro-environmental behaviors are, on the one hand, beneficial to the family budget (saving) and, on the other—money consuming (investment in eco-friendly products), the motivation behind them might be different in people of different socioeconomic status/education. Therefore, the simple effects of these demographic variables disappear.

Limitations of the study and future research directions

Although our study provides some interesting insight into pro-environmental behaviors and intentions, it has limitations that should be considered. First, the study was performed online with limited control over how attentive the respondents answered the survey. It was also purely questionnaire- and declaration-based, potentially producing self-report or social desirability bias. Observational, experimental, intervention, or multi-method studies would be a way to corroborate further the results and conclusions drawn.

Moreover, the participants were recruited with a method of convenience sampling and only registered users of Prolific.co, which formed a specific and non-representative study sample. Despite targeting a broad audience, this data collection method limited the chances of capturing the full complexity of human behavior. Furthermore, this study involves cross-sectional analyses, precluding firm conclusions regarding the causal mechanisms involved. To overcome this limitation, future studies should employ longitudinal designs to, for example, examine the cross-lagged associations of variables. An exciting avenue would be ecological momentary assessment or diary studies on pro-environmental behaviors, which could help us determine how people behave in specific timeframes.

Furthermore, our study relied on a selected theoretical framework, broadened based on the literature review and the new avenues emerging in the field. Given the promising role of individualizing moral foundations in predicting pro-environmental behaviors/intentions/opinions, future studies should continue to examine this variable to deepen the understanding of the mechanisms underlying this link. Other relevant theoretical frameworks could be applied to enhance the robustness of the analyses.

We gathered data from two countries differing in the quality of their green policies and the level of support for pro-environmental causes in current politics. Future studies could control for more specific factors helpful in determining under what conditions future time perspective shapes pro-environmental opinions/behaviors. From the contextual level, it could be the general income in a country, wealth of a place of living, inflation indices at the time of conducting the study, indicators of green policies in the place of residence, and measures of state support for the environment. Furthermore, from the individual level, the propensity to save

money or to spend it on valued causes could be used as potential covariates/moderators of the future time perspective effect on pro-environmental opinions/behaviors.

Implications for practice

Our data supported the idea regarding the role of future time perspective for green behaviors only in the case of past pro-environmental behaviors. Regardless of the participant's country of origin, future time perspective was related to pro-environmental behaviors in the last 6 months only when social value orientation was low. It suggests that not the cultural aspects but the level of orientation toward others' welfare plays a role in the case of this behavior. For example, the results might be used when advertising pro-environmental behaviors and designing campaigns. When encouraging more competitive (compared to altruistic) people to behave in a green way, it might be crucial to underline the future consequences and benefits, consistent with the future time perspective. The pro-environmental campaigns could, therefore, highlight how green behavior may bring personal gains in the future, which are typically valued by individualistic people, such as savings or social status. Existent pro-environmental programs based on competitiveness, such as Greencoin (Duda et al., 2022), which, based on the mobile application, encourages learning and reporting own green behaviors to obtain rewards, can be a good example of a way to go in order to encourage competitive people to behave pro-environmentally. Moreover, individualizing moral foundations of care and justice concerns appeared to predict behaviors, intentions, and opinions regarding pro-environmental issues. When educating and raising pro-environmental awareness, activation of this kind of morality may help promote green behaviors. This could happen by highlighting how attentiveness to the environment can contribute to caring for vulnerable members of society or how fair it is in the context of the community. For example, it is worth showing that behaving pro-environmentally encourages social equality and supports individual people's welfare.

Author's note

The study has been preregistered with AsPredicted.org: https://aspredicted.org/blind.php?x=GF6_4W3.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://osf.io/wcszy/ (Open Science Framework).

Ethics statement

The studies involving humans were approved by Research Ethics Committee at The Maria Grzegorzewska University, approval number 89/2022. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

IN: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing—original draft, writing—review and editing, visualization, supervision, project administration, and funding acquisition. MR: conceptualization, methodology, writing—original draft, and writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

TABLE A1 Descriptive statistics of variables of interest and intergroup comparisons.

Variable	Polish sample				Swedish sample				*t*	*p*
	M	*SD*	Skewness	Kurtosis	*M*	*SD*	Skewness	Kurtosis		
Age	25.45	7.55	1.79	3.19	31.32	9.81	1.25	1.17	−5.82	<0.001
Education	14.99	2.13	0.51	−0.41	14.84	2.99	0.24	1.88	0.49	0.626
Socioeconomic status	5.81	1.74	−0.34	0.08	5.52	2.36	−0.11	−0.45	1.21	0.226
SVO	30.91	12.27	−0.98	0.76	32.22	13.00	−1.50	3.11	−0.90	0.370
Future TP	3.40	0.62	−0.59	0.21	3.27	0.55	0.03	0.07	1.95	0.052
Present-hedonistic TP	3.32	0.53	0.19	−0.07	2.96	0.60	−0.04	−0.21	5.44	<0.001
Present-fatalistic TP	2.77	0.61	0.26	−0.10	2.69	0.63	0.09	−0.45	1.18	0.240
MFQ—individualizing	4.77	0.63	−0.81	1.40	4.42	0.64	−0.16	−0.11	4.85	<0.001
MFQ-binding	3.26	0.70	0.04	−0.21	3.04	0.70	0.04	−0.33	2.69	0.008
Pro-environmental behaviors—past 6 months	5.51	1.67	−0.70	0.61	5.63	2.00	−0.26	−0.67	−0.60	0.551
Pro-environmental intentions—next 6 months	6.39	1.79	−0.89	1.22	5.95	1.86	−0.66	0.06	2.09	0.037
Pandemic threat-pro-environmental behaviors link opinion	2.76	1.04	−0.19	−0.64	2.76	1.15	0.27	−0.79	−0.03	0.976

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Collectivist culture, environmental regulation and pollution emissions: evidence from China

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Collectivist culture serves as a significant cultural foundation in China. It could, to some extent, shape public attitudes toward the environment and thus influence the implementation of related policies. To examine this hypothesis, this study constructs the collectivist culture intensity index for 25 Chinese provinces spanning from 2010 to 2020. Through a fixed-effect model, we explore how the collectivist culture intensity affects pollution emissions in China. The empirical results indicate the significance of collectivism in enhancing emission reduction through environmental regulations. This conclusion remains robust even when excluding the impact of endogeneity concerns by adopting the instrumental variable approach. Heterogeneity analysis shows that collectivism is more effective in enhancing market-based environmental regulations rather than those driven by policies. Further mechanism analysis confirms that green innovation is a crucial pathway through which collectivism influences pollution emissions. These findings here will offer guidance to policymakers when formulating environmental policies for contexts with different regional cultures.

KEYWORDS

collectivist culture, environmental regulation, pollution reduction, environment governance, fixed-effect model

1 Introduction

With China's rapid economic development, environmental protection issues have become more prominent. Fast-paced industrialization and urbanization have led to significant energy consumption and waste emissions, severely impacting environmental quality. Pressing challenges include addressing coal and automobile exhaust emissions, industrial wastewater, and solid waste management, exerting immense pressure on both the ecological environment and public health (Alford and Liebman, 2000). According to the Environmental Performance Index Report (Wendling et al., 2020), China ranked 120th out of 180 countries and regions assessed, reflecting the multitude of environmental challenges to be confronted.

Environmental pollution not only undermines the physical and mental well-being of citizens (Schlenker and Walker, 2011; Chen and Chen, 2018; Weinmayr and Forastiere, 2022), but also carries substantial economic costs (Ito and Zhang, 2020). In response, the Chinese government has made efforts to strike a balance between economic growth and environmental protection (Tu and Chen, 2015), and implemented environmental regulations to enhance the management and control of pollutant emissions (Chen et al., 2021; Luo and Qi, 2021; Dong and Chang, 2023).

However, regulations often fall short of effectively addressing environmental issues due to deficiencies in environmental governance and policy implementation. Economic development pursuit by local officials may take precedence over environmental protection due to promotion incentives (Jia, 2017). Collusion between the government and enterprises can lead to increased pollution emissions after inspection periods (Sun et al., 2022). Relying solely on legislative measures without robust enforcement and supervision is insufficient to significantly curb pollution intensity (Bao et al., 2013). Informal institutions, from the perspective of new institutional economics, encompass a broader range of constraints and exhibit contagious continuity compared to formal regulations (Hu et al., 2017). Therefore, informal institutions can enhance the effectiveness of environmental regulations when formal regulations prove ineffective (Tietenberg, 1998; Xu, 2014).

The informal institutions are the unwritten and widely recognized behavioral norms that develop unconsciously through long-term social interactions (North, 1990). They stem from trust and consensus among individuals. Current research on informal institutions related to environmental regulations mainly centers around factors such as religion and lineage (Bi et al., 2015), trust (He et al., 2015; Yang and Niu, 2023), hometown identification (Hu et al., 2017), and individual consciousness (Boiral et al., 2018). Collectivism is a prominent cultural characteristic worldwide and significantly shapes individual and societal behaviors (Lonner et al., 1980). Given this influence, it is reasonable to hypothesize that individuals from various collectivist cultural backgrounds may display distinct attitudes and behaviors toward the environment, potentially impacting the effectiveness of environmental regulations. Thus, this study aims to investigate how collectivist culture influences environmental regulations as an informal institution.

The characteristic of collectivism is evident in individuals forming close group relationships for mutual protection (Lonner et al., 1980). In collectivist cultures, when an individual's opinions differ from those of the larger group, consideration is given to the impact of individual behavior on others. As a result, individual interests are often subordinated to the collective well-being. In contrast, in individualistic cultures, individuals tend to prioritize personal achievements or immediate benefits (Bhagat, 2002). Therefore, these two cultures, collectivism and individualism, have different influences on people's propensity to engage in environmental behaviors.

There is scope for improving the assessment of collectivist culture, not only theoretically but also in quantitative analysis. For instance, relying solely on methods like the rice theory (Talhelm et al., 2014) and dummy variables to measure collectivist intensity might overlook relevant information (Xu et al., 2016; Han et al., 2021). Hence, employing more refined quantitative methodologies is essential to validate the influence of collectivist culture on environmental regulations.

In this study, we aim to explore the combined impact of collectivist culture and individual environmental behaviors on regulatory effects, especially those related to environmental regulations. Our study has several distinct characteristics compared to previous research. Firstly, we have improved the methodology for constructing collectivism indicators based on existing studies. By creating a continuous measure of collectivism at the provincial level in China, we are able to better capture the temporal and spatial heterogeneity of collectivism in the country. Secondly, we have focused specifically on the role of regional collectivist culture in moderating formal environmental regulations, examining the robustness of our findings from multiple perspectives. Lastly, our study has validated the pathways and mechanisms through which collectivism influences pollution emissions.

2 Literature review and hypothesis development

2.1 Collectivist culture and environmental regulation

China has the strongest collectivist culture in the world (Van de Vliert et al., 2013). Existing research attributes the origins of China's collectivism to Confucian culture (Bond and Hwang, 1986), widespread diseases (Fincher and Thornhill, 2012), agricultural patterns (Talhelm et al., 2014), climate (Van de Vliert, 2011), and urbanization (Freeman, 1997), among many other factors. And studies acknowledge the presence of regional variations in collectivism within China (Gong et al., 2021).

The impact of regional collectivist culture on environmental regulations and pollution emissions encompasses various dimensions. Firstly, both environmental regulations and collectivist culture exert considerable influence on individuals, particularly in shaping their environmental attitudes and behaviors. Individuals within collectivist cultures tend to exhibit inclinations toward resource conservation and engagement in eco-friendly consumption practices (Dunlap and Liere, 1984; Kim and Choi, 2005). Studies by Cho et al. (2013) focusing on young populations in the United States and South Korea revealed a significant correlation between collectivist tendencies and positive environmental attitudes. Similarly, Nartova-Bochaver et al. (2022) found that respondents from collectivist cultural regions are more attuned to global climate deterioration. Moreover, research by Xue et al. (2016) conducted among participants in Beijing showcased stronger support for climate change control policies among individuals with a collectivist cultural background. Jia et al. (2017) also observed that environmental activists tend to endorse self-transcendent values, aligning closely with collectivist traits.

Beyond individual attitudes, environmental economists scrutinize how collectivism influences enterprise decision-making, particularly in environmental contexts. Studies suggest that managers rooted in collectivist cultures demonstrate a proclivity toward environmentally favorable decisions. Wang et al. (2022) discovered that companies led by CEOs from regions steeped in collectivist culture tend to make more environmentally conscious

investments and R&D choices to comply with environmental regulations. Similarly, Qu (2023) identified that collectivist culture contributes to managerial decisions favoring regional green transformation. Collectivists, both at the individual level and within policymaking spheres, tend to share unified environmental protection goals and foster positive environmental attitudes. Consequently, collectivist culture, operating as an informal institutional force, can complement environmental regulatory frameworks effectively.

Secondly, Sivadas et al. (2008) classified collectivism into horizontal collectivism (HC) and vertical collectivism (VC). While both recognize the significance of interdependence, HC emphasizes individuals' pursuit of personal goals, whereas VC individuals are more inclined to sacrifice personal objectives for the sake of the group's goals (Triandis and Gelfand, 1998). Therefore, in regions characterized by higher levels of vertical collectivism, individuals are more willing to adhere to constraints and norms when regulations contribute to collective goals, such as emission reduction. For instance, during the COVID-19 pandemic, collectivist cultures facilitated greater adherence to government directives among local populations (Song and Choi, 2023), ensuring effective implementation of preventive measures like wearing masks (Lu et al., 2021), consequently reducing infection rates. Kumar's (2021) global study on collectivist cultures and the severity of COVID-19 confirmed this observation. Similarly, Xue et al. (2016) found in samples from Beijing that respondents with a collectivist cultural background expressed greater support for climate change control policies compared to individualists.

Comparable evidence exists within collectivist groups, where survey research demonstrates their heightened concern for ecological conservation (Semenova, 2015; Peng et al., 2019; Naiman et al., 2023) and greater likelihood to endorse corresponding policies. Enterprises are also influenced similarly; collectivist culture impacts managerial decisions within companies (Fok et al., 2016), stimulating corporate social responsibility (Thanetsunthorn, 2015), compliance with environmental policies, and reduction of carbon emissions (Rahman et al., 2023). Therefore, we propose *Hypothesis 1a: Collectivism exhibits a negative moderating effect on the impact of environmental regulations on pollution emissions.*

2.2 How does collectivist culture influence pollution emissions

The impact of collectivist culture itself on pollution emissions remains inconclusive. Some cross-national studies have found a negative correlation between collectivist culture and regional environmental performance (Husted, 2005; Graafland and Noorderhaven, 2018). However, this contradicts the earlier conclusion that collectivists hold more positive environmental attitudes. We suggest several explanations for this discrepancy.

Firstly, regional environmental regulations play a significant role in identifying the relationship between collectivist culture and pollution emissions. Ho et al. (2012) found that developed Asian countries, with collectivist cultures, exhibit higher environmental awareness than North American countries but lower than European countries. This discrepancy stems from the fact that European countries tend to have more stringent regulations, whereas the United States favors self-regulation. Stringent environmental regulations better control heterogeneous regional pollution emissions.

Moreover, when controlling for similar environmental regulations, Asian countries' collectivist culture restricts their discretionary powers, resulting in less societal oversight of corporate environmental practices compared to European countries. For example, due to its collective nature, Asian societies might be less inclined to judge or question the actions of senior executives in a company, even if these actions contradict individual values or beliefs. In a recent study, Muttakin et al. (2022) also discussed the importance of democracy in moderating the influence of culture on greenhouse gas emission intensity. Therefore, when regulatory force weakens, collectivists may engage in actions aligned with their environmental attitudes. Hence, we propose *Hypothesis 1b: Collectivism exhibits a stronger moderating effect in moderate regulations.*

Environmental regulations can be categorized into command-and-control regulations and market-based regulations (Zhao et al., 2009). Command-and-control regulations typically refer to environmental policies established and enforced by the government. On the other hand, market-based regulations involve the government designing market-based mechanisms, such as emission permits, pollution rights trading, and pollution charges, to incentivize firms to adjust their production processes and reduce pollution emissions (Hennessy and Roosen, 1999; Zhao et al., 2009). We will examine in this study whether moderate-intensity market-based policies afford greater discretion to firms in regions with collectivist cultures, enabling them to act in line with their environmental attitudes.

2.3 The effect of collectivist culture on pollution emissions in China

In the context of China, environmental issues exhibit a dual nature, serving as both a political achievement and cost. For local officials, resolving environmental problems can enhance their political reputation, but it also implies limitations on the operational activities of local enterprises, potentially negatively impacting regional Gross Domestic Product (GDP). This factor often significantly influences the assessment and advancement criteria for these officials. Additionally, these regulations commonly elevate production costs for enterprises, posing a challenge to the primary objective of profit maximization for shareholders.

As a result, we suggest that when faced with conflicting goals between economic growth and environmental protection, economic growth tends to be prioritized as a collective interest, potentially leading to the perception that environmental protection is a secondary task that may be overlooked (Kyriacou, 2016). Furthermore, collectivism is more prone to fostering corruption issues (Mazar and Aggarwal, 2011), allowing local governments and polluting enterprises to maintain production by temporarily shutting down businesses, manipulating samples for inspection, or falsifying emission data when faced with higher-level environmental policies. Therefore, we propose *Hypothesis 2: Collectivism exhibits a positive effect on pollution emissions in China, leading to an increase in emissions.* To elucidate the interconnections between hypotheses and diverse factors, we have developed a conceptual model, depicted in **Figure 1**.

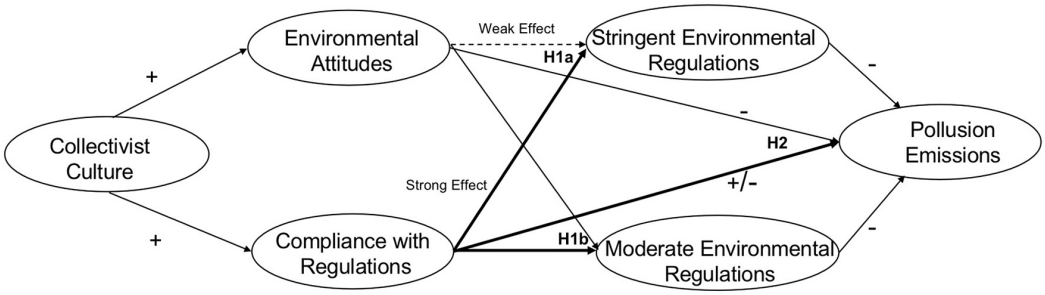

FIGURE 1
Conceptual model.

2.4 The STIRPAT model and control variables

To investigate the relationship between collectivist culture, environmental regulations, and environmental pollution, it is essential to integrate them into a unified model. Leveraging the work of Dietz and Rosa (1997), this study employed the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model to establish a foundational regression framework. The STIRPAT model aims to explore the potential impact of factors such as population growth, economic affluence, and technological advancements on environmental effects. Over time, this model has found widespread application in studies concerning environmental pollution (York et al., 2003; Fan et al., 2006; Shahbaz et al., 2016; Vélez-Henao et al., 2019).

Ayad et al. (2023) utilized the STIRPAT model and data spanning from 1970 to 2020 to examine the influence of economic policy uncertainty on environmental quality in the Middle East and North African countries. Similarly, Sadorsky (2014) investigated the impact of urbanization on the environment using the STIRPAT model in emerging economies. The enduring use of the STIRPAT model stems from its adaptability. For instance, Wang et al. (2013) incorporated energy structure and foreign trade development into the model to analyze environmental stress in China's Guangdong province. Adebayo et al. (2023) introduced factors like risk and renewable energy consumption into the STIRPAT model when studying the ecological footprint of MINT countries. Moreover, York et al. (2003) suggested the inclusion of an ecological resilience index in the STIRPAT model to measure the sensitivity of natural environments to various influencing factors. Ofori et al. (2023) complemented the STIRPAT model with environmental technology, environmental taxes, and institutional frameworks to validate the role of sustainable environmental policies and taxation systems in carbon emissions reduction.

In order to explore the impact of cultural variables in research, Hofstede (2001) recommends controlling for economic development. The main reason is that if economic, biological, and technological variables are more predictable then cultural indexes become redundant. Hence, this study extends the basic framework of the STIRPAT model by incorporating constructed collectivist cultural variables and regional control variables. Gross Domestic Product (GDP) per capita measures the total production of goods and services within a region, reflecting its economic strength and market size. In China, a nation with an industrial base, regions experiencing rapid GDP growth may prioritize economic development over environmental protection (He et al., 2020), influencing local individualistic culture (Hamamura, 2012), hence necessitating control. Current research widely acknowledges the nonlinear relationship between economic growth and environmental pollution (Cole et al., 1997; Stern, 2017). Thus, including the squared term of GDP in linear models is a common approach. Cai et al. (2021) proposed that China's urbanization is linked to its ecological environment, affected by factors such as pollution control measures and economic development (Zhang et al., 2022). Furthermore, urbanization is related to regional collectivist culture (Gong et al., 2021) and hence requires inclusion in the model. Industrial structure represents the proportion of agriculture, industry, and services in the economic structure. The weight of industry and services indicates the trend of industrial structure transitioning from lower to higher forms. Mi et al. (2015) noted that with a rational industrial structure setup, energy consumption intensity can be reduced without affecting economic growth, thereby diminishing environmental pollution. Foreign direct investment (FDI) is a primary form of modern capital internationalization. For developing countries, FDI may relocate highly polluting factories to the invested country, leading to adverse environmental effects (Rafindadi et al., 2018).

2.5 Endogeneity of collectivist culture and environmental regulation

Existing research has demonstrated that air pollution can potentially evoke collectivist tendencies by impacting mental health (Bao et al., 2018; Li and Zhang, 2019). Hence, the connection between collectivism, environmental regulations, and pollution emissions may contain endogeneity. To address this issue, this study aims to employ instrumental variable methods. An effective instrumental variable necessitates a correlation with the original variable, and this section will focus on elucidating the theoretical background of this correlation.

Previous research has established a strong association between divorce rates and collectivism (Dion and Dion, 1996). Individualists are less inclined to sacrifice personal satisfaction for a failed marriage, even when divorce involves emotional and economic costs (Toth and Kemmelmeier, 2009). Consequently, regions with

higher levels of collectivism often exhibit lower divorce rates (Hou et al., 2016; Ji et al., 2023). In this study, we will use the divorce rate per 10,000 individuals as an instrumental variable (iv1) to capture the relationship between divorce rates and collectivism.

Clan systems represent a social organization emphasizing kinship ties, shared responsibilities, and mutual assistance among family members (Peng, 2004). These systems foster social trust and facilitate collective action (Zhang and Ma, 2017). Thus, there exists a positive correlation between clan culture and the intensity of collectivist values. Consistent with prior research, we will adopt the density of genealogical records per 10,000 individuals as a proxy for clan culture (iv2).

Confucianism emphasizes the stability and harmony of family, community, and society, as well as individual responsibilities, obligations, and loyalty. These values have shaped a collective orientation within Chinese society, where individuals prioritize community interests over personal gains and believe their behavior should adhere to social norms and moral principles. Park (1998) defines Confucian collectivism as a specific dimension based on group behavior regulation, conformity, interdependence, and face-saving. To measure the strength of Confucian culture, we have chosen the number of successful candidates (also known as "Jinshi") in the imperial examinations during the Qing Dynasty as a representative indicator. During this period, success in these exams granted individuals official positions and social status, reflecting the local population's adherence to Confucian ideology, indirectly indicating the intensity of Confucian culture (iv3).

Lastly, Local governments typically summarize previous-year achievements, propose developmental objectives, and outline policy directions for the subsequent year in their annual reports. Hence, the frequency of environmental-related terms (iv4) in these reports signifies the government's willingness, determination, and overall capacity in environmental governance. Moreover, as government reports precede environmental data for the year, this temporal difference mitigates concerns about timing-induced endogeneity issues (Yang and Niu, 2023).

3 Materials and methods

3.1 Baseline model

Dietz and Rosa (1997) proposed the STIRPAT model based on the IPAT framework, which categorizes the human factors influencing environmental pollution into population size, wealth, and technology. The IPAT model is typically represented as $I = \alpha P_{it}^{b} A_{it}^{c} T_{it}^{d} e_{it}$,where I, P, A, T represent environmental pollution, population, wealth, and technology, respectively, and e represents the error term. Taking the logarithm of both sides of the IPAT equation yields the STIRPAT model, which can be expressed as:

$$\ln I_{it} = \alpha + b\ln P_{it} + c\ln A_{it} + d\ln T_{it} + e_{it} \quad (1)$$

To examine the effect of environmental regulation on pollution reduction, we extend Model (1) and obtain the baseline model as shown in Equation (2):

$$PI = \beta_1 ER_{it} + \beta_2 L\_ER_{it} + \beta_3 control + u_i + v_t + \varepsilon_{it} \quad (2)$$

Where, PI represents the environmental pollution intensity constructed using the entropy weight method. Recognizing the potential lagged effect of environmental regulation, we include both the current variable of environmental regulation (ER) and its lagged 1 year variable (L_ER) in the model. To ensure sample size and panel data balance, we selected the lagged period to be 1 year, using data from 2009, 2011, 2013, 2015, 2017, and 2019 as L_ER. Control represents a series of control variables, including economic growth, population density, technological progress, and others. The terms u and v represent the fixed effects of provinces and years, respectively.

3.2 Moderation effects model

The concept of moderation effect refers to the variation in the relationship between an explanatory variable and a dependent variable due to changes in a moderating variable. A basic model for moderation effect is shown in Equations (3) and (4), where D represents the explanatory variable, Y represents the dependent variable, and M is the moderating variable. With the inclusion of the moderating variable M, the marginal effect of the explanatory variable on the dependent variable changes from β_1 to $\beta_1' + \beta_3 \times M$. In the context of interaction effects, when the coefficient $\beta_3 > 0$, it signifies that the positive influence of the explanatory variable on the dependent variable intensifies with an increase in the moderating variable. Conversely, when $\beta_3 < 0$, it indicates that the positive impact of the explanatory variable on the dependent variable diminishes as the moderating variable increases. Therefore, the coefficient β_3 is typically examined to assess the presence of a moderation effect within the model.

$$Y = \beta_0 + \beta_1 D + \beta_2 M + \varepsilon \quad (3)$$

$$Y = \beta_0' + \beta_1' D + \beta_2' M + \beta_3 M \times D + \varepsilon \quad (4)$$

To examine the moderating effect of collectivist culture on environmental regulations, we introduce the collectivism variable into model (2) and construct model (5) to test its moderation effect.

$$PI = \alpha_1 Col_{it} + \beta_1 ER_{it} + \beta_2 L\_ER_{it} + \alpha_2 Col_{it} \times L\_ER_{it} + \beta_3 control + u_i + v_t + \varepsilon_{it} \quad (5)$$

Where Col denotes the collectivism index of each province, and $Col \times L\_ER$ represents the interaction term between collectivism and environmental regulations.

3.3 Variable selection and data sources

3.3.1 Dependent variables

Pollution Intensity (PI): To obtain a comprehensive assessment of pollution emissions in Chinese provinces, we curated data on three principal pollutants: industrial wastewater emissions, sulfur dioxide emissions in industrial exhaust gases, and the generation of general industrial solid waste. These data were sourced from the "China Environmental Statistics Yearbook" for the period spanning 2010–2020. Following the approach employed by Wang and Sun (2017), we applied the entropy weighting method to combine these

three variables. The entropy weighting method is an objective technique that assigns weights to indicators based on the amount of information provided by each indicator's observed values. In our study, we standardized the three pollution indicators and calculated weight coefficients based on their entropy values or redundancy degree. Ultimately, a comprehensive pollution intensity index is created by a multiple linear weighting function. This index offers a more holistic representation of pollution emissions at the provincial level compared to considering individual pollutant categories in isolation.

3.3.2 Explanatory variables

Environmental regulations (ER): The quantification of environmental regulation intensity in China has been lacking a standardized measure (Tu and Chen, 2015). Previous studies have often employed alternative indicators, considering input costs and post-implementation outcomes, to evaluate environmental regulations. This study adopts environmental pollution control investment (Zhong and Chen, 2022) as a proxy for assessing the environmental regulations, utilizing data sourced from the "China Environmental Statistical Yearbook."

Collectivism (Col): This study constructs the provincial-level collectivism variable using data from the China Family Panel Studies (CFPS)[1]. The CFPS, implemented by the Institute of Social Science Survey (ISSS) at Peking University, aims to track and collect data at the individual, household, and community levels, providing insights into the social, economic, demographic, educational, and health changes in China. The sample covers 31 provincial-level units[2] in mainland China. The survey includes all members of the sampled households, with a sample size of approximately 16,000 households. The CFPS started in 2010 and has been conducted every year with data available up to 2020. Therefore, based on data availability, we utilize data from 2010, 2012, 2014, 2016, 2018, and 2020 to construct a panel indicator of collectivism with lag years.

Brewer and Chen (2007) decomposed collectivist culture into three dimensions: "Self-Representations," "Beliefs," and "Values." Based on this classification, we selected questions from CFPS that correspond to each dimension and created a comprehensive index of collectivist culture. In the "Self-Representations" dimension, which refers to identity and emphasizes group identification, we selected the question "Are most people primarily out for themselves or willing to help others?" This question reflects respondents' perception of the group (who are we) and measures the extent to which collectivist individuals believe that the group will provide them with assistance, indicating an interdependent self (Gorodnichenko and Roland, 2012). In the "Beliefs" dimension, which pertains to understanding social functioning, we chose the question "In today's society, hard work brings rewards" to measure respondents' attribution of personal achievements. Collectivist individuals are more likely to attribute achievements to external factors (Oyserman et al., 2002). In the "Values" dimension, we selected the question "Trust in local officials/government" as an indicator. Collectivist individuals tend to prioritize collective interests over personal ones and believe that collective decision-making can achieve greater common benefits. Since CFPS does not provide specific city information for each sample household to protect respondents' privacy, we constructed a provincial-level collectivism intensity variable based on the province of the sample. For each year's data, we standardized and combined the three dimensions of collectivism using max-min normalization to obtain a single collectivism score for each sample. Finally, we averaged the scores based on the province to obtain annual provincial-level collectivism indicators.

We selected collectivism indicators from the years 2010, 2014, 2018, and 2020 and created four maps of China to illustrate the spatial-temporal heterogeneity of collectivism changes from 2010 to 2020. The results are shown in **Figure 2**. The regional analysis reveals a distinct north-south divide in collectivist culture. Provinces in the northern region, such as Beijing, Hebei, Shandong, Shanxi, Henan, and Anhui, exhibit a stronger prevalence of collectivism compared to provinces in the southern region. This can be attributed to the influence of traditional Confucian culture, which emphasizes collective interests and social responsibility, and originated in the northern region of China. The agricultural nature of the northern region, with its emphasis on collective cooperation and rural community support, further reinforces the prevalence of collectivism in these areas. In terms of temporal changes, the southeastern coastal regions, including Shanghai, Zhejiang, and Jiangsu, demonstrate a gradual decline in collectivism. These regions, characterized by rapid modernization and urbanization, have experienced increased social mobility and reduced interpersonal connections. As a result, individuals in these areas tend to prioritize personal economic interests and competition, leading to a weakening of the collectivist culture. Moreover, the year 2020 shows a notable increase in overall collectivism across China compared to 2018. This finding aligns with the pathogen-prevalence hypothesis, which suggests that the COVID-19 pandemic has prompted individuals to embrace collectivist values as a means of protecting themselves and others from perceived threats.

3.3.3 Control variables

Based on previous studies, we included several control variables in our analysis. Per capita GDP (pgdp) and its squared term (sqr_pgdp) were considered as proxies for economic development. The urbanization rate (Urb), calculated as the proportion of urban population to total population within each province, was included to account for the level of urbanization. The composition of GDP between the secondary and tertiary sectors was captured by the ratio of the second industry to the third industry (IS). Moreover, we constructed an indicator of industrial upgrading (ISU) by comparing the increment of GDP in the tertiary industry to that in the second industry. Consistent with the "pollution haven" hypothesis (Tang et al., 2022), we used the annual realized amount of foreign investment as a measure of foreign direct investment (FDI). The data sources for these variables were the "China Statistical Yearbook" and the National Bureau of Statistics of China. For a more detailed description of the relevant variables, please refer to **Table 1**.

Due to the limitations of the CFPS questionnaire, we used data from 2010, 2012, 2014, 2016, 2018, and 2020 to construct the collectivism index with gap years. For provinces

1 http://www.isss.pku.edu.cn/cfps/en/index.htm

2 Due to practical constraints in conducting the survey, data for the regions of Xinjiang, Tibet, Inner Mongolia, Ningxia, Qinghai, and Hainan before 2018 have partial missing values.

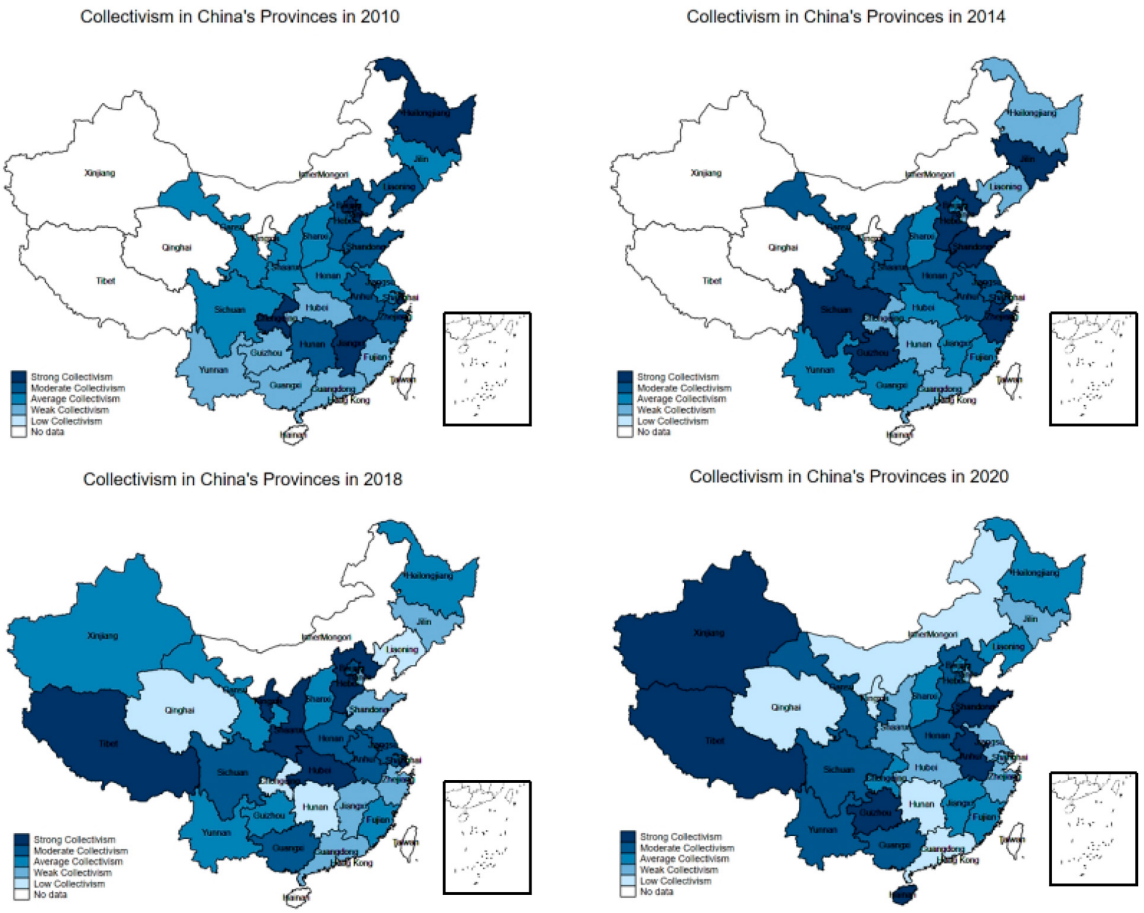

FIGURE 2
The distribution of collectivism intensity in China from 2010 to 2020. The map template is from the Map Technology Review Center of the Ministry of Natural Resources (GS (2022) 4312).

including Xinjiang, Tibet, Inner Mongolia, Ningxia, Qinghai, and Hainan, data with missing values before 2018 were excluded from the regression analysis. To address heteroscedasticity, we logarithmically transformed variables such as environmental pollution intensity, environmental regulations, GDP, and foreign direct investment. Please refer to Table 2 for more details. To improve model stability and interpretability while avoiding multicollinearity, all interaction terms in the model were centered.

4 Results of empirical analysis

4.1 Baseline regression analysis

Table 3 (1) reports the regression results of the baseline model examining the emission reduction effect of environmental regulations. The findings demonstrate a significant long-term inhibitory effect of environmental regulations on pollution emissions, albeit with a lag effect. Specifically, both the current environmental regulations (ER) and lagged environmental regulations (L_ER) coefficients are significant at the 1% level with opposite signs. An increase of 1% in current environmental regulations leads to a 0.048% increase in pollution emissions for the same year, whereas a 1% increase in lagged environmental regulations results in a 0.085% decrease in pollution emissions. This outcome suggests a combined effect of the "green paradox" and "closure emissions reduction." The "green paradox" effect arises as government-regulated environmental regulations force polluting enterprises to adopt emission reduction measures. Small-scale enterprises facing financial constraints may struggle to comply with the emission standards, potentially resulting in production reductions or closures. Consequently, these enterprises may strategically increase pollution emissions during the window period between policy announcement and implementation to minimize losses. On the other hand, large-scale enterprises with sufficient resources tend to transition to cleaner production methods and invest in clean energy and green technologies to achieve emission reduction goals. However, such adjustments may require more time for implementation. Furthermore, there might be a reverse causality between current environmental regulations and pollution emissions. Regions experiencing severe environmental pollution may prompt government authorities to improve the environment through policy interventions to showcase their performance. Consequently, the combined effect of these factors can lead to short-term increases in pollution emissions, while promoting long-term emission reductions.

TABLE 1 Variable definitions and data sources.

Types of variables	Abbreviation	Variable	Data sources
Key variables	PI	Environmental pollution emission intensity	«China Environmental Statistical Yearbook»
	ER	Environmental regulation	
	Col	collectivism	China Family Panel Studies(CFPS)
Control variables	pgdp	Per Capita GDP	«China Statistical Yearbook» and China National Bureau of Statistics
	sqr_pgdp	Square of per capita GDP	
	Urb	Urbanization rate	
	IS	Industrial structure	
	ISU	Industrial structure upgrading	
	FDI	Foreign direct investment	
Instrumental variables	iv1	Divorce rate	China National Bureau of Statistics
	iv2	Clan genealogical density	«General Catalogue of Chinese Genealogy»
	iv3	Number of Jinshi in the Qing Dynasty	«Index of Ming and Qing Jinshi Inscription Steles»
	iv4	The frequency of vocabulary related to environmental protection appearing in local government work reports	The Government Work Report of provinces
Mediating variables	inno	Proportion of green patent applications to total patent applications	«China Statistical Yearbook»
Other variables	Col2	The number of Monuments for Virtuous Women in each province of China	«History of Ming Dynasty·Biographies of Chaste Female»«The draft of Qing History»
	Col3	Number of Existing Confucian Temples in China	China Research Data Service Platform(CNRDS)
	PI2	Environmental pollution emission intensity	«China Statistical Yearbook on Environment»
	NO_X	Nitrogen oxide	«China Energy Statistical Yearbook»

TABLE 2 Descriptive statistics of variables.

Variable	Mean	SD	Min	Max	N	Unit
PI	0.297	0.183	0.000	0.728	186	–
ER	11.654	1.326	6.165	14.164	186	ln Ten thousand yuan
Col	2.001	0.221	1.000	2.667	163	–
pgdp	10.720	0.484	9.464	12.009	186	Ten thousand yuan/person
sqr_pgdp	115.148	10.438	89.559	144.206	186	Ten thousand $yuan^2$/ $person^2$
Urb	0.574	0.135	0.227	0.893	186	Urban population/total population
IS	0.996	0.351	0.189	2.002	186	Output value of Secondary sector of the economy/output value of Tertiary sector of the economy
ISU	0.892	0.295	0.191	1.757	186	Newly increased output value of Tertiary sector of the economy/newly increased output value of Secondary sector of the economy
FDI	11.101	1.585	6.280	14.825	186	Ln Ten thousand dollars

4.2 The moderation effects of collectivism

According to equation (5), we constructed a moderated effect model that includes the collectivism variable. The regression results in column (3) of Table 3 show that, after introducing the collectivism variable, the coefficient of environmental regulations (L_ER) remains significant at the 5% level, but slightly reduced compared to the previous model. Considering that we centered the interaction terms, indicates that when collectivism is at its average level, i.e., when ColxL_ER is 0, a 1% increase in environmental regulation intensity will lead to a reduction in pollution emissions by approximately 0.07%.

