

# *Going green with AI-powered virtual influencers: the role of social cues, source credibility and environmental identity*

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# Going Green with AI-Powered Virtual Influencers: The Role of Social Cues, Source Credibility and Environmental Identity

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## ABSTRACT

This study examines how AI-powered virtual influencers (VIs) encouraging green behavior among social media users. Drawing on the Computers-Are-Social-Actors (CASA) paradigm and integrating Source Attractiveness and Source Credibility models, this study proposes a framework that offers comprehensive insights into the psychological mechanisms through which virtual influencers (VIs) impact their followers' pro-environmental intentions. An online survey collected 603 valid responses from users who had interacted with sustainability content shared by VIs. Social cues (anthropomorphism, warmth, and competence) and source credibility (attractiveness, homophily, authenticity, and expertise) positively influenced social presence and trust, which in turn shaped pro-environmental intentions. Environmental self-identity strengthens the relationship between social presence and pro-environmental intention but attenuates the effect of credibility on these intentions. These findings advance understanding of VIs' role in sustainable behavior and offer actionable insights for designing VI-driven campaigns to foster greener consumer practices.

## KEYWORDS

Artificial intelligence; sustainable behavior; social cues; source attractiveness; environmental identity

## 1. Introduction

### 1.1. AI-powered virtual influencers

In 2025, global spending in the influencer advertising market reached USD 39 billion, with an annual growth rate of 9.37%, and it is expected to increase to USD 56 billion by 2029 (Statista, 2025). Human influencers—such as celebrities, athletes, and singers—are widely recognized for their ability to promote brands and products on social media (Kim & Kim, 2021). However, these influencers are susceptible to negative scandals that become associated with their respective brand images, inducing adverse impacts and unfavorable outcomes for investors (Kintu & Ben-Slimane, 2020). Therefore, companies have begun to adopt AI-powered virtual influencers (VIs) as an alternative to human influencers, seeking to minimize reputational risks and potential financial losses (Thomas & Fowler, 2021; Xin et al., 2024). VIs are computer-generated characters designed to mimic real-life personalities, facilitating interactions that feel authentic and natural (Allal-Chérif et al., 2024). The use of VIs has been examined in different commercial settings, such as retail (Ozdemir et al., 2025), fashion (Y. Zhang et al., 2025), luxury (Mo & Wang, 2025), and tourism (K. Zhang et al., 2025). This demonstrated a trend for reshaping the landscape of influencer marketing and brand promotion (Baudier et al., 2023). Recent research studies have also explored their potential in promoting social and environmental causes. For example, You and Liu (2024) demonstrated that VIs can be leveraged in social advocacy campaigns and may be perceived as less egoistically motivated than human influencers. Similarly, Hong et al. (2024) showed that VIs can be involved in social movements. Chen et al. (2025) further illustrated that VIs can enhance

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engagement and message credibility in social marketing. These emerging studies highlighted that VIs not only serve as for commercial purposes but also help advocate for social good.

The virtual influencer market industry has reached USD 9.34 billion in 2024, and is expected to grow to USD 224.36 billion in 2034 (Market Research Future, 2025). Such advanced innovative technologies have profound implications for influencer marketing (Y. Wang et al., 2025). While some studies suggest that VIs can be effective in supporting brand strategies and engaging audiences (e.g., Franke et al., 2023; Vo et al., 2025), others suggested excessive reliance on VIs may reduce engagement (Guo et al., 2025) and trigger consumer animosity towards the brand (Sands et al., 2022). These findings suggested that while VIs provide marketers with opportunities for enhancing engagement and control, their use must be approached with caution, particularly in the pro-social contexts such as sustainability (Cheng & Toung, 2025; Gerrath et al., 2024).

### **1.2. Using virtual influencers to encourage pro-environmental behaviors**

As companies increasingly use VIs to engage with consumers, it is essential to investigate how VIs can be leveraged to enhance pro-environmental behaviors given the growing demand for green and ethical consumer practices. Integrating pro-environmental behaviors into virtual influencer marketing has led to a shift toward environmental sustainability (e.g., Hoai Lan et al., 2025; J. Wang et al., 2025). With growing awareness of climate change, biodiversity loss, and unsustainable consumption, environmentally conscious consumers are more likely to support brands that demonstrate genuine commitments to ecological sustainability (Iglesias & Ind, 2020; Lee et al., 2025). However, human influencers often face challenges of authenticity, as inconsistencies between their promotion of green causes and their personal or professional unsustainable behaviors can lead to reputational risks and reduce the effectiveness of their pro-environmental messaging (Boerman et al., 2022; Gerrath & Usrey, 2021; Giambastiani et al., 2025). In contrast, VIs present a promising alternative by offering marketers greater control over messaging and image, minimizing risks of scandals or contradictory behaviors (Gerrath et al., 2024; J. Kim et al., 2025). Brands have been capitalizing on this advantage, for example, BMW partnered with Lil Miquela (@lilmiquela) to promote its new energy vehicle, and WWF collaborated with Noonouri (@noonouri) for its Earth Hour campaign, exemplifying how VIs are becoming influential advocates for environmental sustainability.

### **1.3. Study aim and objectives**

Although numerous studies have focused on comparing the impact of human influencers with that of VIs (e.g., Armeen et al., 2024; Arsenyan & Mirowska, 2021; Meng et al., 2025), there is still a notable research gap in terms of how VIs can serve as influential agents by leveraging AI technology to raise awareness about global climate issues and promote pro-environmental behaviors (Gerrath et al., 2024; Wan et al., 2024). While some recent research has explored the role of VIs in encouraging prosocial actions, these studies often focus on anthropomorphic design of VIs or specific communication tactics, such as flattery (Quach et al., 2024), message warmth (Gerrath et al., 2024), narrative storytelling (Kim et al., 2024), contents and visuals (Hoai Lan et al., 2025), and framing strategies (Nazir & Wani, 2025). However, these approaches overlook the broader underlying psychological processes that govern how audiences perceive, relate to, and are ultimately persuaded by VIs in sustainability contexts unexplored. To address this gap, we propose a comprehensive theoretical framework that integrates key social-cognitive mechanisms to provide a holistic explanation of how VIs can effectively motivate pro-environmental behaviors.

Drawing on the Computers-Are-Social-Actors (CASA) paradigm (Nass et al., 1994), this study investigated users' sense of social connection to AI-powered VIs. By leveraging two foundational communication framework, i.e., the source attractiveness model (McGuire, 1985) and the source credibility model (Ohanian, 1990), we explored how the source characteristics of VIs influence their credibility. Despite their relevance, these models have not yet been fully applied to VIs in the context of environmental communication. We integrated the CASA paradigm with the two models to enhance our understanding of how VIs can effectively promote pro-environmental behaviors. Additionally, this study

explores the moderating role of environmental self-identity (Wicklund & Gollwitzer, 1981), advancing our understanding of how VI characteristics interact with audiences' psychological self-perceptions. By integrating these factors, we developed and tested a comprehensive framework to better understand how VIs influence pro-environmental intentions. The findings of this study contribute to the extant literature on VI strategies and green behaviors and provide practical insights for businesses and marketers on how to effectively utilize VIs to convey pro-environmental messages.

