Journal of Cleaner Production 405 (2023) 136874

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

The role of climate literacy in individual response to climate change: evidence from China

Wu-Lin Pan [a,b], Ruguo Fan [a], Wei Pan [c,*], Xinyu Ma [a], Cheng Hu [a], Piao Fu [a], Jingyi Su [d]

[a] School of Economics and Management, Wuhan University, Wuhan, 430072, China
[b] Bartlett School of Sustainable Construction, University College London, London, WC1E 7HB, UK
[c] School of Applied Economics, Renmin University of China, Beijing, 100872, China
[d] School of Information Management, Wuhan University, Wuhan, 430072, China

ARTICLE INFO

Handling Editor: Giovanni Baiocchi

ABSTRACT

As a basic tool for understanding and making informed decisions about global warming, climate literacy could potentially affect the whole process from individual awareness to public engagement with global climate change. We conducted a nationwide online survey ($N = 3067$) to assess climate literacy in China and investigate its role in climate change concern and climate policy support. Respondents in our sample were generally well informed about the cause and public engagement dimensions of climate literacy, while demonstrated polarized performance in regard to the consequences of climate change. Climate literacy is a stronger predictor of climate change concern and policy support than other variables such as demographics, experience, and values and can largely enhance the effects of media coverage through the mediation effect. Education and media coverage are found to be significantly associated with climate literacy, while climate experience has little to no effect on climate literacy. Our results somewhat undermine the central role of climate change concern in climate communications and public engagement. Instead, enhancing public climate literacy by disseminating scientific and result-based information from reliable institutions seems to be a more promising path in China.

1. Introduction

Individual responses to climate change have not only direct and indirect impacts on human efforts to address global warming but also multiple implications for sustainable human development and well-being (Burke et al., 2018; UN). The process that shifts people's perception of global warming toward taking mitigation or adaptative actions may involve various common determinants, such as socioeconomic status (SES), psychological and cognitive factors, information and experience, worldview and culture, and other regional and country-specific determinants (Arıkan and Günay, 2021; Wang and Zhou, 2020). Climate literacy, for example, is not only a pivotal predictor of some major outcome variables (e.g., adaptation behaviors) along the awareness-action chain but also exerts a significant indirect effect on or has meaningful interactions with them (Chen et al., 2020; Hart et al., 2015; Schuldt et al., 2020).

As a part of science literacy, climate literacy provides tools and a shared basis for understanding global climate change and helps people make informed decisions and create solutions (USGCRP, 2009). Climate literacy is a vital element for persons dealing with climate change and one of the few yet most practical and effective methods; it has both objective (knowledge as a subscale) and subjective (close to climate change perception) implications and could be considered a combination of science, education, and policy. Previous works have demonstrated the relevance of climate literacy for risk perception, climate change concern, pro-environmental behavior, climate policy acceptance, etc., most of which have positive effects. However, some contrary results have also been reported; for example (Shi et al., 2015), has identified a negative relationship between result-based knowledge and behavior intention. In addition, the influence of climate literacy on mitigation or adaptation behavior may be indirect and could be mediated by other variables, such as concern or efficacy (Aruta, 2022; Stevenson et al., 2018). These inconsistences could be a reflection of the complex impact of climate literacy on people's responses to climate change, to which insufficient work has been devoted.

Due to the complex and multidisciplinary nature of climate change, the connotation of climate literacy could have a wide coverage, extending from perceived general knowledge to biogeophysical science

* Corresponding author.
E-mail address: mrpanwei2000@163.com (W. Pan).

https://doi.org/10.1016/j.jclepro.2023.136874
Received 31 January 2023; Received in revised form 12 March 2023; Accepted 19 March 2023
Available online 22 March 2023

knowledge and even the social sciences, particularly those on human engagement and solutions. The definition and measurement of climate literacy itself is a challenge and can generate different results and model implications (Shi et al., 2016; Stoutenborough and Vedlitz, 2014). The influences of cultural identities and confounding climate science comprehension with affection towards global warming could also be potential problems (Kahan, 2015). Moreover, recent studies have been mostly confined to the field of science education and focus on the knowledge subdimension; thus analysis of its predictors has been very limited. All these gaps hinder a better understanding of the role of climate literacy in people's responses to climate change.