The results confirm Hypothesis 1a, indicating that collectivism plays a negative moderating effect in the relationship between environmental regulations and pollution emissions. The interaction term ColxL_ER is significant at the 1% level and negative, indicating that as the level of collectivism increases, the emission reduction effect of environmental regulations also increases. In addition, the variable of collectivism (Col1) is

TABLE 3 Results of the baseline regression and moderation regression.

	(1)	(2)	(3)
	Model1	Model2	Model3
VARIABLES	PI	PI	PI
Col		0.4062***	0.6073***
		(3.90)	(5.21)
lnER	0.0479*	0.0270	0.0231
	(1.80)	(1.02)	(1.20)
L_lnER	−0.0845*	−0.0767***	−0.0674***
	(−1.95)	(−2.45)	(−2.20)
ColxL_lnER			−0.0064***
			(−3.84)
lnpgdp	2.0470	3.2580***	5.0535***
	(1.15)	(1.82)	(2.92)
sqr_lnpgdp	−0.1147	−0.1656***	−0.2451***
	(−1.44)	(−2.11)	(−3.12)
IS	0.0522	0.4036**	0.5356***
	(0.25)	(2.70)	(2.89)
ISU	0.1479	−0.3141**	−0.4015**
	(0.50)	(−2.13)	(−2.53)
Urb	3.7180**	1.4705	1.5408
	(2.68)	(0.99)	(1.03)
FDI	0.0083	−0.0359	−0.0513
	(0.23)	(−0.74)	(−1.20)
N	163	163	163
R^2	0.206	0.402	0.589
Provinces fixed effect	Y	Y	Y
Year fixed effect		Y	Y

***, **, and * indicate significant at significance levels of 1, 5, and 10%, respectively.

positively correlated with pollution emissions at the significance level of 1%, confirming hypothesis 2 that regional collectivism has a positive effect on pollution emissions. The regression results for the control variables reveal that the relationship between environmental pollution and economic growth, as indicated by the coefficients of GDP growth (pgdp) and its quadratic term (sqr_pgdp), still follows an inverted "U" shape and has not yet reached the turning point. This finding confirms that China's economic growth over the past decade has come at the expense of the environment. Additionally, the coefficients for industrial structure (IS) and industrial structure upgrading (ISU) validate the fact that the service sector is more environmentally friendly compared to the manufacturing sector. This further supports the positive impact of upgrading the industrial structure on improving environmental quality.

4.3 Robustness analysis

To ensure the robustness of our regression results, we conducted rigorous robustness tests. We employed principal component analysis to construct a new dependent variable using nitrogen oxide emission intensity as an alternative pollution indicator. Furthermore, we considered additional measures of collectivism to broaden the sample size and validate the moderating effect. These measures strengthen the reliability and robustness of our research findings.

4.3.1 Replace the explained variable

Principal Component Analysis (PCA) is a method commonly used to transform high-dimensional data into a lower-dimensional representation through linear transformations. Similar to the entropy weighting method, PCA aims to create a comprehensive pollution emission index by preserving the essential components while reducing the dimensionality of the variables. Instead of using entropy values as weights, PCA determines the weights based on the eigenvalues of the covariance matrix between variables. In our study, we applied PCA to reduce the dimensionality of the variables, namely industrial wastewater emissions, sulfur dioxide emissions in waste gases, and general industrial solid waste generation (Chao and Ren, 2011). This allowed us to generate a new composite index called PI2, which was then included as the dependent variable in the regression model. The regression results presented in **Table 4** (2) indicate that the signs and coefficients of the core explanatory variables and moderating variables remain stable and statistically significant at a significance level of 5%.

Nitrogen oxides (NO_x) are air pollutants composed of nitrogen and oxygen elements, including nitric oxide (NO) and nitrogen dioxide (NO_2). They are mainly generated from human activities such as combustion processes, industrial production, and transportation (Heck, 1999). Therefore, nitrogen oxides serve as important surrogate indicators for pollution emissions, particularly industrial pollution emissions. We compiled carbon oxide emission indicators from the "China Energy Statistical Yearbook" and included them in the model. The regression results in **Table 4** (3) demonstrate that the signs and coefficients of the moderating variables remain stable and statistically significant at a 5% significance level.

4.3.2 Replace the moderating variable

The Monument for Virtuous Women is a commemorative architectural structure in Chinese traditional culture (Zhao et al., 2016), which honors and memorializes women known for their moral integrity and adherence to virtuous principles (Wu, 2015). During the late 18th to the 19th centuries, Chinese societal expectations placed significant emphasis on individuals upholding filial piety and moral principles. Women who demonstrated exemplary behavior in maintaining moral standards, particularly in their roles as wives and daughters-in-law, were celebrated and memorialized through the construction of these monuments. The presence of the Monument for Virtuous Women in a region signifies the cultural importance placed on moral values and virtuous behavior. It reflects the collective recognition and reverence for individuals who uphold traditional ethical principles and contribute to the preservation of social harmony and moral integrity. The data on these monuments used in this study were obtained from historical records and texts, including "The Biographies of Exemplary Women" within "History of Ming Dynasty- Biographies of Chaste Female" and "The draft of Qing dynasty history."

TABLE 4 Results of robustness analysis.

	(1)	(2)	(3)	(4)	(5)
	Model3	Replace the dependent variable	Replace the dependent variable	Replace the moderator	Replace the moderator
VARIABLES	PI	PI2	NOx	Col2	Col3
L_ER	−0.0674**	−0.0796***	−0.0310	−0.0106*	−0.0090*
	(−2.20)	(−2.80)	(−1.21)	(−1.78)	(−1.67)
Col	0.6073***	0.2465***	0.1398**		
	(5.21)	(2.98)	(2.40)		
ColxL_ER	−0.0064***	−0.0054**	−0.0131**		
	(−3.84)	(−2.56)	(−2.29)		
Col2				0.0001**	
				(2.55)	
Col2xL_lnER				−0.0002***	
				(−2.64)	
Col3					0.0001***
					(4.66)
Col3xL_lnER					−0.0001**
					(−2.30)
Control variables	Y	Y	Y	Y	Y
Provinces fixed effect	Y	Y	Y	Y	Y
Year fixed effect	Y	Y	Y	Y	Y
N	163	163	163	310	308
R^2	0.589	0.511	0.871	0.355	0.304

***, **, and * indicate significant at significance levels of 1, 5, and 10%, respectively.

The Confucius Temple, a significant site for venerating Confucius and propagating Confucian philosophy, stands as a principal channel for disseminating Confucian culture. Central to Confucian ideology is the emphasis on individuals pursuing social harmony, prioritizing collective interests, and fulfilling societal roles and responsibilities. In nations and regions deeply influenced by Confucianism, there is a tendency to prioritize collective welfare (Morling and Lamoreaux, 2008; Ma X. R. et al., 2016), respect elders and traditional authorities, and value social order and public morality. Since the Han Dynasty, the Confucius Temple has served the societal function of "civilizing the populace" (Yeo, 2014). Over ensuing centuries, it has continued to propagate Confucian ideology, transcending ethnic boundaries (Han, 2007) to become a primary avenue for disseminating Confucian culture. The symbiotic relationship between the Confucius Temple and Confucian culture, coupled with the robustness of historical data, has led numerous scholars to consider the quantity of Confucius Temples as an indicator of the strength of local Confucian culture and collectivist values (Du, 2015, 2016; Jin et al., 2017). The data on Confucius Temples utilized in this study were sourced from the China National Research Data Center.

Due to the limited availability of CFPS data, the previously constructed collectivism index (Col) in this study only covers a span of 6 years. To further examine the robustness of the collectivism moderation effect, we expanded our analysis by incorporating data on monuments for virtuous women and existing Confucius Temples, and interacted them with yearly dummy variables from 2010 to 2020. This allowed us to construct two additional collectivism indicators, Col2 and Col3, spanning a period of 11 years from 2010 to 2020.

Analyzing the regression results in **Tables 4** (4) and (5), we find that even after these variable adjustments, the interaction term between collectivism and environmental regulations remains significantly negative at the 1% level. Moreover, the effect of collectivism on pollution emissions shows significant positive associations at the 5 and 1% levels, respectively. These findings affirm the robustness of the moderation effect and provide further support for Hypotheses 1a and 2.

4.4 Endogeneity analysis

To ensure the accuracy of the impact of collectivism and to address potential endogeneity concerns, this study utilized appropriate instrumental variables in the analysis. While the fixed effects model employed in the initial regression helps mitigate endogeneity to a certain extent, there's a possibility of a reverse causality existing between collectivism and pollution emissions. For instance, a worsening ecological situation might

TABLE 5 Results of instrumental variable regression.

	(1)	(2)	(3)	(4)
	Model 3	iv1&iv4	iv2&iv4	iv3&iv4
VARIABLES	PI	PI	PI	PI
L_ER	−0.0674**	0.0669	−0.0808	−0.7892**
	(−2.20)	(0.41)	(−0.41)	(−2.03)
Col	0.6073***	0.9561**	1.0716**	1.6257
	(5.21)	(1.98)	(2.24)	(1.44)
ColxL_ER	−0.0064***	−0.0096**	−0.0112**	−0.0185*
	(−3.84)	(−2.08)	(−2.16)	(−1.82)
Control variables	Y	Y	Y	Y
Provinces fixed effect	Y	Y	Y	Y
Year fixed effect	Y	Y	Y	Y
Kleibergen-Paap rank (rk) Wald statistic		11.12	8.68	13.26
N	163	163	163	163

***, **, and * indicate significant at significance levels of 1, 5, and 10%, respectively.

elevate public attention toward environmental concerns, leading to the adoption of collectivist values (Fincher et al., 2008; Bao et al., 2018). To tackle this challenge, this study introduced divorce rates, provincial genealogy records, and the number of successful candidates in the Qing Dynasty's imperial examinations as instrumental variables. Here, we used the divorce rate per 10,000 individuals as an instrumental variable (iv1), and similarly, we employed the density of genealogical records per 10,000 individuals as a proxy for clan culture (iv2) and the count of "Jinshi" (iv3) as an indicator of Confucian culture.

Furthermore, potential reverse causality issues might exist concerning environmental regulations (Wang et al., 2019). Hence, this study utilized the frequency of environment-related terms in local government work reports as an instrumental variable for environmental regulations. These instrumental variables enhance the identification strategy and bolster the robustness of the findings. Building upon the methodologies of Chen and Chen (2018) and Yin and Wu (2021), we adopted the frequency of environment-related terms in local government work reports as an instrumental variable (iv4) for environmental regulations.

Given the potential endogeneity in both collectivism and environmental regulations, we separately paired the three collectivism variables (iv1, iv2, iv3) with the environmental regulation variable (iv4) and employed them as instrumental variables in a two-stage least squares (2SLS) regression. The Kleibergen-Paap rank (rk) Wald test statistics for the regression models all exceeded 10, rejecting the null hypothesis of weak instrumental variables. The outcomes in **Table 5** (2) to (4) demonstrate that, after addressing endogeneity concerns, the moderating effects of collectivism are amplified, and the regression outcomes remain robust compared to the baseline model.

TABLE 6 Heterogeneity analysis results for market-based environmental regulations.

	(1)	(2)
	Model3	heterogeneity
VARIABLES	ER	ER2
Col	0.6073***	0.4015***
	(5.21)	(4.46)
L_lnER	−0.0674**	
	(−2.20)	
ColxL_lnER	−0.0064***	
	(−3.84)	
L_lnER2		−0.1006***
		(−3.42)
ColxL_lnER2		−0.0053***
		(−2.86)
lnpgdp	5.0535***	3.8031***
	(2.92)	(3.17)
sqr_lnpgdp	−0.2451***	−0.1922***
	(−3.12)	(−3.57)
IS	0.5356***	0.5201***
	(2.89)	(4.09)
ISU	−0.4015**	−0.3553**
	(−2.53)	(−2.45)
Urb	1.5408	1.9324**
	(1.03)	(2.04)
Provinces fixed effect	Y	Y
Year fixed effect	Y	Y
N	163	163
R^2	0.589	0.402

*** and ** indicate significant at significance levels of 1% and 5% respectively.

4.5 Heterogeneity analysis of environmental regulations

In light of the growing importance of market-based environmental regulations within China's regulatory framework (Xu and Sun, 2023), this section endeavors to validate *Hypothesis 1b* by investigating how collectivism moderates the effects within this specific environmental regulatory structure.

We measure market-based environmental regulations using the annual pollution fees levied in each province, obtained from the "China Environmental Yearbook"[3] and the "China Tax Yearbook." (see text footnote 3) Although China transitioned from pollution fees to pollution taxes in 2018 for pollution-intensive industries, the implementation followed a "smooth transition" principle. The entities that previously paid pollution fees became taxpayers for the environmental protection tax, and the tax rates were designed to avoid imposing additional financial burdens on businesses.

3 http://cnki.nbsti.net/CSYDMirror/Trade/yearbook/single/N2020100004?z=Z024

TABLE 7 Results of mechanism analysis for green innovation.

	(1)	(2)	(3)
	Step 1	Step 2	Step 2 (iv)
VARIABLES	Inno	PI	PI
Inno		−0.0561*	−4.2929*
		(−1.97)	(−1.73)
Col	0.0581***	0.2623**	1.7819**
	(5.57)	(2.65)	(2.36)
L_lnER	−0.0081**	−0.0410	0.1555
	(−2.66)	(−1.48)	(0.49)
ColxL_lnER	−0.0007***	−0.0034*	−0.0171**
	(−2.84)	(−1.72)	(−2.29)
Observations	150	150	150
Provinces fixed effect	Y	Y	Y
Year fixed effect	Y	Y	Y
R^2	0.507	0.344	
N	25	25	25

***, **, and * indicate significant at significance levels of 1, 5, and 10%, respectively.

Therefore, we believe that this reform would not significantly affect the data for 2020, considering the use of fixed-effect models.

The regression results in Table 6 demonstrate that market-based environmental regulations (−0.101) have a more pronounced effect in reducing pollution emissions compared to policy-based environmental regulations (−0.067). Market-based regulations utilize flexible incentive mechanisms that can optimize resource allocation and foster the autonomy of enterprises. These findings align with previous research findings (Feng Y. et al., 2023). In terms of the moderation effect, collectivism exhibits a stronger influence on market-based environmental regulations. The effectiveness of market-based regulations relies on cooperation among market participants, and collectivism can effectively facilitate collaboration and coordination among stakeholders, thereby enhancing policy implementation and effectiveness.

4.6 Mechanism analysis of the impact of collectivism on environmental regulations

Existing research consistently suggests a strong link between culture and innovation (Fiordelisi et al., 2019; Wang et al., 2021). Thus, in this section, we aim to examine whether green innovation serves as a mediating mechanism for the moderating effect of collectivism on environmental regulations.

We employs the proportion of green patent applications to total patent applications as an indicator of green innovation (Inno). Previous research has found that patent indicators can control for unobservable factors in macroeconomics (Popp, 2006), and patent technologies are likely to have an impact on firms during the application process. Therefore, green patent applications effectively reflect a firm's current level of green innovation.

Drawing on the method proposed by Baron and Kenny (1986), we used a stepwise approach to examine whether green innovation serves as a mediating channel for the moderating effect of collectivism. Firstly, we regressed green innovation as the dependent variable. The results in Table 7 (1) show a significant positive correlation between collectivism and green invention. It is worth noting that there is a slight negative relationship between environmental regulations and green innovation, suggesting the existence of a "crowding-out effect" (Link, 1982; Roediger-Schluga, 2003) in the measured environmental regulations. When firms face stricter environmental regulations, they tend to reallocate resources, such as purchasing more environmentally friendly equipment or adopting stricter emission control measures. These additional costs may reduce the firm's investment in research and development, resulting in a certain degree of negative impact on green innovation.

To examine the effect of green innovation (Inno) on pollution emissions, we included it as an explanatory variable in the baseline model. The regression results in Table 7 (2) demonstrate that green innovation effectively reduces pollution emissions, and the absolute value of the moderating effect of collectivism decreases compared to the original model, indicating that green innovation serves as an effective mediating channel for the moderation effect. To address potential endogeneity concerns and accurately identify the emission-reducing effect of green innovation, we re-estimated the model using instrumental variables for collectivism and environmental regulations (iv3 and iv4). The results in Table 7 (3) further validate the pollution-reducing effect of green innovation.

5 Discussion

With the growing environmental awareness at both societal and individual levels, formal and informal institutional factors related to environmental regulations continue to garner increasing attention. Current studies on informal institutional aspects of environmental regulations predominantly focus on elements like religion, clans, trust, local identity, and individual consciousness, with limited attention to the impact of collectivist cultural orientation on environmental regulations. From a cultural perspective, this research investigates the moderating effects of collectivist culture on different types of environmental regulations and their underlying mechanisms.

The findings of this study indicate, firstly, that environmental regulatory policies exhibit a significant positive impact on environmental pollution during their implementation period, yet with noticeable lagged effects on emission reduction. This implies that the effects of environmental regulatory measures become evident only after a certain period post-implementation. This conclusion aligns with the research findings of Lu et al. (2022), who discovered complex effects of environmental regulatory policies on carbon emissions across different stages, displaying a reverse U-shaped relationship at specific emission levels. Specifically, this manifests as the "green paradox" effect at certain stages, followed by a transition to the "emission reduction" effect. The reason behind this phenomenon might be attributed to the government's regulatory approach, which often involves setting emission limits that compel polluting enterprises to

adopt measures to reduce emissions. Enterprises failing to meet these standards might face closure, which could lead smaller polluting enterprises with limited funds to pay emission fees or implement pollution control techniques to reduce production or even shut down. Under this pressure, smaller entities may increase pollution emissions during the window period between the announcement and enforcement of environmental policies to mitigate losses, resulting in short-term emission escalation. On the other hand, larger, more financially robust enterprises tend to change their production methods by adopting clean energy and green equipment to reduce pollution emissions. Although these measures effectively reduce emissions in the long term, they might not promptly alter the existing production models in the short term. Furthermore, there might be a certain reverse causality between current environmental regulations and pollution emissions. Regions experiencing severe environmental pollution might incentivize governmental departments to improve the environment through policy instruments to gain performance accolades. Consequently, environmental regulations might lead to short-term increases in pollution emissions due to various factors; however, in the medium to long term, these regulations could drive a reduction in pollution emissions.

Secondly, the research findings demonstrate a positive relationship between the intensity of collectivist culture and pollution emissions, confirming Hypothesis 2, aligning with evidence from cross-national studies. Ioannou and Serafeim (2012) propose that granting autonomy to economic entities is a critical factor for them to demonstrate environmentally conscious behaviors in alignment with local cultural values. In individualistic cultures, this environmental behavior is reflected in corporations undertaking explicit and voluntary environmental initiatives, whereas in collectivist cultures, this behavior is represented by corporations aligning with externally imposed environmental policies. However, when regulatory authority becomes excessively stringent, or completely suppresses the discretionary power of economic entities, the impact of culture on corporate behavior may diminish or distort. Research by Yu and Gao (2015) in China suggests that strict environmental regulations by governmental bodies over official economic activities might prompt economic sectors to shift certain economic activities into the hidden economy (Frey and Weck-Hanneman, 1984).

China is characterized by a dominant culture of vertical collectivism and a high degree of power distance (Hofstede and Minkov, 2014). Individuals perceive themselves as part of a collective and consider inequality among members as a natural element of social order (Ma J. et al., 2016). Cho et al. (2013) discovered a negative impact of vertical collectivism on environmental attitudes, possibly due to a partial alignment of personal environmental attitudes with collective interests. Vertical collectivist culture encourages prioritizing collective interests and acknowledges status disparities within the group. When the collective interest involves sustaining production (thus maintaining pollution emissions) rather than reducing emissions, decisions might be made to shift production to informal economic activities. In such scenarios, the collectivist variable encompasses measurements of the informal economy, hence correlating positively with pollution emissions.

Thirdly, when the orientation of collectivist culture interacts with environmental regulation, the symbol turns negative, validating Hypothesis 1a. The collectivist cultural orientation plays a negative moderating effect on the impact of environmental regulations on pollution emissions, indicating that an increase in collectivism at the mean level will significantly enhance the emission reduction effect of environmental regulations. This conclusion aligns with some existing research theories. Collectivism, as a cultural background, effectively influences individuals and groups in a region, including managers in pollution emission sectors and employees engaged in actual production activities, by strengthening their willingness to comply with environmental regulatory policies (Rahman et al., 2023), and by enhancing execution strength, thereby reducing pollution emissions. Furthermore, previous studies (Xue et al., 2016; Kaplan Mintz and Kurman, 2020; Qu, 2023) have also demonstrated that collectivist groups have a higher ecological consciousness, incline toward green investments, research and recycling behaviors. When faced with mandatory government environmental regulations, highly collectivist groups tend to strictly adhere to these policies and abandon personal interests, making environmental policies more effective.

However, some studies reveal contradictory findings in this dimension (Ioannou and Serafeim, 2012; Eom et al., 2016; Graafland and Noorderhaven, 2018). These studies find a significant positive association between individualism and environmental performance. Despite seeming contradictory, Cho et al. (2013) indicated that both horizontal individualism and horizontal collectivism have a positive relationship with environmental attitudes. In horizontal individualism culture, individuals believe they benefit from environmentally friendly behavior and consider the formation of a societal consensus on environmental protection crucial. And in horizontal collectivist cultures, individuals typically see themselves as part of a group, and their behavior, decisions, and interests are often influenced by the expectations of the entire group or society. Thus, individuals in both cultures may comply with environmental protection regulations based on personal or collective interests. This study primarily emphasizes that under strict environmental protection policies, individuals within collectivist cultures may strengthen environmental regulations' energy-saving and emission reduction effects by strictly adhering to the rules.

Moreover, compared to command-and-control regulations, collectivism has a more significant moderating effect on moderate market-based environmental regulations, confirming Hypothesis 1b. The moderating effect of collectivism varies under different types of environmental regulations, where overly stringent regulations limit the discretion of enterprises, thereby reducing the impact of collectivist culture. This conclusion aligns with previous research findings (Feng Q. et al., 2023), indicating that the effectiveness of incentive-based environmental regulations relies on cooperation among market individuals, and collectivist culture can effectively promote cooperation and coordination among various stakeholders, thereby enhancing the strength and effectiveness of policy implementation.

Lastly, the analysis of mechanisms validates that within the context of regional collectivist culture, green innovation emerges as a pivotal mechanism influencing pollution emissions. This phenomenon stems from the substantial impact of collectivist culture on both corporate leadership and the workforce, thereby fortifying green innovation through dual perspectives:

strategic decision-making (Wang and Gao, 2022) and practical execution (Kong et al., 2017). The fabric of collectivism augments collaboration and trust among employees (Brockman et al., 2018), diminishing the potential for knowledge leakage and opportunistic behaviors, such as free-riding, within internal collaborations. This reduction in internal innovation hurdles notably enhances the efficacy of implementing green innovations within corporate environments. Furthermore, the conspicuous positive correlation observed between collectivism and green innovations reaffirms the notion that collectivist groups exhibit heightened ecological consciousness and a proclivity toward investments in green initiatives, including research and development. This conclusion further underscores the intricate pathways through which culture intertwines with endeavors toward environmental preservation.

6 Conclusion

Given the escalating environmental challenges, China is tasked with a significant mission of pursuing a green transformation. The Chinese government has implemented a series of environmental policies aimed at strengthening environmental protection and optimizing ecological sustainability in response to these pressing challenges. While prior research has primarily focused on examining environmental regulations through the government actions, the regulatory role of informal institutions remains an area that requires further exploration. This study aims to contribute to the existing literature by delving into the impact of Chinese collectivist culture on environmental regulations.

To capture the temporal and spatial heterogeneity of Chinese collectivism, this study constructs a measure of collectivist tendencies for 31 provinces in China from 2010 to 2020, utilizing data from the esteemed "China Family Panel Studies (CFPS)." Based on this measure, a panel model incorporating pollution emissions intensity and environmental regulation strength is developed. Employing a panel fixed-effect model, this study examines the moderating effects of collectivist cultural intensity on different types of environmental regulations, shedding light on the underlying mechanisms at play. Various robustness tests, including sensitivity analyses and instrumental variable approaches, are employed to enhance the robustness and validity of the regression results.

However, it is important to acknowledge the limitations of our study. Firstly, the availability of CFPS data restricted us to constructing an unbalanced panel dataset spanning only 6 years, which may have implications for the robustness of our findings. While we have undertaken robustness tests by expanding the sample through the replacement of explanatory variables, further validation of our results is warranted. Secondly, the construction of provincial-level collectivism indicators relied on using provincial-level proxies, as specific city/district-level information for the samples was not accessible. Consequently, this approach may not fully capture the regional heterogeneity of collectivism within provinces, potentially overlooking valuable information on collectivism's variation at the city level. Lastly, the measurement of hidden economic activities is inherently challenging, requiring extensive efforts to accurately quantify. In this study, we did not investigate the impact of collectivism on pollution emissions through the channel of the hidden economy, as measuring the impact of collectivism on pollution emissions through the hidden economy would require significant additional work. And this will be one of our future research directions.

In conclusion, this study has provided insights into the impact of collectivist culture on environmental regulations from the perspective of informal institutions, thereby holds various theoretical significances. Firstly, it optimized the construction methodology of collectivist indicators, establishing a continuous provincial-level collectivist index for China, thereby more accurately depicting the spatiotemporal variations in Chinese collectivism. Secondly, the research focused on exploring the regional collectivist culture's regulatory role in formal environmental regulations from the perspective of informal institutions, substantiating conclusions through multifaceted validations. Thirdly, by delving into collectivist culture, this study elaborated extensively on the mechanisms of its influence on diverse types of environmental regulations, providing a profound analysis of how informal institutions shape formal environmental regulations in practical settings. Finally, this research expanded the existing findings on the impact of collectivist culture on regional pollution emissions by incorporating pertinent empirical evidence from China.

The conclusions drawn from this study also offer potential insights for policy formulation and implementation. Firstly, the outcomes of this study could serve as practical guidance for governments in tailoring relevant environmental policies according to local contexts. Given the cultural diversity in China, governments could finely tune environmental policies to maximize the positive impact of cultural traits on environmental regulations, thereby enhancing policy efficacy. Secondly, this study highlights the impact of collectivist culture on pollution emissions through fostering green innovation, offering practical recommendations for policies encouraging green technology innovation. Governments and businesses could incentivize team collaboration and innovative spirit to drive advancements in environmental technology, thereby facilitating sustainable environmental development. Lastly, recognizing the potential time-lag effects in environmental regulation policies, governments should pay closer attention to implementation delays when formulating such policies, aiding continual improvements and optimizations to enhance the actual effectiveness of environmental policies.

Data availability statement

The original contributions presented in this study are included in this article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

LZ: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review and editing. MZ: Methodology, Visualization, Writing – review and editing. JJ: Data curation, Formal analysis, Visualization, Writing – original draft. XP: Formal analysis, Software, Writing – original draft. JZ: Writing – review and editing. SY: Conceptualization, Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Communication, socialization, and ITC. The psychosocial construction of sustainability

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Over the past two decades, the facets related to environmental crises (in the plural) have grown increasingly intricate. What began as environmentalists' apprehension over nature degradation and the encouragement of citizen-driven initiatives has evolved. The current shift in emphasis and prevailing message strives to foster a culture where citizens refrain from independent initiatives. Instead, the directive is to heed the guidance of the knowledgeable (scientists, politicians, corporations, interest groups, etc.), as substantiated by our investigative findings, which align, in part, with existing literature. Conversely, our exploration into environmental communication, notably the insights gleaned from longitudinal research concerning pro-environmental knowledge, attitudes, and actions, reveals a decline in citizens' effective inclinations toward embracing pro-environmental behaviors. Meanwhile, the escalation of the climate crisis is fueling heightened levels of echo-anxiety and solastalgia. This trajectory is closely intertwined with a growing global disillusionment within society – *not just regarding the future* – instilling a sense of disillusionment concerning pro-environmental messages and slogans disseminated by governing bodies and corporations. This has led to a state resembling learned helplessness, as articulated by Seligman, or what we prefer to term "induced" helplessness, rather than fostering conditions conducive to empowerment. This article comprehensively examines various reports and our inquiries, revealing how communication management and its constituents lie at the heart of forging novel narratives, fresh cognitive dissonances, and emerging social representations. Notably emphasized is the pivotal role played by information and communication technologies (ICT), particularly through dissemination on widely-used social networks. Since the 2010s, these platforms have assumed a paramount role in shaping socialization processes, surpassing educational institutions and conventional mass media.

KEYWORDS

sustainability, environmental communication, environmental education, socialization, mass media, social media, ITC

1 Introduction

Undoubtedly, the information disseminated by *mass media* wields a defining influence in the societal shaping of reality, as posited by Berger and Luckman (1966), referring to a collective imagination that serves as a crucial touchstone for individuals and social collectives, steering their choices. These news items are scrutinized as narratives, discourses, imaginaries, and representations. While various theoretical and epistemological frameworks employ different terms to address a similar "subject" of study, they invariably entail distinct conceptualizations to elucidate their functions. An illustrative instance lies in the assorted perspectives on social influence explored by seminal figures in social psychology, such as Ash, Sheriff, and Milgram, among others of note. Further contributing to this realm is Moscovici's theory of Social Representations (SR), which holds considerable sway in the Francophone and Latin American environmental psychology domains, though its presence is comparatively less pronounced in the Anglophone sphere (yet still extant). This compels us to confront the initial inquiry we intend to address with our data: What portrayal of Environment, Sustainability, Climate Change, and similar topics have the mass media constructed? Additionally, who are the primary touchpoints facilitating the comprehension of pro-environmental conduct – or the inclination toward specific behaviors – among individuals and society?

The second research query directs our attention to the psychological mechanisms within these processes. One such exemplar is the cluster of theories stemming from Festinger's experimental groundwork on "cognitive dissonance" (Festinger, 1957). Festinger's insights guide us to the deduction that human beings tend to be more "rationalizing" than strictly "rational" (Fointiat, 1998; Fointiat et al., 2013). Furthermore, this perspective has engendered a line of investigation centered on creating scenarios that elicit cognitive dissonance. This approach aims to induce contradiction within individuals, compelling them to reevaluate their stance and conduct through the discomfort experienced, ultimately fostering a shift in perspective and behavior (Fointiat et al., 2011).

An additional dimension pertains to the contributions that cognitive and developmental theories proposed by figures such as Piaget, Vygotsky, Bruner, and Erikson, as well as their respective followers, can furnish. Furthermore, the theories of social influence (as previously mentioned) also play a pertinent role. Another realm of relevance encompasses the theories concerning attitudes and their alteration, as proposed by Thurstone (1931), Allport (1935), and Heider (1946, 1958), among others. Those theories that endeavor to effect behavior modification are of particular significance, with a pronounced emphasis on environmentally conscious or sustainable behaviors (Steg and Vlek, 2009, among others). Additionally, it's imperative to consider viewpoints that address shifts in environmental behavior, often associating it predominantly with formal education while occasionally overlooking the pivotal role of socialization – both from a psychosocial and psychoeducational standpoint.

This article delves into select findings derived from our original research encompassing diverse facets linked to these intricate processes. Our scrutiny extends to assessing the degree to which present dynamics bolster empowerment or, conversely, foster circumstances of "induced" learned helplessness (in alignment with Seligman's formulation). Furthermore, we present the latest insights from a longitudinal study on knowledge and inclinations toward sustainable behaviors. This study was conducted across three time points: 2006–2007, 2014, and 2022–2023. We examine the repercussions of these findings on the core concepts previously elucidated. Rooted in these data, we will explore how the role of information and communication technologies (ICTs) and social networks rejuvenates certain concepts that have experienced waning prominence in psychology over recent decades, notably social influence processes and socialization mechanisms.

2 The environment in the mass media

Throughout the initial two decades of the 21st century, sustainability emerged as a novel and affirmative social value, permeating various advertising campaigns. These encompassed commercial ventures, institutional initiatives, and those with an overt pro-environmental focus originating from various sources. The climate emergency, although infrequently addressed – primarily coinciding with the convening of COPs[1] – was more often framed in the relatively moderate term 'climate change' than the more urgent term "climate emergency." From the Earth Summit of Rio '92, where emphasis was placed on three high-risk aspects: desertification, loss of biodiversity, and climate change, the last one has gained increasing relevance as an alert and emergent element. The first COP in Berlin in 1995 solidified climate change as a priority problem. This momentum led to COP-3 in Kyoto in 1997, formulating the first major protocol for controlling emissions. Subsequent milestones include COP 21 in Paris (2015) and COP 26 in Glasgow (2021), which committed to reducing emissions by 30% by 2030 and halting deforestation. Despite the growing urgency to address climate change, the COP27 held in 2022 in Sharm el-Sheikh and the COP28 held in 2023 in Dubai were marked by inconsistencies and contradictions regarding objectives, format, settings, and the utilization of natural resources during the conferences.

The COPs evolution has brought both relevance and visibility to climate change as an element of alert and emergency. However, the credibility of the messages and slogans has been undermined by the uncertain outcomes and performance of the agreements among participating countries. Simultaneously, these meetings have been accompanied by demanding social movements, occurring in parallel gatherings and occasionally even participating within the COP (refer to Postigo et al., 2013). Among these movements, perhaps the most emblematic case was Greta Thunberg's presence at COP 24 in Katowice, Poland, in December 2018, along with some subsequent interventions. These movements play a pivotal role in introducing fresh perspectives and new narratives, such as the concept of "climate justice."

The burgeoning global movement for climate justice possesses a robust social foundation capable of coordinated mobilization in what are termed "counter-summits," as well as decentralized actions across various regions worldwide (Borràs, 2016). A prime instance is the Fridays for Future movement, a global climate initiative advocating systemic transformation and urging politicians to fulfill their responsibilities. Regrettably, these actions have sometimes been employed in the media,

1 COP is the acronym for the "Conference of the Parties," Annual Summit carried out by the United Nations Framework Convention on Climate Change (UNFCCC) where they bring together the 196 countries that make up the Parties.

or at least by certain outlets, to undermine these movements and individuals. According to Borràs (2016), the prevalence of adult perspectives in media coverage can disempower young protestors by deconstructing the political nature of their agenda and demands. A study conducted in Germany (Von Zabern and Tulloch, 2021) unveiled that media portrayal tends to fortify existing power dynamics, depicting young protestors as being manipulated by adult interests. This exclusionary stance can impede the political efficacy of young individuals, further contributing to their sense of disempowerment.

Contemporary media faces the formidable task of aptly communicating the escalating information and intricacies inherent in environmental concerns. The deficiency in awareness and comprehension regarding the challenges and potential remedies poses a hurdle for individuals, organized collectives, and governments to undertake substantial and resolute actions to achieve efficacious socio-ecological adaptation (CEIA-Centre d'Estudis d'Informació Ambiental, 1999).

The media wields a significant influence in shaping this paradox. Nonetheless, despite the surge in extreme weather events like droughts, hurricanes, floods, or fires, many individuals do not always perceive an immediate impact. Multilateral conferences might be remote and detached, while scientific models projecting sea-level rise or migration can prove challenging to grasp. Furthermore, the media grapples with the added complexity of making climate change coverage engaging for diverse segments, encompassing youth, "believers," and those currently disinterested in the subject (Newman et al., 2021). However, we must not overlook the phenomenon Uzzell (2004) termed environmental hypermetropia: an apparent profound concern for global issues coupled with an inability to recognize and shoulder the responsibility for nearby environmental challenges, which necessitate personal involvement and action.

However, this scenario has also evolved over time, bringing into prominence three relatively new terms: eco-anxiety, solastalgia and ecofatigue. The first concept encompasses the emotional responses individuals experience when confronted with environmental issues, whether directly or indirectly, including through exposure to news and media coverage (Albrecht, 2011). The second concept, solastalgia describes the distress that is produced by environmental change impacting on people (Albrecht et al., 2007). The third concept, eco-fatigue, also known as green fatigue, arises from an overwhelming sense of responsibility or guilt stemming from excessive environmental information or pressure. It serves as a coping mechanism to avoid perpetual anxiety, leading to a tendency to detach oneself from environmental issues (Pol, 2000; Pol and Marchand, 2023). These concepts represent the various ways in which individuals grapple with the environmental challenges of our time, highlighting the multifaceted impact of environmental concerns on human well-being.

Although traditional newspapers and mass media serve as the primary conduits of environmental information, they are often regarded as offering subpar information quality. Despite this, numerous studies and surveys have indicated that they retain the highest level of credibility as an information source (CEIA-Centre d'Estudis d'Informació Ambiental, 1999; Valencia et al., 2010; Newman et al., 2021). It becomes necessary to ponder what constitutes a source's "actual" and perceived quality or trustworthiness. It is crucial to acknowledge that according to Festinger, one of the fundamental inclinations among individuals is to evade cognitive dissonance. A classic response to this is disregarding or negating information that contradicts personal beliefs unless compelled otherwise.

Consequently, individuals tend to gravitate towards media outlets that echo their existing viewpoints, reinforcing their chosen stance. In essence, if the information is presented by "my" newspaper, "my" radio, "my" television, or within "my" social networks, it is deemed truthful (instilling trust). Conversely, if a source is not perceived as "mine" or aligned with one's affiliations, the information is dismissed as falsehood and labeled fake news. In simpler terms, the medium that resonates with one's preconceived notions is the one they place faith in.

This prompts us to delve into a comprehensive examination of environmental communication. We approach this task from the vantage point of communication sciences and the psycho-socio-environmental standpoint. We draw upon findings from two of our research endeavors to illuminate this endeavor. These investigations aim to scrutinize the treatment of environmental matters within specific media outlets. Before delving into these research outcomes, it is essential to outline the underlying processes from the purview of communication sciences.

3 Mass media, social media, and environmental education: influences and effects

The study of environmental communication and the exploration of the environmental impacts of various technologies intertwined with the progression of conventional mass media and social networks has garnered substantial interest across diverse realms of knowledge (Bergillos, 2020, 2021). Furthermore, the landscape of communication processes has experienced profound transformations after the global COVID-19 pandemic. These changes encompass not only the utilization of new technologies by citizens but also extend to the aesthetics and manner in which messages are conveyed. This pertains to the desired content and the orchestrated presentation to convey these messages (Deuze, 2020).

As demonstrated by Bergillos (2021), the presence of media is ubiquitous, exerting influence over both social environments and individuals. Simultaneously, these media are shaped by societal influences. Despite this intricate interplay, many aspects regarding their roles, influences, and consequences remain relatively unexplored. Furthermore, the emergence of virtual networks and novel technologies integrated into traditional media has significantly transformed their functions and impacts. This shift affects their operational mechanisms and the resulting content, thereby shaping the construction of new realities.

For instance, as highlighted by the author, the issue of climate change has fostered a pronounced polarization within the information ecosystem. This has led to an increase in misinformation, contradictions, and ambivalence surrounding the origins and repercussions of climate change, as well as the roles of individuals and mass media in shaping human behavior and societal dynamics. Opel (2015) elaborates on this point, elucidating that from a communication sciences perspective, *mass media* not only provide information about the environment but also contribute to establishing its value and significance. This aligns with the longstanding observations of social psychology spanning over a century.

Similarly, Bergillos (2021, p3) suggests that we must reflect on the leading role of communication sciences:

> "*In an uncertain context that is being shaped by invisible phenomena, such as climate change and media effects … we have to face the contradiction of the supposed human influence that has transformed the Earth's ecosystems and the powerlessness of not knowing to what extent our activities are involved in this transformation, matching the ambivalence of the presumed media presence and influence in people's lives*." (Bergillos, 2021, p. 3).

The role of agency in environmental matters, encompassing both human and non-human elements, has gained increasing attention in communication sciences, reflecting the consequences of diverse communication management strategies. This engrossment extends to the realms of social and behavioral sciences. Indeed, the prevalence of environmental-related information in media has surged, concurrently accompanied by persistent depictions of nature on our digital screens, as underscored by Opel (2015). While media serves as a conduit of environmental awareness, it concurrently assumes the role of attributing significance and interpretation to it. This dual role is articulated by Ruiz (2015), who characterizes communicators as "symbolic architects."

Castrechini (2008) accentuate the necessity for research into the interplay between "representations" and reality, encompassing the environment and the impact of its portrayal as news. This inquiry extends to probing the environment's role within popular culture, questioning whether this dynamic represents genuine interconnectedness or constitutes a form of "environmental fiction." Furthermore, communication is a pivotal component of facilitating public engagement in environmental decision-making processes, and it holds the potential to address and dissect the complexities of climate change, as underscored by Boykoff et al. (2015, 2020) and Pezzullo and Cox (2018).