## 2. Theoretical background

### 2.1. Computer-are-social-actors paradigm

The CASA paradigm explains users' social reactions to computers and other technologies (Nass et al., 1994) and it suggested that when digital technologies display human-like social cues – including appearance, conversational style, and problem-solving capabilities – users are inclined to regard these technologies as real people, enhancing their engagement with said technologies (Xu et al., 2022). This framework has been widely applied in the study of various technological contexts such as service robots (de Kervenoael et al., 2024), chatbots (Gnewuch et al., 2018), and voice assistants (Hari et al., 2024). Social cues are integral to user engagement, as they instill a sense of presence and trust that connects humans and artificial entities (Lankton et al., 2015).

In the context of VIs, CASA emphasizes the importance of social cues such as human-like appearance, emotional expression, and conversational behavior in eliciting favorable responses from users and fostering engagement (Ham et al., 2024). Specifically, VIs leverage three core social cues: anthropomorphism, warmth, and competence. Anthropomorphism is conveyed through human-like characteristics that enhance users' perceptions of VIs as more relatable and lifelike (Wan et al., 2024). Warmth is achieved through friendly and engaging conversational styles and emotional expressions, which lead VIs to be perceived as more approachable and empathetic (Gerrath et al., 2024). Finally, competence is demonstrated through the VI's ability to provide relevant advice and facilitate problem solving for users (Roy & Naidoo, 2021; Xie-Carson et al., 2023). Therefore, CASA posits that social cues in technologies can create a presence to elicit human-like social responses (Karr-Wisniewski & Prietula, 2010). Other studies have also shown that the social cues of VIs can influence user engagement (Arsenyan & Mirowska, 2021).

### 2.2. Source attractiveness and source credibility models

The source attractiveness and source credibility models are two important frameworks that highlight the different dimensions influencing the effectiveness of a message (Vrontis et al., 2021). The source attractiveness model, proposed by McGuire (1985), focuses on characteristics of the message source, including its physical appearance and similarity to the audience. In the context of social media influencers, physical attractiveness and homophily (i.e., similarity between the influencer and audience) are key factors motivating user engagement (Gupta et al., 2023). In addition to source attractiveness, the source credibility model, developed by Ohanian (1990) highlights expertise and authenticity as key components of credibility. Credibility generally comprises two primary dimensions: expertise, which reflects the source's knowledge, and authenticity, which refers to perceived reliability and the absence of hidden agendas (Hovland & Weiss, 1951). The impact of source credibility has been widely demonstrated (Knight et al., 2022; Lou & Yuan, 2019). Although these are two distinct models, prior studies have often integrated attractiveness and credibility to provide a more comprehensive understanding of how these source characteristics influence audience perceptions (e.g., Frank & Mitsumoto, 2023; Ladhari et al., 2020).

In the context of VIs, these two models provide a valuable framework for understanding how AI-generated characters affect user perceptions and engagement. VIs often use visually appealing designs to enhance their attractiveness and foster a greater sense of homophily with audiences (Yoo et al., 2025). In addition, VIs can enhance perceived trustworthiness by demonstrating expertise and authenticity, as well as sharing relevant and useful information with their followers (Ameen et al., 2024;

Lee et al., 2024). Therefore, the interplay between attractiveness and credibility in VIs is crucial for fostering user engagement, influencing perceptions, and motivating behaviors of their followers.

### **2.3. Integrating CASA and source credibility in the context of virtual influencers**

Although CASA and source credibility models primarily focus on social reaction and communication persuasiveness respectively, they offer complementary insights into how audiences perceive and engage with VIs. The CASA paradigm helps explain how users attribute human traits to VIs based on social cues such as anthropomorphism, warmth, and competence (De Cicco et al., 2024). These social cues trigger relational and affective responses, influencing users' sense of social presence and interpersonal connection with VIs (Zourrig et al., 2025). On the other hand, the source credibility model focuses on more deliberative assessments of a communicator's persuasiveness, emphasizing attributes like attractiveness, homophily, authenticity, and expertise, which are important in shaping message persuasiveness (Agnihotri et al., 2025; J. Kim et al., 2025; Yoo et al., 2025).

In this study, the dimensions drawn from CASA (i.e., anthropomorphism, warmth, and competence) are viewed as social cues that elicit more emotional and relational engagement and shape how users feel connected to VIs. The dimensions drawn from the source credibility framework, i.e., attractiveness, homophily, authenticity, and expertise, are treated as persuasive source characteristics that lead users to make more evaluative judgments about a VI's credibility. By integrating these perspectives, the study provides a theoretically grounded and comprehensive explanation on how users both feel connected to and evaluate the persuasiveness of VIs. This integrated approach strengthens the conceptual coherence of the model by integrating affective and cognitive pathways to user trust, social presence, and ultimately pro-environmental behaviors (Chan et al., 2024; Voss et al., 2024). In this framework, social presence refers to users' perceived sense of psychological closeness and interpersonal connection with the VI (Zourrig et al., 2025), while trust reflects users' confidence in the VI's reliability and integrity (Wan et al., 2024).

### **2.4. Environmental self-identity**

Self-identity refers to how individuals define and describe oneself (Truelove et al., 2016). It can be used to differentiate oneself from others (Whitmarsh & O'Neill, 2010) and prescribe a course of behavior that aligns with our selfhood (van der Werff et al., 2014b). Thus, environmental self-identity can be defined as the extent to which individuals perceive themselves as environmentally friendly (van der Werff et al., 2013b). Engaging in pro-environmental behaviors varies according to the level of environmental self-identity (Ng et al., 2024). People who perceive themselves as eco-friendly often pay greater attention to the environment, and are more likely to engage in environmentally friendly behaviors (e.g., Gatersleben et al., 2014; van der Werff et al., 2014a).

In addition, strong environmental self-identity can influence individuals' responses to messages about sustainability (Arpan et al., 2022; Brick et al., 2017), such as perceived persuasiveness and intention to act. This identity not only reinforces consistent behavior, but also strengthens the motivation to align one's actions with broader environmental goals (Yang et al., 2015). Therefore, environmental self-identity is an important factor in understanding how and why individuals commit to sustainable practices over time (Dresner et al., 2015). Exploring this in the context of VIs offers valuable insights into how VIs can shape and reinforce environmentally friendly behaviors among their followers.