People's reactions to climate change could be regarded as a chain extending from awareness to final response, where the concern about climate change is at a central link. Many countries and regions have reported a considerably high level of climate change concern, although this fluctuates during some key events, such as COVID-19 or an economic recession (Capstick et al., 2015; Drews et al., 2022; Lee et al., 2015). A high level of concern is usually accompanied by strong risk perception and can lead to a greater psychological response, willingness to act, support for climate policy and public engagement level (Arıkan and Günay, 2021). Meanwhile, climate concern could exert more impacts through the mediating or moderating roles of the interlinks of these outcome variables (Milfont, 2012). Increasing concern has been a main strategy in climate change communication and public engagement under the prerequisite that greater concern leads to more positive responses to climate change. The extant evidence is generally in line with this premise when the outcome variables are pro-environmental behavior or willingness to act (Jakučionytė-Skodienė and Liobikienė, 2022). However, in regard to support for climate policies, these results are inconsistent and inconclusive; for example, decreased climate concern could coexist with increased climate policy support (Drews et al., 2022). Furthermore, relevant research about the public support for climate policy has seldom controlled for climate literacy or considered its indirect role; thus, further examination is needed.

A very limited number of peer-viewed papers have assessed public climate literacy in China, let alone investigated its role in climate change concern and climate policy support. (Wu and Otsuka, 2021) has conducted an initial investigation of climate literacy among high school students in Shanghai. In addition, a few other works have focused on climate change knowledge and its implications (Shi et al., 2016; Yang et al., 2018). Although these preliminary works have provided some important insights, a more comprehensive understanding could be reached via the expansion of a student sample to the general population. Thus, the main contribution of this work is that we update the understanding of public climate literacy in China by conducting a large national survey and investigating its determinants and the role it plays in individual responses to climate change.

The key research questions of this research include: (1) what is the level of climate literacy in Chinese general population? (2) how to measure climate literacy in China context? and (3)what is the role of climate literacy to some key variables related to individual response to climate change, such as climate change concern and the support for climate policy? Thus, we conducted a large national survey that covers almost all its provinces to assess climate literacy in China for the first time. We first compared 5 one-dimensional measurements as well as the subdimension constructs of climate literacy to determine the suitable instrument for measuring climate literacy in the East Asian environment. Then, the determinants of climate literacy and its subscales were discussed. Finally, the effect of climate literacy on climate change concern and support for climate policy was analyzed while controlling for, among others, self-reported climate experiences, value orientations and media factors.

2. Literature review

2.1. Climate literacy

2.1.1. Definition and evolvement of climate literacy

Climate literacy, also known as climate science literacy or climate change literacy, has emerged in the literature during this century and is connected with or a subdimension of science literacy (Azevedo and Marques, 2017; Niepold et al., 2008). Perhaps the most important reference for climate literacy is the Essential Principles of Climate Science produced by the U.S. Global Change Research Program (USGCRP), which defines the term as "an understanding of your influence on climate and climate's influence on you and society". This definition assumes that a climate-literate person understands climate systems, knows how to access credible information, communicates meaningfully, and makes informed decisions with respect to climate change (USGCRP, 2009). Following more research on this topic, this definition of climate literacy has been supplemented and adapted to more specific scenarios, e.g., complementing climate change solutions or drawing from the social sciences to enhance climate literacy (Cooper et al., 2019; Shwom et al., 2017). In this paper, we acknowledge the USGRP's definition and focus more on providing a suitable measurement for reference in the Chinese context.

Only a few studies on this topic have incorporated climate literacy into climate-related cognitive or behavioral research (Azevedo and Marques, 2017), usually adopting a simplified or subset of the concept. For example (Simpson et al., 2021), focuses on two aspects: the awareness of climate change and the understanding of its anthropogenic causes. (Shi et al., 2015) measures 4 scales of climate change knowledge in the German-speaking part of Switzerland.

There are overlaps between climate literacy and some perception-relevant concepts, e.g., climate-related attitudes, beliefs, and awareness (Clifford and Travis, 2018). For example (Stoutenborough and Vedlitz, 2014), measures two parallel scales, i.e., perceived and assessed knowledge. (Kuthe et al., 2020) even includes attitude and personal concern as subsets of climate change literacy. Although climate literacy may inherently have both objective and subjective implications and can even share some measuring items with climate change perception, it should be distinguished from them and clearly anchored in science and effective communication (Clifford and Travis, 2018). Different measures could have different model implications (Stoutenborough and Vedlitz, 2014), and the confusion among concepts and mixed uses of measurements may hinder understanding the importance of the different predictors of climate change literacy (Simpson et al., 2021).