Communication systems have undergone significant changes, and in conjunction with these evolving networks, the monitoring of messages and the construction of meanings have grown increasingly intricate. In addition to this, as noted by Silverston (2010), it is imperative to acknowledge that within the digital media realm, encountering the "Other" proves to be an elusive endeavor. The "Other" appears on my screen, blurring the lines between absence and presence, making the distance feel near. As elucidated by Silverston (2010, p. 27), this spatial disconnect erodes the anticipated sense of responsibility among individuals.

Gladwell (2011) accentuates how the emergence of novel communication technologies, particularly within social networks, has fostered an environment where concise and uncomplicated messages prevail. This environment tends to favor the establishment of "weak ties," as underscored by Gladwell (2011), which, regrettably, fails to cultivate robust activism or strategic deliberation.

Aran-Ramspott et al. (2018, 2022) have delved into media and networks' role in socialization. In tandem with Jenkins et al. (2016), they expound on how the youth are presented with an increasingly expansive array of choices, ranging from devices and screens to social networks and applications, all of which they access at ever-younger ages. Furthermore, spanning various formats over time and technological advancements, the identification of preadolescents as a distinct market segment dates back to the 1980s (Ekström and Tufte, 2007). Given their heightened susceptibility to environmental influences in shaping their sense of self (Bernete, 2010), adolescents necessitate a comprehensive grasp of their interactions within the digital landscape (Blomfield Neira and Barber, 2014). Nonetheless, a research gap remains concerning the role of "influencers" as potential guides in the intricate socialization processes and identity formation among preadolescents.

Beyond the socialization role assumed by social networks, it is equally imperative to consider the significance of Environmental Education (EE) within the educational milieu, spanning schools and universities. EE is pivotal in enhancing environmental knowledge and fostering positive attitudes towards ecological concerns (Duerden and Witt, 2010; van de Wetering et al., 2022).

As per Díaz-Pont and Tarragona's assessment (2003), educational programs addressing the environment and sustainability stand as the primary wellspring of environmental knowledge. Following this, social networks and other media contribute, as Mühlhäusler and Peace (2006) noted. However, as we have just seen, other authors point to the dominant role of networks, and certain authors emphasize the imperative to rejuvenate EE programs to foster more profound, experiential and standardized learning engagement.

The pioneering environmental education of the 1970s, once considered a "revolutionary" undertaking of nascent environmental movements, has since been institutionalized in the late 1980s, 1990s, and beyond. This transition has undoubtedly brought about changes in both the content and strategies employed, as well as the sources and promoters of environmental messaging. These changes have raised concerns about the credibility and trustworthiness of broadcasters and their messages (Newman et al., 2021).

In the context of environmental education, two distinct emphases and strategies emerge when teaching about the natural world from a scientific perspective. One approach focuses on the positive impact of nature contact on student well-being and academic performance. The other emphasizes how knowledge of the natural environment fosters more responsible ecological behavior. An often-overlooked yet crucial factor in both approaches is the role that environmental experiences play in shaping a child's intelligence (in the sense of Piaget and Inhelder) as well as their emotional inclination to preserve what they psychologically consider their own, leading to a sense of stewardship [theories of spatial appropriation by Korosec-Serfaty, 1976 and Pol, 1996, 2002 and attachment theories Lewicka, 2011].

Carrus et al. (2012) demonstrated the positive impact of school activities in naturalized environments on the psychological well-being of young children. However, subsequent research by the same team (Pirchio et al., 2021) yielded less conclusive and even contradictory results, indicating that occasional nature-based activities are insufficient to enhance well-being and promote sustainable lifestyles. Their findings underscore the need for immersive and meaningful nature experiences that go beyond mere cognitive engagement.

The spectrum of EE program typologies is notably diverse in its execution, encompassing variations in both frequency and methodology (García-Vinuesa et al., 2022). It is often integrated as a cross-cutting theme across various subjects, while at other times, specific slots within the curriculum are dedicated to its exploration (Díaz-Pont and Tarragona, 2003, ECEA). Content emphasis may vary depending on whether the focus is on emotional or practical components, or on passive or active engagement. Projects that encourage solution development appear to be particularly effective (Murat, 2015). It is important to recognize that formal education is just one source of environmental input for children and adults. In-depth analysis of the primary and secondary socialization effects

of values and models transmitted through increasingly influential virtual networks is crucial, alongside the reality construction undertaken by traditional mass media.

Within this framework, this paper aims to review the findings of three independent studies that delve into the treatment of environmental news in the written press and the pro-environmental involvement of primary, secondary, and university students. The main methodological characteristics of these studies are summarized in Table 1.

4 From the first and second study: evolution of the image of the environment in media environments

Through a systematic analysis of two prominent Spanish newspapers, namely El País (headquartered in Madrid) and La Vanguardia (based in Barcelona), spanning the period from the Rio Summit to the Johannesburg Summit (1992–2006), a discernible and sustained trend towards augmenting coverage of environmental news emerges. The visual portrayal and the accompanying explications, which encapsulate the SR propagated by the press during these years, undergo a significant transformation, inclusive of the utilization of photographs and graphics, gaining substantial prominence throughout this duration (Castrechini, 2008; Castrechini et al., 2014). When examining absolute figures, the quantity of news coverage essentially doubles from the 1990s to the 2000s. The daily variability inherently hinges on the unfolding of events and occurrences alongside other pertinent variables. Consequently, occurrences like the Prestige catastrophe, as well as significant gatherings such as the Rio Summits, Johannesburg, Kyoto, and the COP meetings, usher in information surges. Yet, irrespective of these specific events, the longitudinal analysis reveals statistically noteworthy disparities affirming a gradual escalation in the daily publication volume of environmental articles each year ($\chi^2 = 7273.000$; df = 672; $p < 0.001$).

The Figure 1 illustrates the changes in the social representation of the environment between 1992 and 2006 in the Barcelona press. Thematic categories that are closely associated with each other are clustered together on the map, with some occupying the central position and others located on the periphery of social representation. Three distinct types of discourse can be clearly identified: conservationist, scientific, and political. The evolution of environmental discourse is evident in the transition from conservationist to scientific and ultimately to political discourse, highlighting the increasing politicization of environmental issues during this period.

Please note that 'climate change' is absent from this figure as it pertains to the findings of Study 1, which focused on the period between 1992 and 2006. During this timeframe, the term 'climate change' was still emerging, with discussions primarily centered on the concept of the 'greenhouse effect.'

Based on the analysis conducted in this study, it is noteworthy that there is instability and variability in the themes, emphasis, slogans, and ways of labeling the environmentally problematic aspects. Until 2006, a significant increase in environmental coverage within mass media was observed; however, this period also witnessed a rise in confusion. A continual shift in emphasis and methods of labelling the highlighted environmental aspects exists, contributing to a sense of distrust among citizens towards environmental and sustainability messages. These shifts in emphasis, often lacking clear explanation or justification, capture the audience's attention, accomplishing the goal of gaining visibility. However, an unintended consequence emerges: uncertainty propagation and a perception of deceit (Pol, 2011). Leff (1986) asserts that sustainable development cannot materialize without the concurrent development of knowledge; hence, the

TABLE 1 Main methodological characteristics of the studies included in this review.

Study	Reference	Population	Sample size	Period of study	Data collection	Variables	Data Analysis
Study 1	Castrechini (2008) and Castrechini et al. (2014)	Newspaper news	La Vanguardia: 522. El País: 517. Total: 1039 news.	1992–2006 (pair years only)	Manual collection through microfilm and digital archives.	Number, content and format of the news	Content analysis. Comparative and longitudinal analysis: Chi square, *T*-student and Multiple Correspondence Analysis (MCA)
Study 2	Castrechini et al. (2015) and Pol et al. (2017)	Newspaper news	Year 2004: 53 news. Year 2011: 43 news. Total: 96 news from La Vanguardia.	2004 and 2011	Manual collection through digital archives	Number, content and format of the news	Content analysis. Comparative and longitudinal analysis: Chi square, *T*-student
Study 3	Pol and Castrechini (2013), Castrechini et al. (2015), and Pol et al. (2021)	Primary, high school and university students. Ages: 9–35 years old	Year 2007: 2304. Year 2024: 2487. Year 2023: 2264. Total: 7055 students	Three waves: 1rst study: 2007. 2nd Study: 2014. 3rd Study: 2023.	Questionnaire *ad hoc*, based on the theoretical "Model of four spheres" (Pol, 2000)	Pro-environmental attitudes, believes and behaviours	Analysis of variance (ANOVA)

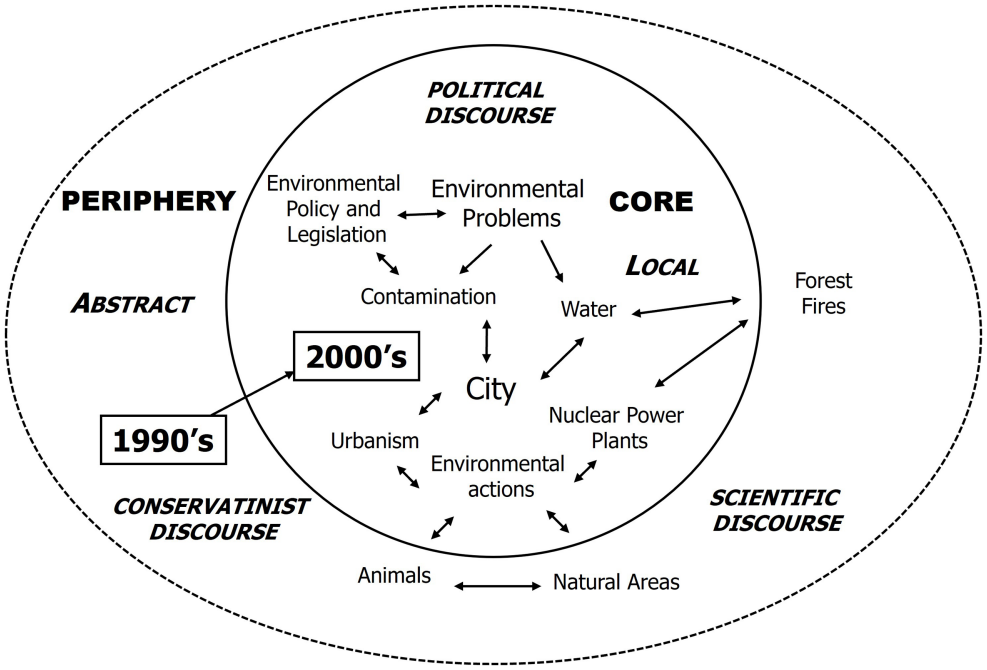

FIGURE 1
Social representation of the environment in the Barcelona Press (1992–2006) (Castrechini, 2008).

communication of information transformable into knowledge becomes imperative.

The second research piece we aim to discuss furnishes us with insights into the transformation of the image of AM in media contexts. It delves into a juxtaposition of environmental information preceding, during, and after the 2008 global crisis (Pol et al., 2017). This analysis encompasses 2004 to 2011, encompassing the quantity and nature of news pieces featured in "La Vanguardia." The study captures the proportional significance of environmental news and delves into a granular exploration of the specific themes covered before, during, and after the crisis.

Globally, a larger number of articles and environmental news pieces were published before the crisis (55.2%) compared to post-crisis (44.8%). However, these differences do not hold statistical significance. Regarding content, the majority (63.7%) pertains to local matters, emphasizing proximity to citizens, while 33.3% of the news covers international, global, or abstract topics. When considering the reference scope of the published information, the contrast between the 2004 and 2011 publications reveals a statistically noteworthy distinction ($\chi^2 = 13.128$, $p = 0.001$). This divergence was particularly pronounced in 2004, when most environmental publications revolved around local and regional concerns. After the crisis, there was an increase in news items within the International and Economy sections, implying a certain level of abstraction and detachment from the aspects of daily readers' lives. Moreover, apart from a few generic and abstract reports, brief reports take precedence as the most prevalent journalistic genre during the crisis-post-crisis period. These reports predominantly employ agency news rather than content produced by in-house authors, indicating an allocation of fewer resources and reflecting a diminished prioritization of environmental and sustainability matters.

Furthermore, during the pre-crisis era, the information predominantly encouraged reader involvement and initiative in rectifying environmental concerns. However, in the crisis and post-crisis periods, the disseminated information adopts a notably abstract stance, subtly implying that the intricacies of the environmental issue are so convoluted that it might be wiser for individuals as citizens to refrain from pursuing personal or collective endeavors. Instead, the message suggests adhering to the directives propagated by authoritative entities, presumably substantiated by the "weight of scientific expertise." (This perspective has been particularly reinforced by the prevailing communication style and official narratives during the pandemic).

These two studies collectively indicate a consistent presence of environmental coverage in the press, although its focal points experience an evolutionary shift over time. Furthermore, during periods of crisis, environmental information tends to diminish in prominence, transitioning from a focus on proximity and citizen engagement to more abstract dimensions that appear distant and less readily identifiable as immediate concerns. Consequently, this phenomenon contributes to what Uzzell (2004) has termed 'environmental hyperopia', as discussed in the preceding section. As noted on previous occasions (Pol et al., 2017), this change in emphasis leads to cognitive perplexity and a weakened emotional connection, resulting in reduced personal investment and commitment. This sets the stage for the relevance of the third study we present below.

5 From the third study: disruptions in education, awareness and environmental behavior. A longitudinal study

Not too many years ago, the primary challenge of EE was that citizens, particularly children, possessed minimal environmental

knowledge required to enhance their 'awareness' of the subject. EE programs provided information to address this issue, primarily focusing on the 'natural' environment. They facilitated contact with nature whenever feasible, often through rural centers or nature facilities. The aim of imparting knowledge and enabling firsthand experiences was to influence the core components of values, beliefs, attitudes, and behaviors. With many limits, environmental education in the last two decades has provided important achievements and positive examples, particularly when it comes to outdoor education programs that try to go beyond the simple provision of factual information or traditional knowledge transfer in school standard teaching, which also showed the possibility of interesting connections between pro-environmental attitudes and behaviors on the one hand, and subjective well being on the other hand (Carrus et al., 2012; De Dominicis et al., 2017; Pirchio et al., 2021).

More recently, processes of curricular 'environmentalization' or 'sustainability' have been initiated, entailing the integration and 'normalization' of environmental matters as cross-cutting content within formal educational curricula. These efforts align with the Sustainable Development Goals (SDGs). Moreover, periodic scales and questionnaires have been deployed for assessment purposes. A noteworthy example in this context is the New Environmental Paradigm (NEP) proposed by Dunlap and Van Liere (1978), subsequently revised by the same authors (Dunlap et al., 2000; Dunlap, 2008), and applied to diverse populations across various countries (Amérigo and González, 2001; Vozmediano and San Juan, 2005; Ogunbode, 2013; Moyano-Díaz and Palomo-Vélez, 2014). Although widely embraced, this scale has not been exempt from critical scrutiny concerning its application and potential misuse (e.g., Hawcroft and Milfont, 2010).

One notable strength of the NEP scale is its facilitation of cross-national comparisons, offering insights into the progression of environmentalism across different regions of the world—sometimes yielding optimistic outcomes, while at other times, starkly pessimistic ones.

In any case, in the present day, it is a challenging task to encounter young individuals who have not undergone some form of EE in various formats. Knowledge has undeniably expanded; nevertheless, there appears to be a limited substantial enhancement in citizen behavior. Moreover, certain stages in the life cycle seem to be more pivotal than others in this regard. It becomes imperative to question why this is the case and what factors might contribute to this disparity.

An initial study that prompted concern and raised new questions was conducted by Uzzell (1996). Observing children and young individuals before and after their participation in a nature school course or program showed that the participants' inclination to engage in responsible ecological behavior (CER) had notably decreased. This discovery led Uzzell to validate that, contrary to the intended educational goals of the center's program, the participants had concluded that the environmental predicament was indeed significant yet incredibly intricate and challenging. Fortunately, they believed there were competent experts, such as their instructors during their time at the center, who could offer solutions. In their view, individual students held no agency to effect change. Additionally, as noted in Uzzell's subsequent work (2004), he asserts that it is often simpler to express concern for distant environmental issues than to acknowledge those nearer to us—matters that impact our day-to-day existence. This line of thought leads him to introduce the concept of "environmental hypermetropia," as previously discussed.

Amidst the escalating climate crisis, there has been a notable surge in studies examining the intricate interplay between values, attitudes, and behaviors. These studies span diverse theoretical and epistemological perspectives, often yielding conflicting outcomes. Noteworthy examples among the consulted sources include Corraliza and Martín (1996), Corraliza and Berenguer (2000), Steg and Vlek (2009), Hawcroft and Milfont (2010), Kaiser and Wilson (2019), Kaiser and Wittenberg (2023), and Weis (2023), along with the contributions of Corral-Verdugo (2023). It is important to acknowledge studies that emphasize beliefs and values, such as Bechtel et al. (1999), Dunlap and Van Liere (1978), Dunlap et al. (2000), and Weigel and Weigel (1978), as well as those focus on behaviors (Hess, 1996; Real and García Mira, 2001; Hernández et al., 2002; García Mira et al., 2006).

Against this backdrop and building upon the insights from preceding research endeavors, our research team initiated a study on environmental knowledge and behaviors [2] from 2006 to 2007 (Pol and Castrechini, 2013). The outcomes of this investigation yielded unforeseen findings, prompting us to replicate the study a few years subsequently, in 2014 (Castrechini et al., 2015). Furthermore, a third iteration was undertaken, spanning 2022 to 2023 (Pol et al., 2021).

In developing the instrument, a comprehensive review of the literature about scales assessing attitudes, beliefs, and environmentally responsible behaviors, as mentioned earlier, was undertaken. An *ad hoc* questionnaire was meticulously crafted and rigorously validated to suit the various age groups encompassed by the study. The construction of the questionnaire adhered to the 4 Spheres Model (Pol, 2000; Pol et al., 2001). This model delineates four underlying components within attitudes and behaviors: Information and Rationality, Emotionality, Functionality, and social influence processes. A fifth dimension, Directly Expressed Behaviors, was introduced in longitudinal research.

The goal was not to establish a hierarchy of attitudes but rather to encompass the active presence of knowledge regarding 'what needs to be done and how to do it'—as indicated by the realms of cognition and functionality. This encompasses the willingness to engage in desired behaviors, referred to as the "subjective norm" by Ajzen and Fishbein (1980). Additionally, the emotions influencing the pace or initiation of matters concerning the environment and sustainability—sometimes linked to illusions, desires, and fears—fall within the domain of emotions. Moreover, the impact of external individuals on personal conduct (including imitation, modeling, and the fear of social ridicule for action or inaction) is consolidated under the umbrella of social influence.

A questionnaire was designed to collect data with straightforward inquiries about specific environmental behaviors. This encompassed various actions related to waste management, energy consumption, water usage, and mobility patterns (Pol and Castrechini, 2013).

2 When the study began, the research team was linked to the Catalan Network for Research in Education for Sustainability (www.Edusost.cat), currently the research group is part of the consolidated Research Group of the University of Barcelona in Psychology Social, Environmental and Organizational (PSICOSAO) (http://www.ub.edu/grc_psicosao2/index.php?lang=es).

The approach employed for sample selection, data acquisition, and analysis remained consistent across the three waves, maintaining both the sample size and the participation of training institutions. The only notable divergence pertained to the data collection method: in the initial and second waves, paper-based questionnaires were administered within classrooms, with the cooperation of the teaching staff. Conversely, the third wave adopted an online system utilizing the Qualtrics software while encouraging the participating faculty to engage in classroom responses.

Throughout all three instances, efforts were made to ensure sample uniformity within the four defined age groups: 8–9 years to 12–13 years (primary education); 13–14–15 years (secondary education); 16–17–18 years (baccalaureate and vocational training); and over 18 years (university level). The composition of each study's samples is outlined in Table 2. Across the waves, the gender distribution remained relatively constant, with an average of 44.7% male participants and 55.3% female participants.

The questionnaire results underwent thorough statistical analysis. The data from the initial wave unveiled that children aged 8 to 9 through 12 possessed a firm grasp of the prevailing 'correct' environmental behaviors at that juncture. These youngsters exhibited greater awareness and espoused more favorable values and beliefs aligned with environmental and sustainability perspectives. Nevertheless, during adolescence, a statistically significant decline in these values was observed ($F = 35.71$, $p < 0.001$, df = 3). This dip was followed by a tendency of recovery as individuals transitioned into the realms of youth and adulthood (university-level sample). Yet, even with this recovery, the attained scores fell short of the commendable benchmarks set by the children's cohort.

Importantly, it's worth noting that the adolescents' scores, albeit diminished, remained remarkably elevated on the scale employed for assessment. Furthermore, the outcomes exhibited nuanced variations contingent upon the specific program and the approach embraced by the educational institution. This divergence stemmed from what was then termed 'transversality' or the integration of sustainability education into the core academic curriculum versus 'exceptionality' or distinctive actions set apart from the conventional academic routine. These exceptional actions bestowed special prominence upon EE.

The inaugural administration of the questionnaire, referred to as the first wave, yielded conclusions that offer valuable insights into the conventional paradigms of EE—a topic we will revisit in the ensuing discussion. The advent of the global economic crisis in 2008 prompted us to grapple with the task of dissecting its potential impact on predispositions towards sustainability, as well as on the knowledge and behaviors manifested by individuals.

TABLE 2 Composition of the samples of the different applications "Study on the disruption in Education towards Sustainability."

Age ranges	5–12	13–15	16–17	>18	Total
1rst Study 2006–2007	974	451	320	559	2,304
2nd Study 2014	810	523	464	690	2,487
3th Study 2022–2023	325	761	129	1,049	2,264
Total	2,109	1735	913	2,298	7,055

In 2014, the second phase of the same research was conducted, yielding distinct and, once again, unexpected outcomes: the scores of the youngest participants had nearly equaled those of adolescents. However, a perturbation during the adolescent phase persisted ($H = 138.705$, df = 3, $p < 0.001$, Kramer's V: 0.167), engendering fresh inquiries. This downward shift prompted contemplation. What could account for this decline, particularly because educational programs remained unaltered and the sampling centers were consistent with or comparable to the previous wave?

Upon comprehensive analysis, our focus coalesced around the emergence of a novel factor – one absent in 2006–2007: the rapid proliferation of virtual social networks. These platforms, increasingly accessible to minors, exerted a potent influence, not primarily on education, but rather on the intricate socialization processes.

More recently, a new set of conjunctural and structural factors has emerged, providing indications of shifts in the third wave of our study, conducted between 2019 and 2022. This period encompassed the repercussions of the COVID-19 pandemic, exacerbations in the climate crisis, and the escalation of the Russia-Ukraine conflict. The pressing question arises: to what extent have these global factors impacted the general populace's perceptions, sensitivities, and pro-environmental inclinations?

From 2022 to 2023, the third wave of our research unveils a discernible trend towards decreased overall scores across all age groups. Yet, elucidating the underlying causes has grown considerably more intricate than previous waves, as expounded upon in subsequent sections.

Figure 2 presents the outcomes from the three successive waves of application. The scores for 2006–2007 and 2014 were notably elevated, even at their lowest. However, the 2022–23 wave discloses a discernible decline in scores, which assumes significance when contextualized within the prevailing climate emergency framework and the pervasive information dissemination regarding environmental concerns across media and social networks.

The variations among each wave (application) necessitate distinct explanations for each scenario. The wave from 2006 to 2007 prompted an exploration into the reasons behind the phenomenon termed 'disruption' in EE, as noted by Pol and Castrechini (2013). The wave from 2014 brought to the forefront inquiries regarding alterations within the social context, shedding light on why the performance of the youngest group decreased even more significantly than that of the adolescents. The data from 2022 to 2023 raises a pertinent question: why, during a period characterized by heightened concerns about sustainability and the climate emergency, do global scores experience a notable decline?

Furthermore, the outcomes allow us to reaffirm a fact widely recognized in environmental psychology and other social and behavioral sciences yet frequently overlooked, resulting in misguided educational and training strategies. It's important to note that information and/or knowledge alone does not guarantee appropriate, consistent behavior, nor do they effectively alter habits or routines. In essence, while information is essential, it remains insufficient. Moreover, this phenomenon can be observed (particularly within the university sample), where specific training can paradoxically lead to a rebound effect in behavior or, at the very least, a degree of desensitization or relativization of the problem. This observation holds

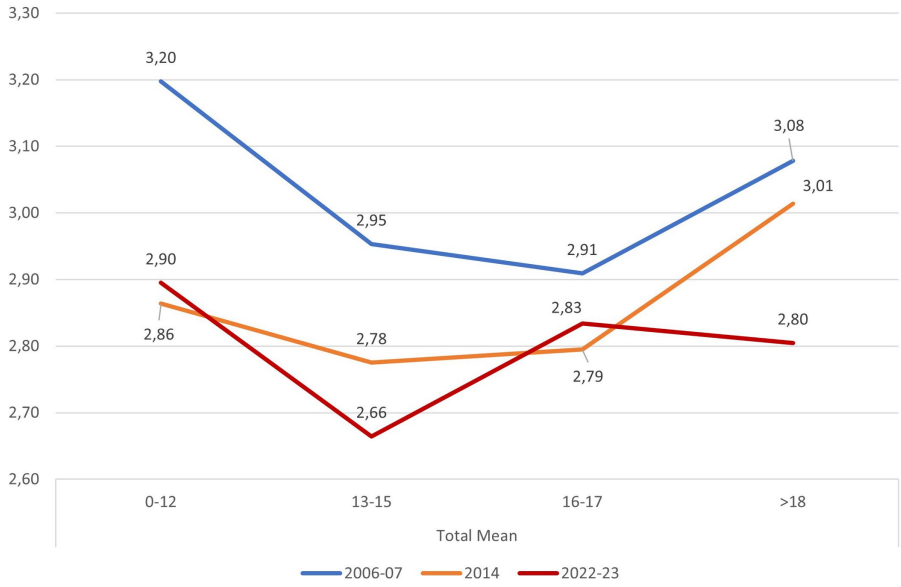

FIGURE 2
Comparison of scores 2007–2014–2023 by age. The graph represents the results of each of the three applications, showing the scores by age range.

particularly true when the recipients are prospective professionals in environmental technologies.

In the initial wave, the youngest participants achieved the highest scores and exhibited the greatest responsiveness to the social norm. This tendency can likely be attributed to their evolutionary or maturation stage, a concept expounded by Piaget and Inhelder (1969). According to these scholars, children aged 9 to 11 find themselves in the concrete operational stage, progressing to the abstract operational stage from ages 11 to 12. Nevertheless, this perspective – when applied to EE as per the viewpoints of Spencer and Darvizeh (1981) – resulted in a significant underestimation of the competencies and environmental aptitude inherent in younger children. Concurrently, it led to a certain disregard for the more contentious aspects of adolescence and its associated crises.

During adolescence, an observable inclination toward deliberately transgressive behaviors becomes apparent (Funes, 2010) – a tendency, it's important to note, that's prevalent among all individuals. This penchant for transgression during adolescence stems more from the evolutionary crisis inherent to this phase, closely tied to the imperative of self-identification and differentiation rather than from inadequacies within training programs. This phenomenon is closely interwoven with external factors beyond the school environment. Moreover, it is pertinent to contemplate the extent to which the incorporation of environmental values advocated by EE initiatives and certain media influences the perception of these values as "formal and official tenets of the societal framework." Adolescents often oppose these values during identity crises as they search for meaning. Therefore, the disruption experienced during adolescence is more aligned with the inclination to 'transgress' rather than a dearth of training, information, or ignorance concerning desirable behavioral norms.

Within the European context, Grønhoj and Thøgersen (2009) similarly observed a phenomenon wherein adolescents display lower environmental commitment compared to their parents – an occurrence the authors call the "generation gap." While attitudes towards the environment generally skew positive, a discernible discrepancy exists in the manifestation of values and behaviors. This discrepancy is ascribed to the challenges inherent in the developmental stage experienced by adolescents, during which the prevailing priority values diverge from those upheld by adults.

In the initial two studies, university students exhibit more favorable behavior than adolescents, although they cannot "attain" the levels observed in primary school children during the 2006–2007 period. However, in the third wave, their scores remain stagnant at the same level as the adolescent cohort. Additionally, several unexpected trends become apparent in the disaggregated analyses. For instance, attitudes and behaviors concerning waste management fare worse than the broader sample. Furthermore, a noteworthy observation emerges from 2007: the university (or institution of study) that allocated greater time and resources to environmental management and the restructuring of their curricula to provide targeted sustainability education to students yielded inferior outcomes in values tied to civility and processes of social influence, as opposed to other universities.

The resurgence of scores within the university setting appears to hinge more on contextual factors that enhance these values and behaviors rather than solely on the training imparted. Furthermore, this resurgence seems to be counteracted or reduced by a sense of familiarity, knowledge, or a perception of control over environmental challenges and technologies – factors poised to shape their forthcoming professional endeavors.

5.1 Transversality vs. exceptionality?

The findings raise suspicions that the 'normalization' of environmental training as a pervasive value in certain school and academic curricula causes these values to go unnoticed. Conversely, the exceptional nature of specific actions appears to enhance their memorability and serve as stronger catalysts for the expression of current behavior. The analyses

indicate notable disparities between students who recall participating in environmental training activities and those who do not.

Moreover, based on the data provided to educational institutions, the count of respondents who have completed environmental and sustainability training significantly surpasses the count of those who remember having engaged in such activities. This trend aligns with observations from other studies in different contexts (e.g., labor) and various countries, wherein 'mainstreaming' (typically perceived as the earnest and desirable approach) proves less effective than 'exceptionalism' – referring to specific acts with a certain festive or folkloric quality, often criticized as superficial and shallow.

A similar scenario unfolds concerning awareness of environmental issues or policies within organizations that have attained an EMAS certification (a European system somewhat akin to ISO 14,000). This occurs when they employ an "integrated management system," resulting in a dilution of environmental focus. Conversely, this dilution is absent when a specialized environmental management system is employed (Pol et al., 2006). Comparable outcomes emerged in other contexts, such as Brazil (Bolzan de Campos, 2008; Bolzan de Campos and Pol, 2009) and Mexico (Manzano, 2016; Peña, 2016).

The suspicion that specific training might lead to a rebound effect on behavioral aspects while failing to instill environmentally suitable habits and behaviors challenges the current sustainability model implemented in schools and colleges. These suspicions are grounded in empirical observations; however, they warrant further dedicated studies to provide more conclusive insights. Nonetheless, a mounting number of indications are pointing in this direction. This is a significant motivator behind our undertaking of this longitudinal study.

6 Discussion

As observed in the results of the various synthesized investigations, distinct interaction and interdependence exist among the conceptual axes explored in each study. This point becomes even more evident when we consider the outcomes of longitudinal research. The fluctuations in the results across the three waves of knowledge and predisposition analysis toward more ecologically respectful behavior cannot be comprehended without accounting for the shifts in communication technologies, alterations in perceptions or societal portrayals of the environment, sustainability, and the climate crisis.

Moreover, understanding these changes requires acknowledging the evolving nature of socialization processes and the influential sources or stimuli that significantly shape this progression. Notably, this aspect has strikingly vanished from scientific literature in recent decades, encompassing various fields such as psychology (including general, social, and environmental psychology), education, and sociology.

As demonstrated by Castrechini (2008), the media's coverage of environmental issues experienced a substantial increase between 1992 and 2006. Its content transitioned from primarily scientific to political and legislative during the 1990s. This transformation can be largely attributed to the influence of the Brundtland report (Brundtland, 1987) and the Porto Alegre Earth Summit (1992), which emphasized the need to establish appropriate legislative bodies and encouraged active engagement from environmental movements. This involvement expanded to encompass not only grassroots organizations but also governmental agencies.

Moving into the 2000s, the discourse surrounding environmental issues further evolved, taking on a more abstract tone. There was a heightened focus on conservation and scientific dialogues while still retaining a strong emphasis on the importance of citizen engagement.

In the second analyzed investigation, the data again reveals a significant shift when comparing the periods before and immediately after the economic crisis of 2008. The pre-crisis phase focused on empowerment, consistently emphasizing the need for people's involvement and commitment to initiate actions. However, the post-crisis period witnessed a change in the positioning and underlying message of the information, even though the volume of information remained consistent with the previous phase. Following the crisis, environmental information began to be situated within more abstract contexts, conveying the message that the issue is of such gravity and complexity that personal, social, or community initiatives should not be pursued. Instead, the emphasis shifted to macro-level politics, economics, and "science," the narrative urged compliance with these broader frameworks. This shift led to a sense of helplessness, reliance, and impotence. To a large extent, it generated a sense of deception, especially because the scientific discourse on environmental issues evolves over time, with emphases and explanations that are sometimes contradictory, thus running the risk of losing credibility, as mentioned above.

This effect aligns with the findings of Uzzell (1996, 2004), who observed a discouraging impact on children after participating in a nature school. These children perceived the environmental issue as so intricate that grasping it was challenging, and they considered themselves fortunate that there were experts who understood it comprehensively, thus alleviating the need for a personal concern. In the context of the nature school, this outcome starkly contradicted the institution's intended purpose. However, concerning media coverage, whether this outcome is unintentional becomes less apparent. Both mass media and social networks play pivotal roles in constructing narratives and shaping SR recall Ruiz's (2015) characterization of "communicators" as symbolic "architects" of realities. This is particularly pertinent within the broader context of profound societal shifts catalyzed by the 2008 crisis on both local and global scales. Consequently, if collective actions by individuals can contribute to addressing environmental challenges, they also possess the potential to confront and transform various socioeconomic and political dimensions of local and global societies. Yet, these latter implications might not align with certain segments' interests.

If we delve further into the past, the evolution of EE, often considered the cornerstone for catalyzing shifts in individuals' attitudes and behaviors, is worth examining. As we have mentioned during the 1970s, it emerged as a 'revolutionary' endeavor championed by nascent environmental movements. However, as we progressed into the late 1980s, the 1990s, and beyond, it transitioned to being endorsed by institutional bodies. This change in the source of promotion brings forth pertinent discussions surrounding the credibility and trustworthiness of the message disseminators (Newman et al., 2021). The shift to 'institutional' sources, associated with power and authority, to a significant extent, explains the notable decline in adolescent engagement observed in the study conducted between 2006 and 2007. Moreover, this trend of diminishing involvement is consistent with downward trajectories witnessed in subsequent studies.

The noteworthy decline in the scores achieved by the youngest participants in 2014, a decline surpassing the scores of adolescents in 2006–2007, persists into the 2022–23 timeframe. Moreover, the third wave saw a universal drop in overall scores across all age groups. While we do not primarily attribute this phenomenon to deficiencies in formal classroom education, it appears to be influenced by the emergent role of virtual social networks and media as powerful agents of socialization. This role began to take shape in 2006–2007 and has since increasingly assumed the role of a primary socialization agent, often overshadowing other traditional agents, particularly in the case of children and adolescents (Stasova and Khynova, 2012).

As we alluded to earlier, literature regarding the impact of social networks on socialization remains relatively scarce. The existing literature concentrates more on the potential "addictive" and pathological effects on adolescent development (Malo Cerrato et al., 2023) rather than conducting comprehensive analyses of the content, values, or behavioral patterns propagated by these networks. Nevertheless, it is these patterns that wield considerable influence over subtle processes of socialization. This situation underscores a significant pending challenge: a thorough and rigorous examination of the transformed landscape in transmitting values, personal paradigms, and behavioral norms. This exploration needs to be undertaken in a future context and within the immediacy of the present. Furthermore, this imperative extends beyond environmental values and behaviors, encompassing a contribution to comprehending the escalation of aggressive behaviors and gender-based violence among children – a distressing trend that appears to be proliferating across society.

Another dimension illuminated by our data pertains to educational strategies and the standardization of environmental knowledge within formal educational curricula (García-Vinuesa et al., 2022). As early as the 2006–2007 sample, a striking trend emerged. Students attending institutions with fully integrated EE content and activities seemed to recall these experiences less or exhibited diminished awareness of their participation compared to their counterparts in schools where pro-environmental initiatives were positioned as distinctive or exceptional occurrences. This pattern persisted through the subsequent two waves, despite concerted endeavors to enhance EE programs (Martí, 2003; Rodrigo-Cano et al., 2019).

A comparable contradiction emerges in the context of the university samples across the three waves, necessitating an alternate theoretical interpretation. Our analysis compares what we have classified as education directly engaged with environmental concerns versus non-environmentalized education. Strikingly, paradoxically, students categorized as "non-greened" consistently achieve higher scores across the three waves than their peers enrolled in environmentally integrated or actively engaged environmental coursework.

As demonstrated in the results section, the university-aged cohort in the first two waves reveals a resurgence concerning environmental awareness compared to their adolescent counterparts. However, this improvement does not hold in the 2022–2023 sample. Yet, across all three instances, a comparable phenomenon akin to that observed in primary and secondary education manifests, albeit with distinctive nuances. Individuals pursuing non-environmentalized academic tracks consistently score more than those directly engaged with environmental subjects or issues. In the initial and subsequent waves, university students generally display a slightly heightened sensitivity to environmental concerns, likely influenced by the impact of narratives, imagery, and SR that accentuate the topic. This heightened sensitivity will diminish by 2023.

However, a striking trend common to all three waves is the lower scores attained by those actively engaged with environmental subjects. Regarding a theoretical interpretation, this pattern might resemble the concept of objective risk versus risk perception. Exposure or acclimatization to risk can reduce perception, even when the objective risk remains substantial (Lima et al., 2005). Additionally, a degree of cognitive dissonance (in Festinger's sense) might emerge between being trained to rectify or transform environmental issues and perceiving the situation as exceedingly critical. A prevailing sense of self-assuredness in their capacity to positively influence environmental improvement often supersedes the belief that, as experts, they might be incapable of rectifying the situation. This inclination aligns with the trend described by Fointiat (1998) and Fointiat et al. (2011) in their exploration of 'rationalization' instead of 'rationality.'

All of these insights collectively lead us to conclude that a paramount and integral aspect lies in enhancing information processing and communication management. These factors are foundational to the psychological and societal construction of sustainability. The advancement of knowledge concerning sustainability and the climate crisis is inherently dynamic and subject to ongoing progress. This becomes clear with the phenomenon of solastalgia and which could be understood as the feeling of sorrow that comes with the loss of previous environmental conditions (Albrecht et al., 2007). The mismanagement of this information engenders scenarios rife with message inconsistencies, ultimately breeding uncertainties, fostering distrust, cultivating a sense of deception, and contributing to a surge in eco-fatigue (Pol, 2000) and eco-anxiety (Albrecht, 2011).

Thus, the perspective pioneered by Festinger, which still garners adherents, elucidated how individuals tend to incorporate only information that aligns with their pre-existing beliefs (rationalization). This phenomenon hinders implementing initiatives to foster sustainable behaviors, as it complicates efforts to prompt actions that foster sustainability-aligned conduct.

This rationalization process similarly influences the inherent construction of realities, narratives, and social representations stemming from human behavior, potentially exacerbating confusion. Moreover, scrutiny of socialization processes is imperative, spanning both the formative years of childhood and the adult population. In the ICTs age, images and value frameworks proliferate, obscuring the origins of these constructs, making it challenging to ascertain definitively who authored them, the methods of creation, and the underlying motivations. At best, we can discern the sender of these materials.

7 Conclusion and new challenges

Our review of literature from various fields, combined with our own synthesized research findings, has enabled us to propose a series of relationships and explanatory statements that shed light on aspects of contemporary reality. However, we must mention that the main

limitation of this review has focused on some specific studies from the authors' own research output. A broader and more diverse review could have provided a more contrasted view. Additionally, due to the inherent difficulty in establishing clear causal relationships that do not oversimplify or distort reality, many of our assertions and conclusions require further theoretical and empirical analysis.

A crucial area of research lies in examining, contrasting, and empirically quantifying the values, personal models, and behavioral patterns being disseminated through social networks, particularly among young people and children. Understanding these influences is essential not only for shaping environmental values and behaviors but also for deciphering the rise of aggressive behavior and gender-based violence among youth.

Another element demanding ongoing attention is the evolving image of the environment, sustainability, climate change, and related issues constructed by mass and social media. This knowledge is essential for developing effective change strategies and education programs. Moreover, understanding and evaluating the key effects of socialization, often overlooked in current theoretical and empirical analyses, is particularly important in this context.

We have explored how current dynamics can enhance empowerment or create "induced" situations of learned helplessness (in Seligman's sense), facilitated by relational alterations (losses) induced by ICTs and especially social media. We have detected and described a fundamental implicit change in the contents and strategies of environmental communication before and after the 2008 global economic crisis.

However, we must continue to analyze the prevalence of specific communication strategies in the present and future. Assessing the overall credibility of environmental information reaching the public requires examining the self-interested use and abuse of such information, for instance, in greenwashing and in explicit and subtle economic and political maneuvering. This underscores the importance of environmental information management. Poor information management leads to contradictions that generate uncertainty, a sense of deception, loss of credibility, and increased eco-fatigue, eco-anxiety and solastalgia.