## **3. Research model and hypothesis**

### **3.1. Social cues, social presence and trust**

Drawing on the CASA framework, social cues play a crucial role in shaping user perceptions of and responses to technology (Nass et al., 1994). Social cues are defined as signals or indicators of an object that elicits social responses (Gambino et al., 2020). In this study, we propose three key dimensions of social cues based on prior VI studies: anthropomorphism, warmth, and competence (Gerrath et al.,

2024; Wan et al., 2024; Xie-Carson et al., 2023). Social cues have been shown to significantly influence social presence, or the user's feelings of connection with another entity (Mitchell & Jeon, 2025; Yan et al., 2025). Social presence refers to the degree to which followers perceive influencers as psychologically present and relatable (Jin et al., 2019). Therefore, the social cues of VIs influence the social presence perceived by followers, providing a sense of connectedness and engagement (Munnukka et al., 2022). We therefore propose the following hypothesis:

**Hypothesis 1a (H1a):** Social cues positively influence social presence.

Social cues influence not only social presence, but also the degree of trust users place in technologies (Lee & Nass, 2010). In the context of influencers, trust refers to the extent to which they are perceived as honest, truthful, and reliable sources of unbiased information (Ohanian, 1990). A growing body of research has shown that social cues can significantly enhance trust in various technological agents. For example, De Visser et al. (2016) demonstrated that social cues positively affect trust in automated cognitive agents, while Van Pinxteren et al. (2019) reported similar effects in the context of humanoid service robots. Similarly, Foehr and Germelmann (2020) demonstrated that voice interfaces using human-like cues can foster greater trust in smart technologies. More recently, Yan et al. (2025) revealed that combining two key social cues, warmth and competence, further amplifies user trust. We therefore propose the following hypothesis:

**Hypothesis 1b (H1b):** Social cues positively influence trust.

### **3.2. Source credibility, social presence and trust**

Based on the source attractiveness and source credibility models, we adopted four dimensions of source credibility for VIs: attractiveness, homophily, authenticity, and expertise (Kim & Kim, 2021). When VIs are perceived as attractive and credible through these dimensions, followers are more likely to experience a heightened sense of social presence, as their sense of psychological connection is strengthened through relevant engaging interactions (Go & Sundar, 2019; Kim & Wang, 2024). Prior studies have shown that source credibility significantly influences how audiences perceive their psychological connections with digital entities (Kim et al., 2022; Yuan & Lou, 2020). Therefore, we argue that when VIs are perceived as more credible, their followers' perceptions of their social presence are enhanced. We therefore propose the following hypothesis:

**Hypothesis 2a (H2a):** Credibility positively influences social presence.

In addition to fostering social presence, source credibility plays a pivotal role in shaping trust in VIs (Kim & Kim, 2021; Wan et al., 2024). Prior studies have demonstrated that source credibility impacts trust in influencers. For example, Lou and Yuan (2019) found that attractiveness and perceived credibility positively affect followers' trust in influencers' posts, which in turn shapes their behavioral responses. Similarly, Reinikainen et al. (2020) reported that influencer credibility fosters brand trust and strengthens behavioral intentions. J. Kim et al. (2025) showed that perceived expertise conveyed through VIs' content enhances audience trust. These findings underscore the importance of credibility dimensions in establishing trust, therefore, we propose the following hypothesis:

**Hypothesis 2b (H2b):** Credibility positively influences trust.

### **3.3. Social presence, trust and pro-environmental intentions**

Social presence has been proven to be an important factor driving user behavior across various contexts. In digital commerce, social presence has been shown to significantly affect purchase intentions (Li et al., 2024; Lu et al., 2016). Kim (2022) showed that social presence can effectively engage audiences and motivate their behavior in an AI learning environment. Social presence has also been identified as a key driver for shaping user behaviors across various digital contexts, including social media (Ham et al., 2019; Woo et al., 2024), livestreaming e-commerce (Q. Wang et al., 2025) and the metaverse

(Ghali et al., 2024). Given that pro-environmental behaviors can be driven by social influence (Farrow et al., 2017), when VIs exhibit a high level of social presence, audiences are likely to perceive the behaviors they promote as being endorsed by significant social others (Davlembayeva et al., 2025; Zourrig et al., 2025). This perception can enhance the followers' intentions to engage in pro-environmental actions. We therefore propose the following hypothesis:

**Hypothesis 3 (H3):** Social presence positively influences pro-environmental intentions.

Trust in the context of social media influence is a key driver of various positive outcomes, such as increased customer loyalty, shaping purchasing decisions and encouraging adherence to recommendations (Chetioui et al., 2020; Kim & Kim, 2021; Lou & Yuan, 2019). When users regard influencers as credible sources of information and guidance, they are more inclined to embrace the pro-environmental behaviors promoted by these influencers (Boerman et al., 2022; Hoai Lan et al., 2025). Moreover, trust plays a significant role in shaping individuals' perspectives on environmental issues and enhancing their motivation to participate in sustainable practices (Pittman & Abell, 2021). Trust in VIs has been found to significantly influence a wide range of behaviors (E. Kim et al., 2025; J. Kim et al., 2025), including pro-environmental behaviors (Wan et al., 2024). Therefore, we propose the following hypothesis:

**Hypothesis 4 (H4):** Trust positively influences pro-environmental intentions.

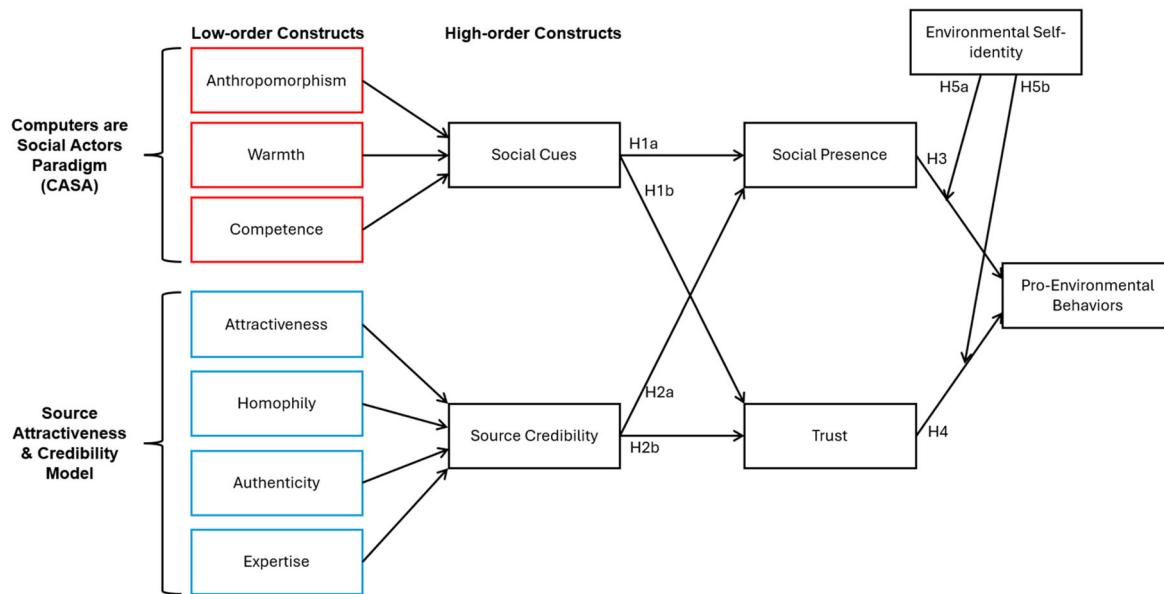
### **3.4. The moderating effect of environmental self-identity**