2.1.2. Predictors of climate literacy

Well-studied factors influencing climate literacy have mainly been evaluated in the area of science education, including SES, access to science education, curriculum design, instructor, content and pedagogical approach (Anyanwu and Grange, 2017; Cooper et al., 2019; Klapp and Bouvier-Brown, 2021; Powers et al., 2021). Little attention has been directed toward the determinants of climate literacy in a general science framework. We were only able to retrieve relevant two peer-viewed papers, both concerning Africa. (Simpson et al., 2021) has found that education and mobility are the most important factors related to climate literacy and that perceived drought experiences and trends in precipitation are also important predictors. (Alenda, 2021) has revealed the central role of direct experiences in climate literacy.

Some studies have focused on the determinants of climate-related knowledge, a key domain in climate literacy. (Stoutenborough and Vedlitz, 2014) indicates that ecological values, confidence in climate science, and concern about climate change are related to assessed knowledge. (Lewandowsky et al., 2013) also confirms that a scientific consensus or perceived consensus causally contributes to the acceptance of science, whereas (Fernbach et al., 2019) shows that anticonsensus views can change the relationship between self-assessed and objective

knowledge in issues other than climate change. (Liu et al., 2014) has found that partisan affiliation, political ideology, and gender have strong impacts on climate change knowledge. (Hannibal and Vedlitz, 2018) has examined the influence of interpersonal discussion networks on concerns about climate change and has found that people discussing the climate have higher levels of perceived knowledge than assessed knowledge.

2.2. Individual response to climate change

2.2.1. Concern about climate change

Climate change concern is a key link in the chain from awareness to final action regarding climate change, as it directly relates to and may interact with some key variables, such as risk perception, willingness to act, and acceptance of policy measures. It can also have psychological impacts (McBride et al., 2021). Climate change concern has been found to consistently increase mitigation and adaptation behavior with only a few exceptions. It is usually a stronger predictor of behavioral change than other variables (Di Giusto et al., 2018). (Dienes, 2015) indicates that people with a higher level of concern are more likely to take mitigating actions as well as pay for them. However, the existing evidences for the impact of concern on climate policy support are inconclusive. On the one hand, climate concern and awareness can increase support for government climate policies (Douenne and Fabre, 2020; Hall et al., 2018). On the other hand, decreased climate concern and increased climate policy support have been identified in the same sample (Drews et al., 2022). Social identities, norms, and other sociocultural factors can affect public policy support for and shape people's opinions about climate policy, but these are less connected to climate concern (Van Boven and Sherman, 2021). Additionally, the two largest groups of respondents in (Crawley et al., 2020) tend to view climate change as a salience issue and are wary of climate policy, although they have a strong belief in climate change.

Many factors have been found to be associated with climate change concern, including socioeconomic, individual, psychological and cognitive factors in addition to some from a broader perspective, such as culture, climate experience, and media coverage as well as political factors (Driscoll, 2019; Maran and Begotti, 2021; Sambrook et al., 2021). Women have been consistently reported to have a greater concern about climate change than men (McCright, 2010), and this gender difference can be generally extended to other environmental beliefs and attitudes (Xiao and McCright, 2015). (Poortinga et al., 2019) indicates that values and political orientation are important predictors of climate change beliefs and concerns. However (Scruggs and Benegal, 2012), claims that economic conditions are more critical predictors of public concern than alternative factors such as partisan politicization, media coverage, and weather conditions. Climate change literacy is also thought to be an important determinant of the concern about climate change, although there is inconsistent evidence for this. (Stoutenborough and Vedlitz, 2014) has indicated that while people with greater assessed knowledge have higher levels of concern, those with high levels of perceived knowledge do not. However (Shi et al., 2016), has found that self-assessed knowledge is not related to concern, arguing that an objective measure of knowledge is more effective than a subjective measure in explaining climate change concern. On the other hand (Kahan et al., 2012), has found that science literacy is weakly and negatively related to the concern about climate change, which is moderated by cultural worldview.