Further research is needed to investigate why individuals actively working on environmental issues or pursuing related education tend to score lower in some surveys of environmental concern. To what extent is this a personal strategy to reduce cognitive dissonance (in Festinger's sense) between working or training to address environmental problems and perceiving the situation as very serious or irreversible? Does self-confidence in one's ability to positively influence environmental correction outweigh the belief that, as technicians, one cannot fully remedy the situation?

In conclusion, while studying the relationships between values, attitudes, and behaviors from a psycho-socio-environmental perspective is essential, we must also consider the interconnected processes of reality construction, mass media's influence on shaping meaning, networks' impact on societal socialization, and the challenges posed to traditional education by technological, structural, socio-economic, and political shifts. These factors ultimately influence what is taught, what is not, what is recognized and prioritized as "science," and how the emphasis placed on specific aspects or processes, intentionally or unintentionally, affects the credibility of sources, public trust, and the willingness to engage in ecologically responsible and active behaviors. Understanding these dynamics is crucial for preventing a sense of powerlessness stemming from "induced" helplessness, socio-economic factors, and the questionable effects of emerging technologies.

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EP: Conceptualization, Funding acquisition, Methodology, Project administration, Writing – original draft, Writing – review & editing. AC-T: Methodology, Project administration, Writing – original draft, Writing – review & editing. IP-C: Investigation, Methodology, Writing – original draft, Writing – review & editing. CC-M: Data curation, Formal analysis, Visualization, Writing – review & editing.

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Conflict of interest

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Sustainable materials: a linking bridge between material perception, affordance, and aesthetics

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The perception of material properties, which refers to the way in which individuals perceive and interpret materials through their sensory experiences, plays a crucial role in our interaction with the environment. Affordance, on the other hand, refers to the potential actions and uses that materials offer to users. In turn, the perception of the affordances is modulated by the aesthetic appreciation that individuals experience when interacting with the environment. Although material perception, affordances, and aesthetic appreciation are recognized as essential to fostering sustainability in society, only a few studies have investigated this subject matter systematically and their reciprocal influences. This scarcity is partially due to the challenges offered by the complexity of combining interdisciplinary topics that explore interactions between various disciplines, such as psychophysics, neurophysiology, affective science, aesthetics, and social and environmental sciences. Outlining the main findings across disciplines, this review highlights the pivotal role of material perception in shaping sustainable behaviors. It establishes connections between material perception, affordance, aesthetics, and sustainability, emphasizing the need for interdisciplinary research and integrated approaches in environmental psychology. This integration is essential as it can provide insight into how to foster sustainable and durable changes.

KEYWORDS

sustainability, material property, beauty, affordances, aesthetic appreciation, aesthetics

Introduction

In today's rapidly evolving world, the interconnectedness of human behavior, material perception, and sustainability have become increasingly important. From a psychological point of view, understanding how we perceive and interact with the materials around us, as well as the *tertiary qualities* (Koffka, 1940; Sinico, 2015) or "affordances" they offer, may play a crucial role in shaping sustainable practices and design strategies. This intricate relationship between human perception and material affordances forms the core of our exploration into the concept of affordance.

Coined by the environmental psychologist Gibson (1977), affordance refers to the perceived possibilities for *action* that an object or environment offers. It suggests that our

perception of materials goes beyond physical attributes, extending to the potential actions they enable or constrain. Gibson stated, "I assume that affordances are not simply phenomenal qualities of subjective experience … instead, they are ecological, in the sense that they are properties of the environment relative to an animal" (Gibson, 1966, p. 285). This concept was highly influenced by the Gestalt theory and prefigured by the work of Lewin and Koffka, who stressed the dynamic and functional relationship between environmental objects and what a perceiving and acting organism can do (Buxton, 1985) and highlighted the inter-subjective character of tertiary qualities (Koffka, 1940). In this context, tertiary qualities, for example, the "expressive" or "physiognomic" properties, are functional qualities that express a particular (moral, psychological, intersensory) character (e.g., velvet is kind) and, although they need the activity of an organism to perceive them (through the nervous system), they are independent of the subject (Koffka, 1940, p. 191). As the concept of *affordance* has been used in many different contexts and research fields, with slight variations in meaning, here we define affordance for a given function as the perception of the "how-to-use it" when seeing the object or when the surface correlates with the structure (functionalism). Moreover, we adhere to the defining criteria proposed by Evans et al. (2017): (i) it is neither the object nor a feature of the object; (ii) it is not an outcome; (iii) it has variability.

Material perception comes into play as we interpret and understand the qualities and properties of different materials through our senses, particularly vision and touch. Materials' texture, weight, and temperature provide vital information about their composition and potential uses. This perceptual understanding influences how we interact with materials and make decisions regarding their sustainable usage.

This review addresses environmental sustainability challenges, traditionally tackled with technological innovations, emphasizing a shift in paradigms and theoretical frameworks that consider people's attitudes, values, beliefs, and emotional needs. As awareness grows about the environmental impact of our actions, there is a growing need to consider the affordances of sustainable materials, aesthetic appreciation, and practices. Designers and innovators are exploring ways to create materials and products that meet our functional needs and align with ecological considerations. Hence, this review aims to examine the relationship between surface material perception (as the predictor) and sustainable actions (as the outcome), exploring the potential mediating roles of object affordance and aesthetic appreciation, encompassing research on beauty, aesthetic pleasure, and preference. Understanding the functional and aesthetic aspects of sustainable materials fosters thoughtful and environmentally conscious consumption choices by increasing the perceived object's value and lifespan.

In the following sections, we will begin by discussing the psychophysics and neural correlates of material perception. Next, we will delve deeper into the intricate relationship between material perception, affordance, and sustainability, exploring how these concepts interact and influence one another. Additionally, we will explore the connection between sustainable materials and aesthetic appreciation. Our goal is to bridge disciplinary gaps, bringing together fields that typically operate independently. This exploration enhances our understanding of these interconnected phenomena and contributes to fostering environmentally conscious choices and sustainable behaviors.

Visual psychophysics of material perception

Material perception is how we perceive what things are made of, the material composition of objects. Although this function may encompass all our senses, we will focus on how material categories and properties are extracted from the visual environment.

When tested using high-level material categories and real-world images, it has been shown that visual recognition of materials is a rapid process despite the visual ambiguity, where similarities in visual appearance are found across different types of materials and variations in visual appearance are found within a single type of material (Sharan et al., 2009, 2014). In a study by Sharan et al. (2009), the participant's task was to identify the material types in photographs taken in the real world. The authors used photographs from the Flickr.com material image database to test material detection in a rapid serial visual presentation (RSVP) paradigm (Sharan et al., 2009). The results showed that observers could still complete the recognition task even with stimulus display times as brief as 40 ms. The recognition was not based on other cues such as object recognition, shape, texture, and color discrimination (Sharan et al., 2009; Scorolli and Borghi, 2015). These results are consistent with a more recent study that has shown that the categorization of materials is accurate but slower than object recognition (Wiebel et al., 2013). Using a backward-masking paradigm, the authors looked at how material categorization in natural photographs changes over time in relation to superordinate and basic-level object categorization. The findings demonstrated that the speed of material categorization is slower than that associated with superordinate object categorization but generally equivalent to the speed of basic-level object categorization. Subjects' performance was modulated by color, which significantly increased performance for material categorization, suggesting that low-level features are crucial in mediating performance. Although modulated by low-level features, material recognition seems to occur at a higher stage of the visual hierarchy compared to the processing of low-level features such as color, motion, and orientation. Indeed, Wolfe and Myers (2010) have shown, with a visual search paradigm, that material type is associated with inefficient search results, suggesting that this attribute does not guide our visual search in the visual environment, and it is probably challenged by the visual phenomenon of "crowding" presented in the peripheral vision (Pelli et al., 2004; Strappini et al., 2017; Wolfe and Horowitz, 2017).

A recent theoretical framework, namely, the "statistical appearance models," has been proposed by Fleming (2014, 2017) to explain material recognition. This model presupposes the existence of a high-dimensional feature space, and it uses generative models that are specific for encoding and recognizing materials. This paradigm proposes that rather than learning the fundamental physical laws of the outside world, we learn to encode the systematic changes related to low-level attributes such as size and contrast, both within and between materials. For this reason, this framework may explain why the judgment of a certain property surface material (e.g., gloss) is strongly influenced by the judgment of another surface attribute, as perceivers seem to compare the relative salience of segmented parts when they are asked to judge the material properties (Fleming, 2014).

Neural correlates of material perception

There is a general agreement in considering material perception as a mid-stage, cross-modal process with a hierarchical structure in terms of visual perception. However, its neural basis and how material properties are encoded on a neuronal or network level it is not clearly understood. Functional magnetic resonance (fMRI) studies in humans have found that visual material processing is associated with the blood oxygenation level-dependent (BOLD) activity in the medial regions of the ventral extrastriate cortex (e.g., Newman et al., 2005; Cant and Goodale, 2007, 2011; Jacobs et al., 2014) and the high-order visual areas, such as the parahippocampal gyrus, fusiform gyrus, and collateral sulcus (Hiramatsu et al., 2011; Goda et al., 2014; Komatsu and Goda, 2018). Only a few studies have investigated the neural processing associated with processing specific material properties. For instance, Sun et al. (2016) have found that surface properties significantly modulate the activity in the early visual and somatosensory cortex. Gloss, which is one of the most studied material properties, seems to be associated with neural activity in the posterior fusiform sulcus and in area V3B/KO (Sun et al., 2015) in humans and the inferior temporal cortex in monkeys (Nishio et al., 2012; Baba et al., 2021).

Hiramatsu et al. (2011) performed an fMRI experiment to examine how the human brain categorizes material categories utilizing multivoxel pattern analysis. They showed that low-level image statistics, including contrast, spatial frequency, and color information, greatly influence how materials are represented in the early visual areas. This result is consistent with a recent study that showed that roughness and texturedness could be classified based on image statistics as early as the striate cortex, and therefore, that category information is already present in V1 (Baumgartner and Gegenfurtner, 2016). These results are consistent with an event-related potentials (ERPs) study showing that material categories, such as wood and stone, can be discriminated systematically around 100 ms after stimulus onset, probably due to differences in the low-level image attributes between the surface material properties (Wiebel et al., 2014).

Overall, these neuroimaging studies seem to suggest that the neural processing in material perception may range from identifying basic image features in the primary and secondary visual cortex (Baumgartner and Gegenfurtner, 2016) to classifying surface materials in higher-order category areas, such as the parahippocampal gyrus, fusiform gyrus, and collateral sulcus (Hiramatsu et al., 2011; Goda et al., 2014; Jacobs et al., 2014; Komatsu and Goda, 2018).

At the clinical level, this pattern of results is consistent with neuropsychological studies showing a dissociation between shape, size, and orientation processing, which seem more related to the occipitotemporal portion of the lateral occipital complex (LOC) and the material properties processing, which seems more associated with the lateral subdivision of LOC (James et al., 2003).

Active perception and material affordance

The information gained through material perception can be used to appropriately control the movements of one's fingers when grasping objects or one's feet when walking on a road or deciding whether to purchase a product. These functions are performed thanks to learning the relationship between object attributes and effective object interaction.

Among object categories like faces, body parts, animals, houses, and scenes, tools automatically engage "unconscious" sensorimotor modules and corresponding cortical regions in the posterior parietal cortex (the "dorsal stream") even during passive viewing (e.g., Creem-Regehr and Lee, 2005; Kourtis et al., 2018; Whitwell et al., 2020). This process is similar to the motor "affordance" phenomenon, which occurs when the perception of a graspable object prompts motor actions that are consistent with the object's orientation or size (Tucker and Ellis, 1998, 2001; Ellis and Tucker, 2000; Phillips and Ward, 2002). Clinically, patients with manual groping or utilization behavior that forces the patient's hand to follow, grip, or utilize tools can exhibit the automatic nature of uninhibited motor affordances (Lhermitte, 1983).

The enhancement of an action provided by an object may happen automatically (Tucker and Ellis, 1998). However, it also depends on several factors, including the attention given to the object as a whole (Riggio et al., 2008) or to an action-relevant feature of the object (Pellicano et al., 2010), the shaping of the prospective individual's hands (Ansuini et al., 2008), the actual possibility of reaching the object (Cardellicchio et al., 2011), the parallel linguistic processing (Ambrosini et al., 2012), the possible social request from a conspecific (Scorolli et al., 2014), as well as the involvement of the affective dimension (Caravà and Scorolli, 2020). The affordances of an object can also vary based on the non-permanent attributes of an object and its time-invariant features (Borghi and Riggio, 2009, 2015).

Few studies have examined the affordances related to material properties and whether changes in material surface appearance affect motor movements of prehension (reaching and grasping). Grasping involves preparing the grip by opening and shutting the hand according to the desired object's characteristics, whereas reaching involves directing the hand to the desired position (Jeannerod, 1981, 1984).

Paulun et al. (2016) investigated how material properties and object orientation influence precision grip kinematics. They gave participants cylinders to hold, raise, and carry to a specific location, which were composed of different materials (styrofoam, wood, brass, and a vaseline-coated) and displayed at six distinct orientations (0°, 30°, 60°, 90°, 120°, and 150°) in relation to the participants. Differences in time and spatial modulation at all stages of the movement were found by analyzing their grasping kinematics, which depended on both material and orientation. Specifically, the material had an impact on the selection of local grasp locations as well as the length of the movement from the initial visual input to the object's release (Paulun et al., 2016).

A recent study employed a seated reach-to-grasp paradigm, where participants performed a lifting movement transporting familiar objects, paper cups, from one location to another, varying the surface glossiness and object weight. The authors found that the temporal and spatial components of the reach-to-grasp movements were modulated not only by the weight, as previously shown, but also by variations in the surface material properties (matte vs. varnished surface) (Ingvarsdóttir and Balkenius, 2020). In a follow-up study, the authors investigated how material properties influence the early grip force control exerted by each of the five fingers while lifting paper cups (Ingvarsdóttir and Balkenius, 2020). As in the previous study, object weight and surface glossiness were modulated across conditions. The

outcomes confirmed the importance of visual material qualities in prehension control. Moreover, it was shown that early grip force scaling was affected not only by the weight of the cups but also by their surface glossiness (Ingvarsdóttir and Balkenius, 2020).

Finally, one study examined the development of material property perception for grasping and reaching in early childhood for objects with different rigidity using a 3D motion capture system (Preißler et al., 2021). The task consisted in lifting objects with one of two handles that varied in rigidity (soft and hard) after visual and visual-haptic exploration. The findings showed that after visual exploration, infants had no specific material preference; thus, the material did not ease grasping. However, after visual-haptic exploration, the infants preferred the soft handles, although they were more challenging to use when lifting the object. Conversely, adults showed the opposite pattern as they preferred using rigid handles to grasp the object and were efficient with both conditions. Interestingly, 3 years-old children seemed to be in an in-between stage of development and showed no preference for the soft or rigid type of handle. These results suggest that reaching and grasping objects is influenced by the material property, such as rigidity, and that it is a learned skill that requires a long development process (Purpura et al., 2018), as the efficient use of visual and visual-haptic information presumably appears later than the age of 3 years.

Aesthetic sustainability of materials perception

How individuals perceive materials significantly influences their decisions and actions towards sustainable practices and design choices. Understanding the determinants of material perception is important for promoting environmentally conscious behaviors and informing sustainable design practices.

Recent research has highlighted the relationship between material perception and sustainable decision-making, emphasizing the importance of sensory experiences in driving environmentally conscious choices. Studies have shown that individuals' perception of materials can influence their willingness to engage in sustainable practices. For example, research by Bjelkemyr et al. (2015) found that participants who perceived materials as more environmentally friendly in terms of life cycle assessment were more likely to think about pro-environmental behaviors, such as recycling and energy conservation. Specifically, the authors found that metals are considered the most important materials to recycle, while plastics are within the waste fractions. This suggests that a positive perception of sustainable materials can contribute to a greater motivation for sustainable action. Furthermore, materials' tactile and visual qualities can significantly impact their perceived sustainability. Research by Thundathil et al. (2023) showed that when individuals interacted with materials that were visually and haptically associated with sustainability (biobased composites), they exhibited a greater likelihood of attributing eco-friendly characteristics to these materials in terms of beauty, naturality, and value. This association between sensory experiences and sustainability perception highlights the potential for utilizing materials with sustainable attributes to enhance positive perceptions and promote sustainable choices.

On the other hand, other studies have highlighted the importance of the type of material for the perception of sustainability in packaging and how this relationship is associated with eco-friendly choices. For instance, de Oliveira et al. (2023) showed that the perception of sustainability and environmental value was higher when the packaging used materials such as paperboard and glass. Conversely, materials like metals and polymers undermine the perception of this value.

Although product designers are eager to promote sustainable materials, how users feel about them and how material properties interact with sustainability perception still needs to be determined. For instance, bio-plastics are only now available in relatively few niche markets. However, it is still uncertain how consumers would react (Brockhaus et al., 2016). It appears appropriate to look into how people interact with these materials, given the progressive development of sustainable materials by various product developers. When users interact with sustainable materials, their distinctive surface material properties and the "ingredients" that the materials are built of will operate as active cognitive stimuli and, as a result, trigger a range of emotions. In this regard, research on the mediating role of affective responses and emotions on the relationship between material perception and sustainable actions has the potential to inform the development of innovative sustainable materials and products.

A study by Bahrudin and Aurisicchio (2018) found that participants' evaluation of sustainable materials induced various positive and negative emotions. In particular, the most frequent positive and negative emotions were surprise and disgust, respectively. When the materials were appraised in terms of sustainability and lifecycle parameters, they were perceived as more connected to positive emotions than when they were appraised based on their technical themes or sensorial properties. Thus, the authors conclude that systemic appraisals, for instance, based on the lifecycle assessment of the material, have the benefit of impacting product use. These findings highlight the importance of the narrative, or "biography," of a sustainable material that can potentially amplify positive emotions. Self-positive and moral emotions also play a role in sustainable perception, in particular positive emotions that promote happiness, health, and quality of life, feeling morally righteous in relation to the environment, and feeling powerful by an increase in the social status (Hain, 2017). Positive emotions are also associated with developing an emotional attachment to the product, which ultimately induces more frequent use and helps extend its lifecycle (Wu et al., 2021). Given that positive emotions are associated with sustainability, several theories have been proposed to explain the relationship between product design and emotions. For instance, the emotionally durable design (EDD) is a method proposed by Chapman (2012) to enhance emotional processing and thus extend a product's lifecycle.

Several studies suggested the importance of creating customer loyalty inducing emotional attachment with sustainable products and eco-friendly practices. Indeed, it has been found that individuals who feel emotionally connected to sustainable materials are more likely to engage in sustainable behaviors and express a greater willingness to pay for sustainable products (e.g., Laroche et al., 2001; Han et al., 2010). This emotional attachment can be fostered through design strategies that evoke positive sensory experiences, such as using materials with pleasing textures and visual aesthetics that evoke nature or sustainability values. In the realm of design and innovation, the perception of attractive materials can drive sustainable practices. Indeed, aesthetic appreciation, related to materials' sensory and emotional appeal, seems to influence affordance and sustainable choices. Aesthetically pleasing designs evoke positive emotional

responses, increasing product satisfaction and longer product lifespans. Research in this field has focused on finding the best strategy to improve emotional durability and consumers' aesthetic appreciation of the product (Ji and Lin, 2022). Although the aesthetic appreciation of materials is considered essential to induce sustainable actions, only a few studies have investigated this relationship. A study exploring the perception of the beauty of materials-derived waste based on visual and tactile stimulation found that modifying visual and tactile properties may shift how individuals perceive material aesthetics. Specifically, the authors suggest that for introducing an unfamiliar material, changing the perceptual properties in an incongruent, contrasting way might be a possible strategy to elicit a positive emotion of surprise and, ultimately, appreciation (Sauerwein et al., 2017).

Finally, some studies within the environmental psychology of building design have highlighted the meaningful impact of naturalness, i.e., how a product has a natural-looking aspect, on aesthetic evaluation. In seeking to quantify the low-level features and visual statistics underlying natural-looking environments, researchers have found that the high frequency of contrast changes and high density of curved edges predict aesthetic appreciation (Berman et al., 2014; Kardan et al., 2015). A recent study has found that scaling and contrast patterns (Alexander et al., 2004) are associated with the perception of naturalness and predict the aesthetic preference in interior and exterior architectural images (Coburn et al., 2019). These results suggest that aesthetic preference for naturalistic architectures, regardless of the types, is mediated by a common mechanism. Further studies have also shown that these perceptual mechanisms are shared among non-professionals and professionals, such as architects, as both have the same accuracy in evaluating how a material has a natural look, thus suggesting the importance of maintaining the naturalness of the surface materials in building sustainable products (Zhang et al., 2023). Thus, understanding how we see materials is not just about vision; it guides us toward sustainable choices and eco-friendly designs.

Concluding remarks

Positive perceptions of sustainable materials, driven by sensory experiences, emotional connections, and visual aesthetics, can influence sustainable decision-making and foster environmentally conscious behaviors leading toward "aesthetic sustainability" (Harper, 2018) or "echo-aesthetics." Understanding the psychophysics and neural basis of material perception, as a low-mid level phenomenon in the visual processing hierarchy, and its emotional and aesthetic experience can reshape our understanding of the aesthetic and artistic concepts associated with material design and inform research within the field of environmental psychology. Indeed, integrating sustainable materials into design and innovation practices can leverage these perceptions to encourage the adoption of sustainable products.

The present work highlights how the current literature supports the link between material perception, affordance, aesthetics, and sustainability. We believe that this frontier research deserves a focused and joint effort by researchers from different disciplines, from cognitive sciences to design, toward a rethinking of "flexible objects" where the dimension of sustainability is addressed along with the motor and aesthetic components.

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Does environmental management system certification affect green innovation performance?—Based on a moderated mediating effects model

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What is the impact of environmental management system certification on green innovation performance, and is it a futile endeavor or a profitable one? Grounded in the principles of ecological civilization construction and green development, this study embarks on a comprehensive examination. Initially, it investigates the varying impacts of environmental management system certification on both traditional innovation performance and green innovation performance. Subsequently, it dissects the underlying mechanisms and moderating factors influencing the latter, including an exploration of intermediary effects. The empirical findings of this study are as follows: (i) Environmental management system certification emerges as a catalyst for innovation performance, with the primary impact observed in the realm of green innovation performance. (ii) Social responsibility disclosure is identified as a mediating factor in the relationship between environmental management system certification and green innovation performance. (iii) Larger enterprises, those equipped with robust equity incentives, and those operating in less competitive markets are more prone to benefit from the impact of environmental management system certification on social responsibility disclosure. This, in turn, amplifies the promotion of green innovation performance. However, the moderating effect of property rights on the mediating path remains statistically insignificant. (iv) Environmental management system certification exerts a more pronounced influence on green innovation performance in regions characterized by lower economic development. Moreover, it particularly stimulates exploratory green innovation performance, surpassing its impact on exploitative green innovation performance.

KEYWORDS

environmental management system certification, social responsibility disclosure, green innovation performance, traditional innovation performance, moderated mediating effect

1 Introduction

Currently, China is undergoing a transformative phase, aiming to transcend its previous low-end position within the global value chain and attain high-quality economic development. The adoption of an innovation-driven development strategy has emerged as the path forward. The conventional long-term economic growth model has inflicted considerable harm on the ecological environment.

Environmental issues have not only impacted the quality of life but have also posed as impediments to economic and social progress (Wang et al., 2020). In the Fifth Plenary Session of the 18th CPC Central Committee, a set of five major development concepts—"innovation, coordination, green, openness, and sharing"—were introduced for the first time, elevating green development to an unprecedented level of importance. Nevertheless, while the significance of green development is apparent, translating these principles into action proves challenging. This challenge is exemplified by China's ranking of 120th in the annual Global Environmental Performance Index by Yale University in 2018, underscoring the severity of environmental pollution and the inadequacy of environmental regulation in China. Confronted with the dual imperatives of green development and fostering innovation, the Party Central Committee, during the Sixth Plenary Session of the 19th Central Committee, reiterated the critical strategic importance of ecological civilization construction. Green technology innovation is widely recognized as a pivotal means of reconciling the dilemmas of environmental protection, pollution prevention, resource recovery, and economic growth (Xiaoxiao and Juntao, 2021; Li and Lu, 2023). Moreover, it empowers enterprises to embrace the mission of environmental stewardship while reaping the benefits of innovation outcomes. While command-based environmental regulations can mitigate the adverse environmental effects of enterprise activities within the innovation sphere, it is challenging to surmount the ecological civilization construction bottleneck solely through external coercive policies. Thus, China has taken a proactive stance by introducing environmental management system certification, bridging gaps, and granting enterprises greater flexibility and autonomy. Subsequently, command-based and voluntary environmental regulations have synergized. Porter's hypothesis corroborates that environmental regulations can generate "innovation compensation effects" through mechanisms like "product compensation" and "production process compensation." These effects effectively offset the compliance costs associated with environmental regulations, affirming the innovation-driven role of command-based environmental regulations. Nonetheless, the relationship between environmental management system certification, a form of voluntary environmental regulation, and innovation performance remains a pertinent question. Additionally, given that green innovation represents a distinct form of technological innovation within the context of ecological civilization, the extent to which green innovation performance reflects the impact of environmental management system certification is an open query. The formation of the transmission mechanism and the factors influencing it remain areas requiring further exploration, as current studies do not provide sufficient depth on these topics. Addressing these questions is crucial for realizing the five development concepts.

This study contributes significantly in three key dimensions: Firstly, it augments the body of literature on environmental management system certification in China. It does so by conducting an in-depth exploration of the impact of environmental management system certification on innovation performance. Simultaneously, it analyzes the differential effects on traditional innovation performance and green innovation performance within the framework of sustainable development, thereby deepening our understanding of green innovation performance. Secondly, this study delves into the mediating role of social responsibility disclosure based on stakeholder theory and signaling theory. This fills a void in existing research that has not thoroughly examined indirect influence mechanisms. The study mitigates endogeneity concerns by employing instrumental variable methods and further validates the existence of the mediating path using bootstrap models. Furthermore, it applies a moderated mediation model to explore how firm characteristics, nature, internal governance, and external environmental factors moderate these paths. This aids firms in tailoring their environmental management strategies effectively in various contexts. Lastly, the study conducts a heterogeneity analysis to assess the effects of environmental management system certification on both exploratory and exploitative green innovation performance. Additionally, it examines the role of environmental management system certification in green innovation performance across regions with varying degrees of economic development. This analysis sheds light on the inner workings and conditions of environmental management system certification effectiveness. In summation, this study significantly advances our comprehension of the intricate interplay between environmental management system certification and innovation performance, offering valuable insights for both scholars and practitioners.

2 Literature review

Given the increasing significance of environmental management system (EMS) certification among companies, scholars have initiated investigations into the antecedents and outcomes of this certification. Numerous internal and external factors influencing corporate certification have been explored, encompassing environmental and ethical motivations, management perceptions, governmental regulations, competitive dynamics, stakeholder pressures, and more. As the number of certifications has grown, studies have shifted their focus to analyze the consequences of EMS certification, primarily with respect to environmental performance (Graafland, 2018; Erauskin-Tolosa et al., 2020), economic performance (Arocena et al., 2020; Wang and Mao, 2020), and its impact on innovation activities. Research findings concerning the first two types of performance have been mixed, revealing both positive and negative effects (Heras-Saizarbitoria et al., 2020; Zhang et al., 2021). For instance, Erauskin-Tolosa et al. (2020) demonstrated that ISO 14001 and EMAS certification had a positive influence on corporate environmental performance. Arocena et al. (2020) found that ISO 14001 certification led to a reduction in carbon intensity and improved profitability. A substantial portion of the academic literature has centered on the ISO 14001 market and environmental benefits. Treacy et al., adopting a practice-based perspective and an event study approach derived from prior ISO 14001 research, determined that corporate adoption of ISO 14001 resulted in significant enhancements in employee productivity, fixed asset turnover, return on assets, and operating performance (He and Shen, 2019). Nonetheless, it is worth noting

that environmental management system certification entails not only benefits but also costs. Scholars such as Miroshnychenko et al. (2017) and Riaz and Saeed (2020) identified negative impacts of ISO 4001 on corporate performance. Unlike environmental and financial performance, green technological innovation stands out as the most comprehensive and fundamental solution for addressing environmental pollution (Su et al., 2022). Consequently, studies exploring the relationship between environmental management system certification and corporate innovation have primarily concentrated on green innovation, yielding more consistent conclusions.

This study posits that, in line with the principles of ecological civilization construction and green development, the resolution to environmental management issues must be sought through green innovation. There exist gaps in the analysis of the impact pathways of environmental management system certification on enterprises' green innovation performance within existing literature. The effects of indirect impact pathways in distinct contexts remain largely unexplored in prior research. This study endeavors to provide empirical evidence and illuminate the mechanisms that underlie the effectiveness of environmental management system certification.

3 Mechanistic analysis and hypotheses

3.1 Environmental management system certification and corporate innovation performance

According to neoclassical economics, environmental regulation, while effective in controlling the environmental impact of enterprises, necessitates resource allocation for environmental management. This allocation increases the cost of pollution control and results in a "crowding-out effect" on R&D funds, which is detrimental to green technological innovation and hinders the enhancement of a firm's competitiveness (Kemp and Pontoglio, 2011). In contrast, scholars like Porter argue that environmental regulation and economic development can be mutually reinforcing. While environmental regulation may increase short-term operational costs for businesses, it also incentivizes innovation activities, leading to additional returns that offset the costs of environmental management. This theory, known as the "Porter hypothesis," has injected vitality into the field of environmental management and innovation. Scholars have scrutinized the validity of the Porter hypothesis across various contexts, challenging the notion that environmental regulation is confined to mandatory government directives and passive compliance by enterprises. Over time, the concept of environmental regulation has evolved to encompass a blend of mandatory and voluntary practices. Even voluntary environmental regulation has demonstrated its capacity to empower enterprises with greater initiative (Ni et al., 2019).

Environmental management system certification, as a voluntary environmental regulatory tool, guides companies in implementing and enhancing their environmental management systems (Ni et al., 2019). Many countries actively endorse voluntary environmental policies. For instance, the U.S. government stipulates that companies establishing effective environmental management systems, such as ISO 14001 certification, may receive reduced penalties from the Environmental Protection Agency when environmental regulations are violated (Daddi et al., 2015). Certification signifies a company's capability to comply with pertinent environmental standards and requirements (Mosgaard and Kristensen, 2020). Drawing on the concept of the innovation compensation effect, a certified company's environmental management processes effectively control key environmental factors, optimize resource allocation, and establish a foundation for innovation activities (He and Shen, 2019). Hicks' theory of induced innovation suggests that environmental management, by increasing input costs, compels companies to adopt technological innovation as a solution (Cai et al., 2020). Environmental management system certification acts as a catalyst for enterprise innovation activities, facilitating improved innovation performance. Based on the above analysis, the following hypotheses are proposed:

H1a: Environmental management system certification positively influences enterprise innovation performance.

However, traditional innovation activities often disregard environmental concerns in their processes, making them susceptible to resource and environmental crises. In contrast, green technology innovation seamlessly integrates economic and ecological benefits within the constraints of resource and environmental sustainability. As the principles of sustainable development are increasingly implemented in practice, traditional technological innovation is gradually giving way to green technological innovation. Green innovation activities inherently prioritize environmental conservation and are well-supported by resources (Wiengarten et al., 2017). This alignment with the ethos of environmental management system certification leads businesses to favor green innovation as a means of addressing the challenges posed by environmental management (Zhang et al., 2023). Green innovation performance can effectively offset the short-term negative impact of environmental management costs on profitability. Consequently, the contribution of environmental management system certification to traditional innovation performance is comparatively weaker than its impact on green innovation performance. In summary, environmental management system certification has a positive influence on enterprise innovation performance, with its primary impact being on green innovation performance. Subsequent research will accordingly focus on green innovation performance. In summary, the following hypothesis is proposed:

H1b: Environmental management system certification has a more pronounced positive effect on enterprise green innovation performance compared to traditional innovation performance.

3.2 Environmental management system certification, social responsibility disclosure and corporate green innovation performance

Stakeholder theory, rooted in the concept of pressure, asserts that growing concern for environmental issues among

stakeholder groups, including government entities, consumers, suppliers, and employees, has exerted mounting public pressure on companies. Consequently, organizations are increasingly compelled to balance the maximization of shareholder value with the fulfillment of environmental obligations. Failure to meet these environmental responsibilities exposes companies to public criticism regarding environmental pollution, unsafe products, and more. When a company achieves environmental management system certification, it signifies compliance with international environmental standards. These standards encompass the establishment and implementation of an environmental management system in accordance with regulations, successful completion of initial assessments, and thorough planning for the execution of the environmental management system. Drawing on the insights of signaling theory and reputation theory, certified companies, in a bid to shield themselves from adverse market reactions, engage in the disclosure of information regarding their social responsibility commitments. This disclosure underscores their dedication to fulfilling social responsibilities, portraying them as responsible and dedicated corporate entities in the eyes of consumers (Imed et al., 2020; Lu et al., 2020; Paweł et al., 2021). Simultaneously, it communicates to the public a strong alignment between corporate philosophy and social values (Valenciano-Salazar et al., 2021). This alignment endears them to the external influencers of corporate green innovation—stakeholder decisions—thus reducing financial risks associated with green innovation activities and enhancing their green innovation performance (Lu et al., 2020; Bai et al., 2021). The role of environmental management system certification in promoting social responsibility disclosure, and consequently bolstering green innovation performance, establishes the potential for enterprises to achieve a dual victory encompassing both environmental preservation and economic prosperity. For example, Haier Group, a global leader in the electrical appliance industry, has exemplified its commitment to social responsibility through environmental management system certification. By doing so, it has demonstrated its integration of environmental protection principles and energy-efficient technologies into product design. This strategic approach has enabled the company to realize green technological innovation, particularly in the development of fluorine-free products. As a result, Haier Group has gained a significant foothold in the blue ocean market of electrical appliances, reaping not only economic benefits but also substantial environmental advantages. In cases like that of Haier Group, environmental management system certification does not impede enterprise development; rather, it serves as a catalyst for the disclosure of corporate social responsibility, enhancing green innovation performance and unlocking new profit opportunities in the process. In light of the above analysis, the following hypothesis is proposed:

H2: Environmental management system certification enhances corporate green innovation performance by promoting social responsibility disclosure.

3.3 Analysis of moderated mediating effects based on firm size

In the context of corporate Environmental Management System (EMS) certification influencing green innovation performance through social responsibility disclosure, the size of the firm assumes a pivotal role in determining the availability of resources for executing environmental management and subsequent certification. The cost associated with undertaking EMS certification can be substantial (Frondel et al., 2018). Smaller enterprises embarking on EMS certification might grapple with resource constraints, or worse, could perceive EMS certification as a mere symbolic gesture in response to customer and competitor pressures regarding environmental strategies. This symbolic approach often translates into a lack of confidence in disclosing social responsibility information. In contrast, larger corporations are better positioned to embrace EMS certification in earnest, integrating the environmental management framework seamlessly into their day-to-day operations and demonstrating proactive engagement in social responsibility disclosure. There are several reasons behind this trend. First, the implementation of an operational framework for EMS certification involves significant costs and time investments. When viewed through the lens of traditional cost theory, which operates in accordance with the principle of economies of scale, it becomes evident that production costs for enterprises tend to decrease as their scale expands until reaching an optimal point (O'Reilly et al., 2023). Large-scale enterprises possess the requisite resource levels to manage these costs efficiently and maintain lower marginal expenses, thereby facilitating the efficient implementation of environmental management system certification. The study conducted by González et al. (2008) also indicated that larger enterprises exhibit greater efficiency in implementing practices aimed at reducing material costs. Secondly, larger companies attract more attention, and their actions, or lack thereof, are subject to heightened scrutiny and monitoring by the public. Any irresponsible conduct on their part is more likely to be exposed and condemned by the media and other stakeholders. Consequently, such actions entail greater political costs for the company and can result in the deterioration of the company's image and its relationships with stakeholders. This, in turn, can stifle green innovation activities. Therefore, larger enterprises have a greater capacity to eliminate the occurrence of superficial and insincere certification processes. Their heightened enthusiasm for social responsibility disclosure consequently leads to improved green innovation performance. In essence, the size of the enterprise exerts a moderating influence on the process of environmental management system certification, driving social responsibility disclosure, and subsequently enhancing green innovation performance. Building upon the above analysis, the following hypothesis is posited:

H3: The larger the firm size, the more it can enhance the impact of environmental management system certification on social responsibility disclosure, thus amplifying its influence on green innovation performance.

3.4 Analysis of moderated mediating effects based on the nature of ownership

The distinct characteristics of property rights have given rise to discernible variations in corporate management practices (Caselli and Figueira, 2023). To examine whether the impacts of different property rights attributes, in the context of advancing social responsibility disclosure through environmental management system (EMS) certification and consequently augmenting green innovation performance, are consistent, this study conducts an analysis of the moderating effects of property rights attributes. This analysis is conducted through the lens of property rights theory and is rooted in the concept of property rights heterogeneity. Firstly, it's important to note that non-state-owned enterprises (non-SOEs) exhibit a slight advantage over state-owned enterprises (SOEs) in terms of resource utilization efficiency and the decision-making process. In the Chinese context, SOEs often grapple with inefficiencies in decision-making and possess redundant assets. Due to their direct government backing, SOEs are more inclined to utilize their advantageous resources for green innovation activities. The assurance of government support diminishes the necessity for SOEs to acquire additional innovation resources through the disclosure of social responsibility information. In contrast, non-SOEs contend with relatively limited resources and lack robust government support. Consequently, non-SOEs place greater emphasis on the benefits stemming from environmental management. Secondly, the phenomenon of soft budget constraints prevalent among SOEs often leads to a lack of innovative dynamism. Property rights theory posits that private enterprise owners enjoy the right to residual profits, instilling in them a strong incentive to continuously enhance organizational efficiency. Thus, in terms of profit incentives, private enterprises surpass traditional SOEs. Non-SOEs are more motivated to seek opportunities for realizing innovative value, and they possess a greater incentive to implement environmental protection strategies. This motivation prompts them to disclose social responsibility information through EMS certification, creating a reservoir of valuable resources to propel green innovation performance within the organization. Therefore, the nature of property rights assumes a moderating role in the process of propelling social responsibility disclosure through EMS certification, thereby intensifying its impact on green innovation performance. Building upon the above analysis, the following hypothesis is proposed:

H4: In comparison to state-owned enterprises, non-state-owned enterprises are more inclined to witness the promotion of social responsibility disclosure through environmental management system certification, resulting in a more pronounced effect on green innovation performance.

3.5 Analysis of moderated mediating effects based on equity incentives

Management, occupying a pivotal position as corporate decision-makers, wields significant authority in the realm of corporate governance and exercises decisive control over voluntary environmental regulation, specifically environmental management system certification (EMS). By drawing on the principles of principal-agent theory and the economic man hypothesis, it becomes evident that management's stance toward green innovation is largely contingent on the delicate balance between private costs and private benefits. Green innovation initiatives inherently carry a degree of risk. While shareholders advocate for corporate engagement in innovative endeavors to maximize overall corporate value, managers frequently shy away from these investments due to their short-term self-interest horizons. Within the framework of principal-agent theory, rooted in contract theory, it is posited that endowing executives with a certain level of equity within the firm can effectively tether their income to the firm's surplus, serving as a potent motivator for increased effort and commitment (Ma and Wang, 2022). Consequently, the interests of shareholders and the utility of executives become intricately entwined, giving rise to a mechanism that both shares benefits and risks (Chen et al., 2023). Equity incentives, to a significant extent, intimately connect managerial wealth with the future valuation of the company (Fabrizi, 2014). In response, companies deploy concerted management efforts to enhance the firm's share price and bolster its reputation through the implementation of equity incentives (Assaf and Saleh, 2021). Moreover, a more pronounced degree of equity incentives corresponds to an intensified capacity of EMS certification to stimulate social responsibility disclosure. This, in turn, fosters an enhancement in green innovation performance and serves to alleviate agency problems associated with innovation, which often arise due to conflicting interests between shareholders and management (Albert et al., 2021). Based on the comprehensive analysis provided, the following hypothesis is postulated:

H5: The stronger the equity incentive the more it promotes the enhancing effect of environmental management system certification on social responsibility disclosure, and thus on green innovation performance.