According to the self-completion theory (Wicklund & Gollwitzer, 1981, 1982), as long as a person is committed to a self-defining goal, they will continue working towards achieving that goal. Kashima et al. (2014) highlighted a similar view: people are motivated to act based on how they see themselves to achieve what they aim to be or take a congruent action. Accordingly, a person with stronger environmental self-identity is more likely to engage in pro-environmental behaviors. Prior studies have examined the moderating effect of environmental self-identity; for example, Carfora et al. (2017) demonstrated that the perceived ease of engaging in pro-environmental behavior became less important when individuals have a strong self-identity, Liu et al. (2021) found that self-identity positively moderates environmental behavior as symbolized by the adoption of electric vehicles, and Neves and Oliveira (2021) showed that self-identity positively moderates the relationship between energy labels and the intention to use energy-efficient heat appliances. Carfora et al. (2024) gained additional insights into how self-identity moderates the influence of cognitive versus affective attitudes on sustainable apparel purchases, demonstrating that self-identity weakens the impact of the former while strengthening the influence of the latter. This study examined the moderating effect of self-identity on the relationship between social presence and pro-environmental intention, as well as that between credibility and pro-environmental intention. Because social presence is more psychologically driven whereas credibility is primarily rationally driven (Barreda-Ángeles & Hartmann, 2022; Metzger & Flanagan, 2013), we propose that self-identity will strengthen the influence of social presence on pro-environmental intentions but weaken the influence of trust on these intentions. Social presence reflects an individual's sense of connectedness and closeness to VIs. A strong self-identity can reinforce the pro-environmental messages shared by VIs, leading to a higher level of behavioral intention. In contrast, trust pertains to how individuals perceive the reliability of VIs as information sources. Characteristics associated with trust may become less influential for individuals with a strong self-identity because their own values already guide their intentions. Therefore, the following hypotheses are proposed:

**Hypothesis 5a (H5a):** Self-identity positively moderates the relationship between social presence and pro-environmental intentions.

**Hypothesis 5b (H5b):** Self-identity negatively moderates the relationship between trust and pro-environmental intentions.

The proposed conceptual framework integrates key constructs from the CASA paradigm, source attractiveness and credibility models, and environmental self-identity theory to explain how AI-powered VIs promote pro-environmental intentions among social media users. Specifically, social



**Figure 1.** Conceptual framework.

Low-order constructs (anthropomorphism, warmth, competence) and source credibility dimensions (attractiveness, homophily, authenticity, expertise) are posited to positively influence users' perceptions of social presence and trust. In turn, both social presence and trust are hypothesized to increase followers' pro-environmental intentions. Additionally, environmental self-identity is included as a moderating variable that strengthens the relationship between social presence and pro-environmental intentions, while weakening the influence of trust on these intentions. Figure 1 illustrates these hypothesized relationships and the overall research model.

## 4. Methodology

### 4.1. Data collection

All the participants were recruited using a panel service provided by a Chinese marketing research agency ([www.wjx.cn](http://www.wjx.cn)), and participants were selected using random sampling. The agency's online panel encompasses over 300 million Chinese consumers, ensuring a representative cross-section of the population. Ethical approval was obtained from the author's institution. We focused on Chinese customers owing to the prominent role of China's virtual influencer market and its critical imperative in tackling environmental issues (Khan et al., 2022). Forecasts indicate that China's virtual influencer market is expected to exceed USD 2,500 million by 2030 (D'Souza & Singh, 2024). Therefore, Chinese respondents represent a crucial and compelling study sample for analyzing the effects of VI traits on individuals' behaviors. Before conducting the study, the minimum sample size was estimated using the G\*Power 3.1 software (Faul et al., 2009). Using a significance level of 5%, a power of 95%, and an estimated medium effect size of 0.15, a minimum of 184 respondents were recruited.

To verify the suitability of prospective respondents, we implemented a pre-screening process to confirm that participants had prior exposure to VIs on social media and had encountered pro-environmental content shared by these VIs. At the beginning of the survey, participants were presented with a clear definition of virtual influencers, described as computer-generated digital personas that resemble humans and operate as content creators or brand endorsers on social media platforms. This ensured a shared understanding of the concept across participants. Respondents were then instructed to reflect on and answer questions based on their most recent experience engaging with sustainability-related content shared by a VI they had seen online. A total of 603 valid responses were collected. Table 1 provides an overview of the respondents' characteristics. Among those surveyed, 41% were male and 59% were female. The vast majority (79%) held a bachelor's degree, and 74% stated that they followed at least one VI.

**Table 1.** Profile of respondents' demographics.

Demographic variables	Category	Frequency (N = 603)	%
Gender	Male	249	41
	Female	354	59
Age	<18	3	0
	18–25	138	23
	26–30	204	34
	31–40	222	37
	41–50	25	4
	51–60	9	1
	>60	2	0
Education level	Below secondary	2	0
	Secondary	25	4
	Diploma or associate degree	49	8
	Bachelor's degree	478	79
	Master's degree or higher	49	8
No. of virtual influencers following	None	159	26
	1–2	301	50
	3–5	132	22
	6–10	7	1
	>10	4	1

#### 4.2. Measures

All measurement items were adapted from prior virtual influencer research, with slight adaptations for the pro-environmental context. Appendix A presents the scales and measurement items used in the questionnaire. Anthropomorphism (Bartneck et al., 2009) was measured using three items. Attractiveness was measured using three items based on Ohanian (1990). Authenticity was measured using three items as adopted from Choi and Lee (2013). Competence was measured using four items as adopted from prior social media studies by Ohanian (1990) and Teng et al. (2014). Environmental self-identity (van der Werff et al., 2013a) was measured using three items. Expertise (Kim, 2019) was measured using three items. Homophily and trust, as adopted from Kim and Kim (2021), were measured using three and four items, respectively. Pro-environmental behavior, as adopted from the scales used by Ajzen (1991) and Wan et al. (2024), was measured using three items. Social presence was measured using five items based on a chatbot study by Konya-Baumbach et al. (2023). Warmth (Kim et al., 2019) was measured by four items. All variables except anthropomorphism were measured using a seven-point Likert scale (1 = strongly disagree, 7 = strongly agree). Anthropomorphism was measured using a seven-point semantic scale with bipolar adjectives. Given that the survey was conducted in China and all items were initially developed in English, we employed a forward-backward translation method (Brislin, 1976) to ensure translation accuracy. A panel of four experts—three marketing professors and one research specialist—evaluated the items to determine their clarity and relevance in reflecting the constructs being measured.