2.2.2. Support for climate policy

Governments should play a leading role in the human response to climate change, and reducing the risks of global warming requires strong climate policies. Many factors contribute to public attitudes toward climate change policy. (Drews and Van den Bergh, 2016) has reviewed these factors, dividing them into three general categories: social-psychological factors, perceptions of climate policy and contextual factors. Generally, perceptions or subjective factors, such as concern about climate change, account for more variability in policy support. For example (Smith and Mayer, 2018), has found that trust and risk perceptions are positively associated with ameliorative behavior and policy support. (GOLDBERG et al., 2021) found that beliefs, risk perceptions, worries and the consequences of global warming are the most important predictors of climate policy support.

Climate policy support has also been thought to be connected to climate literacy. However (Rhodes et al., 2014), has found that knowledgeable and well-informed people may not necessarily be associated with greater policy support. A recent meta-analysis has identified 15 predictors of public opinion about climate-related taxes and laws, concluding that while values and climate literacy have weak relationships, demographic variables have only weak or close to no effects (Bergquist et al., 2022). The literature seems to indicate that climate literacy more commonly exerts an indirect impact on climate policy through mediation (Hannibal and Vedlitz, 2018) or is mediated by climate concern (Shi et al., 2015). As the findings on the relation between climate concern and policy support are inconsistent, further exploration of the role of climate literacy and climate concern in climate policy support is needed.

2.3. Research gaps

The main research gap identified from literature in that there is only one paper has studied students' climate literacy in Shanghai; and there are limited works investigated climate change knowledge in China, but they did not analyze the relationship of climate literacy and climate policy and the relevant mechanism. Besides, the measurement of climate literacy could potentially generate varying results and implications. Current measurements are mostly based on western countries, it is necessary to further check these items and develop a scale applicable to China content. Meanwhile, the research on the predictors of climate literacy remains insufficient; the two most relevant papers provide African content, where climate experience is the most prominent predictor (Alenda, 2021; Simpson et al., 2021). We would extend these works by examining more factors such as subjective perceptions and media coverage on global warming.

Finally, the role of climate literacy in people's responses to climate change has not been explicitly elaborated. Some studies have demonstrated that the role of climate literacy in the outcome variables could be insignificant, indirect, or even negative, which calls for further analysis, preferably in the Chinese context.

3. Method & data

3.1. The survey

We conducted an online survey in 29 provinces in China from February 4 to March 3, 2022. Two parallel surveys were launched simultaneously to prevent bias from a single survey provider. The first was administered by the commercial service Questionnaire Star (https://www.wjx.cn), a professional Chinese survey corporation that has users in over 346 cities in China and has collected over 14 billion questionnaires. The second survey involved snowball sampling among users of the most popular instant messaging and social media mobile app, WeChat; electronic red packets were offered for each valid response with a random reward (a narrow range near the average) to enhance the interest and participation in the survey. Respondents were randomly recruited without any criteria for a target population. To overcome potential survey fraud in online sampling, we established a very strict screening standard and process to identify valid responses. Specifically, three techniques, i.e., response time, long string and average string, and consistency in similar questions, were applied to detect careless responses (Curran, 2016). The specific parameters of these techniques were determined with the empirical results and statistics from 31

respondents in an *ad hoc* "trust sample" from our research group (according to the final standard, 3 respondents in the "trust sample" who reported slight carelessness were detected to have insufficient effort responses). In sum, 929 of the 1522 respondents provided by Questionnaire Star and 2138 of the 3865 from WeChat were combined, totalling 3067 valid responses for further analysis.

A total of 3067 eligible respondents in our sample were selected for analysis, consisting of 54.2% men ($n = 1662$) and 45.8% women ($n = 1405$), from 29 provinces of mainland China. Participants cover 6 age groups from under 17 to above 65, whereas 80.3% are between 18 and 34. The majority of respondents had received higher education, approximately 73% ($n = 2248$) had an educational level of university or college, and only 2.2% ($n = 67$) had just finished compulsory education or below. Note that the high college rate is mainly due to the nature of online survey, and we acknowledge its bias from the general education level. Nevertheless, the general Chinese peer college rate in recent years has reached nearly 50% (e.g., 15.94 million children were born in 2003, 10.01 million have been accepted into college in 2021). We strictly follow the data processing procedure without any manual screening, and we believe our sample is considerately representative of Chinese online attitude and cognition about climate change.