3.6 Analysis of moderated mediating effects based on the intensity of market competition

Market competition, serving as an external environmental factor, engenders a developmental paradigm characterized by "survival of the fittest" and heightens the moral hazard dilemma faced by enterprises. To ascertain whether disparities exist in the impact of environmental management system certification, mediated by social responsibility disclosure, on green innovation performance across varying levels of market competition intensity, this study delves into the moderating influence of market competition intensity on this intermediary pathway. The liquidation threat hypothesis posits that intensified competition elevates the risk of bankruptcy and liquidation, exerting substantial pressure on firms to refocus their developmental objectives toward enhancing firm performance (Adamolekun et al., 2022). Within markets characterized by heightened competition, the heightened comparability among firms and the concomitant reduction in monitoring costs compel management to prioritize the capture of market share and the fortification of their competitive standing. This, in turn, often results in an unabated pursuit of profits,

relegating environmental management to the periphery and fostering an environment where socially responsible behavior is sidelined. Consequently, the likelihood of fostering the disclosure of social responsibility information through environmental management system certification diminishes. Conversely, in markets characterized by less cutthroat competition, enterprises are less inclined to sacrifice the ecological environment solely for survival. Instead, the market environment becomes conducive to the cultivation of a corporate reputation rooted in environmental responsibility. The pursuit of environmental management system certification and the subsequent disclosure of social responsibility are perceived as advantageous endeavors that enhance corporate standing and confer benefits upon enterprises. Consequently, these enterprises are more inclined to engage in environmental management and social responsibility disclosure, ultimately resulting in an augmentation of their green innovation performance. It is evident that within less competitive markets, environmental management system certification and social responsibility disclosure assume a more central role in corporate priorities, stimulating greater corporate commitment to green innovation. Drawing from the above analysis, the following hypotheses are posited:

H6: Diminished market competition intensity positively correlates with an augmented influence of environmental management system certification on social responsibility disclosure, consequently amplifying its impact on green innovation performance.

In summary, the conceptual model of this paper is shown in Figure 1.

4 Data and empirical model

4.1 Data collection and the sample

The concept of Ecological Civilization Construction and Green Development was first introduced during the Fifth Plenary Session of the 18th CPC Central Committee in 2012. Subsequently, it gained national prominence, and environmental protection and green development became top priorities. Furthermore, the global outbreak of COVID-19 occurred after 2020. To minimize potential interference with this research, the study focused on the period between 2012 and 2020.The choice of the Shanghai and Shenzhen A-share markets as the research context is based on several considerations. Firstly, these markets are among the largest and most influential stock markets in China, making them highly representative of the nation's economic landscape. Secondly, the vast number of companies listed on the Shanghai and Shenzhen A-share markets spans a wide range of industries and sectors, ensuring a comprehensive and extensive dataset for more effective research. Moreover, these stock markets are significantly influenced by Chinese government policies and regulations, which hold substantial sway over the nation's economic dynamics. Exploring these markets offers valuable insights into the operation and development of the Chinese economy. Consequently, this study focused on Shanghai and Shenzhen A-share listed companies that disclosed patent applications between 2012 and 2020 as the initial sample. The sample was further refined by excluding financial and insurance companies and eliminating enterprises categorized as ST and *ST. To mitigate the impact of extreme values, all continuous variables were Winsorized at the 1% upper and lower levels. Data on social responsibility fulfillment was sourced from the social responsibility scores of listed companies on Hexun.com, while green patent data was obtained from the CNRDS database. All other data used in the study was extracted from the Guotai'an (CSMAR) database.

4.2 Definition of main variables

4.2.1 Explained variables

Innovation Performance (Tpatant), Traditional Innovation Performance (Bpatant), and Green Innovation Performance (Gpatant): This study differentiates between traditional and green innovation performance, focusing on the latter as the primary explanatory variable. Given that patents often yield economic benefits to firms even before they are officially granted, measuring innovation performance in a timely manner relies on the number of corporate patent applications (Wang et al., 2023). Green innovation performance is assessed using the number of green patent applications, while traditional innovation performance is determined by subtracting green patent applications from the total number of patent applications. To reduce data dispersion, the natural logarithm of the number of patent applications is employed (Jiang et al., 2020).

4.2.2 Explanatory variable

4.2.2.1 Environmental management system certification (ISO)

This variable is binary, signifying whether a company holds ISO14001 certification in a given year. A value of 1 is assigned to companies with valid ISO14001 certification, while a value of 0 represents companies without certification or with invalid certification (Dominguez et al., 2016).

4.2.3 Mediating variable

4.2.3.1 Social responsibility disclosure (Csr)

Social responsibility disclosure is assessed using data derived from the social responsibility ratings published by Hexun.com. This evaluation system relies on stakeholder theory to calculate scores based on weighted allocations specific to different industries.

4.2.4 Moderating variables

4.2.4.1 Enterprise size (Size)

Depending on the research objectives and data availability, several metrics are relevant for measuring firm size. Prior studies frequently employ three key indicators: sales, number of employees, and total assets. Other indicators, such as cost of sales, number of subsidiaries, market value of stocks and bonds, and enterprise added value, have also been used to gauge enterprise scale (George et al., 2021; Cheng et al., 2022; Jarrod et al., 2022). In this study, we adopt the logarithm of total assets as our

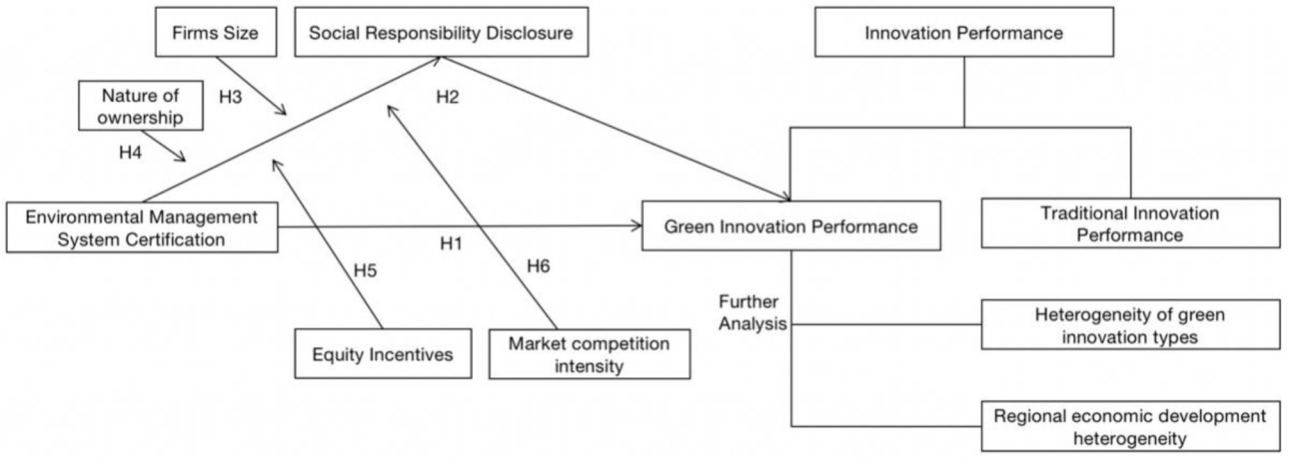

FIGURE 1
Conceptual model of the main research content.

size measurement. Total assets represent the resources under a corporation's management, represented as the sum of liabilities and owner's equity.

4.2.4.2 Nature of property rights (Soe)

We classify enterprises as state-owned (Soe = 1) or non-state-owned (Soe = 0).

4.2.4.3 Stock incentive (Stock)

Equity incentive models in practice can be intricate, including various structures such as equity options, restricted shares, performance stocks, and employee stock ownership plans (Jones et al., 2019; Martin et al., 2019). However, regardless of the specific incentive mechanism, changes in ownership stake ultimately reflect the incentive's impact. Following Davidson (2022) as a reference, this study measures the intensity of management equity incentives using the proportion of total shares held by directors, supervisors, and senior managers relative to total share capital.

4.2.4.4 Market competition intensity (HHI)

The Herfindahl index (HHI) serves as a measure of market competition intensity. Grounded in the structure-operate-performance theory, a smaller HHI indicates lower industry concentration and more significant market competition, while a larger HHI signifies greater industry concentration, potentially leading to monopolistic conditions and reduced market competition.

4.2.5 Control variables

This study draws on previous research literature on environmental management system certification and green innovation performance (Feng et al., 2021, 2022; Wang et al., 2021, 2022; Wan et al., 2022), and the control variables selected according to the content and purpose of this paper include: research and development investment (Rd), measured using the ratio of research and development investment to main business revenue; executive overseas experience (Ovesea), measured using the ratio of 1 when the executive has overseas experience and 0 otherwise; independent (Board), measured by the ratio of the number of independent directors to the number of directors on the board of directors; the balance sheet ratio (Lev), measured by the ratio of total liabilities to total assets; the current ratio (Cur), measured by the ratio of total current assets to total current liabilities; the profitability (Roa), measured by the ratio of net income to total assets. Capital intensity (Fixed), measured by the ratio of fixed assets to total assets; equity concentration (Top), measured by the percentage of shares held by the largest shareholder; growth capacity (Grow), selected the growth rate of operating revenue as a proxy variable; and also controlled for industry and year.

4.3 Regression model

Multiple regression models (Models 1, 2, and 3) are constructed to test Hypotheses 1, followed by Models 4 and 5 to test Hypothesis 2. The analysis begins by examining the impact of environmental management system certification on innovation performance and subsequently dissects traditional innovation performance and green innovation performance in separate groups. The study selects green innovation performance, which exhibits a more significant association with environmental management system certification, for deeper investigation. The mediating effect of social responsibility disclosure is then explored. Finally, Models 6, 7, and 8 are formulated to assess Hypotheses 3 to 6, scrutinizing the moderating influences of firm size, property rights nature, equity incentives, and market competition intensity on the mediating pathway.

$$Tpatant = \alpha 0 + \alpha 1\ ISO + \sum Controls + Industry + Year + \varepsilon \quad (1)$$

$$Bpatant = \pi 0 + \pi 1\ ISO + \sum Controls + Industry + Year + \varepsilon \quad (2)$$

$$Gpatant = \lambda 0 + \lambda 1\ ISO + \sum Controls + Industry + Year + \varepsilon \quad (3)$$

$$Csr = \beta 0 + \beta 1\ ISO + \sum Controls + Industry + Year + \varepsilon \quad (4)$$

$$Gpatant = \gamma 0 + \gamma 1\ ISO + \gamma 2 Csr + \sum Controls + Industry + Year + \varepsilon \quad (5)$$

$$Gpatant = \theta 0 + \theta 1\ ISO + \theta 2\ W + \theta 3\ ISO \times W + \sum Controls + Industry + Year + \varepsilon \quad (6)$$

$$Csr = \vartheta\ 0 + \vartheta\ 1\ ISO + \vartheta\ 2\ W + \vartheta\ 3\ ISO \times W + \sum Controls + Industry + Year + \varepsilon \quad (7)$$

$$Gpatant = \mu 0 + \mu 1\ ISO + \mu 2\ W + \mu 3\ ISO \times W + \mu 4 Csr + \mu 5 Csr \times W + \sum Controls + Industry + Year + \varepsilon \quad (8)$$

W in the model is each moderating variable, Controls represents a set of control variables, and ε is the error term.

5 Results

5.1 Descriptive statistics and correlation analysis of variables

Table 1 presents the descriptive statistics for the study's primary variables. The mean innovation performance score is 3.341, with a standard deviation of 1.342. The range of innovation performance spans from 0.693 to 7.101, highlighting significant variation among sample companies. Traditional innovation performance has a mean of 3.187, while green innovation performance averages 1.106. This suggests that traditional innovation performance surpasses green innovation performance on average. Environmental management system certification, with a mean value of 0.285, indicates that only 28.5% of the sample companies possess such certification, signifying its relatively low prevalence. Social responsibility disclosure scores exhibit a mean of 24.435, with a median score of 21.750, indicating a generally low level of disclosure.

Table 2 displays the results of the correlation analysis among the main study variables. The highest absolute correlation coefficient observed is 0.508, and the variance inflation factor (VIF) for each variable is <10, indicating no issues of multicollinearity. Furthermore, green innovation performance shows significant correlations with all primary variables, and the explanatory variables also exhibit significant correlations with the mediating variables, supporting the validity of variable selection.

5.2 Analysis of regression

5.2.1 Main effects test

To evaluate Hypothesis H1, regression analyses were carried out, incorporating innovation performance, traditional innovation performance, and green innovation performance as explanatory variables. Environmental management system certification, alongside several control variables, was included as explanatory variables. The regression results are presented in Table 3. Notably, the coefficients of ISO were found to be 0.082 and 0.096 when innovation performance and green innovation performance were considered as explanatory variables, respectively. Both coefficients were statistically significant at the 5% significance level. However, the coefficient was 0.057 and not statistically significant when applied to traditional innovation performance. In essence, this indicates that environmental management system certification has the potential to enhance innovation performance. Moreover, when compared with traditional innovation performance, it was observed that environmental management system certification can more effectively promote green innovation performance. This suggests that after certification, businesses are more inclined to engage in green innovation activities aimed at mitigating environmental risks, pollution, and other adverse resource utilization effects. As a result, their green innovation performance improves, thereby corroborating Hypothesis H1. Subsequent investigations

TABLE 1 Descriptive statistics of the main variables.

Variables	*N*	Mean	P50	S.D.	Min	Max
Tpatant	3.949	3.341	3.258	1.342	0.693	7.101
Bpatant	3.949	3.187	3.135	1.396	0	7.055
Gpatant	3.949	1.106	0.693	1.214	0	4.673
ISO	3.949	0.285	0	0.452	0	1
Csr	3.949	24.435	21.750	14.569	1.390	74.160
Size	3.949	12.792	12.629	1.187	10.862	16.518
Soe	3.949	0.309	0	0.462	0	1
Stock	3.949	0.165	0.037	0.208	0	0.683
HHI	3.949	0.165	0.109	0.164	0.023	1
Rd	3.949	0.049	0.039	0.041	0.001	0.239
Ovesea	3.949	0.253	0	0.435	0	1
Board	3.949	0.373	0.333	0.052	0.333	0.571
Lev	3.949	0.374	0.360	0.191	0.045	0.822
Cur	3.949	2.981	1.903	3.186	0.480	20.451
Roa	3.949	0.049	0.043	0.045	−0.073	0.192
Fixed	3.949	0.216	0.192	0.137	0.009	0.616
Top	3.949	0.339	0.322	0.143	0.083	0.729
Grow	3.949	0.155	0.099	0.302	−0.401	1.705

TABLE 2 Pearson correlation coefficients among variables.

	Gpatant	ISO	Csr	Size	Soe	Stock	HHI
Gpatant	1	0.038**	0.055***	0.486***	0.201***	−0.161***	0.077***
ISO	0.038**	1	0.158***	0.045***	0.050***	−0.052***	0.007
Csr	0.055***	0.158***	1	0.160***	0.072***	−0.02	0.012
Size	0.486***	0.045***	0.160***	1	0.391***	−0.401***	0.067***
Soe	0.201***	0.050***	0.072***	0.391***	1	−0.508***	−0.028*
Stock	−0.161***	−0.052***	−0.02	−0.401***	−0.508***	1	−0.009
HHI	0.077***	0.007	0.012	0.067***	−0.028*	−0.009	1

***, ** and * indicate significant at the 1, 5, and 10% significance levels, respectively.

TABLE 3 Main effects test and mediating effects test.

	Model 1	Model 2	Model 3	Model 4	Model 5
	Tpatant	Bpatant	Gpatant	Csr	Gpatant
ISO	0.082**	0.057	0.096**	5.602***	0.038
	−0.042	−0.044	−0.038	−0.453	−0.039
Csr					0.010***
					−0.001
_cons	1.531***	1.394***	−0.237	14.725***	−0.388**
	−0.182	−0.193	−0.167	−1.985	−0.167
Controls	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
N	3.949	3.949	3.949	3.949	3.949
R^2	0.259	0.233	0.236	0.253	0.247

***, ** and * indicate significant at the 1, 5, and 10% significance levels, respectively.

will continue to focus on environmental management system certification and its impact on green innovation performance.

5.2.2 Mediating effect test

To examine the mediating effect of social responsibility disclosure, this study follows a three-step approach. Firstly, the preceding analysis has already established that environmental management system certification facilitates corporate green innovation performance. Secondly, the influence of environmental management system certification on social responsibility disclosure is investigated. In Model 4, the coefficient for environmental management system certification and social responsibility disclosure is determined to be 5.602, and this coefficient is statistically significant at the 1% significance level. This finding substantiates the enhancing impact of environmental management system certification on social responsibility disclosure. Finally, the mediating variable is introduced. The regression results of Model 5 reveal that the coefficient for environmental management system certification becomes 0.038 and is no longer statistically significant, whereas the coefficient for social responsibility disclosure is 0.01 and passes the significance test at the 1% level. Consequently, the mediating effect of social responsibility disclosure is significant, amounting to 58.36%. In essence, this means that 58.36% of the influence of environmental management system certification on green innovation performance is mediated through the effect of social responsibility disclosure. The ultimate outcome suggests that, following certification, enterprises tend to bolster their social responsibility disclosure efforts with the aim of enhancing their reputation. This, in turn, biases stakeholders' decision-making processes in a manner conducive to boosting green innovation performance, thus confirming Hypothesis H2.

5.2.3 Mediating effects test with moderation

The outcomes of the regulatory impact evaluation for enterprise scale are presented in Table 4. Firstly, the coefficient of the main effect interaction term was found to be statistically insignificant. However, in Model 7, the coefficient of the interaction term was positive and demonstrated statistical significance at the 5% level. This suggests that the regulatory effect of enterprise scale operates in the first part of the intermediary path, effectively establishing the intermediary effect with regulation. In essence, this means that larger-scale enterprises tend to prioritize their image construction and actively disclose social responsibility information after obtaining environmental management system certification.

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TABLE 4 Mediating effect test with moderation.

	Firm size			Nature of ownership			Equity incentives			Market competition		
	Gpatant	Csr	Gpatant	Gpatant	Csr	Gpatant	Gpatant	Csr	Gpatant	Gpatant	Csr	Gpatant
ISO	−0.047	−4.79	0.011	0.160***	5.427***	0.11**	0.011	4.757***	−0.035	0.129**	4.439***	0.107
	−0.388	−4.868	−0.391	−0.046	−0.548	−0.047	−0.048	−0.567	−0.048	−0.054	−0.642	−0.055
Csr			−0.008			0.009***			0.01***			0.008***
			−0.011			−0.002			−0.002			−0.002
Size	0.469***	3.161***	0.443***									
	−0.019	−0.24	−0.029									
ISO × size	0.009	0.795**	0.004									
	−0.03	−0.377	−0.03									
Csr × size			0.001									
			−0.001									
Soe				0.449***	3.654**	0.435***						
				−0.048	−0.567	−0.072						
ISO × Soe				−0.242***	0.082	−0.238***						
				−0.08	−0.95	−0.08						
Csr×Soe						−0.001						
						−0.002						
Stock							−0.733***	−6.539**	−0.635**			
							−0.103	−1.222	−0.178			
ISO×Stock							0.509***	5.1**	0.47**			
							−0.186	−2.211	−0.189			
Csr × Stock									−0.002			
									−0.006			
HHI										0.233	−1.195	−0.066
										−0.152	−1.808	−0.219
ISO × HHI										−0.209	7.002**	−0.432
										−0.232	−2.754	−0.243
Csr × HHI												0.014
												−0.007
_cons	−5.069***	−24.51***	−4.769***	−0.300**	7.944***	−0.256	−0.103	9.125***	−0.114		8.193***	−0.205
	−0.261	−3.287	−0.377	−0.166	−1.938	−0.163	−0.167	−1.953	−0.165	−0.169	−1.97	−0.167
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	3.949	3.949	3.949	3.949	3.949	3.949	3.949	3.949	3.949	3.949	3.949	3.949
R^2	0.357	0.3	0.358	0.254	0.264	0.262	0.246	0.258	0.256	0.236	0.254	0.256

***, ** and * indicate significant at the 1, 5, and 10% significance levels, respectively.

This proactive stance benefits them in acquiring innovation resources, thereby enhancing their green innovation performance. Additionally, the economies of scale effect, stemming from scale expansion that reduces various costs, including disclosure costs, positively contributes to the improvement of green innovation performance. Consequently, larger enterprises experience a more pronounced promotional effect of environmental management system certification on social responsibility disclosure, which, in turn, enhances their green innovation performance, thus confirming Hypothesis H3.

The moderating influence of the nature of property rights on the main effect and the mediating path was analyzed in

accordance with Hypothesis H4. According to the analysis of the test results in Model 6, the coefficient of the interaction term was −0.242, signifying significance at the 1% level. This indicates that the facilitation effect is more pronounced in non-state enterprises. While the coefficients of the interaction term in the intermediary path were not statistically significant, it was observed that the intermediary effect of the nature of property rights with regulation is not valid. This suggests that enterprises, regardless of their property rights nature, tend to engage in environmental management work once they have obtained environmental management system certification. Property rights nature does not substantially impact the mediation path. However, the coefficient of the direct effect interaction term was −0.238 and demonstrated statistical significance at the 1% level. This implies that the moderating influence of property rights nature primarily operates on the direct path of environmental management system certification and green innovation performance. In state-owned enterprises, where resource acquisition costs are relatively low, the marginal utility of voluntary environmental management in optimizing resource allocation to enhance green innovation performance is weak. Conversely, non-state-owned enterprises rely on environmental management system certification to boost their green innovation performance. As a result, the moderating effect of environmental management system certification on the social responsibility disclosure path is not significant in non-state-owned enterprises, and the direct enhancement of green innovation performance is more pronounced. These findings affirm Hypothesis H4.

The moderating influence of equity incentives on the mediating path was investigated in accordance with Hypothesis H5. As per the analysis of the test results in Model 6, the coefficient of the interaction term was 0.509 and demonstrated statistical significance at the 1% level. This suggests that stronger equity incentives within an enterprise can amplify the role of environmental management system certification in enhancing green innovation performance. In Model 7, the coefficient of the interaction term was significantly positive, thus establishing a moderating mediating effect. Consequently, it can be inferred that corporate equity incentives heighten management's awareness of social responsibility, align corporate sustainable development with their individual interests, and alleviate the principal-agent problem. A higher degree of equity incentives fosters management decisions favoring social responsibility disclosure when the enterprise is certified. This, in turn, enhances the enterprise's green innovation performance, thus confirming Hypothesis H5.

The moderating influence of market competition intensity on the intermediation path was assessed in line with Hypothesis H6. The results indicated that, in Model 6, the coefficient of the interaction term was not statistically significant. However, in Model 7, the coefficient of the interaction term was 7.002 and demonstrated statistical significance at the 5% level. This suggests that the moderating effect of market competition intensity is indeed present. When the Herfindahl index (HHI) is larger, indicating weaker market competition intensity, the enhancement effect of environmental management system certification on social responsibility disclosure is more pronounced. This, in turn, promotes green innovation performance, thereby verifying Hypothesis H6. In scenarios of high market competition intensity, the short-term profit-seeking behavior of enterprises tends to influence corporate social responsibility disclosure decisions. Even after obtaining environmental management system certification, they factor in the cost of social responsibility disclosure, which inhibits the promotion effect of environmental management system certification on social responsibility disclosure. In contrast, when competition intensity is lower, enterprises prioritize environmental

TABLE 5 Comparison of hypotheses and conclusions.

Hypothese	Conclusion
H1a: Environmental management system certification positively influences enterprise innovation performance.	Environmental management system certification exerts an augmenting influence on innovation performance, with its effect on green innovation performance being notably more pronounced when contrasted with conventional innovation performance.
H1b: Environmental management system certification has a more pronounced positive effect on enterprise green innovation performance compared to traditional innovation performance.	
H2: Environmental management system certification enhances corporate green innovation performance by promoting social responsibility disclosure.	Hypothesis is valid. Environmental management system certification exercises its influence on green innovation performance by virtue of social responsibility disclosure.
H3: The larger the firm size, the more it can enhance the impact of environmental management system certification on social responsibility disclosure, thus amplifying its influence on green innovation performance.	Hypothesis is valid. The magnitude of a firm's size, the extent of equity incentives extended, and the intensity of market competition faced collectively amplify the promotional effect of environmental management system certification on social responsibility disclosure, consequently reinforcing its enhancement effect on green innovation performance.
H4: In comparison to state-owned enterprises, non-state-owned enterprises are more inclined to witness the promotion of social responsibility disclosure through environmental management system certification, resulting in a more pronounced effect on green innovation performance.	
H5: The stronger the equity incentive the more it promotes the enhancing effect of environmental management system certification on social responsibility disclosure, and thus on green innovation performance.	
H6: Diminished market competition intensity positively correlates with an augmented influence of environmental management system certification on social responsibility disclosure, consequently amplifying its impact on green innovation performance.	

management, promote social responsibility disclosure, and consequently, bolster green innovation performance.

The comparison results of specific hypotheses and conclusions are shown in Table 5.

5.3 Robustness testing

5.3.1 Endogeneity

The previous results suggest that environmental management system certification holds the potential to enhance firms' green innovation performance. However, it's essential to consider the possibility that firms with lower green innovation performance might be using environmental management system certification as a means to finance their green innovation activities, thus introducing endogeneity concerns. To address this issue, we conducted a robust heteroskedasticity test using the Durbin-Wu-Hausman (DWH) method, yielding a *p*-value below 0.05, which rejects the initial hypothesis of exogeneity and indicates the presence of endogeneity problems. In response, we employed instrumental variables through a two-stage least squares (2SLS) approach. In the first stage, we utilized instrumental variables—specifically, "Disclose" and "Action with ISO." The results, as shown in Table 6, demonstrated significant coefficients of 0.246 and 0.091, respectively, both at the 1% significance level. Subsequently, in the second stage, the coefficient for "ISO with Gpatant" was 1.989, also passing the 1% significance threshold. Furthermore, we conducted weak instrumental variables tests and over-identification tests to validate the instrumental variables. The weak instrumental variables test yielded an *F*-value exceeding 10, while the over-identification test resulted in a *p*-value of 0.880, surpassing 0.05. These outcomes indicate the absence of weak instrumental variables and affirm the original hypothesis that all variables are exogenous. Overall, these results confirm that environmental management system certification maintains its capacity to promote green innovation performance even after accounting for endogeneity issues, consistent with our prior findings.

5.3.2 Substitution of dependent variables

Given that green patents applied for by enterprises do not always lead to eventual authorization, and recognizing the considerable time lag in the patent process, this study sought to investigate the long-term sustainability of the impact of environmental management system (EMS) certification. To achieve this, we substituted the number of green patents authorized by enterprises, introducing one and two-period lags, in place of the number of patent applications. The results of this substitution are presented in Table 6. Remarkably, the regression outcomes align consistently with our earlier findings, thereby providing additional substantiation for Hypothesis H1.

5.3.3 Transformation test method

In pursuit of a comprehensive examination of the mediating effect, our study employed a Bootstrap test. The results, as depicted in Table 7, unveil a 95% confidence interval for the indirect effect of ISO on Gpatant spanning from (0.0408, 0.0785). Importantly, this interval does not encompass 0, decisively confirming the existence of a mediating effect. Additionally, the 95% confidence interval for the direct effect of ISO on Gpatant ranges from (−0.0374, 0.1141), with this interval including 0. This implies that corporate social responsibility (CSR) entirely mediates the effect, accounting for 60.1%. These outcomes robustly corroborate our previous conclusions, providing further support for Hypothesis H2.

5.4 Further analysis

Our preceding findings conclusively indicate that environmental management system (EMS) certification exerts a significantly positive impact on green innovation performance. In light of these results, we proceeded to delve into the nuances of green innovation performance by categorizing it into two distinct types: exploratory green innovation performance and utilization green innovation performance. Exploratory green innovation represents a strategic avenue for allocating enterprise resources, constituting a pivotal means to bolster a firm's core competitiveness. Conversely, utilization green innovation entails iterative improvements on existing resources with a focus on expanding possibilities on a smaller scale. In the context of enhancing enterprise green innovation performance via EMS certification, our hypothesis posited a predilection toward exploratory green innovation performance. To gauge and validate these distinctions, we quantified exploratory vs. exploitative green innovation performance by employing the natural logarithm of the number of green invention patent applications and green utility model patent applications. The regression results are meticulously documented in Table 6, where the initial two columns offer enlightening insights. Specifically, these results underscore that EMS certification is markedly more inclined to stimulate exploratory green innovation performance as opposed to exploitative green innovation performance.

Our investigation unearthed a profound linkage between the impact of EMS certification on green innovation performance and the prevailing degree of regional economic development. In regions characterized by elevated economic development, enterprises benefit from reduced innovation financing costs, facilitating their access to resources conducive to green innovation performance, even in the absence of EMS certification. Conversely, regions grappling with lower levels of economic development present enterprises with financing challenges. Under these circumstances, leveraging EMS certification to fulfill social responsibility emerges as a strategy to bolster stakeholders' confidence, mitigate innovation financing risks, and streamline the acquisition of green innovation-related resources, all while minimizing capital costs. Our metric for gauging regional economic development rested upon regional GDP per capita. Specifically, regions boasting a per capita GDP surpassing the sample median were classified as experiencing high economic development, while those falling below the median were deemed to exhibit low economic development. The regression outcomes, systematically presented in Table 6, offer compelling insights. In regions characterized by high

TABLE 6 **Endogeneity test and robustness test.**

	Two-stage regression of instrumental variables		Substitution of dependent variables and lagged regression			Further analysis and testing			
	First Stage Regression	Second Stage Regression	Substitution of dependent variable	Lag one period	Lag two periods	Exploratory innovation	Utilization innovation	High level	Low level
	ISO	Gpatant	Gpatant	L.Gpatant	L2.Gpatant	Gpatant	Gpatant	Gpatant	Gpatant
ISO		1.989***	0.140***	0.140***	0.150***	0.091***	0.029	0.072	0.122**
		−0.182	−0.027	−0.038	−0.043	(−0.033)	(−0.031)	(−0.058)	(−0.053)
Disclose	0.246***								
	−0.019								
Action	0.091***								
	−0.023								
_cons	0.381***	−0.824***	0.065	0.078	0.118	−0.422***	−0.243*	0.033	−0.06
	−0.067	−0.219	−0.119	−0.121	−0.191	(−0.142)	(−0.137)	(−0.239)	(−0.224)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

***,** and * indicate significant at the 1, 5, and 10% significance levels, respectively.

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TABLE 7 Bootstrap mediating effect test.

Total effect of ISO on Gpatant					
Effect	SE	t	p	LLCI	ULCI
0.096	0.0382	2.5152	0.0119	0.0212	0.1709
Direct effect of ISO on Gpatant					
Effect	SE	t	p	LLCI	ULCI
0.0383	0.0386	0.9919	0.3213	−0.0374	0.1141
Indirect effect of ISO on Gpatant					
Effect	BootSE		BootLLCI		BootULCI
0.0577	0.0094		0.0408		0.0785

economic development, the ISO regression coefficient proves statistically insignificant. Conversely, regions grappling with low economic development levels yield a significantly positive ISO regression coefficient. These outcomes decisively affirm that EMS certification is substantially more effective in propelling green innovation performance within regions marked by lower economic development levels.

6 Conclusions and discussions

Environmental management system certification, functioning as a voluntary environmental regulatory instrument, exerts a positive influence on the green innovation performance of enterprises. While previous studies have delved into the impact of environmental management system certification on the advancement of corporate green innovation performance from the vantage point of innovation theory, they have left notable gaps in scrutinizing the pathways through which these impacts manifest. Consequently, this study delves into the nuanced, indirect effect of environmental management system certification on corporate green innovation performance, within the contextual framework of stakeholder theory, signaling theory, and reputation theory, among others. The empirical analysis yields the following salient conclusions: (i) Environmental management system certification exerts an augmenting influence on innovation performance, with its effect on green innovation performance being notably more pronounced when contrasted with conventional innovation performance. (ii) Environmental management system certification exercises its influence on green innovation performance by virtue of social responsibility disclosure. (iii) The magnitude of a firm's size, the extent of equity incentives extended, and the intensity of market competition faced collectively amplify the promotional effect of environmental management system certification on social responsibility disclosure, consequently reinforcing its enhancement effect on green innovation performance. (iv) The moderating impact of property rights nature on the mediating path does not achieve statistical significance. However, the moderating effect on the direct influence path is indeed substantial; this implies that the direct promotional effect of environmental management system certification on green innovation performance is markedly more conspicuous in non-state enterprises. (v) Environmental management system certification exerts a more pronounced influence on enhancing green innovation performance within regions characterized by a lower level of economic development. Furthermore, in comparison to exploitative green innovation performance, it significantly fosters exploratory green innovation performance. These findings collectively contribute to our understanding of the multifaceted relationship between environmental management system certification and green innovation performance.

6.1 Policy applications

This study extends the purview of environmental protection to encompass the realm of corporate green innovation through social responsibility disclosure. This expansion augments the existing body of research and furnishes valuable practical insights: (i) Promoting Active Pursuit of Environmental Management System Certification: Encouraging enterprises to proactively seek environmental management system certification is essential. This approach harnesses their subjective initiative to assume societal responsibility. Consequently, it not only contributes to the preservation of regional ecological environments but also enhances corporate green innovation performance. This 2-fold benefit ensures the normalization and long-term effectiveness of environmental protection endeavors. (ii) Energizing State-Owned Enterprises: The findings underscore the significance of invigorating state-owned enterprises. By leveraging environmental management to fuel enthusiasm for green innovation, these enterprises can achieve sustainable development. (iii) Strengthening Equity Incentive Mechanisms: To motivate management to embrace corporate and social development as their responsibility, enhancing equity incentive mechanisms is paramount. Aligning management's interests with environmental management systems can stimulate green innovation and economic development. (iv) Mitigating Backlash from Excessive Competition: To forestall adverse repercussions stemming from excessive competition, optimizing the allocation of market resources is pivotal. This optimization should encompass the utilization of environmental management strategies to promote

green innovation development, thereby fostering healthy market competition.

6.2 Limitations and future directions

While this study holds significant implications, it is not without limitations. Firstly, from a research perspective, this paper primarily explores the influence mechanism of environmental management on green innovation through the lens of environmental management system certification—a voluntary, participatory environmental regulation. The study has yet to delve into other forms of environmental regulation and governance mechanisms. Future research should broaden its scope to encompass these aspects. Secondly, this study conducts an analysis of environmental information disclosure within developing countries. It's important to recognize that our findings may not be universally applicable to countries with different cultural climates and economic systems. These findings should be subjected to further scrutiny to ascertain their reproducibility and generalizability across different research frameworks. Addressing these research gaps, future studies may prioritize the following areas: (i) Exploring Environmental Systems and Governance Mechanisms: Future research can further investigate how environmental systems, corporate governance, and internal controls can be harnessed to maximize the utility of environmental management system certification in enhancing innovation output. Such studies can provide additional theoretical underpinnings and policy insights for the implementation of innovation-driven strategies. (ii) Investigating Imitation and Spillover Effects: In regions where data availability permits, it is valuable to continue exploring the impact of environmental management system certification on the green innovation performance of enterprises in developed countries. Such research can shed light on potential imitation and spillover effects, contributing to a more comprehensive understanding of the subject.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Exploring the non-linear relationship and synergistic effect between urban built environment and public sentiment integrating macro- and micro-level perspective: a case study in San Francisco

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Public sentiment can effectively evaluate the public's feelings of well-being in the urban environment and reflect the quality of the spatial environment to a certain extent. Previous studies on the relationship between public sentiment and urban built environmental factors have yielded meaningful results. However, few studies have focused on the effect of micro-built environment on public sentiment at the street level, which directly shapes people's perceptions. In addition, the nonlinear relationship and synergistic effect among urban built environmental factors have been commonly disregarded in previous studies, resulting in an incomplete understanding of the impact of urban built environment on public emotions. Therefore, this paper takes San Francisco as a study case to explore the complex relationship between urban built environmental factors and public emotions. Specifically, this paper measures the polarity of public emotions through sentiment analysis on Twitter data, establishes a comprehensive built environment index system from both macro- and micro- perspectives, and subsequently explores the complex relationship between the urban built environment and public sentiment through the OLS model and Shapley Additive Explanation algorithm. Results show that: (1) micro-built environmental factors have a significant influence on public emotion, although they have been frequently ignored. (2) Public sentiment tends to be more positive in areas with recreation facilities, mixed land use, rich street view visual environment, suitable thermal and acoustic environment, balanced income, and a suitable degree of high population density. (3) A nonlinear relationship and threshold effect exist between the built environmental variables and the semantic orientations of public emotion. Environment improvement strategies based on the synergic effect between variables can effectively promote the generation of positive emotions. Our empirical findings can offer valuable insights to promote feelings of well-being and foster an urban development approach through strategic interventions within the urban built environment.

KEYWORDS

public sentiment, urban built environment, street visual environment, thermal comfort, non-linearity, synergistic effect

1 Introduction

1.1 Background

The urban environment has undergone significant changes due to rapid urbanization. The human perception of the urban environment has also changed over time. According to Richard Sennett, a city is not just a physical space, but a product of human interaction with the environment. This interaction shapes citizens' identity, social relations, and sentimental cognition and influences the evolution and development of urban spatial form (Sennett, 1970). Human perception and emotion in the urban built environment can be used to measure the interaction between humans and the environment, improving the comprehensibility of urban environmental quality (Sénécal, 2007). Accordingly, understanding the relationship between public emotions and the urban environment can better reveal the dynamic urban environment from the perspective of citizens and help gain insight into how the urban environment can promote people's happiness and well-being (Yang et al., 2022).

Emotion, as a basic motivational component of human behavior, is the result of the coordination of various factors (including human physiological characteristics, cultural background, and growth environment; Tsuchiya and Adolphs, 2006), and it fluctuates with a variety of factors, such as social, environmental, and perception (Huai and Van De Voorde, 2022). Research on the relationship between emotion and space can be traced back to the 1950s. Byrne pointed out that space can evoke emotions, and the impact of space on emotions can vary over time (Byrne, 1958). Kevin Lynch proposed the concept of "mental map," which is an abstract spatial representation of a specific environment (space) formed in the mind of an individual based on their perception and awareness. It reflects the perceived and cognitive representation of environmental space by the human brain (Lynch, 1962). Based on this framework, Brian Goodey analyzed people's perceptions of the urban center (i.e., the environmental space in their mind) based on the individual experience and information fragments in their mind, and furtherly established a weighted mental map to clarify people's environmental preferences (Goodey, 1974). However, this theory only focused on subjective feelings of people and disregarded the interaction between space and people. Researchers have highlighted that while space can evoke rich human emotions, human emotions can also help improve the urban environment and the quality of space (Li et al., 2018). Therefore, clarifying the complex relationship between public emotions and the urban built environment will provide meaningful reference for urban planners and policy makers when making urban development and renewal decisions.

1.2 Literature review

Anderson and Smith (2001) introduced the concept of emotional geography which focuses on the relationship between emotions and geographical spaces (Anderson and Smith, 2001), marking the shift of research on human perception and urban environment from purely subjective psychological domains toward a broader social space dimension. Since then, many studies have explored the interaction between urban spaces and public emotions and accumulated meaningful results. Previous studies have demonstrated that the urban form, landscape, and climate environment have significant influences on public emotions (Leyden et al., 2011; Mouratidis and Hassan, 2020). For example, researchers observed that good spatial accessibility (Lai and Deal, 2022; Sun et al., 2023), ample and high-quality urban greenery (Huai and Van De Voorde, 2022), and a good visibility of blue and green spaces (Qiang et al., 2019) in the city can help trigger people's positive emotions. In contrast, unfavorable climate conditions, such as drought, heat waves, and heat island, can lead to negative public emotions (Fritze et al., 2008; Holly et al., 2015). Nevertheless, researchers found that the relationship between the urban environment and public emotions is not comprehensively consistent. For example, many studies have reported that a high building density tends to evoke negative emotion (He et al., 2022) However, J. Huang et al. observed that the high building density in Hong Kong is positively correlated with urban functional diversity and can promote positive emotions among residents (Huang J. et al., 2023).

In addition, the majority of existing studies have focused on the relationship between the built environment and public emotions from a macro-perspective at the city level. However, establishing a sound and adequate indicator system for the built environment at the macro-city level is challenging for the complexity of a city. Yang et al. (2022) summarized the environmental factors affecting public emotions into four types: objective, perceived, physical, and social environments. However, which type is the most significant is obscured. How the environmental indicators at the macrolevel affect public emotions in the long term also remains unclear. Liu et al. found that the distance to the urban center have a negative impact on public emotions (Liu et al., 2020). Nevertheless, it remains unclear whether the impact is direct or indirect because the multiple collinearities and synergies might exist between the distance and other factors such as income, quality of infrastructure, and amenity facilities. Furthermore, the indicators at the city level can hardly reflect how human individuals perceive the urban environment from the micro-perspective. For example, some studies observed that people's feelings of well-being is negatively correlated with the distance to recreation areas (such as beaches or entertainment facilities; Brereton et al., 2008), and highlighted the significant impact of urban spatial form on people's well-being (Ma et al., 2021). However, from the perspective of individuals, the macro-level urban environmental indicators are hardly directly perceptible, resulting in the intelligibility when attempting to elucidate the impact mechanisms between such indicators and public emotions. Besides, although there are studies discussing the impact of perceptible environmental factors, such as street view and micro-level urban physical environments, on public emotions from the micro- individual perspective, most of them focused on only one or some of the environmental factors. Public emotions are comprehensively related to both objective urban environment from the macro-perspective and the individual's perception of the urban environment from the micro-perspective. Therefore, further studies are needed to explore how urban built environment from the macro- and micro- perspective integratively impact public emotions and elucidate the complex impact mechanisms.