#### 4.3. Data analysis

Demographic profiling and common method bias analyses were performed using SPSS (version 29). The proposed model was examined using SmartPLS 4. A disjoint dual-stage approach was employed to investigate the reflective-formative type of the higher-order construct (Sarstedt et al., 2019). First, the measurement model was evaluated to examine whether the indicator loadings exceeded the threshold of 0.708, AVE exceeded 0.5, and the Cronbach's alpha and composite reliability indicators were between 0.60 (for exploratory research) and 0.95 to confirm a good representation of internal consistency reliability and convergent validity (Hair et al., 2019, 2020). Second, discriminant validity was evaluated according to guidelines adopted from Hair et al. (2019) by reviewing whether the HTMT ratio was significantly lower than the threshold value of 0.85. Third, a disjoint two-stage approach (Sarstedt et al., 2019) was employed to assess the two higher-order constructs (HOCs) of social cues and source credibility. Upon validating the measurement model, all lower-order constructs (LOCs) were converted to latent variables and used to test the convergent validity of the HOCs using redundancy analysis. Finally, model fit and structural model assessments were conducted to examine the hypotheses (Hair et al., 2019).

## 5. Results

### 5.1. Common method bias

Although this study design included a cross-sectional survey, we used two post-hoc tests to examine the potential occurrence of common method variance when responses exhibited systematic variation due to a consistent scaling approach to measures derived from a single data source (Fuller et al., 2016). Following Kock (2020), we conducted a factor-based PLS-SEM implementation of Harman's single-factor test. The full collinearity test presented in Table 2 shows that the variance inflation factor (VIF) values of all constructs were between 1.371 and 2.335. The highest full-collinearity variance inflation was less than the threshold of 3.33, suggesting that no common method bias exists. Moreover, Harman's one-factor test, conducted with all study variables using SPSS, revealed that the variance explained by the first factor was 34.501%, confirming the absence of common method bias, as the first factor accounted for less than 50% of the variance among the variables.

### 5.2. Measurement model

The validity and reliability of the measurement model were assessed as described by Hair et al. (2019), with results summarized in Table 2. Indicator reliability was confirmed as all reflective indicator loadings exceeded 0.708 except for item AUT3, which was reasonably close at 0.697. Because AUT1 and AUT2 both had high loading scores to complement the AVE and composite reliability values, the loading of AUT3 was considered adequate for inclusion (Fornell & Larcker, 1981). Internal consistency reliability was achieved, as Cronbach's alpha and the composite reliability values of all constructs were within the range of 0.70 and 0.90 (Hulland, 1999). Although Cronbach's alpha for authenticity was less than 0.70, its value of 0.60 is considered acceptable in exploratory research (Hair et al., 2019, p. 8). The AVE of all constructs was significant (i.e., greater than 0.50), indicating good convergent validity (Fornell & Larcker, 1981). Discriminant validity was assessed using the HTMT ratio (Henseler et al., 2015). The HTMT values of all constructs were lower than the threshold of 0.90, confirming discriminant validity. Table 3 summarizes the HTMT matrices of the constructs.

### 5.3. Higher-order constructs

After validating the measurement model and LOCs, the reflectively measured LOCs were transformed into latent variables for the assessment of HOCs using a disjoint two-stage approach (Sarstedt et al., 2019). A redundancy analysis using a global single item found that the path coefficients of social cues (0.753) and source credibility (0.711) exceeded the 0.70 threshold (Hair et al., 2019), confirming the convergent validity of all HOCs. The results of the HOC assessment are summarized in Table 4. As seen from the table, the VIF values for all LOCs were below 3, indicating no multicollinearity issues (Becker et al., 2015). Moreover, the outer weights of all LOCs were statistically significant, validating the higher-order formative constructs of social cues and source credibility. Thus, HOC validity was established as all criteria listed in Table 4 were met.

### 5.4. Structural model and hypothesis testing

The structural model and hypotheses were assessed according to PLS-SEM reporting guidelines (Hair et al., 2019; 2020), with results shown in Table 5. First, the VIF of each set of predictor constructs fell between 0.2 and 5, indicating that the structural model had no collinearity problems. Second, bootstrapping with 10,000 subsamples revealed significant relationships between the hypothesized model constructs. As shown in Table 5, social cues were positively associated with social presence ( $\beta = 0.525$ ;  $p \leq 0.01$ ) and trust ( $\beta = 0.457$ ;  $p \leq 0.01$ ), supporting hypotheses H1a and H1b. Source credibility also had positive relationships with social presence ( $\beta = 0.268$ ;  $p \leq 0.01$ ) and trust ( $\beta = 0.322$ ;  $p \leq 0.01$ ), supporting hypotheses H2a and H2b. Moreover, social presence positively influenced pro-environmental behavior ( $\beta = 0.061$ ;  $p \leq 0.05$ ), supporting hypothesis H3. Trust also positively affected pro-environmental behavior ( $\beta = 0.121$ ;  $p \leq 0.01$ ), supporting hypothesis H4. Third, the  $R^2$  values of the endogenous constructs were evaluated to examine the explanatory power of the hypothesized model.

**Table 2.** Assessment of measurement model.

Construct	Item	Loadings	Full collinearity	Cronbach's alpha	Composite reliability	AVE
Authenticity	AUT1	0.779	1.711	0.600	0.788	0.555
	AUT2	0.754				
	AUT3	0.697				
Anthropomorphism	ANT1	0.861	1.521	0.855	0.912	0.775
	ANT2	0.894				
	ANT3	0.887				
Attractiveness	ATT1	0.917	1.444	0.898	0.936	0.831
	ATT2	0.904				
	ATT3	0.911				
Behavior	BEH1	0.849	1.371	0.728	0.845	0.647
	BEH2	0.722				
	BEH3	0.835				
Competence	COM1	0.727	2.335	0.776	0.856	0.599
	COM2	0.764				
	COM3	0.826				
Expertise	EXP1	0.827	2.112	0.748	0.856	0.665
	EXP2	0.803				
	EXP3	0.815				
Homophily	HOM1	0.858	2.010	0.770	0.867	0.685
	HOM2	0.854				
	HOM3	0.768				
Self-identity	ID1	0.759	1.446	0.775	0.870	0.691
	ID2	0.844				
	ID3	0.886				
Social presence	SPRE1	0.793	1.371	0.867	0.904	0.654
	SPRE2	0.756				
	SPRE3	0.844				
Trust	SPRE4	0.835	1.371	0.828	0.885	0.659
	SPRE5	0.812				
	TRUST1	0.768				
Warmth	TRUST2	0.826	1.715	0.848	0.898	0.687
	TRUST3	0.819				
	TRUST4	0.834				
WARM1	WARM1	0.819	1.715	0.848	0.898	0.687
	WARM2	0.831				
	WARM3	0.839				
	WARM4	0.825				

**Table 3.** Assessment of discriminant validity (HTMT ratio).

	1	2	3	4	5	6	7	8	9	10	11
1. Anthropomorphism											
2. Attractiveness	0.414										
3. Authenticity	0.464	0.445									
4. Behavior	0.224	0.328	0.530								
5. Competence	0.538	0.472	0.847	0.556							
6. Expertise	0.619	0.445	0.849	0.463	0.828						
7. Homophily	0.617	0.485	0.737	0.507	0.809	0.760					
8. Self-identity	0.255	0.317	0.543	0.696	0.524	0.565	0.631				
9. Social presence	0.741	0.529	0.602	0.330	0.621	0.666	0.745	0.388			
10. Trust	0.605	0.420	0.690	0.434	0.874	0.747	0.751	0.482	0.614		
11. Warmth	0.476	0.569	0.537	0.357	0.673	0.565	0.588	0.376	0.736	0.535	

The model explained 56.8% of the variance in social presence, 54.3% in trust, and 31.1% in pro-environmental behavior, reflecting moderate explanatory power. Fourth, apart from the relationships between social cues and social presence ( $f^2 = 0.245$ ) and trust ( $f^2 = 0.176$ ), all effect sizes  $f^2$  were smaller than 0.15, indicating that the exogenous constructs had small to medium effects on the

**Table 4.** Assessment of higher-order constructs.

HOC	LOC	Weights	t-Statistics	Outer loadings	VIF
Social cues	Anthropomorphism	0.466	11.811**	0.798	1.304
	Warmth	0.312	7.875**	0.757	1.501
	Competence	0.466	11.511**	0.842	1.554
Source credibility	Attractiveness	0.227	5.138**	0.619	1.253
	Homophily	0.520	11.220**	0.892	1.689
	Authenticity	0.132	2.591*	0.677	1.597
	Expertise	0.370	6.081**	0.828	1.809

Note: \* $p < 0.05$ ; \*\* $p < 0.001$ .

**Table 5.** Hypothesis testing.

	Path coefficients	t-Statistics	p-Values	VIF
Hypothesis				
H1a: Social cues $\rightarrow$ Social presence	0.525	9.695**	0.000	2.601
H1b: Social cues $\rightarrow$ Trust	0.457	8.715**	0.000	2.601
H2a: Source credibility $\rightarrow$ Social presence	0.268	4.641**	0.000	2.601
H2b: Source credibility $\rightarrow$ Trust	0.322	6.303**	0.000	2.601
H3: Social presence $\rightarrow$ Behavior	0.061	1.625*	0.050	1.440
H4: Trust $\rightarrow$ Behavior	0.121	2.739**	0.003	1.604
H5a: Self-identity $\times$ Social presence $\rightarrow$ Behavior	0.086	2.033*	0.021	1.483
H5b: Self-identity $\times$ Trust $\rightarrow$ Behavior	-0.089	2.201*	0.014	1.553
Control variable				
Age $\rightarrow$ Behavior	0.006	0.178	0.429	
Education $\rightarrow$ Behavior	-0.039	1.347	0.089	
Gender $\rightarrow$ Behavior	0.018	0.264	0.396	
No. of VIs following $\rightarrow$ Behavior	-0.023	0.584	0.280	

Note: \* $p \leq 0.05$ ; \*\* $p \leq 0.01$ .

endogenous variables. Fifth, the predictive accuracy of the path model was examined using the  $Q^2$  value calculated using PLS<sub>predict</sub> (Hair et al., 2019). All  $Q^2$  values exceeded zero ( $Q^2_{predict}$  social presence = 0.560;  $Q^2_{predict}$  trust = 0.537;  $Q^2_{predict}$  behavior = 0.289), suggesting that the model's exogenous constructs had predictive relevance for the endogenous construct. The prediction statistics were also examined following the guidelines set by Shmueli et al. (2019), as shown in Table 6. Because only one behavioral indicator (BEH3) in the PLS-SEM analysis exhibited higher prediction errors than LM\_RMSE, the hypothesized model demonstrated medium predictive power.

Four control variables, age, gender, education level, and the number of VIs followed, were included our structural model. These were selected based on prior research highlighting the potential influence of demographic characteristics (Jang & Yoh, 2020) and VI familiarity on users' attitudinal and behavioral responses (Jin & Viswanathan, 2025; Liu & Wang, 2025). However, the analysis showed that none of these control variables had a statistically significant effect on pro-environmental behavior (Table 5).

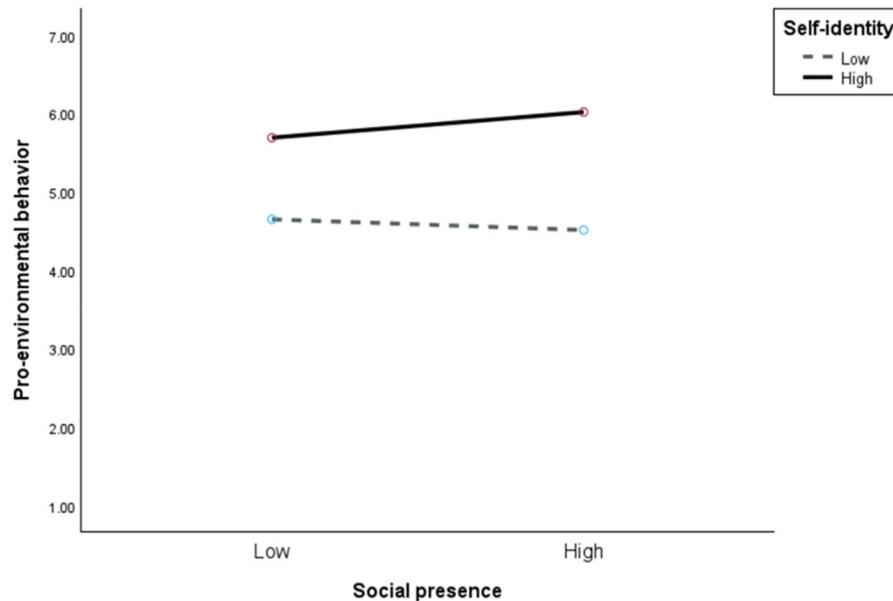
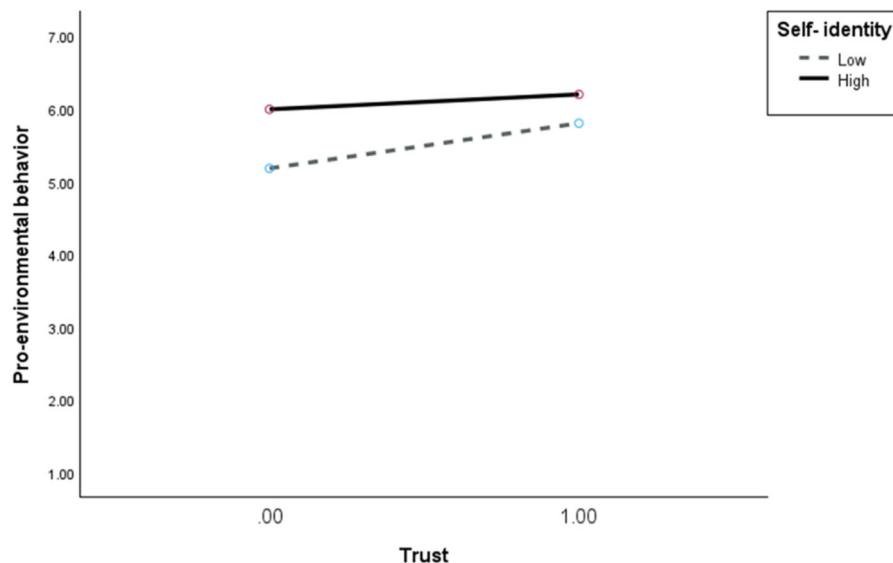
Additionally, the results shown in Table 5 indicate that environmental self-identity significantly moderates the relationship between social presence and behavior ( $\beta = 0.086$ ;  $p \leq 0.05$ ), as well as that between trust and behavior ( $\beta = -0.089$ ;  $p \leq 0.05$ ). The effect sizes  $f^2$  of the moderated paths were 0.009 (interaction of self-identity and social presence on behavior) and 0.010 (interaction of self-identity and trust on behavior), indicating that both moderation paths had medium effects (Kenny & Judd, 2019). Figures 2 and 3 show interaction plots of the moderation relationships. Figure 2 provides a graphical representation of the positive moderating effect of self-identity on the relationship between social presence and behavior. Figure 3 illustrates that self-identity negatively moderates the relationship between trust and behavior.