As to the research methods, most existing studies on public emotions employed questionnaire surveys and interviews, which can hardly support a comprehensive and real-time statistical analysis (Rahnema et al., 2019). These traditional methods have limitations for they are based on passive, static, and small-sized sample data (Duan et al., 2022). With the popularity of social media applications, people get used to sharing their daily lives and expressing their opinions on

social media. In this context, location-based social network (LBSN) data emerged (such as Twitter and Weibo) and quickly presented a large amount of real-time public emotion data. These emerging social media big data make it possible to address the shortcomings of traditional methods of public opinion research (Giuffrida et al., 2020). Despite some controversies, such as privacy, representativeness, and other issues (Murthy et al., 2015), Twitter data are increasingly replacing traditional survey data as a "social sensor" to help better understand the social phenomena in the real world (Naaman et al., 2014). With the help of Natural Language Processing techniques, we can access the API port of Twitter to obtain all data with a certain keyword and understand the public opinion in an emergency. We can also count the tweets with geographical location information and filter them by latitude and longitude coordinates and time to map the spatial distribution of public emotions in a city within a certain time range (Marouane et al., 2021). Spatiotemporal analysis of public emotions by using LBSN data has become a popular research topic in urban research and has yielded notable achievements across various aspects. Examples include the relationship between the built environment and public emotions (Fan et al., 2023), the effect of public green space on public emotions (Chen S. et al., 2022), and the opinions of people on public transportation through Twitter data (Das and Zubaidi, 2023). In addition, previous studies used traditional global regression models, such as ordinary least squares (OLS) to explore the relationship between the built environment and public emotions. In recent years, with the emergence of novel modeling methods such as machine learning, recent studies have demonstrated the existence of threshold and synergistic effects between the built environment and human activities (such as travel, emotions, etc.) (Yang et al., 2020, 2024). However, it remains unclear whether there is a nonlinear relationship and a synergistic influencing mechanism between the built environment and public emotions, warranting further exploration of the intricate associations involved.

1.3 Research purpose

To fill the relevant research gap, this study aims to disentangle the intricate relationship between urban micro- and macro-built environmental factors and the semantic orientations of public emotions. In particular, this study explores following three aspects: (1) to study the relationship between urban built environmental factors and public emotions from both macro- and micro- perspective; (2) to examine the nonlinear relationship and threshold effect between various built environmental factors and public emotions; (3) to explore the synergistic effect between the built environmental factors. This study aims to deepen the understanding of the correlation between urban environment and the semantic orientation of public emotions and provide support for planners to improve public happiness from the perspective of urban planning.

2 Research framework

To achieve the research goals, the research framework is as follows:

(1) First, we obtained the tweet data with geographic information in San Francisco in 2019 through the Twitter API, used the natural language processing algorithm (Vader) to quantify the polarity of the semantic orientations of tweet texts with the sentiment index, and elucidated the spatial characteristics of the public emotions according to the coordinate information of the tweet data.

(2) Then, we established an urban environment indicator system combining the micro- and macro- perspective. The micro-built environmental variables included thermal comfort, street view index, and noise which were computed from diverse multi-source big data, including Landsat 8 satellite imagery, street view images, and urban noise data. The traditional macro-built environmental indicator system was built based on the classical 5D framework and was then used as control variables for testifying the impact of the micro-built environment variables.

(3) Finally, based on the result of the exploration of the Ordinary Least Squares (OLS) regression model, we assumed a nonlinear relationship and synergistic effects among variables in the urban built environment and the polarities of public emotions. The Random Forest (RF) model and SHAP algorithm were employed to further reveal the complex relationship. The specific research framework is shown in Figure 1.

3 Data and method

3.1 Sentiment analysis of tweet data

This study was conducted in San Francisco, the fifth largest city in the United States, as shown in Figure 2. San Francisco is surrounded by sea on three sides, with an urban area of approximately 600.6 km^2 and a permanent population of approximately 850,000. We used the Twitter Streaming API to obtain 121,270 historical tweets from San Francisco between January 1 and December 31, 2019, which was chosen to avoid the effect of the COVID-19 pandemic. All tweet data includes only the content, time, and location information of the tweets, without any involvement of users' real information or privacy. The data were preprocessed to exclude non-text information, such as bot text, useless links, subject tags, and emoticons, to avoid interfering with data processing and model training. Finally, the cleaned data were obtained.

We used the Vader library in Python to analyze the sentiment of the cleaned tweets. Vader is a lexicon and rule-based sentiment analysis tool that is specifically attuned to sentiments or emotions expressed in social media. It employs a combination of a sentiment lexicon, grammatical rules, and syntactical heuristics to determine the semantic orientation of a given text as either positive or negative. Specifically, a sentiment is considered "positive" when the text conveys a favorable or optimistic opinion, emotion, or attitude. Examples of positive sentiments include joy, happiness, satisfaction, or admiration. On the other hand, a sentiment is considered "negative" when the text conveys an unfavorable or pessimistic opinion, emotions, or attitude, such as sadness, anger, disappointment, or frustration. Moreover, Vader not only determines the positivity and negativity of the textual sentiment, but also gives a compound sentiment score about how positive or negative a sentiment is (Hutto and Gilbert, 2015). The score ranges from −1 to 1, and the larger the absolute value of the score is, the higher the emotional intensity will be. In this study, the compound

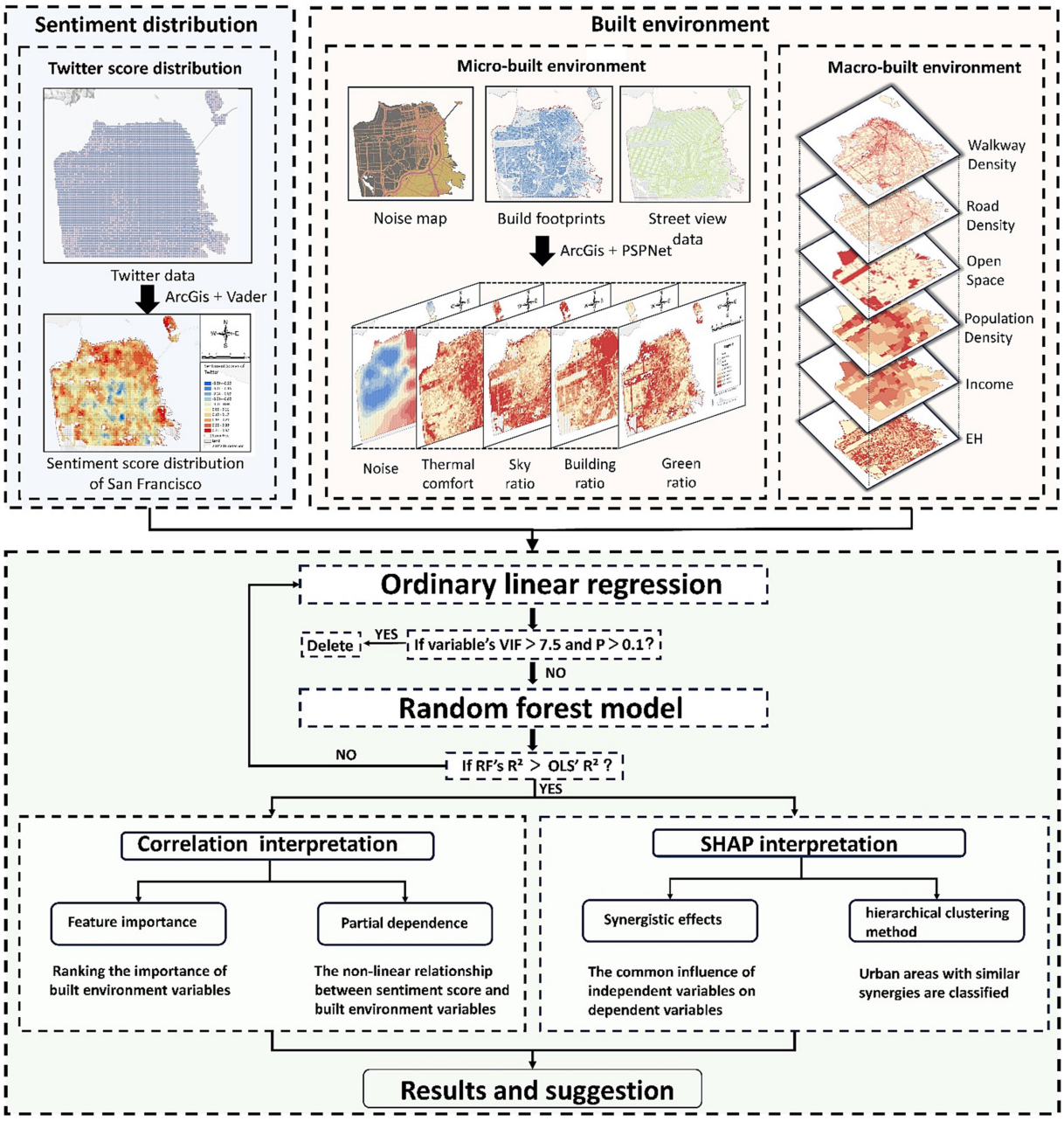

FIGURE 1
Research framework.

sentiment score was defined as the sentiment index measuring the intensity of positive or negative sentiment expressed in a tweet text, helping to understand the semantic orientations of overall public emotions expressed in the tweet data.

With the coordinate information of tweet data, the sentiment index of every tweet was mapped as a spatial point employing ArcGIS pro. To get a better understand of the spatial characteristics of the distribution of the sentiment index and its spatial relationship with the urban environment, this study employed a 200 m × 200 m grid as a basic statistic unit, the sentiment index and the urban environment indicators in each cell were aggregated based on the averages. In addition, the grid with a small number of samples was deleted, and the average sentiment index of each grid was obtained based on the following formula to ensure the normal distribution of data and eliminate the influence of outliers (Gai et al., 2022).

$$\hat{Y}_r = \left(\frac{N}{n}\right)\left[\varphi\left(\varphi^{-1}\left(\sum_{i=1}^{r-1}\frac{n_i}{N}\right)\right) - \varphi\left(\varphi^{-1}\left(\sum_{i=1}^{r}\frac{n_i}{N}\right)\right)\right]$$

where φ^{-1} is the inverse standard normal cumulative density function, r is the score range of positive emotion, n_i is the number of cases in the range r, N is the total number of cases, Y_r is the normal score for range r, and φ is the standard normal density function.

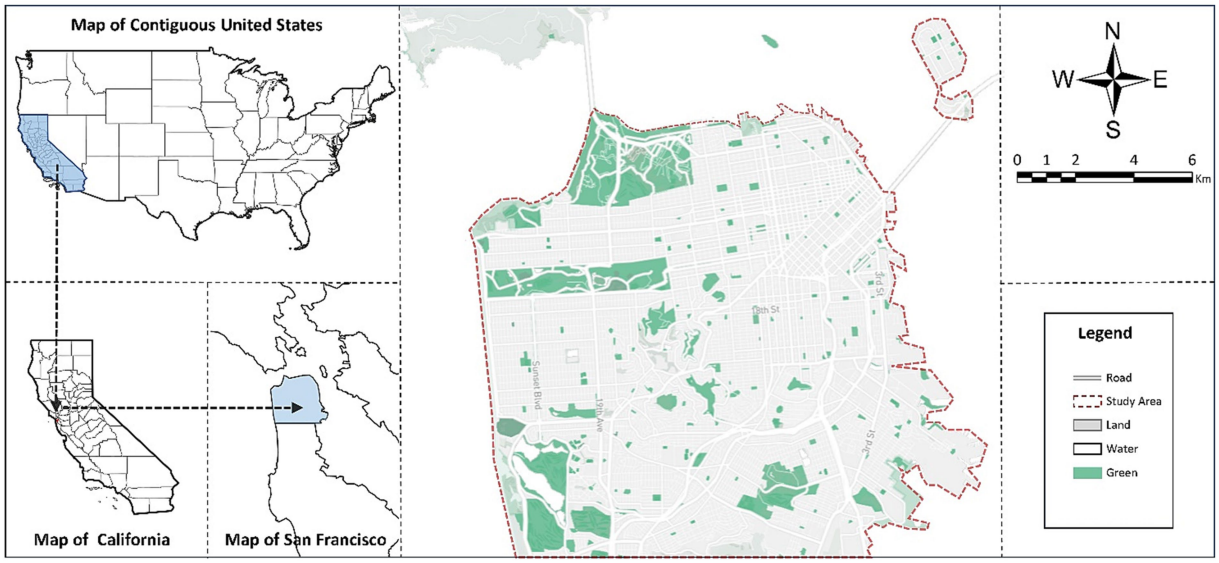

FIGURE 2
Study area.

Higher Y values represent a stronger positive public emotion in the grid.

3.2 Micro-built environment variables

3.2.1 Google street view images index

Real-world street view images with geographic information make it possible to quickly extract street view information from the human perspective and in large quantity (Kaneko and Yanai, 2016). Street view images have rich environmental features and can visually show the urban microenvironment. Recently, research on the quantification of the built-up environmental features of streets by combining street view images with machine learning algorithms has gradually become a major topic (Zhang et al., 2018; Chen L. et al., 2022). For example, the proportion of different environmental elements in street view images can be extracted by semantic segmentation algorithms, which can help efficiently capture the features of the micro-scale urban environments over a wider geographic area (Zhao et al., 2016). Accordingly, this study generated 23,171 sampling points within San Francisco City at 50-m intervals based on the OpenStreetMap street network and grabbed four Google Street View images from different angles at each sampling point through the Google API (Figure 3). A total of 92,684 street view images were obtained, with the angles of each direction being 0°–90°, 90°–180°, 180°–270°, and 270°–360°. The image resolution was 995 × 1,215 pixels, and the camera settings and resolution of each image remained unchanged. Thereafter, the image semantic segmentation processing was conducted using a pretrained Pyramid Scene Parsing Network (PSPNet) model based on the Ade20k dataset (Qiu et al., 2022; Figure 4). Every pixel in an image was labeled with a class number representing its visual category, such as tree, building, and road. For the study purpose, the segmentation results were filtered and reclassified, and the proportion of pixels that could be classified as sky, building and greenery were calculated, respectively. Specifically, the building includes pixels that were labeled as building, wall, house, skyscraper, shanty, tower and shelter, the sky refers to pixels that were labeled as sky, and the greenery refers to pixels that were labeled as tree, grass, plant and flowers. For each sampling point, the sky ratio, the building ratio and the green ratio were calculated based on the average proportion of the corresponding category of pixels in four images of different orientations. The calculation formula for the street view index system is as follows (Luo et al., 2023):

$$View\ index = \frac{\sum_{i=1}^{4} character\ Pixels}{\sum_{i=1}^{4} Total\ Pixels}$$

where the view index is the proportion of environment character pixels in four images, and i is the number of images.

Finally, the three street view indicators, namely the sky ratio, the building ratio, and the green ratio, were aggregated into each of 200 m × 200 m gird cells based on the average, as descriptors of the street-level visual environment from human perspective.

3.2.2 Noise data

A plethora of evidence has demonstrated that long-term exposure to urban noise has a negative influence on people's mental health, resulting in feelings of irritability, anger, and even depression (Huang D. et al., 2023). However, the high cost of land determines that the cities will keep developing toward compactness and density (Haaland and Van Den Bosch, 2015). Consequently, cities are likely to become more densely populated over time, the urban noise pollution problem will become severe correspondingly, which can significantly inhibit the daily emotion of urban residents. On this basis, we obtained the OpenStreetMap urban noise data from the website "noise-map.com" to measure the urban acoustic environment in San Francisco. Noise-map.com is a visual website of urban noise data. This website evaluates and visualizes the noise pollution generated in urban environments and from aircraft and other transport means based on

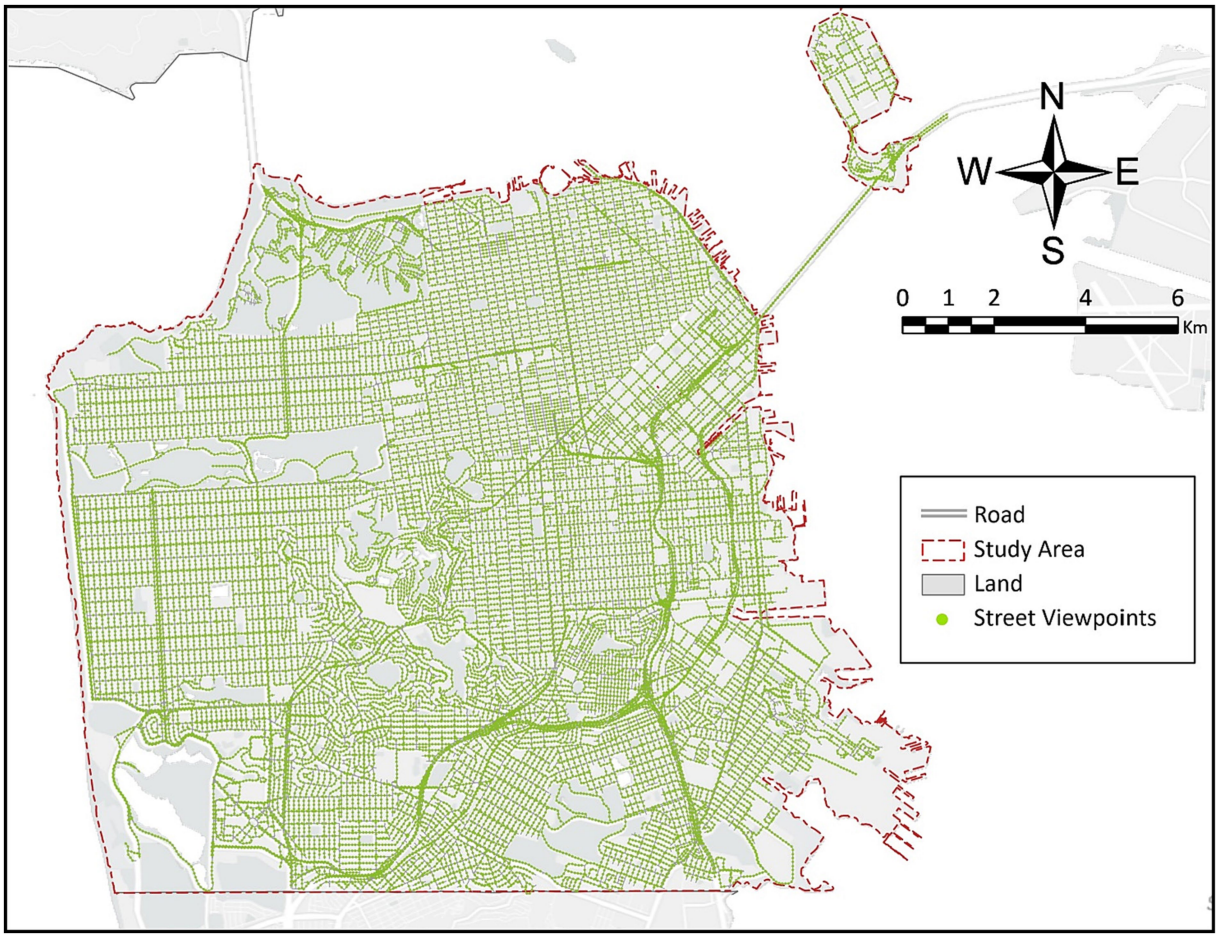

FIGURE 3
Spatial distribution of 23,171 sampling points of a street view image.

real sensor information and transport information. We used the noise data from the noise-map to examine the spatial characteristics of noise pollution in San Francisco. The noise decibel data were resampled into the 200 m × 200 m grid based on the mean value (Figure 5).

3.2.3 Thermal comfort data

The heat island effect and extreme high temperature are becoming increasingly severe, bringing great challenges to environmental sustainability (Luo et al., 2023). The temperature in the urban center area (especially in summer) is typically higher than the surrounding areas, bringing numerous negative effects to human outdoor activities, such as thermal radiation diseases and emotional irritability (Chiang et al., 2023). At present, a commonly used method of evaluating the urban thermal comfort environment is to calculate the urban surface temperature based on the satellite remote sensing images, such as Landsat 8 satellite images and MODIS satellite images. However, there is always a tradeoff between the spatial and temporal resolution of satellite images. The spatial resolution of the Landsat 8 satellite reaches 30 m, but it revisits the same observation area and takes an image every 16 days. On the contrary, the MODIS satellites have a temporal resolution of 1–2 days, but their spatial resolution is 1 km. Considering that the city scale (land area) of San Francisco is approximately 120 km^2, the spatial resolution of the MODIS satellite was considered to be insufficient to reflect the thermal characteristics of the microenvironment from a human perspective. Accordingly, we opted for the Landsat 8 satellite. This study obtained Landsat 8 images of San Francisco in 2019, eliminating cloudy and night images. The satellite images were divided into four seasons (spring: March 21st–June 21st, summer: June 22nd–September 22nd, autumn: September 23rd–December 21st, and winter: December 22nd–March 20th) and the average surface temperatures of each season were calculated and resampled to the 200 m × 200 m grid. Since the comfortable temperature for the human body varies in each season, to make the indicator better interpretable, we subtracted the threshold of comfortable temperature from the surface temperature in each grid cell to get the disparity from the comfortable temperature range. Finally, this study measured the thermal comfort in each grid cell by calculating the average absolute difference with the most comfortable temperature in the four seasons. The smaller thermal comfort index, the fewer disparities with the most comfortable temperature, the more comfortable the thermal environment in the grid cell. The formula is as follows:

$$Atc\ index = \frac{\sum_{i=1}^{4} |a_i - b_i|}{4}$$

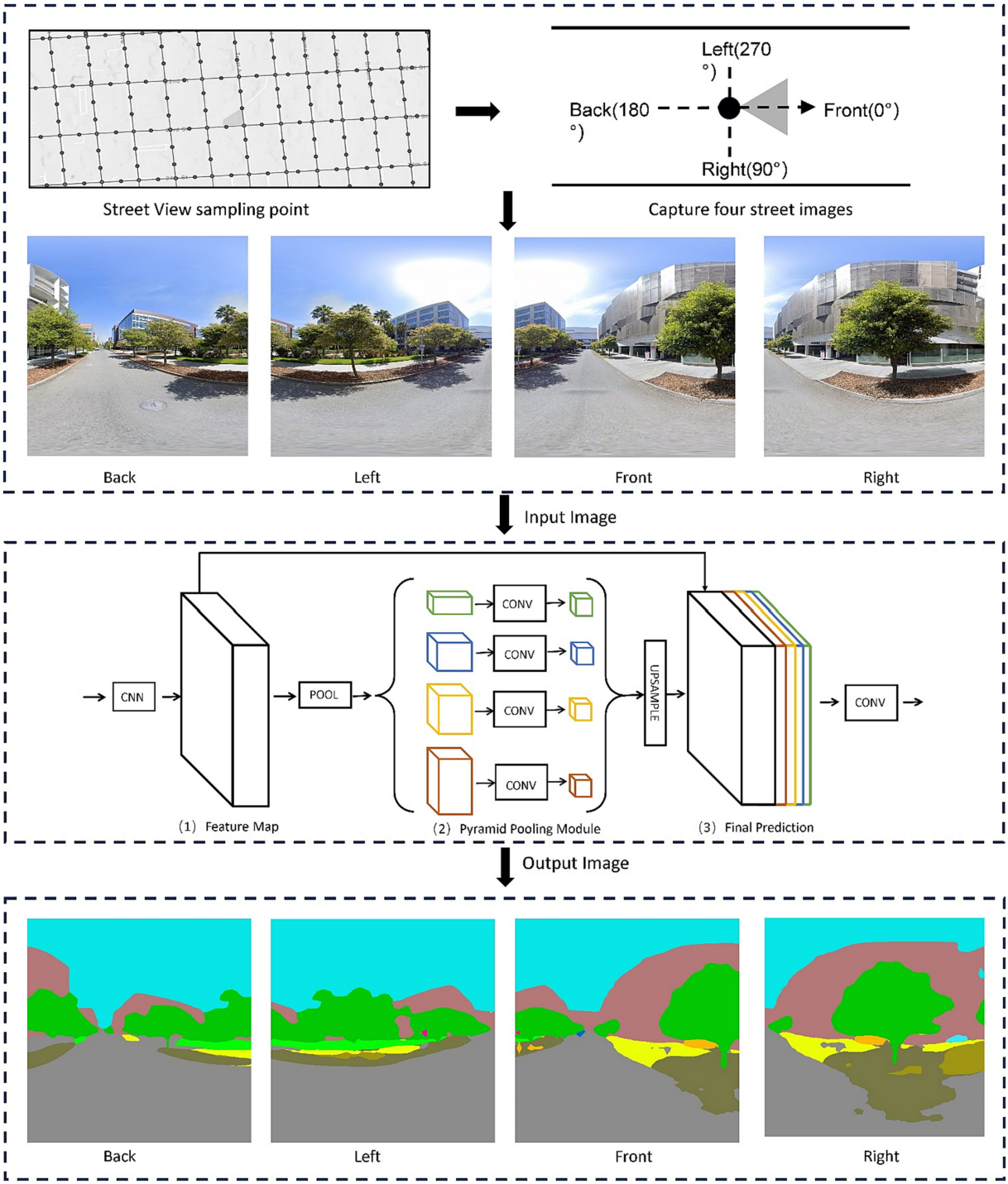

FIGURE 4
Assessing streetscape features from the PSPNet algorithm.

where the *Atc* index is the average thermal comfort index, *a* is land surface temperature, and *b* is comfortable temperature. According to previous research conclusions, the thermal comfort zone in the moderate climate zone of the United States in summer, namely, the dry bulb temperature, is between 22°C and 28°C. Meanwhile, in winter, the dry bulb temperature under the same conditions is between 20°C and 25°C (Potchter et al., 2018). Therefore, we take the above range as the most comfortable temperature range for winter and summer and 20°C–28°C for the two transitional seasons of spring and autumn. Finally, the spatial distribution of thermal comfort for each grid is shown in Figure 5.

3.3 Macro-built environmental variables

In urban environmental research, the 5D (density, diversity, design, destination accessibility, and distance to transit) framework is widely used for the systematic classification of macro built

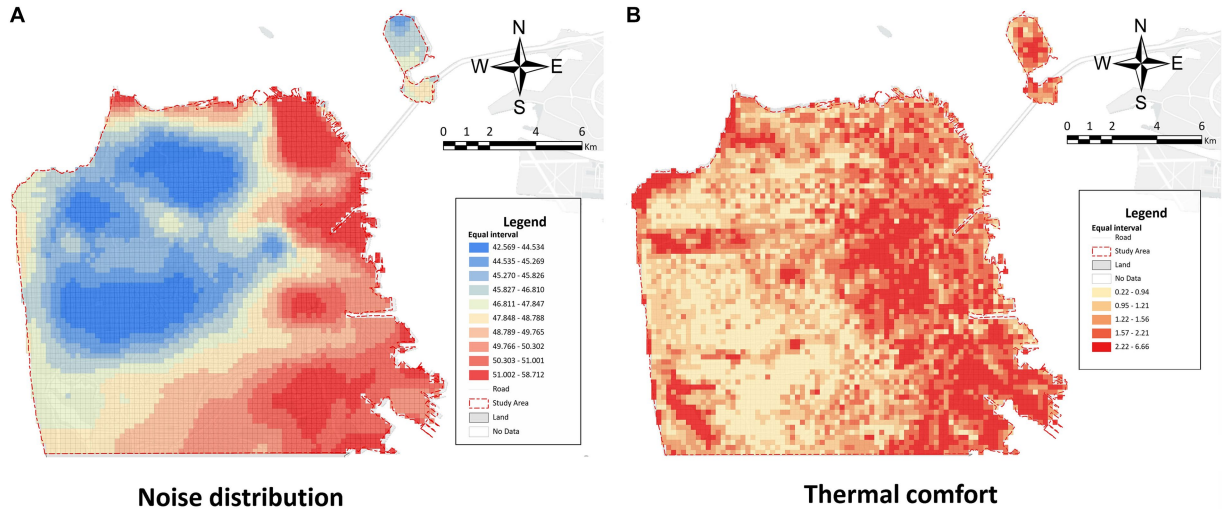

FIGURE 5
Spatial distribution of physical environmental variables in San Francisco. **(A)** the spatial distribution of noise; **(B)** the spatial distribution of thermal comfort.

environment variables (Guzman et al., 2020; Yu et al., 2022). In addition, this study combined socio-economic aspects with the classical 5D framework and preliminarily constructed a set of macro-built environment indicators as control variables to explore their correlation with public emotions. Specifically, density includes population density and building density. Diversity includes the land use diversity, the walkway density, and the green land ratio. The design includes the floor area ratio and the open space ratio. Accessibility includes the road density, the distance to the city center, and the distance to sea.

The original data used to construct the macro- built environment indicators were all from the official public data of the US government.[1] The original data were aggregated into the 200 m × 200 m grid by mean values. For data with different scales, such as the census tract population, we conducted a resampling process using a weighted average based on the proportion of the overlapping areas with each grid cell. In addition, the land use diversity was based on the Shannon Diversity Index E_H, measuring the degree of diversification of land use types, and its calculation formula is as follows (Blair and Launer, 1997):

$$E_H = \frac{-\sum(P_i)\ln P_i}{\ln(S)}$$

where E_H is the diversity index, P_i is the ratio of the i type of land to the total area, and S is the total number of unique land use types. The greater the land use diversity index, the higher degree the land uses are mixed in the study unit.

Before model building, we examined the collinearity between variables based on a correlation analysis. In particular, San Francisco is surrounded by the sea on three sides, and the downtown area is located to the northeast of the city center. The distance to the downtown area and the distance to sea are exactly opposite variables, with a strong negative correlation. Considering that the distance to the coastline also represents the distance to the beach and the relevant recreation places, we excluded the variable of the distance to the downtown area. In addition, a strong correlation existed between the building density, floor area ratio, and the building ratio index in the microenvironmental variables. Furthermore, the green land ratio and the Streetview green ratio index were also highly correlated. Consequently, the variables of the building density, the floor area ratio, and the green land ratio were excluded, the final indicator system for the micro- and macro- built environment and the descriptive statistics are shown in Table 1. The spatial distribution of macro-built environmental variable data is shown in Figure 6.

3.4 Method

After the data preprocessing, we conducted an exploration regression on all variables by using the OLS model and further tested the multicollinearity problem according to the correlation coefficient (P) and the variance inflation factor (VIF) of each variable (Park et al., 2018). If the p value of a variable is greater than 0.1, then it is insignificant. If the VIF is greater than 7.5, then it is multicollinear. The variables that suggested multicollinearity (VIF > 7.5) and not statistically significant ($p > 0.1$) were eliminated for further analysis. Then, this study developed two OLS models: one containing all variables and another that includes only the micro-built environmental variables. The two OLS models were compared to examine the impact of micro-built environmental variables on public emotions.

We used the Random Forest (RF) model to explore the complex relationship between the built environmental variables and public emotions. RF is one of the most powerful and popular machine learning algorithms that can process high-dimensional data (Biau, 2012). This algorithm is an extension of Bagging (a parallel ensemble learning method) and uses a classification regression tree algorithm (CART) as the basic learner to form the entire tree model. RF is highly robust because it can model different data types and is insensitive to multiple collinearities, missing values, outliers, and irrelevant variables

1 https://datasf.org/opendata/

TABLE 1 Descriptive statistics of the variables.

Variables	Obs.	Mean	Std.	Min	Max
Dependent variables					
Sentiment score	4,231	0.139	0.0909	−0.286	0.369
Independent variables					
Macro-built environmental variables					
Distance to sea	4,231	2597.996	1783.724	3.138	6614.741
Income	4,231	121107.63	58442.361	0	250,001
Population density	4,231	0.00779	0.00629	6.74E-06	0.0567
Road density	4,231	0.0137	0.00629	0.000474	0.0635
EH	4,231	0.948	0.442	0	2.034
Open space	4,231	0.133	0.291	0	1
Walkway density	4,231	0.0222	0.0124	0	0.0769
Micro-built environmental variables					
Sky ratio	4,231	0.372	0.0621	0.0574	0.498
Green ratio	4,231	0.0745	0.0677	0	0.493
Building ratio	4,231	0.0939	0.0591	0	0.394
Noise	4,231	47.740	2.631	42.568	58.711
Thermal comfort	4,231	1.534	0.739	0.257	5.985

(Breiman, 2001). First, the RF algorithm extracts a certain proportion of samples from the original dataset to form the sample training and test sets. Second, when building the decision tree model, the RF algorithm generates a set of decision trees. Each set of decision trees is trained on a bootstrap sample from the original dataset, and the optimal node splitting variable is selected from a random subset of all independent variables. Finally, the RF model generates the final prediction by averaging all predictions of the basic CART, whose calculation principle is shown in the following formula:

$$\hat{f}_s(x_s) = E_{x_c}\left[f(x_s, X_C)\right] = \int f(x_s, x_C)\, p(x_C)\, dx_C$$

$$\hat{f}_s(x_s) \approx \frac{1}{M}\sum_{m=1}^{M} f\left(x_s, x_C^{(m)}\right)$$

where f defines the function of the machine learning model, x_s denotes the one or two features of interest, x_C is the set of other features, X_C is used in the model, $f_s(x_s)$ is the partial dependence function for regression at point x_s, $f\left(x_s, x_C^{(m)}\right)$ is the model prediction for a specific mth sample whose feature values are determined by x_s and x_C, and M is the number of samples.

RF models have a host of strengths. First, RF models do not prescribe some kind of correlation between the independent and dependent variables. Accordingly, this model can capture the potential complex nonlinear relationship between the two, which is impossible for traditional linear regression models to do. Second, the advantages of RF compared with other tree models (such as GBDT) are its insensitivity to outliers, ability to handle high-dimensional data, being less prone to overfitting, and being highly adaptable to the dataset: it can handle discrete and continuous data, and the dataset does not need to be normalized. In summary, we employed the RF model to further explore the complex relationship between the built environment and public emotions. Finally, two important data results are outputted: the Shapley value and the partial dependence graph (PDP). Shapley Additive Explanations (SHAP) is a representative interpretable model (Lundberg and Lee, 2017). SHAP can more intuitively represent the local positive or negative effect of all samples of a variable on the model compared with the previous variable importance ranking model and further decompose it into the interaction between the main local effect of the variable and other variables. Meanwhile, PDP can describe the degree of correlation change of variables in different value ranges without assuming a linear correlation (Yang et al., 2023), which helps in improving the interpretability of the model.

4 Results

4.1 Distribution of sentiment index

Figure 7 displays the distribution of the public sentiment index in San Francisco. As the figure shown, the sentiment index ranges from −0.29 to 0.37. Considering the threshold of the sentiment index between −1 and 1, the public sentiment index over all grid cells suggests limited variations. However, this is because we took the mean value of the sentiment scores in each grid cell, which averaged out the extreme values. Nevertheless, we still observed significant spatial heterogeneity in its distribution across the grid cells. For better visualization and easier understanding, the sentiment index of the grids is divided into 10 classes with equal interval, a deeper blue color in a grid cell suggests people in the corresponding area tend to have more negative emotions, while a deeper red color in a grid cell indicates people in the corresponding area generate more positive emotions. Notably, the average sentiment index across the grids is 0.139, with a standard deviation of 0.09, indicating an

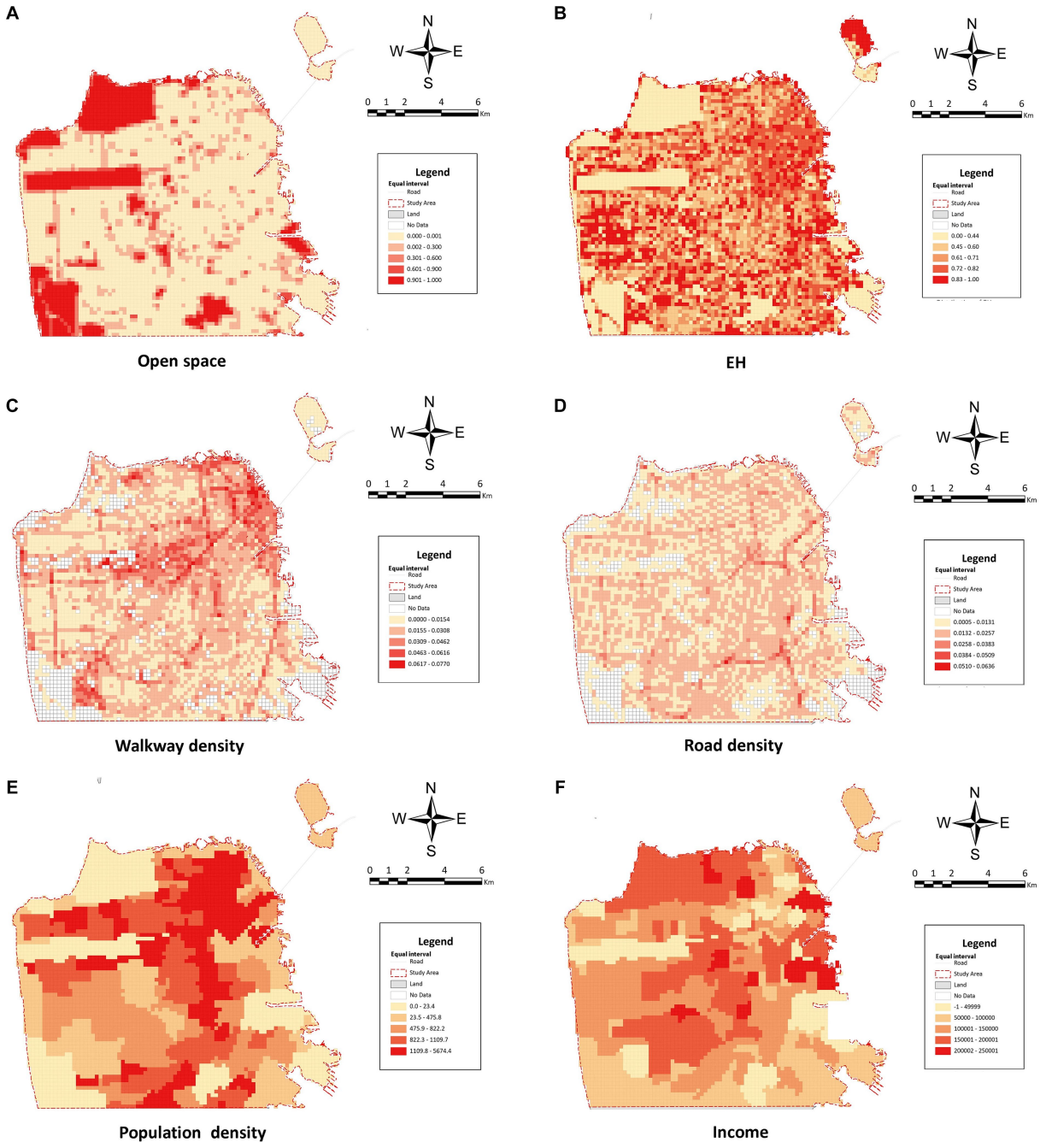

FIGURE 6
Spatial distribution of the macro-built environmental variables. **(A)** Open space; **(B)** EH the Shannon Diversity Index of land use; **(C)** Walkway density; **(D)** Road density; **(E)** Population density; **(F)** Income.

overall positive emotions distribution in San Francisco (Table 1). Figure 7 implies potential spatial correlations between the urban environmental factors and the public sentiment index. For example, the public sentiment index in the northern and northwestern areas of the city, including Marina, North Beach, and Civic Center, are higher than those in the central and southern regions. Additionally, areas near the coastline have a significantly higher sentiment index compared with the central areas farther from the coastline. Moreover, places abundant in vegetation resources exhibit a notably higher sentiment index than areas with limited vegetation resources. These findings suggest that people in areas with specific environmental conditions are more likely to have positive emotions than other areas. However, these findings might not be universally applicable because each city possesses its own distinct social, geographical, and economic attributes. For instance, a study conducted in Bhopal, India revealed that the distance to open spaces and the proximity to slums are the primary determinants of public emotion distribution based on sentiment analysis of Twitter data in that city (Khare and Chatterjee, 2023). Therefore, further studies are needed to elucidate the complex relationship between the environmental factors and the public emotions.