## 6. Discussion

The findings of this study provide convergent empirical evidence that social cues and source credibility significantly enhance the social presence and trust associated with VIs, thereby enhancing audience engagement in pro-environmental behaviors. Moreover, the results demonstrate that social cues are formatively measured by lower-order constructs – including anthropomorphism, warmth, and competence – according to the CASA paradigm (Liew & Tan, 2021). The source credibility of VIs is also a higher-

**Table 6.** Assessment of prediction statistics.

	$Q^2_{\text{predict}}$	PLS-SEM_rMSE	LM_rMSE	PLS-SEM_RMSE – LM_rMSE
BEH1	0.215	1.049	1.056	-0.007
BEH2	0.141	1.236	1.243	-0.007
BEH3	0.207	0.926	0.924	0.002

**Figure 2.** Interaction plots of self-identity and social presence on behavior.**Figure 3.** Interaction plots of self-identity and trust on behavior.

order construct comprising attractiveness, homophily, authenticity, and expertise as formative lower-order constructs (Filieri et al., 2023). Compared to earlier studies, our results suggest a broader behavioral influence beyond marketing contexts. For example, Franke et al. (2023) found that while users generally prefer human influencers, virtual influencers offer novelty that can enhance ad effectiveness. Similarly, Guo et al. (2025) reported a non-linear relationship between VI content and user engagement on TikTok, moderated by user interaction. Our study extends these findings by demonstrating how specific perceptual cues and identity factors can shape meaningful behavioral outcomes in the sustainability domain.

Furthermore, this study examined how environmental self-identity moderates the relationship between social presence and behavior, as well as that between trust and behavior. These findings suggest that for individuals with high environmental self-identity, social presence is a particularly important driver of pro-environmental behavior. In contrast, trust plays a diminished role, as individuals with strong self-identities may rely more on internalized values than on external validation. Notably, among the components of source credibility, homophily and expertise carried the highest weightings, while authenticity, although statistically significant, had the lowest. This indicates that followers who perceive VIs as similar to themselves or as knowledgeable may be more responsive to their messaging. Finally, none of the control variables (age, sex, education, or number of VIs currently followed) showed significant effects, indicating that pro-environmental intentions in this context are broadly consistent across demographic groups.

### **6.1. Theoretical implications**

This study provides significant contributions to existing literature. First, a theoretical framework was developed to examine the role of AI-powered VIs in encouraging pro-environmental behavior. Although VIs have gained considerable scholarly attention, few studies have examined how they align with social cues to be perceived as credible sources, or their impact on pro-environmental behavior. Recent studies have suggested that the effectiveness of VIs relies on social cues and psychological interactions (Arsenyan & Mirowska, 2021; Qu & Baek, 2024; Yoo et al., 2025). These interactions allow VIs to develop a sense of trust and social presence with social media users, enhancing the users' engagement in pro-environmental behaviors. Therefore, it is important to examine the psychological mechanisms of social cues and source credibility to encourage pro-environmental behavior. To address this gap, we integrated the CASA paradigm with source attractiveness and source credibility models in order to provide comprehensive insights into how VIs utilize social cues and creditability to establish trust and social presence with users, fostering pro-environmental behaviors.

Second, this study contributes to the CASA paradigm, source attractiveness, and source credibility models by exploring how environmental self-identity moderates the relationships between constructs in our research model. We analyzed how environmental self-identity influences the connections between social presence and pro-environmental behavior, as well as those between trust and pro-environmental behavior. This moderating effect of individual identity has been largely overlooked in the existing literature on both CASA and source credibility theory. The findings of this study reveal that although social presence positively influences pro-environmental behavior across VI followers, its impact is particularly effective for individuals with high levels of environmental self-identity. This is because the psychological connection fostered by VIs resonates deeply with individuals' pre-existing environmental values, motivating these individuals to translate this connection into pro-environmental actions (Ni et al., 2023). However, trust plays a more significant role in motivating pro-environmental behavior for users with low levels of environmental self-identity. This is because these individuals do not have a strong commitment to pro-environmental actions, and therefore rely more on external guidance (Gil-Giménez et al., 2021). Overall, this study contributes to the literature by offering deeper insights into the roles of social cues, source credibility, and psychological mechanisms in encouraging pro-environmental behavior among social media users.

### **6.2. Practical implications**

This study offers practical insights for VI developers and marketers regarding the psychological mechanisms through which VIs influence pro-environmental intentions in followers. According to our results, social cues – including anthropomorphism, warmth, and competence – and source credibility factors – such as attractiveness, homophily, and authenticity – enable VIs to foster social presence and establish trust, respectively, serving as essential factors in motivating pro-environmental behaviors. In terms of social cues, developers should design VIs to appear more anthropomorphic, conscious, and life-like. Additionally, warm and friendly VIs, which can provide reliable information and expertise on specific topics, are more likely to establish social connections

and build trust with followers (i.e., warmth and competence). For example, Lil Miquela is a human-like approachable virtual influencer that effectively uses social cues to enhance social presence with her more than three million Instagram followers, building trust by providing timely information on the fashion industry (Ahn et al., 2022).

Regarding source credibility, developers should ensure that VIs appear attractive and meet the visual expectations of target users. Additionally, VIs should be designed to reflect the interests, enthusiasm, and values (i.e., homophily) of their audience, as well as maintain reliability and authenticity to followers. When social media users perceive that a VI can match their expectations, values, and lifestyles, they are more likely to trust that VI's advice and recommendations, thereby fostering emotional engagement through social presence. For example, Imma, a Japanese VI, demonstrates key aspects of source credibility through her attractive appearance, relatable personality, and alignment with her followers' values, which enhance the acceptance of her environmental messages (Hoai Lan et al., 2025; Yang et al., 2023).

This study also examines the moderating role of environmental self-identity. Social media marketers should design targeted messages for audiences with different levels of environmental self-identity. For people with high levels of environmental self-identity, practitioners should enhance the social presence of VIs by designing meaningful pro-environmental campaigns, such as zero-waste challenges or carbon footprint reduction weeks, while leveraging social cues, such as warmth and relatability, to foster psychological connections and motivate active pro-environmental engagement (Gerrath et al., 2024; Kim & Park, 2023). For example, VIs can share personal stories or commitments that showcase their own "eco-journeys," expressing empathy for common challenges in adopting sustainable habits, or engaging followers with interactive features like Q & A and polls. VIs should focus on enhancing authenticity and expertise by providing clear, practical, and easily actionable advice tailored to everyday lifestyles. This could include short tutorial videos on simple eco-friendly swaps, fact-based content that highlights the tangible benefits of sustainable choices, or collaborations with credible experts to reinforce trustworthiness. For instance, a VI might demonstrate how to reduce energy use at home with straightforward steps or share endorsements from environmental scientists to build credibility and motivate behavior change. **Table 7** summarizes the key factors in the research model and provides design recommendations that can help VI developers and marketers enhance the effectiveness of virtual influencers in promoting pro-environmental behavior.

### 6.3. Study limitations

There are certain limitations to this study that should be considered in subsequent research. First, the focus on Chinese social media users may limit the generalizability of the findings. Cultural values, such as individualism versus collectivism, can influence how users perceive and engage with VIs, suggesting that responses to social and credibility cues might differ across cultural contexts (Rizzo et al., 2025). Therefore, future research should investigate cross-cultural comparisons to determine the applicability of these findings in diverse settings. Furthermore, we collected cross-sectional data, which may limit the ability to examine users' continuance of pro-environmental behaviors. Expanding the scope to include other cities and countries, as well as integrating cultural variables, could provide a more

**Table 7.** Summary of key practical guidelines for designing effective virtual influencers for encouraging pro-environmental behaviors.

Key factor	Practical guidelines
Social cues (anthropomorphism, warmth, competence)	<ul style="list-style-type: none"> <li>Design VIs to appear human-like, warm, and competent.</li> <li>Use friendly and approachable personas.</li> <li>Provide reliable and expert information.</li> </ul>
Source credibility (Attractiveness, homophily, authenticity, expertise)	<ul style="list-style-type: none"> <li>Ensure VIs match visual expectations of target users.</li> <li>Reflect audience's values, interests, and lifestyles.</li> <li>Maintain authenticity and reliability to build trust.</li> </ul>
Environmental self-identity	<ul style="list-style-type: none"> <li>For high environmental self-identity audiences: use meaningful campaigns (e.g., zero-waste challenges) emphasizing warmth and relatability.</li> <li>For low self-identity audiences: enhance VI authenticity and expertise by delivering clear, practical, and relatable advice tailored to everyday habits, supported by credible information and expert endorsements.</li> </ul>

comprehensive understanding of VIs' effectiveness. Adopting longitudinal designs would enable examination of the long-term impact of social cues and source credibility on pro-environmental behavior, which future studies should consider.

## 7. Conclusions

In this study, we integrated the CASA paradigm with the source attractiveness and source credibility models to interpret the psychological mechanisms through which VIs influence followers' pro-environmental intentions. Furthermore, we examined the moderating role of environmental self-identity on the relationship between social presence and pro-environmental intention, as well as that between trust and pro-environmental intention. Our findings show that social cues (anthropomorphism, warmth, and competence) and source credibility (attractiveness, homophily, authenticity, and expertise) positively influence social presence and trust, which in turn influence pro-environmental intention. These relationships are moderated by environmental self-identity. Overall, this study advances our understanding of how VIs can engage social media users in pro-environmental behaviors by drawing on psychological mechanisms such as social cues, source credibility, and environmental self-identity.

## Author contributions

CRedit: **Calvin Wan**: Conceptualization, Data curation, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing; **Daisy Lee**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing; **Peggy M. L. Ng**: Conceptualization, Investigation, Writing – original draft, Writing – review & editing; **Tiffany Cheng Han Leung**: Writing – original draft, Writing – review & editing.

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## Appendix A

**Table A1.** Scales and measurement items.

Scales	Items
Anthropomorphism (Bartneck et al., 2009)	The virtual influencer is ... 1. Machine-like /human-like 2. Unconscious /conscious 3. Artificial /life-like
Attractiveness (Ohanian, 1990)	1. The virtual influencer is pretty. 2. The virtual influencer is physically attractive. 3. The virtual influencer is good-looking.
Authenticity (Choi & Lee, 2013)	The virtual influencer is likely to ... 1. Provide differential content based on his/her expertise. 2. Strive for his/her expertise with the help from his/her organization/agency. 3. Post content in a consistent manner.
Competence (Ohanian, 1990; Teng et al., 2014)	1. The virtual influencer is an expert on the topic. 2. I trust the information provided by the virtual influencer. 3. The virtual influencer is reliable. 4. The virtual influencer shares truthful experiences.
Environmental self-identity (van der Werff et al., 2013a)	1. Acting environmentally friendly is an important part of who I am. 2. I am the type of person who acts environmentally friendly. 3. I see myself as an environmentally friendly person.
Expertise (Kim, 2019)	1. The virtual influencer is knowledgeable about environmental protection. 2. The virtual influencer is knowledgeable about activities that address environmental issues. 3. The virtual influencer could explain the environmental activities when asked.
Homophily (Kim & Kim, 2021)	The virtual influencer has similar ... to me 1. Interests 2. Enthusiasm 3. Values
Pro-environmental behavior (Ajzen, 1991; Wan et al., 2014)	1. I intend to follow the virtual influencer's suggestions to adopt more environmentally friendly habits. 2. I plan to avoid less eco-friendly choices in my daily life as recommended by the virtual influencer. 3. I will prioritize sustainable actions as encouraged by the virtual influencer in the future.
Social Presence (Konya-Baumbach et al., 2023)	Regarding the virtual influencer, there is a sense of ... 1. Human contact. 2. Personalness. 3. Sociability. 4. Human warmth. 5. Human sensitivity.
Trust (Kim & Kim, 2021)	1. The virtual influencer can be relied upon on his (her) content. 2. I believe what this virtual influencer says and that he/she would not try to take advantage of the followers. 3. The virtual influencer is straightforward and honest even though his/her self-interests are involved. 4. The virtual influencer would not tell a lie even if he/she could gain from it.
Warmth (Kim et al., 2019)	The virtual influencer seems to be ... 1. Warm. 2. Kind. 3. Friendly. 4. Sincere.