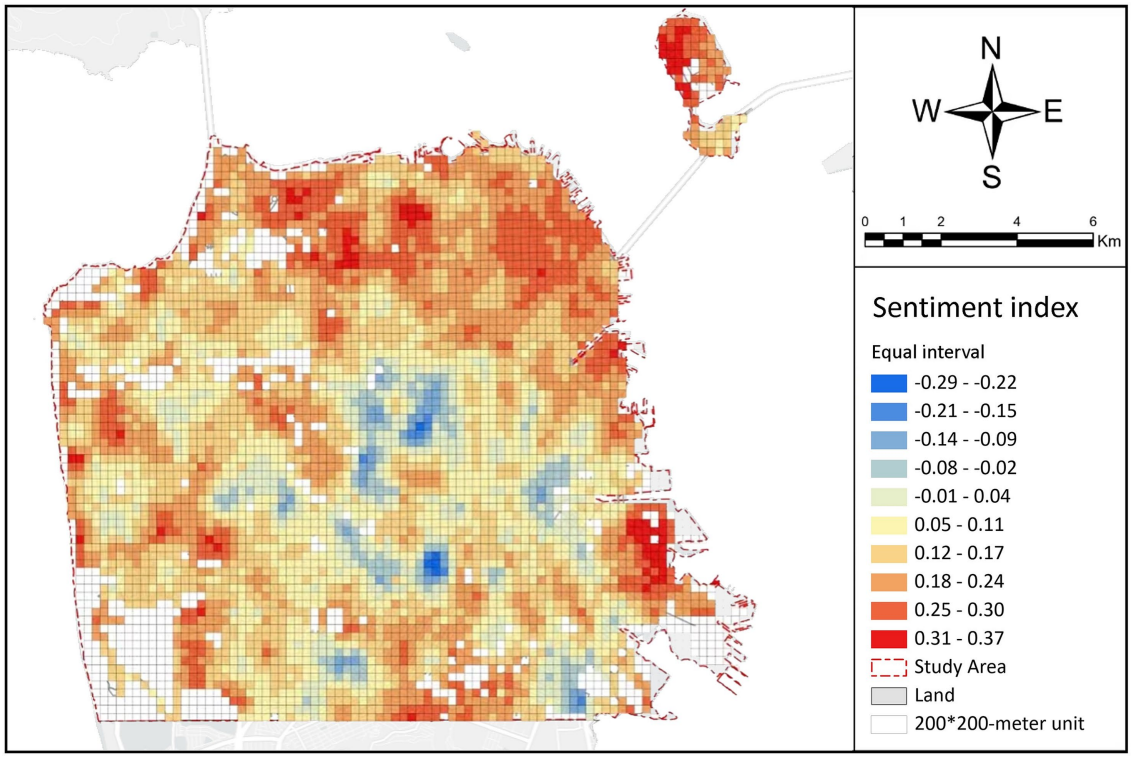

FIGURE 7
Spatial distribution of sentiment index.

4.2 Results of the OLS and RF models

Table 2 compares the results of two OLS regression models, namely, the model of all built environmental variables and the model of the micro-built environmental variables. The explanatory power of all built environmental variables for the public sentiment index is 21.1%, with each variable having a VIF below 7.5, indicating no multiple collinearity issues between variables. Three micro-built and six macro-built environmental variables show significant correlations with the public sentiment index ($p < 0.1$). From the micro-built environment aspects, the green ratio index (Coef = 0.0592, $p < 0.05$) and building ratio index (Coef = 0.1298, $p < 0.01$) demonstrate a positive correlation with the sentiment index. Thermal comfort (Coef = −0.1185, $p < 0.05$) negatively affects the sentiment index, while the sky ratio and the noise exhibit no significant correlation with the sentiment index. In terms of the macro-built environment, the sentiment index is significantly positively correlated with the open space, the land use diversity, and the walkway density. Meanwhile, there is a significant negative correlation between the sentiment index and both road density and distance to the sea. Besides, this study also observed a negative correlation between income and the sentiment index, which differs from previous research (Ngamaba, 2016) and warrants further discussion.

After the exploration regression of OLS models, we import the sample data into the RF model for cross-validation and hyperparameter tuning to optimize the model's performance. As a result, this study adopted the following hyperparameters to achieve a sound result without overfitting: 80% of the sample was allocated to the training set, while the remaining 20% was the test set. The number of learners (n_estimators) was 100, and the max_features was set to 3. Table 3 presents the model performance metrics, including MAE of 0.039, MSE of 0.0027, MAPE of 1.092, and an R^2 value of 0.6819. These results indicate that the model exhibits good accuracy and possesses predictive capabilities. Moreover, compared with the OLS models, the RF model significantly fits better with a higher R^2, implying that there exists a complex relationship between the built environment variables and the sentiment index that OLS models cannot explain. Therefore, the SHAP and PDP analyses are conducted based on the RF model to further interpret the complex relationship between the built environment variables and the sentiment index.

4.3 Relative importance of the sentiment score

Figure 8 illustrates the relative importance and the ranking of the built environmental factors when predicting the sentiment index in the RF model, with all independent variables contributing to a total importance of 100%. On the left part of Figure 8, the variables are arranged in descending order based on the average value of the global feature importance, calculated by the weighted average of the absolute Shapley value of each sample. This average indicates the variable's overall contribution to the model. The specific contribution values for each variable are listed in Table 4. The macro-built environmental factors account for 61.8% of the total, while the micro-built environmental factors contribute 38.2%. This significant difference in

TABLE 2 Results of the OLS models.

	BE OLS model				Micro-BE OLS model			
Variables	Coef.	St. Er.	p-Value	VIF	Coef.	St. Er.	p-Value	VIF
Micro-BE variables								
Noise	0.0028	0.009	0.756	1.376	0.0501	0.009	0.000	1.222
Thermal comfort	−0.119***	0.0011	0.000	1.260	−0.0487***	0.011	0.000	1.176
Sky ratio	0.0030	0.024	0.898	7.264	−0.0212	0.025	0.402	7.015
Green ratio	0.0428*	0.025	0.086	7.327	−0.0385	0.026	0.145	7.240
Building ratio	0.1108***	0.023	0.000	6.92	0.0993***	0.024	0.000	6.896
Macro-BE variables								
Distance to sea	−0.1270***	0.005	0.000	1.315				
Income	−0.0263***	0.006	0.000	1.172				
Population density	0.0157	0.014	0.274	1.355				
Road density	−0.1369***	0.014	0.000	1.355				
EH	0.0141**	0.007	0.032					
Open space	0.0401***	0.007	0.000	2.398				
Walkway density	0.0289***	0.009	0.001	1.363				
R-squared	0.211				0.071			
Log-likelihood	4646.8				4295.2			
AIC	−9,268				−8,576			

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

TABLE 3 Performance of the RF models.

	MAE	MSE	MAPE	R-squared	Train
RF	0.039	0.0027	1.092	0.68	0.8

influence between the macro and micro factors highlights the essential role of both in affecting public emotions.

Among the macro-built environmental factors, the distance to sea is the most important variable, with an effect of 23.6% on predicting the sentiment index. This finding is consistent with the conclusions of previous studies (Brereton et al., 2008; Vlker and Kistemann, 2013), highlighting that people's feelings of well-being is significantly related to the distance to beaches and other recreation places. San Francisco is surrounded by the sea on three sides and has rich natural resources, such as the ocean and green land. In comparison with other cities, people living in San Francisco are more likely to be affected by the richness of the natural environment in their living areas, which can also be confirmed from the spatial distribution of the sentiment index in Section 4.1. Additionally, income (16.9%), population density (7.7%), road density (4.8%), and land use diversity (4.3%) emerge as subsequent important macro-built environmental variables, with open space (1.7%) having a relatively lower importance. These conclusions align with expectations and existing research.

Streetview indicators suggest the most significant (16.7% overall) impact among the micro-built environmental variables. In the three streetscape indicators affecting the sentiment index, the building ratio index holds the highest importance (6.7%), followed by the sky ratio index (5.2%) and the green ratio index (4.8%). This finding underscores the significance of visual perception when studying and evaluating the micro-built environment. Noise is the second-most important factor, affecting the sentiment index by 14.2%. This notion supports the findings of Roe et al. (2020), indicating that the noise in the micro-built environment significantly influences human emotion and even mental health. Although thermal comfort is equally important (5.6%), it is lower than our expectations and the reports in relevant existing research. This discrepancy may be attributed to San Francisco's pleasant climate, characterized by a minimal temperature variation throughout the year, resulting in a reduced impact of the temperature difference on the sentiment index compared with cities with significant temperature fluctuations.

On the right part of Figure 8, each dot represents a sample. The vertical axis represents different built environmental variables, while the x-axis shows the sample's Shapley value of each variable (i.e., local effect). The color indicates the feature value's size (red for high value, blue for low value, and purple for median value). The direction on both sides of the axis indicates the positive or negative effect. This summary chart partially reveals the strength, distribution, and direction of the impact. For instance, the red line on the left side of the distance to sea variable is longer than the blue line on the right side, indicating that high-value samples significantly influence people's emotions more than low-value samples. Moreover, the Shapley value of high-value samples far from the coastline is mostly negative, while that of low-value samples is predominantly positive. This notion indicates that the high-value samples inhibit positive emotions, while the low-value ones promote positive emotions. In summary, a significant negative correlation exists between the distance to sea and the public sentiment index. Although this chart offers valuable information, it cannot precisely quantify the effect of different value ranges on the sentiment index. Therefore, this study employed the

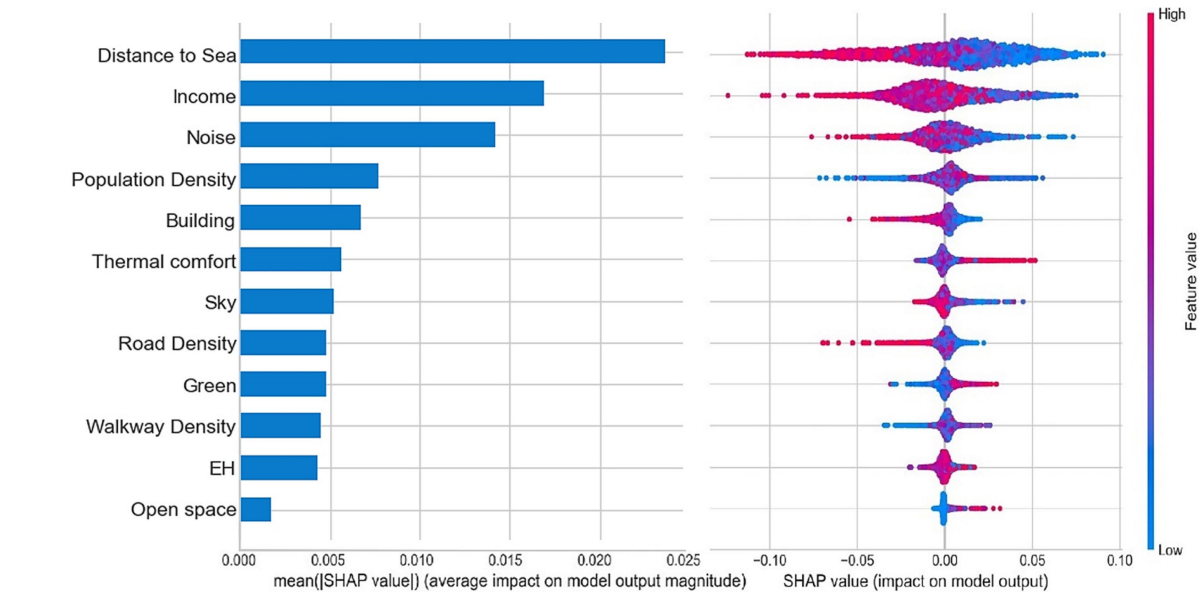

FIGURE 8
Relative importance of independent variables and a summary of local explanations.

TABLE 4 Relative importance of independent variables.

Categories	Variable	Sentiment score		
		Rank	Relative importance (%)	Total
Macro-BE variables	Distance to sea	1	23.6	
	Income	2	16.9	
	Population density	4	7.7	
	Road density	8	4.8	
	Walkway density	10	4.5	
	EH	11	4.3	
				61.8
Micro-BE variables	Noise	3	14.2	
	Building ratio	5	6.7	
	Thermal comfort	6	5.6	
	Sky ratio	7	5.2	
	Green ratio	9	4.8	
	Open space	12	1.7	
				38.2

local dependence chart to elucidate the influence of the local effect on sentiment index changes.

4.4 PDPs between the built environmental variables and the sentiment index

We calculated the interaction of each factor on the independent variable and visualized the complex nonlinear relationship between the two using PDPs, as shown in Figure 9. Each PDP corresponds to an independent variable of the built environment, demonstrating how the variable influences the sentiment index at different values. Most variables exhibit a nonlinear relationship with the sentiment index, with evident threshold effects, demonstrating that the correlation slope differs in various ranges. Among the macro-built environmental variables, the distance to sea and the road density both show a downward trend, indicating negative correlations with the sentiment index. When the distance to sea is greater than 2.8 km, the interaction effect becomes more prominent, suggesting a marginal effect of the distance to sea, namely, the shortening of the distance to sea will no longer bring additional impact on promoting individuals' positive emotions when one already lives in proximity to a certain range (2.8 km)

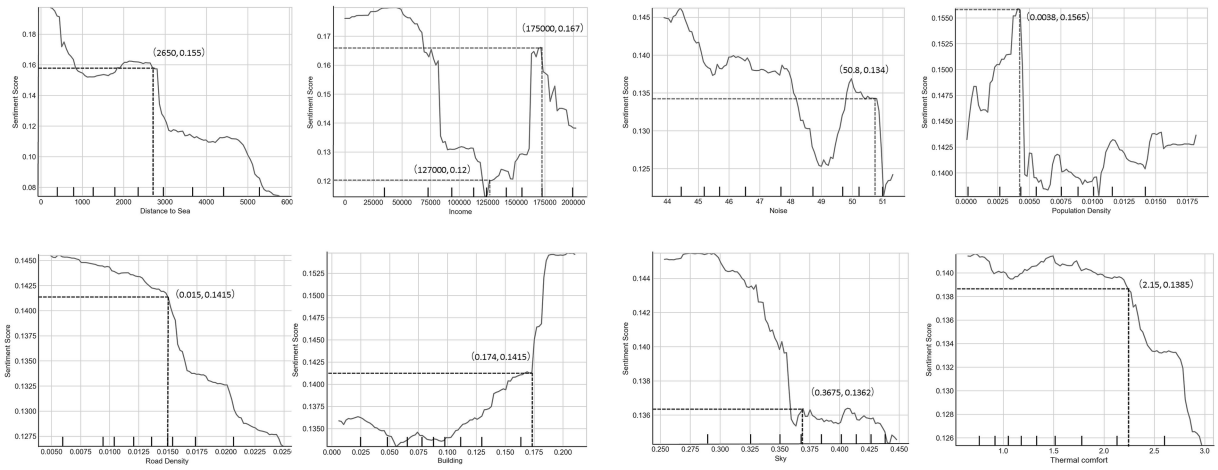

FIGURE 9
PDPs of the built environmental variables.

of coastlines. In the proportion of road density exceeding 0.015, the slope significantly increases, and the two variables are close to a negative linear relationship. This indicates that people may have a threshold to the acceptance of road density, when the road density surpasses the threshold, the corresponding transportation environment will have a more pronounced influence on emotions. The negative impact between the income and the sentiment index changes turns positive at $125,000. Below this threshold, the income and the sentiment index exhibit a negative correlation. This finding is inconsistent with common sense and previous research (Ball and Chernova, 2008). We found that the median household income in San Francisco is approximately $121,107, which is close to this threshold. Therefore, this inconsistency may be related to the corresponding nature of work at different income levels. To be specific, residents with an income below the average level are more likely to engage in more strenuous manual labor, and the increase in income usually means a longer work time or a larger workload, which causes more negative emotions. However, the incomes of the high-income individuals are not necessarily correlated with the work hours or workload, their income growth is more likely to be driven by favorable external factors, such as an upward trend in the stock market. Hence, the relationship between income and the sentiment index is complex, the income heterogeneity and inequality requires further discussion (Schurer and Yong, 2016). Besides, the appropriate high population density can enhance street vitality thus promoting the generation of positive emotions. The promotion effect sharply diminishes after the density exceeds 0.0035 person/m^2, suggesting that overcrowding resulting from increased population density inhibits further improvement in positive emotions. Finally, the land use diversity is also positively correlated with the sentiment index. When the land use diversity index exceeds 0.38, mixed land use can significantly trigger more socioeconomic activities, promoting the generation of positive emotions.

In the micro-built environmental variables, the noise, the thermal comfort, and the sky ratio all show a trend of downward impact on the sentiment index, indicating that they are significantly negatively correlated with the sentiment index. The results about the noise and the thermal comfort are consistent with the study's expectations. Specifically, the increase of the noise index (i.e., the noise decibel value) and the thermal comfort index (i.e., the difference from the comfortable temperature) would have a significant negative effect on the sentiment index. Unlike social, cultural, urban, and other factors, this negative effect is directly caused by physiological factors, but it is often disregarded in previous studies. The increase in the sky ratio index means a decrease in the proportion of other cityscape elements, such as buildings and green space, in city street views, the visual experience of desolation and emptiness can bring up negative emotions. On the other hand, the increase of greenery visibility in the environment can make people happy, which has been unanimously recognized by scholars (He et al., 2022).

4.5 Interaction effects among built environmental variables

This section delves deeper into the local interaction effects among built environmental variables through the PDP analysis. We computed the pairwise interaction effects between the built environment variables using the absolute value of Shapley. Figure 10 displays the groups of built environment variables that have instructive interaction effects. In each graph of Figure 10, the X-axis represents the variable of interest, and the right Y-axis suggests the variable that has the strongest interaction effect with the variable of interest. The color of the dots corresponds with the value of the right Y-axis. Meanwhile, the positive and negative Shapley values on the left Y-axis indicate the correlation between the dependent and independent variables. A Shapley value greater than zero indicates a synergistic effect, jointly promoting the increase of the dependent variable, while a value less than zero indicates an antagonistic effect. The distance on the Y-axis represents the degree of significance of the correlation.

The distance to sea exhibits the strongest interaction with the income variable. In areas located within 3 km from the coastline, an increase in the residents' income significantly promotes the increase of the sentiment index. This suggests that low-income individuals might have poorer access to the surrounding beaches and recreation places compared with high-income individuals, possibly due to time and energy constraints for enjoying holidays and entertainment

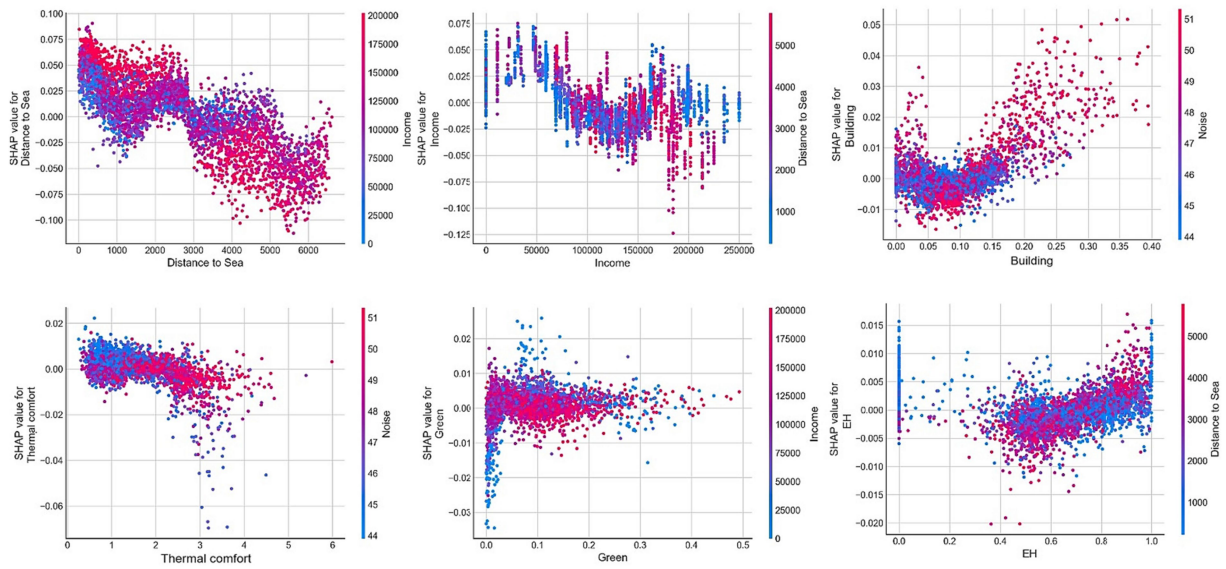

FIGURE 10
Local interaction effects among built environmental variables.

among low-income groups. In terms of the building ratio index, a worth noting interaction effect is noise. When the building ratio index is between 0.04 and 0.1, and the noise levels are higher (above 49 dB), the two variables exhibit antagonism. However, when the building ratio index exceeds 0.2, the interaction between two variables turns into synergy. This may be because a low building ratio index can indicate a location in the suburbs or a high-quality low-density residential area where people are more sensitive to noise. In the central city area with a high building ratio index, people might get accustomed to noise and be less sensitive to it. Besides, high noise levels also occur in those vibrant city areas where various socioeconomic activities aggregate, thus promoting the generation of positive emotions. Furthermore, the synergistic effect between the thermal comfort index and the noise is strongest. Under appropriate thermal comfort conditions (the absolute difference from the comfortable temperature is less than 2°C) and a quiet acoustic environment (less than 47 dB), the two variables exhibit synergy. This finding aligns with existing research that indicates that a comfortable microenvironment contributes to physical and mental well-being (Nagano and Horikoshi, 2005), thereby stimulating positive emotions. Finally, the synergistic effect between land use diversity and the distance to sea is strongest. For areas far from the coastline (over 4 km), a synergistic effect can be observed when the land use diversity exceeds 0.7, while the opposite effect becomes antagonistic. This result is reasonable because areas far from recreational places tend to have less land use diversity. Higher land use diversity implies more diverse urban function and enables rich activities, thereby promoting positive emotions.

4.6 Hierarchical clustering analysis of sentiment index

The above-mentioned studies have demonstrated the complex relationship between the built environment and the semantic orientations of public emotion. Assessing the effect of built environmental variables on public emotion based on the Twitter sentiment analysis can help provide useful policy recommendations for promoting overall positive emotions at the city level. As previously mentioned, the distribution of the public sentiment index is determined by complex environmental factors, including spatial, environmental, and population differences. Hence, relatively general policy recommendations are not universal and cannot meet the detailed requirements of precisely promoting overall positive emotions in different regions. We conducted the hierarchical clustering analysis on the grid cells based on the synergistic effects of the environmental variables (SHAP values; Xiao et al., 2021). As a result, the grid cells were classified into three clusters according to the Elbow Method, in grid cells of the same cluster, the built environment variables have similar local effects on the sentiment index. Among the three clusters, Cluster 1 exhibits the highest sentiment index values, while Cluster 2 shows the lowest (Figure 11). As shown in the right part of Figure 11, the number of grid cells in three clusters is 1,655, 582, and 1994 respectively, and they are sorted on the X-axis according to similarity. Blue represents negative Shapley values, which inhibit the sentiment index. Red represents positive Shapley values, which increase the sentiment index. The lower left part of Figure 11 also shows the spatial distribution of the three clusters. Cluster 2, which has significantly more negative Shapley values among the three groups, is located in the middle of the city. Grid cells of Cluster 1 with more positive Shapley values mainly locate at the periphery area of the city and close to the coastline, while the grid cells of Cluster 3 locate between the Cluster 1 and 2. The three clusters also suggest an aggregation in spatial distribution as Figure 11 shows.

Given the different local effects of each cluster, targeted recommendations are necessary to promote positive emotions in the respective areas. In particular, Cluster 2 located in the central area has the lowest sentiment index among the three clusters and must be given priority consideration. The major environmental variables that decrease the sentiment index in Cluster 2 areas are the distance

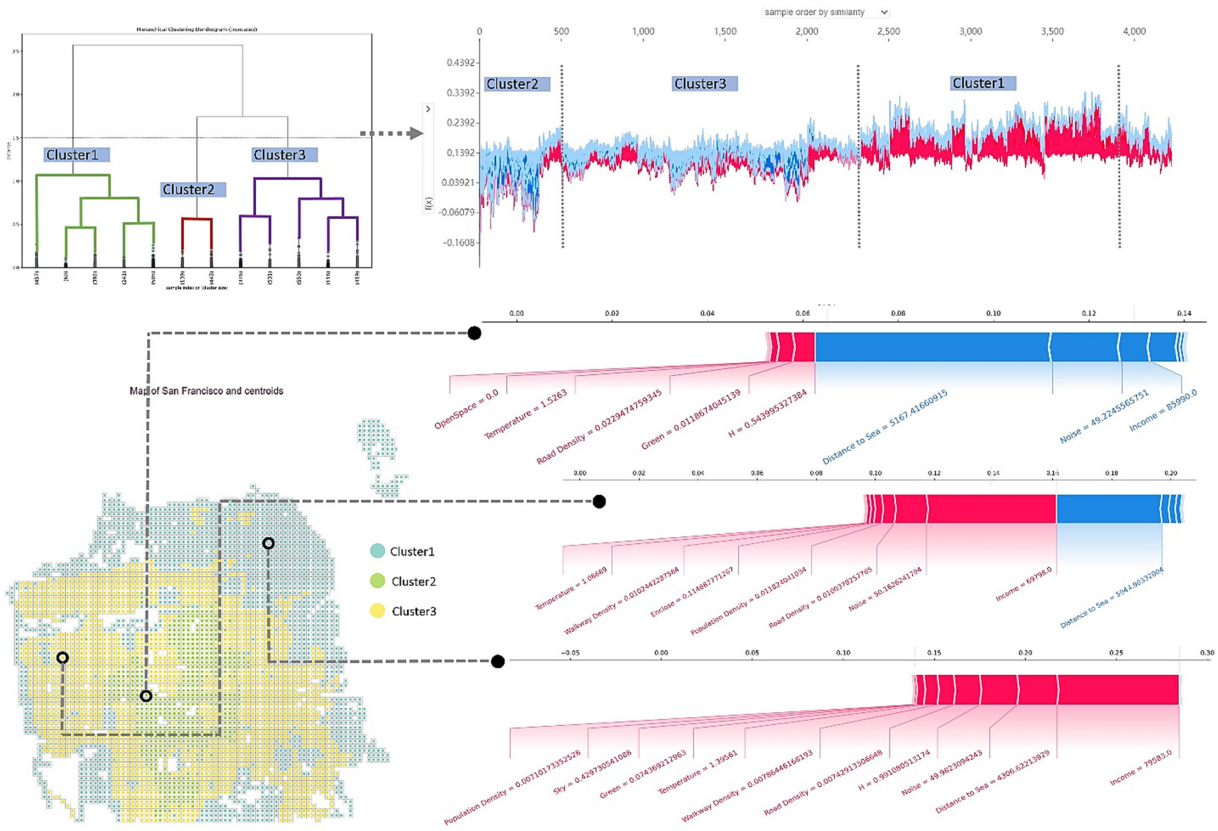

FIGURE 11
Sentiment index distribution clusters identified based on local effects.

to sea and the noise. Meanwhile, the important variables that can effectively stimulate positive emotions in Cluster 2 areas are the land use diversity, the green ratio index, the road density, and the thermal comfort index. This result suggests that the low sentiment index in Cluster 2 areas may be affected by issues related to their distance from the coastline, parks, and other recreational areas. Moreover, the sensitivity to noise and insufficiency in land use diversity and greenery are also major issues that inhibit positive emotions. Considering the nonlinear relationship and synergistic effect, we can propose targeted policy recommendations to promote positive emotions in various urban areas. For instance, in the cluster 2 region characterized by the most negative emotions, initiatives such as constructing parks, lakes, and other recreational spaces should be implemented. Furthermore, efforts should be directed toward enhancing the regional acoustic environment and minimizing both traffic and construction noise. The current land use diversity should be increased from 0.54 to 0.8 or above, and the green ratio index should be increased from 0.011 to 0.07 or above to produce synergistic effects and promote positive emotion. Similarly, according to the local effects of environmental variables in Cluster 3 areas, income inequality should be reduced and population density should be increased, which will effectively help generate more positive emotions in the corresponding grid cells. Besides, the improvement in the micro-environment can also help Cluster 3 areas effectively promote positive emotions, such as increasing the green land ratio, reducing the sky ratio, and enriching the visual diversity of the environment.

5 Conclusion and discussion

This study quantifies the positiveness of public emotions through Tweet sentiment analysis and explores the spatial relationship between the urban environment and public emotions taking San Francisco as a study case. From macro- and micro-built environment perspectives, this study provides a new viewpoint for exploring the complex relationship between the semantic orientation of public emotions and the urban environment.

(1) This paper addresses several key points. Compared to previous studies focusing on the macro-built environment, our research demonstrated that micro-built environmental factors have a significant impact on the semantic orientation of public emotions. For example, visual and auditory experience can affect human perception of an environment and have a greater impact on people's feelings in an environment compared with temperature perception, which is consistent with some existing studies (Jiang et al., 2021). The finding emphasizes the importance of taking a micro-environment perspective when formulating policies to improve the urban environment. Traditional data collection methods, which primarily focus on the macro perspective, are not sufficient in capturing human perceptions of the urban environment. Nevertheless, with the advancement of technology and the widespread use of the internet, we now have access to abundant social data that allows us to directly understand how people feel about the

urban environment. Therefore, this study suggests that urban planners and policymakers should consider the micro perspective based on human feelings in urban environments when designing strategies and initiatives to create better urban environments. This approach is crucial for achieving detailed urban governance and prioritizing public well-being.

(2) Combining Random Forest (RF) and SHAP algorithms, this study confirmed the nonlinear influence of the built environmental factors on the polarity of public emotions. For instance, we observed a marginal effect in the relationship between residents' proximity to the coastline and the sentiment index. As the distance from the coastline increases in residential areas, the sentiment index tends to decrease, signifying a more negative emotional state among residents–a trend that aligns with Brereton's findings (Brereton et al., 2008). However, when this distance is less than 2.8 kilometers, the proximity to the coastline does not significantly impact the sentiment index. Namely, there is a noticeable threshold effect of urban environments on the promotion of public positive emotions. This result is instructive for it helps policymakers to choose the most effective environment improvement decision under finite financial budget based on the impact strength and usefulness range of different environment aspects.

(3) This study discovered various synergistic effects among built environmental variables, thereby further revealing the intricate relationship between the built environment factors and public emotions. There is evident inequality in the promoting effects of built environment factors on public positive emotions, such as heightened sensitivity to noise among residents in suburban areas with lower building density. Moreover, this study also addressed various synergic relationships between urban environmental factors and asserted that considering the synergies between certain variables can maximize the promotion of positive emotions among the public. For instance, an appropriate thermal comfort environment (with an absolute temperature difference less than 2) and suitable acoustic conditions (with decibel levels less than 47) have the greatest impact on fostering positive emotions.

Accordingly, this study proposed a fine-grained urban environment governance approach that formulates customized strategies for promoting positive emotions in regions with different local synergistic effects (i.e., clustering based on SHAP values). Unlike those one-size-fits-all strategies, this approach enables urban planners and policymakers to consider the inequality in environmental perceptions and the interactions between environmental factors. For example, in the relative importance ranking in Section 4.3, we found that for the entire city of San Francisco, income ranked second in its impact on public emotions. However, in the hierarchical clustering analysis in Section 4.6, we discovered that in cluster 2, where public emotions were most negative, the impact of noise was more significant than income. We believe that this will aid in formulating more efficient and targeted strategies for urban improvement, thus holding practical significance in effectively enhancing residents' well-being.

However, this study also has certain limitations. First, this study only focuses on the public emotion distribution in San Francisco, which is surrounded by three seas and has a pleasant climate, and the relationship between the environmental variables and the sentiment index may not necessarily be transferrable to other cities. For example, the distance to sea and the thermal comfort, which have already suggested an inconsistency with previous studies. Future research can explore the emotion distribution and its influencing factors in different types of cities. Second, the greater the size of the tweet data, the more valuable the results may be obtained. More samples (such as more than a few million data) may implicitly suggest deeper influencing relationships, such as spatiotemporal distribution differences in emotion among residents of varying genders, ages, and races. Finally, this study focuses on the nonlinear influence of micro- and macro-built environmental factors on the semantic orientations of public emotions and the synergistic effect between variables, paying limited attention to the spatial heterogeneity of emotion distribution. Despite the shortcomings, we hope that this empirical study can provide references and suggestions for relevant policymakers to reduce inequality and negative sentiment and achieve healthy and sustainable cities.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

PH: Conceptualization, Formal analysis, Investigation, Software, Supervision, Supervision, Writing – review & editing. BY: Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing. JM: Methodology, Software, Writing – original draft, Writing – review & editing. KL: Investigation, Methodology, Software, Writing – review & editing. SC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Resources, Software, Writing – review & editing. ZS: Conceptualization, Data curation, Funding acquisition, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Socio-ecological model as a framework to understand the low participation of Earth Hour among Chinese college students: conflict between belief and practice

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Earth Hour, a global mass effort coordinated to show concern for green urban construction and sustainable development, was first organized by the World Wildlife Fund in Australia in 2007 with a growing trend of participation worldwide. However, analysis of participation in Earth Hour based on a large population are sparse, with only a few studies reporting details in positive results without a clear pattern that explains the potential low participation. This study focuses on the non-participants and analyzed the reasons for low participation in Earth Hour using a questionnaire with 401 college students based on the socio-ecological model. Two aspects are explored: (1) social-demographic features; (2) psychosocial traits (environmental awareness, acceptance for law, social support from family and friends and knowledge about the event). Barriers toward participation are included as mediators to explain how these basic features change students' decision on joining large-scale environmental campaign. A participation analysis method using binary logistic regression and one-way MANOVA is applied in data analysis. This study highlights that the irrelevance between students' belief and practice on environmental protection should not be overlooked, and that college students are inclined to join in groups in relevant activities—conversely, herd effect could greatly reduce their willingness to participation. The findings of this study have wider implications for school educators, practitioners and organizations involved in pro-environmental career. This paper highlights that, from an international perspective, the essence of collective action with a similar nature to Earth Hour and contributes to a global dialogue on fostering sustainable behaviors.

KEYWORDS

socio-ecological model, Earth Hour, participation, college students, pro-environmental behavior

1 Introduction

Organized by the World Wildlife Fund and partners as a symbolic lights-out event in Sydney in 2007, Earth Hour is now one of the largest grassroots movements for the environment (Chan et al., 2020). Held every year on the last Saturday of March, Earth Hour engages millions of people in more than 180 countries and territories, calling for switching off

non-essential electric lights for a single hour of 1 day every year to show support for our planet under climate change (Jechow, 2019). Apart from its significant contribution to raise public awareness of environmental issues, Earth Hour has reduced electricity consumption an average of 4% from 2008 to 2014, leading a fashion of low carbon lifestyle worldwide (Olexsak and Meier, 2014).

Earth Hour was first introduced to China in 2009, with Baoding being the first city to participate officially (Feng, 2009). By 2013, this annual lights-out event took place in 127 cities, including landmarks of more than 4 first-tier cities (e.g., Bird-nest in Beijing, Oriental Pearl TV Tower in Shanghai), eastern China (Environmental Protection Publicity and EDU Center of Canton, 2013). Nonetheless, it remains doubtful whether this event had been put into practice among Chinese citizens, or simply limited to a false image built by local institutions. An investigation by HuiCong D&B Market Research company spoke highly of the positive feedback from the public in Earth Hour (an estimate of 67.3% individual participation rate with a total sample of 4,408 in PRC) (2011), which was believed to be the result of the effective top-down measures. However, when it comes to individual participation, a totally converse picture was shown in Wang's study (2012). Nearly 90% of the respondents heard of Earth Hour, but 2 out of 3 are non-participants among a smaller sample featuring the participation in suburban area (Wang, 2015).

Certain research has reached an agreement on a relatively low participation rate of Earth Hour in China in recent years, indicating a descending trend of individual participation with the change of time. Compared with the positive feedback in 2011, an average participation rate of 2.7 times (out of 8 times) by 2015 was found in Chinese citizens, with 24.2% of them never participated in this event; citizens aged above 55 or with a higher education level outweighed their counterparts in long-term participation (Wang, 2015). Among non-participants, the effect of reducing electricity consumption in Earth Hour was controversial (Solomon, 2008; Vuong et al., 2020), not to mention the insufficient generation requirements and potential grid failure triggered by sharp drops and peaks of electricity use (Olexsak and Meier, 2014). Given the ambiguous findings in both individual participation and citizens' three-minute passion for this activity, it remains essential to carry out this classic research 15 years later since the first launch of Earth Hour.

One of the difficulties in conducting this research is that there is no valid standardized set of reasons accounting for low participation associated with environmental protection nationwide and most results end up in the form of details, adding up obstacles to discover a regular pattern. Given the limited evidence available, we could not predict the respondents' feedback but applied the bottom-up approach. To ensure the validity of the study, social-ecological participation analyzing model (Van Dyck et al., 2017) were used as reference in methodology, with a more accurate sample aiming at college students only.

However, existing academic works are not yet sufficient to explain the potential mechanism leading to the non-participation in Earth Hour, especially the case unique to PRC. Relevant studies mostly focus on small samples and case analysis, ignoring the fact that they are looking into a large-population-based event. By including more respondents in the sample, this study has adopted more quantitative methods which are known to be common in empirical research. Also, it is the first time that socio-ecological model is used in analyzing the participation of pro-environmental events in Asian context, where local regulations and the interplay between different social groups are concerned. Distinguished from other general reports, this paper focus on the respondents who are more likely to underperform based on their extreme scores on certain social psychological features, to figure out more specific reasons indicating low participation rate.

The present study addresses four research questions:

(1) whether there are more non-participants than participants among Chinese college students in Earth Hour?

(2) which socio-ecological factors are related to participation in earth hour event?

(3) how do barriers vary between different subgroups of gender, family income, living environment and educational level?

(4) what are the most prevalent barriers toward participation in the total sample and in students with psychosocial characteristics associated with extreme odds?

2 Literature review

2.1 Conflict between belief and practice

The conflict between belief and practice does exist and has been extensively explored in literature (Desforges and Cockburn, 1987; Farrell and Lim, 2005; Yang, 2019; Lei and Medwell, 2021). Belief was referred to as messy constructs by Pajares (1992), inconsistent with the observed practices in studies concerning teaching behaviors (Duffy and Anderson, 1984).

Likewise, a problem in large-scale environmental protection campaigns unique to China could be the imbalance between its good will and low efficiency to carry out (Liu and Diamond, 2008; Jin et al., 2023). Particularly, the lack of a meaningful institutional framework to allow public participation deserves a bit more reflection in environmental protection (Li et al., 2012). For one thing, the publicity of Earth Hour has been ramping up nationwide, with 127 cities joining this campaign in 2013 which quadrupled the number three years ago (Gu, 2017). With a rapid surge of bus advertisements and celebrity endorsement in the past decade, MCI (i.e., Media Communication Index) for Earth Hour has hit a new record high of 79.9% via printed and online media (HuiCong D&B Research, 2011; Gu, 2017). For another, a few critics have pointed out that some of the college students might place their passion for environmental protection on the "wrong" side, resorting to enterprises and media for funds and fame before they ensure the feasibility and social benefits of their projects (Zhang, 2001; Jin et al., 2023). Despite that the existing research set a solid theoretical foundation for our study, few studies investigate the conflict between belief and practice among college students nationwide in this matter.

2.2 Socio-ecological model

2.2.1 Definition and development

The Socio-ecological Model (SEM) was a concept first suggested by Bronfenbrenner (1977) as an ecological systems theory for human development and was later redefined by McLeroy et al. (1988) as a framework to promote health-related behavioral change. Socio-ecological models were introduced to urban studies by sociologists associated with the Chicago School after the First World War as a

reaction to the narrow scope of most research conducted by developmental psychologists. These models bridge the gap between behavioral theories that focus on small settings and anthropological theories.

The initial theory by Bronfenbrenner was illustrated by nesting circles that place the individual (sex, age, etc.) in the center surrounded by various systems: microsystem (family, peers, school, church), mesosystem (interplay inside of microsystem), exosystem (industry, mass media, social services, neighbors, local politics) and macrosystem (attitudes and ideologies of the culture). The SEM stated that health is affected by the interaction between the characteristics of the individual, the community, and the environment that includes the physical, social, and political components (Kilanowski, 2017). The model was developed to further the understanding of the dynamic interrelations among various personal and environmental factors, and their impact on a specific type of individual's behavior. Generally, it contained four dimensions: Individual, Interpersonal/Relationship, Organizational/Community and Societal (see Figure 1).

2.2.2 Applications of SEM in pro-environmental studies

Previous studies have proved that SEM can be applied to a variety of pro-environmental engagement analysis. Environmentally sustainable behavior (ESB) was interpreted as involving the way that we interact with environmentally relevant things (e.g., automobiles, trashcans, lawn sprinklers, lights, and home heating systems) around us in our everyday lives (Hormuth, 1999). Kurz suggested a social-ecological framework for promoting ESB (2002) to understand and change ESB. It combines Hormuth (1999) ecopsychological approach to ESB and Baron and Misovich (1993) social-ecological framework of attitude and behavioral change. A study of pro-environmental behavior (PEB) among wildscape gardeners (Jones et al., 2021) has shown that applied factors from SEM concerning individual, social environment, physical environment, and policy level would provide a robust result in logistic regression. Smith et al. (2021) research explained how individuals' attachment to community affect their perceived social norms and thus, changing their perception of climate change risk and subsequent willingness to engage in pro-environmental behavior, in a context which is closer to Earth Hour.

According to McLeroy et al. (1988), SEM assumes that appropriate changes in the social environment will produce changes in individuals, and that the support of individuals in the population is essential for implementing environmental changes. Earth Hour operates on the premise that by orchestrating a globally synchronized hour of reduced energy consumption, it can induce a shift in social norms regarding energy usage. Furthermore, the success of Earth Hour relies heavily on the active participation and support of individuals worldwide. Therefore, Earth Hour aligns with the foundational assumptions of SEM, making it a fitting subject for research within the SEM framework.

2.2.3 Socio-ecological factors unique to earth hour

Socio-ecological models of health behavior posit that socio-demographic, psychological, social, and environmental characteristics are all important determinants of health behaviors (Sallis et al., 2015), and can impact participation in pro-environmental events as well (Kurz, 2002).

Some evidence is available regarding the socio-demographic profile of participants, compared with non-participants. Female presented as a more pro-environmental gender in China (Li et al., 2022), since females were more concerned with environmental problems and more supportive of plastic-ban policies; however, the gender gap of PEB is not so apparent among university students (Vicente-Molina et al., 2018). Specifically, in PRC, living environment played a significant role in Earth Hour public engagement. Wang (2015) mentioned that fewer participants were found in rural area where publicity of Earth Hour was rather low; while lately more active and frequent participants were found in third-tier and fourth-tier cities with an extra 13% growth rate compared with metropolitans (Zhuang, 2023). Zhou and Fan (2020) stated that the average income was positively associated with educational level throughout the past two decades in PRC, however, the participation rate for low-income individuals have been increasing in recent years.

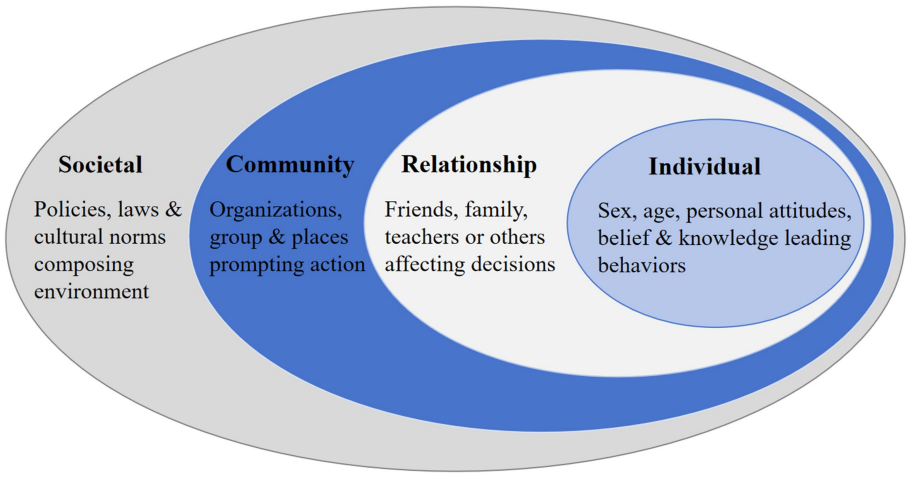

FIGURE 1
The socio-ecological model for general purposes.

Psychological aspects like perceived barriers and motivation, and social aspects can be framed within the Identity Theory (Stryker and Burke, 2000) and Theory of Planned Behavior (TPB) (Ajzen, 1985). Studies have shown that individuals who have a stronger environmental self-identity express stronger pro-environmental intention and perform pro-environmental actions more frequently (Barbarossa et al., 2015; Yang and Li, 2021), thus environmental awareness was introduced to our model. Chan et al. (2020) was established on TPB and suggested that Earth Hour participation is determined by intention, that is in its turn determined by attitude (individual's favorable/unfavorable evaluation of the behavior), behavioral control (perceived ease or barriers to perform the behavior) and subjective norms (perceived pressure from important others). In specific, "social support from family and friends" was measured as subjective norms, due to its significant boost on pro-environmental behaviors in Yang and Li (2021) and college students' engagement in group events (Limniou et al., 2022). "Similarities with other events" was included as behavioral control, given that participants tend to become less motivated and underestimate the importance of an event when it shares a high proximity with other events in PEB studies (Margetts and Kashima, 2017; Chatelain et al., 2018). "Disappointment/doubts in effectiveness" was quired as attitude since existing studies (Solomon, 2008; Vuong et al., 2020) mentioned the controversial effect of energy saving in Earth Hour, and it is believed that such controversy could reduce people's passion to engage.

3 Methodology

3.1 Procedure and participants

This study involved administrating a questionnaire to 401 college students in the PRC. The study was approved to be within the Code of Ethics followed by the collaborators' universities. College students in the PRC were asked to complete an online questionnaire, 372 of the 401 questionnaires distributed were returned (a very high return rate of 93%). The questionnaire had four parts. The first part aimed to sort students by their frequency of participation within 5 years and separate non-participants from the total sample. The second part and third part aimed to capture respondents' demographics and psychosocial features, respectively. The fourth part of the questionnaire examined the significance of each barrier toward participation perceived by respondents. The systematic design and analysis were based on a study concerning various factors as correlates of non-participation in running events (Van Dyck et al., 2017).

The online questionnaires were distributed through an online platform (Wenjuanxing website) to college students within 12 prefecture-level cities across the PRC. The items and format were pilot tested with 43 college students (not involved in the main study) and revised based on their comments and suggestions. A cluster sampling technique was used to select the respondents whose educational backgrounds range from first-class universities to vocational schools, and to include a representative proportion of rural, suburban, and urban schools nationwide. Additional respondents were recruited through snowball sampling. The researchers shared the questionnaire links with currently enrolled research participants and encouraged them to spread the project on social media platforms such as WeChat, QQ, and Weibo to capture a growing chain of participants.

The online questionnaire was available from the end of April to mid-May in 2022 and it took 139 s to complete on average. All personal information in the questionnaires were collected anonymously.

3.2 Modifications to the model

The study was inspired by Van Dyck et al. (2017) who applied the social-ecological model to non-participation analysis of running events in Belgium. In this paper, several modifications were made regarding that the features of sample are unique to Chinese college students and environment-related activities.

For socio-demographic variables, age was excluded from the initial model since a four-year-range among undergraduates was short enough to be neglected in this matter. Monthly family income was added to demonstrate how students' main economic sources affected their choice in participation. Educational level was further divided into undergraduate and junior college for college students. For psycho-social variables, social support from family and from friends were merged into one factor ("social support from family and friends"), with factors related to personal character introduced (Larson and Lach, 2008). Factors unique to running events were not considered, to name a few, bad physical condition, annoyance spectators and insufficient challenging among barriers toward participation; and min/week MVPA among activity-related variables.

It is worth mentioning that psychosocial factors were assessed in separate questionnaires in the previous research, these questionnaires were adapted to one question using five-point Likert scale, respectively, for each factor in this study.

3.3 Measures

3.3.1 An overview of the socio-ecological model

The basic idea of this research is shown as follows (see Figure 2).

3.3.2 Socio-demographic characteristics

The following socio-demographic characteristics were assessed: gender, monthly family income (low, moderate, high, Zhou and Fan, 2020), educational level and living environment.

3.3.3 Psycho-social factors and attitude variables

Four categories of subjective factors were included in the questionnaire: environmental awareness, acceptance for law and regulations, social support from family and friends and knowledge about the Earth Hour event. While the first two factors were concerned with attitude variables depending on personal character (Larson and Lach, 2008), the last two factors were psychosocial which showed how personal choice was influenced by social environment. Detailed standards for selecting these variables have been discussed above (see section 2.2.3).

All factors except knowledge about the Earth Hour event were assessed on a five-point Likert scale from strongly disagree to strongly agree (environmental awareness, acceptance for law and regulations) and from never to very often (social support from family and friends).

Knowledge about the Earth Hour event was assessed by presenting the students an earth hour quiz (CTVNews.ca Staff, 2015) which

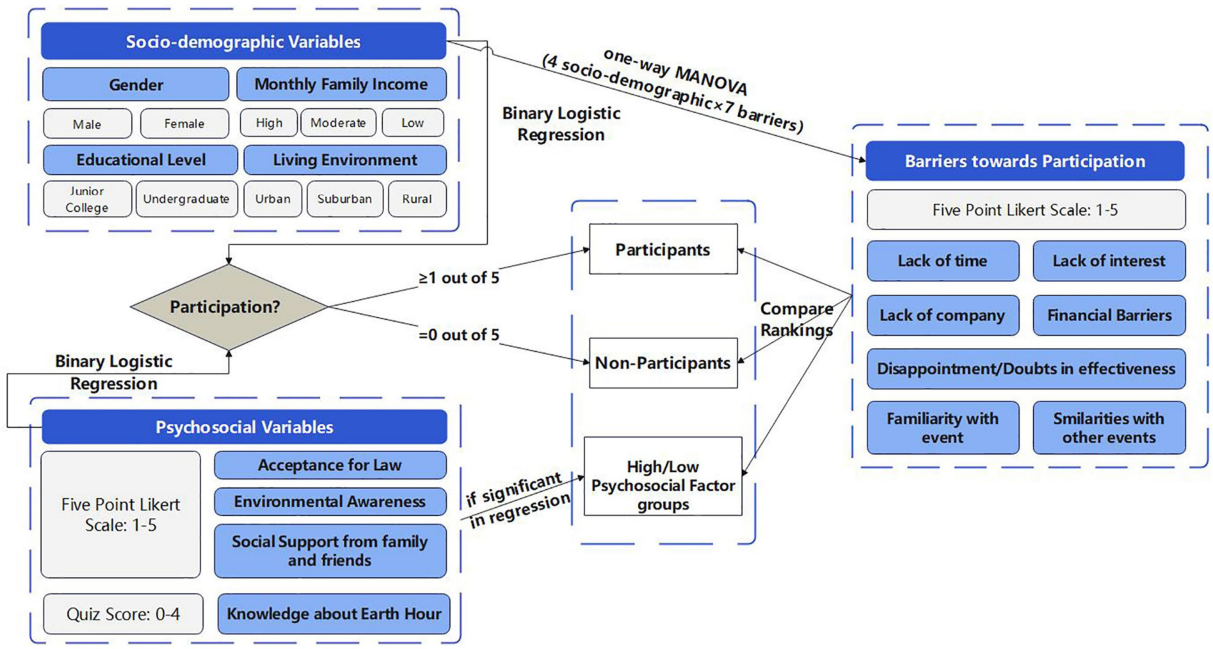

FIGURE 2
Overview of the present research.

contained four questions, including the specific time, originated city, organization, and geographic reasons for earth hour. Scores for "knowledge" could range between 0 and 4.

3.3.4 Participation in the Earth Hour event

Participation in the Earth Hour event was assessed by one question: "How often do you participate in the Earth Hour event in the past 5 years?" Due to the convenience of switching indoor lights for an hour, the quality and thoroughness was not considered. Those who gave an answer would be sorted into three levels, non-participants (never participated), occasional participants (participated for 1–2 times) and regular participants (participated for 3–5 times). For the analysis this variable was dichotomized into non-participation (never participated in 5 year) versus participation (at least one time in 5 years).

3.3.5 Barriers toward participation

Participants were asked about potential barriers preventing participation, except for those individuals that did participate for more than two times in this event in the past 5 years. A list of 10 potential barriers was compiled during an expert meeting with two behavioral research scientists and two psychologists and was based on previous research on perceived barriers toward physical activity (De Bourdeaudhuij and Sallis, 2002; Deforche et al., 2004). With minor modifications, these barriers were catered to better fulfill the topic of an environmental protection activity in this paper (see sections 2.2.3 and 3.2).

The following 7 barriers were queried: lack of interest, lack of time, financial barriers, lack of company/encouragement, disappointment and doubts in the effectiveness, low familiarity with the event, too many similarities compared to other environmental protection events. All items were assessed on a five-point Likert scale ranging from impossible to very likely.

3.4 Data analysis

Before analysis, all variables with scale data were under preprocessing. Item that contains a Cronbach's α above 0.7 would be accepted. The results in Table 1 had made it clear that the following items had passed the test and were to be analyzed.

The analysis of the reliability and validity of the data was completed using the Statistical Package of Social Science (SPSS 28.0) and all figures presented through excel. To examine the socio-demographic and psychosocial correlates of participation in Earth Hour, a binary logistic regression analysis was conducted. Participation in the Earth Hour event during the past 5 years (yes/no) was included in the model as the dependent variable; four socio-demographic factors (i.e., gender, monthly family income, educational level, living environment) and four psychosocial variables (i.e., knowledge, social support from family and friends, environmental awareness, acceptance for regulations) were included as independent variables. Descriptive statistics were used to describe the barriers toward participation present in the overall sample and in those students with characteristics related to lower odds of participation in Earth Hour. To examine the differences in barriers toward participation depending on gender (men versus women), monthly family income (low, moderate, high), living environment (urban, suburban, rural) and educational level (undergraduate, junior college), four one-way MANOVA analyses were conducted. Statistical significance was set at $p < 0.05$ for all analyses.

TABLE 1 Reliability analysis on scale data.

No.	Variable	Correlation between the deleted item and the total	Cronbach's α	Reliability
1	Environmental awareness	0.562	0.856	High
2	Acceptance for law and regulations	0.54	0.835	High
3	Social support from family and friends	0.573	0.836	High
4	Lack of interest	0.534	0.836	High
5	Lack of time	0.576	0.832	High
6	Lack of company	0.746	0.813	High
7	Disappointment/doubts in effectiveness	0.516	0.838	High
8	Familiarity with event	0.659	0.823	High
9	Similarities with other events	0.681	0.82	High

4 Results

4.1 Descriptive characteristics of the sample

4.1.1 Socio-demographic and psychosocial features in sample

In total, 401 students completed the questionnaire, of which 372 responded effectively to all the questions and were included in the sample. The socio-demographic and psychosocial characteristics of the total sample are listed in Table 2. Among the sample, 174 (46.77%) never participated in this event and 198 (53.23%) participated in Earth Hour for at least one time.

Overall, 69.09% of the sample was female, 60.48% had a bachelor's degree, 23.12% lived in urban area and 50.27% shared a rural dwelling, nearly a half of the respondents were from low-income families.

The overall environmental awareness was relatively high, with a per capita score of over 4 among the total sample, participant, and non-participant groups. However, the overall level of knowledge about Earth Hour was low, with an average score of less than 1, indicating that most students had not answered almost one of the four questions correctly and had insufficient knowledge about this activity.

4.1.2 Interval estimation of low-frequency participation ratio

Participants who participate less than 3 times within 5 years are defined as low-frequency participants. Since the low-frequency participation ratio is a dichotomy variable, there is a normal approximation in the case of a large sample, corresponding to a two-point distribution. Therefore, the confidence interval for the overall ratio at the 95% confidence level can be obtained:

$$p \pm Z_{0.025}\sqrt{\frac{p(1-p)}{n}}$$

In total, 401 students completed the questionnaire, among which the non-participants and occasional participants of the Earth Hour event take up 92.77% (i.e., $p = 92.77\%$, $n = 401$) (see Figure 3). As of 2022, the 95% confidence interval of the proportion of non-participants among all Chinese college students in the past 5 years is therefore (38.54, 48.24%), which is above 24.2% non-participation found in previous research by 2015. In this way, it's safe to draw the conclusion that college students in China share a low participation in Earth Hour in the past 5 years.

4.2 Socio-demographic and psychosocial correlates of participation in Earth Hour event

4.2.1 Spearman coefficients between socio-ecological factors

Spearman coefficients were applied for rank correlation between discrete variables (i.e., all socio-demographic and psychosocial characteristics) in our research (see Figure 4). Odds for multicollinearity are very low since no coefficient is larger than 0.5 among significant correlation, which makes it possible for logistic regression.

Acceptance for law is positively related to social support ($\rho = 0.47$, $p < 0.01$) and environmental awareness ($\rho = 0.33$, $p < 0.01$). However, a higher level of knowledge is linked with a lower social support ($\rho = -0.2$, $p < 0.01$); and better-educated students were found to be less tolerant with relevant law ($\rho = -0.15$, $p < 0.01$). A more urbanized dwelling is relevant to higher income and educational level, which is in accordance with common sense.

4.2.2 Binary logistic regression

Since the number of the sample is 10–15 times larger than that of the independent variables (i.e., $372 > 15*8$), the binary logistic regression was applied.

Results of the binary logistic regression analysis are shown in Table 3. The analysis revealed that social support from family and friends was significantly associated with participation in Earth Hour event. Students perceiving more social support from family and friends (OR = 1.790, 95% CI = 1.462, 2.192) were more likely to have participated in Earth Hour for at least one time during the past 5 years than their counterparts. For the socio-demographic and the other psycho-social factors, no significant results were found.

TABLE 2 Descriptive characteristics of the study sample.

Variable	Total sample	Non-participants	Participants
	(*n* = 372)	(*n* = 174)	(*n* = 198)
Socio-demographic variables			
Gender (%)			
Men	30.91	32.76	29.29
Women	69.09	67.24	70.71
Educational level (%)			
Undergraduate	60.48	62.64	58.59
Junior college	39.52	37.36	41.41
Living environment (%)			
Urban	23.12	21.26	24.75
Suburban	26.61	29.89	23.74
Rural	50.27	48.85	51.52
Monthly family income[1] (%)			
Low income	51.34	53.45	49.49
Moderate income	36.02	35.63	36.36
High income	12.63	10.92	14.14
Psychosocial variables [mean (SD)]			
Environmental awareness[2]	4.54(0.83)	4.56(0.88)	4.53(0.97)
Acceptance for law and regulations[2]	3.72(0.94)	3.59(0.99)	3.83(0.88)
Social support from family and friends[3]	3.02(1.31)	2.56(1.39)	3.42(1.08)
Knowledge about the Earth Hour event[4]	0.78(0.97)	0.80(0.94)	0.77(1.01)

SD = standard deviation. 1: measured by CNY, Low∈[0,5000], moderate∈(5000,10000], high∈(10000,+∞); 2: five-point Likert scale from strongly disagree to strongly agree; 3: five-point Likert scale from never to very often; 4: minimum 0, maximum 4.

With a Hosmer significant level below 0.6, however, it remains doubtful whether these correlates were well-explained by the fitting results. Thereby, a further test was taken to investigate the correlation between participation and social support, which suggested a significant result (Pearson Chi-Square = 61.940, $p < 0.01$).

4.3 Differences in barriers toward participation depending on gender, family income, living environment, and educational level

Descriptive statistics of the barriers toward participation depending on gender, family income, living environment and educational level are presented in Table 4. One-way MANOVA analyses revealed differences in perceived barriers between men and women (multivariate $F = 3.232$, $p = 0.002$) and between the different income groups (multivariate $F = 2.122$, $p = 0.041$). Regarding gender, univariate analyses showed that lack of interest was rather perceived as a barrier in men than in women ($F = 9.029$, $p = 0.003$), while perceiving financial barriers was more prevalent in women than in men ($F = 4.584$, $p = 0.033$). Regarding monthly family income, univariate differences between income groups were found for financial barriers ($F = 5.218$, $p = 0.006$), familiarity with the event ($F = 4.398$, $p = 0.013$) and similarities with other events ($F = 5.596$, $p = 0.004$).

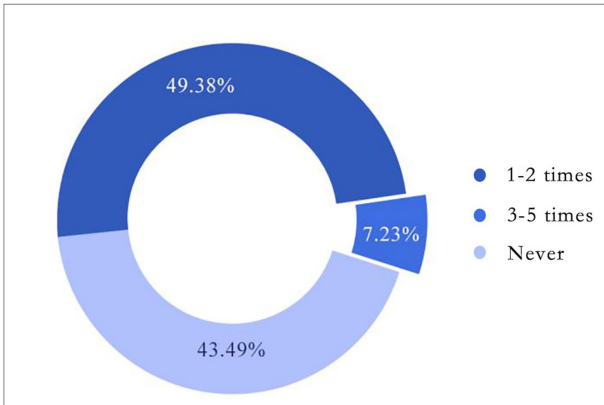

FIGURE 3
Participation of the original sample (*n* = 401).

Post-hoc analyses showed that similarities with other events was rather perceived as a barrier in students from extreme income groups (low: $p = 0.039$, high: $p = 0.007$) than students with moderate monthly family income. Low familiarity with the event was more prevalent in students from moderate-income families than in those from high-income families ($p = 0.01$). Furthermore, low-income group was less likely to be affected by financial barriers regarding this event than moderate income group ($p = 0.007$). For educational level and living environment, the multivariate model was non-significant ($F = 1.168$, $p = 0.321$ and $F = 1.032$, $p = 0.418$ respectively). However, univariate

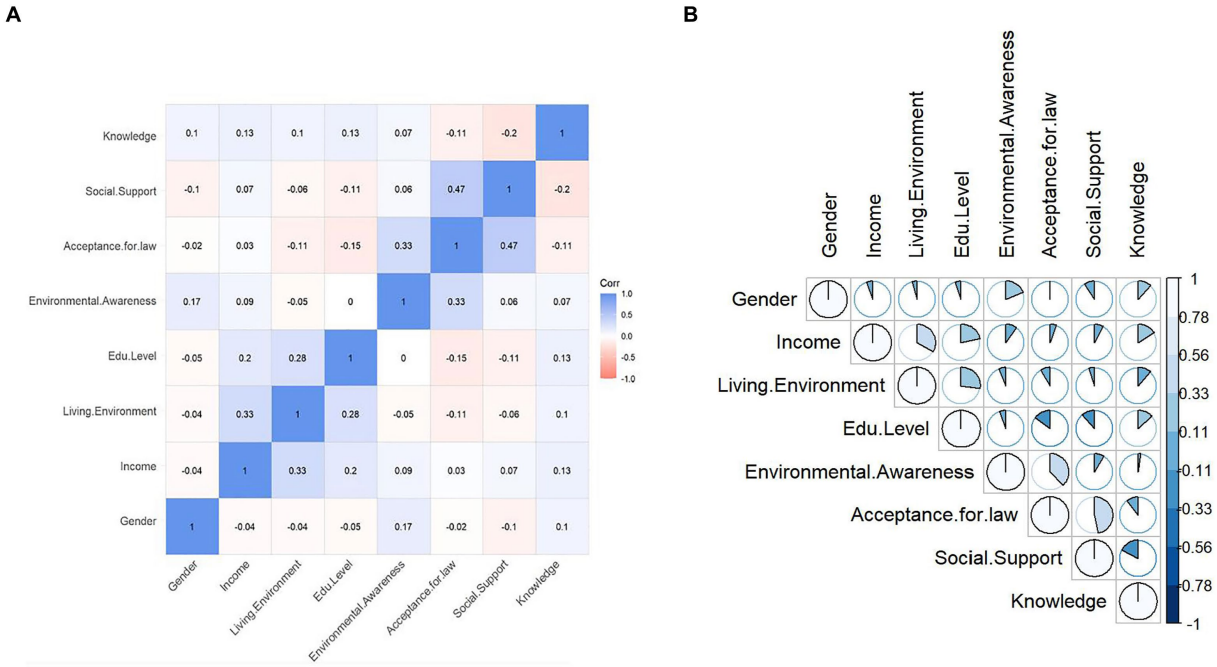

FIGURE 4
Correlation matrix of socio-ecological variables. **(A)** Hierarchical clustering method. **(B)** Pie chart by Spearman coefficients.

analyses showed that lack of company was more prevalent in undergraduates than in junior college students ($F = 4.885$, $p = 0.028$); and univariate differences concerning living environment were found for familiarity with the event ($F = 3.264$, $p = 0.039$) and similarities with other events ($F = 3.285$, $p = 0.039$).

4.4 Ranking of perceived barriers toward participation in the total sample and in students with characteristics associated with extreme odds of participating in Earth Hour event

Table 5 shows a ranking based on the importance (i.e., average item scores) of each potential barrier preventing participation in the different subgroups. In the total sample ($n = 372$), the top three of perceived barriers toward participation consisted to similarities with other events, financial barriers, and lack of company. This stands true for students who participated in Earth Hour for at least one time during the past 5 years and those who never participated as well. In non-participants, lack of company or encouragement was relatively prior to financial barriers compared with the participants. Furthermore, just like in the total sample, lack of time, doubts in effectiveness and lack of interest completed the last three barriers, except in participants who believe that low familiarity with the event was less important than lack of time.

Based on the results of the binary logistic regression analysis (study aim 1), participants scoring "low" on social support associated with participation were selected as our focus on low participation analysis. This was done using a median split (i.e., selection of participants scoring lower than the median score) for all psycho-social factors. Compared with the total sample, non-participant group and participant group, students gaining low support from family and friends were more likely to be baffled by inadequate familiarity with the event than excessive similarity with other events in the low social support group. In other words, lower support from family or friends might prevent college students from knowing this event, which enhanced the negative impact of this barrier on participation.

5 Discussion

Initial sociological studies on Earth Hour participation in PRC focused on cities and institutions, suggesting a high (i.e., above 60% in 1 year) participation rate (HuiCong D&B Research, 2011). More recent work based on a smaller sample, in contrast, demonstrated that individuals' practice in this event is less active than expected (Wang, 2015). Our data establish that more occasional participants were found than regular participants during the past 5 years among Chinese college students, with a lower level of average participation frequency (i.e., 1.03: 5) compared with the previous investigation (i.e., 2.7: 8) (Wang, 2015). Notably, this finding is in line with the existing statistics which has implied a descending trend of participation in Earth Hour nationwide, however, applying a new research method that is more theoretical based (Ajzen, 1985; Van Dyck et al., 2017; Chan et al., 2020).

The findings in this study are in accordance with Van Dyck's study (Van Dyck et al., 2017) when it comes to socio-demographic factors, as no significant differences in participation were found according to gender, monthly family income, educational level and living environment. This is a positive trend and denies the results that rural residents are less inclined to participate in Earth Hour due to its limited exposure in the countryside (Wang, 2015); the finding also supports the latest statistics regarding a rapid surge in participants from third-tier and fourth-tier cities since the gap is no longer

TABLE 3 Binary logistic regression analysis of socio-demographic and psycho-social correlates of participation in Earth Hour event.

Dependent variable: participation in Earth Hour: 0 = no participation during the past 5 years, 1 = participation for at least one time during the past 5 years						
Correlate	β	SE	*P*-value	Odds ratio	95%CI	
Environmental awareness	−0.164	0.151	0.279	0.849	0.631	1.142
Acceptance for law	−0.033	0.146	0.821	0.967	0.726	1.289
Social support	0.582	0.103	0.000	1.790	1.462	2.192
Knowledge about event[1]	0.068	0.119	0.566	1.071	0.848	1.351
Gender (ref: male)	−0.383	0.250	0.127	0.682	0.417	1.115
Monthly family income low	−0.259	0.387	0.503	0.771	0.361	1.648
Monthly family income moderate	0.184	0.382	0.631	0.832	0.393	1.761
Living environment suburban	−0.229	0.280	0.413	0.795	0.460	1.376
Living environment urban	0.083	0.302	0.782	1.087	0.602	1.964
Educational level undergraduate	−0.069	0.241	0.776	0.934	0.582	1.498
Constant	−0.468	0.930	0.615	0.626	–	–

SE, standard error; 95%CI, 95% confidence interval. [1]Range from 1 to 5 with a linear variation.

significant (Zhuang, 2023). Besides, this also indicates a narrowing gender disparity in domestic environmental participation, contrasting with Li et al. (2022) findings that contemporary Chinese women are more actively engaged in PEB activities compared with men. It also validates the conclusion that gender differences are not significant in college students' environmental participation activities (Vicente-Molina et al., 2018). Among non-participants, the top three barriers were similarities with other events, financial barriers, and lack of company. However, it's doubtful whether financial barrier is a credible enough to measure students' participation since students with different levels of monthly family income were rather similar in all barrier ratings. Despite the doubts in effect of reducing electricity consumption in Earth Hour being one of the main reasons for non-participation overseas (Vuong et al., 2020), no clear evidence supportive of this finding was found in our study since disappointment or doubts in effectiveness ranked second to last in the total sample, non-participants and students with characteristics associated with extreme odds of participation (see section 3.4).

No previous studies examined the mismatch between respondents' belief and practice in relevant activities nationwide, particularly, among college students whose behaviors is yet likely to be influenced by higher education. Distinguished from Yang and Li (2021), environmental awareness which is commonly known as a booster for environmental protection activities was not found to be positively related to students' participation. One possible explanation is that the environmental protecting education in China might not be effective enough to make a difference in students' behaviors for schools have put excessive emphasis on plain theoretical education without giving specific instructions or useful advice on how to put it into practice.

A highlight of findings regarding the psychosocial correlates of participation would be the positive relation between participation and social support with a considerable level of significance found ($p < 0.01$), verifying the results from Yang and Li (2021). To be more specific, participation rate increased by 76.32% with each additional unit of social support from family and friends. Sadly, the participation rate in Earth Hour remains low nationwide (see section 3.1), which makes it harder for participants to maintain their passion for this event. In other words, the herd effect has led to a vicious cycle that worsens this issue. To some extent, this is partly due to the immature build of local NGO (i.e., Non-government Organization) concerning environmental protection, in other words, bottom-up attempts are to be taken seriously besides other top-down approach mentioned in previous studies that investigated the institutional framework to allow public participation (Li et al., 2012).

When it comes to potential impact on barriers toward participation by socio-demographic variables, the experienced barriers were relatively similar across subgroups concerning gender, income, educational level and living environment, with some exceptions. For women, having a poor economic condition was more important while men rather considered this event dull, which agreed with the domestic finding that females exhibited a greater propensity for environmental concerns (Li et al., 2022). Furthermore, financial barriers and being unfamiliar to the event were mainly present in individuals with moderate income while boredom caused by similarities to other events had a greater impact on extreme income subgroups. This finding supported existing PEB studies (Margetts and Kashima, 2017; Chatelain et al., 2018) by explaining how similarities with other events applied to specific populations as one of the perceived barriers in Earth Hour. College students better educated were more likely to be affected by people around them. Those who lived in rural area shared a higher level of exposure to this event and named less similar events, which indicated that its publicity could be greatly improved in countryside despite less attention it had raised in cities during the past decade (Wang, 2015).

Finally, an overview of the event-specific barriers preventing participation was given in both the total sample and students with characteristics associated with lower odds for participation. In the overall sample, the main three barriers were similarities to other events, financial barriers, and lack of company. Except for students with lower social support from family and friends, similarities to other events completed the top. When looking specifically at the main barriers in students who are less likely to participate in Earth Hour, lack of company and low familiarity with the event were more prevalent, and results were rather similar as for barriers ranked the bottom three.

TABLE 4 Perceived barriers toward participation in the Earth Hour event: descriptive statistics and differences between socio-demographic subgroups (gender, family income, educational level, living environment).

Barriers toward participation Mean (SD)[1]	Total sample (n = 372)	Gender		Monthly family income		
		Men n = 115	Women n = 257	Low n = 191	Moderate n = 134	High n = 47
Lack of time	3.56(0.92)	3.62(0.89)	3.54(0.93)	3.57(0.90)	3.49(0.90)	3.72(1.05)
Lack of interest	4.03(0.87)	**3.83(0.89)**	**4.12(0.85)**	3.99(0.89)	4.01(0.80)	4.21(0.94)
Lack of company/ encouragement	3.31(1.00)	3.30(1.04)	3.32(0.98)	3.35(1.02)	3.19(0.92)	3.55(1.07)
Disappointment or doubts in effectiveness	3.62(0.96)	3.62(0.98)	3.61(0.96)	3.62(1.04)	3.52(0.82)	3.85(0.99)
Financial barriers	3.29(1.10)	**3.47(1.07)**	**3.21(1.11)**	**3.42(1.07)**^{X}	**3.04(1.08)**^{X}	**3.45(1.13)**
Familiarity with the event	3.44(0.97)	3.51(1.02)	3.41(0.94)	**3.47(0.97)**	**3.29(0.90)**^{X}	**3.77(1.04)**^{X}
Similarities with other events[2]	2.71(1.00)	2.58(1.05)	2.77(0.97)	**2.64(1.00)**^{X}	**2.92(0.97)**^{X,Y}	**2.40(1.00)**^{Y}

Barriers toward participation Mean (SD)[1]	Educational level		Living environment		
	Undergraduate n = 225	Junior college n = 147	Urban n = 86	Suburban n = 99	Rural n = 187
Lack of time	3.55(0.94)	3.59(0.89)	3.59(1.05)	3.44(0.83)	3.61(0.90)
Lack of interest	4.01(0.91)	4.05(0.81)	3.91(0.98)	4.01(0.90)	4.09(0.79)
Lack of company/ encouragement	**3.22(1.00)**	**3.46(0.98)**	3.24(1.08)	3.26(0.97)	3.37(0.98)
Disappointment or doubts in effectiveness	3.63(0.98)	3.60(0.95)	3.56(1.02)	3.59(0.92)	3.66(0.96)
Financial barriers	3.22(1.11)	3.39(1.07)	3.22(1.14)	3.20(0.96)	3.36(1.15)
Familiarity with the event	3.37(0.99)	3.54(0.93)	**3.43(0.99)**	**3.24(0.84)**	**3.55(1.00)**
Similarities with other events[2]	2.78(1.05)	2.61(0.92)	**2.76(1.04)**	**2.91(0.94)**	**2.59(1.00)**

SD = standard deviation. [1]All barriers were scored on a five-point Likert scale from impossible to very likely. [2]Higher index stands for less likelihood to be negatively affected by barriers, including similarities with other events. Bold results represent significant differences between groups (gender, monthly family income, educational level or living environment); *post hoc* tests for income group: same superscript characters (X,Y) = significant difference between groups.

TABLE 5 Ranking of perceived barriers toward participation in the total sample and in students with characteristics associated with extreme odds of participating in Earth Hour event.

Barriers toward participation[1]	Total sample (n = 372) Rank (Mean [SD])	Non-participants (n = 174) Rank (Mean [SD])	Participants (n = 198) Rank (Mean [SD])	Low social support from family and friends[A] (n = 132) Rank (Mean [SD])
Similarities with other events[2]	1(2.71[1.00])	1(2.93[1.03])	1(2.53[0.94])	4(3.25[0.84])
Financial barriers	2(3.29[1.10])	3(3.22[1.09])	2(3.34[1.10])	3(3.00[1.04])
Lack of company/encouragement	3(3.31[1.00])	2(3.06[1.04])	3(3.54[0.90])	1(2.72[0.85])
Familiarity with the event	4(3.44[0.97])	4(3.24[0.99])	5(3.62[0.91])	2(2.95[0.89])
Lack of time	5(3.56[0.92])	5(3.53[0.89])	4(3.59[0.95])	5(3.27[0.90])
Disappointment or doubts in effectiveness	6(3.62[0.96])	6(3.60[0.98])	6(3.63[0.95])	6(3.37[1.00])
Lack of interest	7(4.03[0.87])	7(3.95[0.92])	7(4.10[0.81])	7(3.81[1.00])

SD = standard deviation. [1]All barriers were scored on a five-point Likert scale from impossible to very likely. [2]Higher index stands for less likelihood to be negatively affected by barriers, including similarities with other events; A median split was used to define groups scoring "low/high" on the respective psychosocial variables.

This study gives insights to researchers working on participation analysis of large-scale event in broader socio-ecological context. It highlights the dual nature of interplay between individual and social environment in group activities held with a large population. Being indifferent and less motivated to participate in such events would cause a herd effect among participants, thus reducing the participation

rate in overall. On the other hand, boosting social support would be the key to end the negative feedback and create a virtuous circle instead.

Although this study focused on PRC college students, it has wider implications for many school educators, practitioners and organizations involved in pro-environmental career. The conflict between students' belief and practice in Earth Hour indicates a lack of efficiency in local pro-environmental education, leading curriculum planners' reflection on how to motivate students to engage in PEB via innovative lessons. An effective approach to tackle this problem was mentioned by Jin et al. (2023), where a whole set of adapted curricula covering green perspective was highly recommended rather than separate thematic lectures. For pro-environmental institutes, reinforcing the NGO construction and encouraging the current participants to join in groups is the key to reducing the non-participants since a strong positive correlation was found between social support and participation. Given the high priority of similarities with other events, features unique to Earth Hour are expected to be emphasized to raise public awareness; for local male participants, extra new forms should be advocated in relevant pro-environmental activities as an effort to cater to their interest.

From an international perspective, this paper shed light on the essence of pro-environmental collective action similar to Earth Hour, which is to convert unconcerned members in the general public into active members in the environmental endeavors. The research not only elucidated local dynamics but also contributed to a global dialogue on fostering sustainable behaviors, crucial in mitigating climate change's adverse effects and safeguarding our planet for future generations.

6 Conclusion

In conclusion, this study confirmed the low participation among Chinese college students in Earth Hour event. Despite that no significant mismatch was shown between students' belief and practice on environmental protection, the irrelevance warned that the effect of publicity and education involved were far from ideal. It also showed that low levels of social support were associated with a lower likelihood of participating in the earth hour. Furthermore, similarity with other events, financial barriers and lack of company were the three main barriers preventing Chinese college students from participation. Finally, with a few exceptions, perceived barriers were relatively similar across socio-demographic subgroups.

This study has limitations, naturally. Perhaps the most general limitation arose during the analysis of the questionnaires, that respondents might overstate their engagement. Similar cases were discussed in a study on Earth Hour participation among Sydney residents (Solomon, 2008), which suggested a 36% overstated participation rate potentially triggered by moral cost and pressure from scrutiny according to the model elaborated by Levitt and List (2007). A minor problem would be the error caused by the misconduct in sample collection. Most regular participants (29 out of 401) were excluded from the total sample, which undermined the accuracy of analysis. In addition, the failure to compare respondents' engagement in Earth Hour with that in other types of environmental protection activities is a limitation, otherwise, problems unique to Earth Hour might have been better noticed.

For future studies, an ambiguous question is that whether the herd effect found in our research was a matter unique to the event or to the local population size. Thus, the relation between social support and participation rate is recommended to be analyzed separately under the following two situations: (1) same activity on sparsely populated area; (2) less population-based activities with a similar sample included in this study. In addition, measuring participation in a quantitative way with other methods (if necessary), such as the lasting time for switching lights off, continuity of annual participation or the alternative ways participants take part in this event would be an interesting extension to this study.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Shanghai Normal University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

KY: Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – original draft, Writing – review & editing. YW: Writing – review & editing. HX: Writing – review & editing. ML: Supervision, Validation, Resources, Methodology, Project administration, Conceptualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2024.1288711/full#supplementary-material

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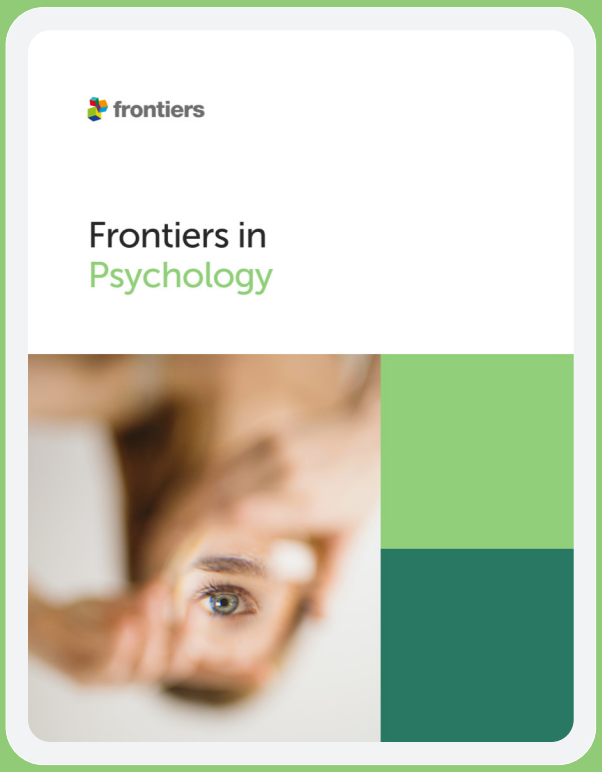

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