3.2. Measurement of climate change literacy

We included 30 items in total to measure climate literacy, the majority of which were adapted from previous research on the topic (Leiserowitz, 2020; Shi et al., 2015; USGCRP, 2009) and then contextualized to China. Most items include 3 options: "true", "false", and "don't know", and there are coded into binary data according to the right answers (1 = "correct"; 0 = "wrong" and "don't know", "don't know" is designed to prevent guesses from participants[9]). Three multiple-choice questions are also dichotomously coded (1 = right answer selected or wrong answer ignored, 0 = opposite to 1).

The items for climate literacy included 4 subscales: causes and consequences of climate change, physical (general) knowledge, human engagement (policy issues). Notably, departing from existing literature, we add some items concerning human engagement and solutions, such as some popular policy issues, e.g., the Paris Agreement and the carbon neutrality targets of China (P. Singh et al., 2019). We also stress scientific reasoning and competence (Liu et al., 2014), and thus include some "hard" questions to distinguish people with a higher level of climate literacy from the less literate ones as well as objective knowledge from perceived knowledge.

One major purpose of this work is to provide a one-dimensional construct for climate literacy. However, most measurement items are adapted from existing studies focused on the western world, and a proper instrument for China or East Asian environment remain unexplored. Thus, we constructed and compared 5 parallel one-dimensional instruments (Table S1). Scope 1 includes only two items about global warming and its anthropogenic causes, and Scope 2 is the recommended instrument in this work. Scopes 3, 4 and 5 are all synthesized from subdimensions. Scopes 3 and 4 differ in terms of consequence subscale, while Scope 5 consists of all 30 items. To determine which construct is better, different climate literacy constructs were regressed with the same independent variables, and we judge via the fit performance of each regression model. The rationale behind this is that we assume that the independent variables in our model are potentially important predictors (which were typically adapted from existing relevant literature) and have satisfactory explanatory power for climate literacy (Driscoll, 2019). Thus, a good fit (R^2) means that the corresponding construct is a satisfactory one. In addition, we also consider the detailed regression results and their practical implications, the scalability and reliability of the construct as supplementary criteria when determining the applicability of the constructs. This methodology may be subject to subjectivity, and a primary deficiency is that the assumptions may not hold, for example, some important determinants for climate literacy may have been omitted.

3.2.1. Scalability and reliability of scales

We used techniques, such as Mokken scale analysis and principal component analysis, to assist our construction of the measuring instrument. For dichotomous items, Mokken scale analysis is recommended to evaluate dimensionality and the internal structure (Shi et al., 2015). Mokken scale analysis is based on the assumption of double monotonicity (van Schuur, 2003). Specifically, people with more knowledge answer correctly no less than less literate people, and respondents can rightly answer rightly an easier question if they know the answer to a difficult question. In mokken analysis, scalability is represented by Loevinger's coefficient (H), and reliability is given by rho (ρ), which is similar to Cronbach's alpha. A scale is considered to have acceptable scalability if $H \geq 0.3$ and acceptable reliability if $\rho \geq 0.6$ (Shi et al., 2016).

However, climate literacy itself is a very broad notion that may hardly be scaled by a responsive latent variable, and the construct for climate literacy should then be formative instead of responsive. Specifically, due to the inclusion of some perception-related items, monotonicity in Mokken analysis may not hold, although "don't know" was added to reduce subjective influences. In addition, the one-dimensional constructs (Scope 3~5) are built on the weighted average of subscales, some of which may be not highly correlated with or even contradict each other. Thus, the Mokken analysis is not an exclusive standard in our work, some results from sub-scales with unacceptable (slightly) scalability and reliability are also reported (but we interpreted the results with caution and made further relevant discussions).

3.3. Measures of other variables

In addition to demographics (gender, age, education, income), we introduced 3 categories of factors as the predictors of climate literacy: subjective perception, climate experience and media exposure. We use three single items to gauge different levels of subjective feelings about climate change, i.e., awareness/belief (Q5), perception (Q9) and psychological distance from climate change (Q10). In addition, respondents were asked to report a count of their experiences of extreme weather events in the past 2 years (experience 1, Q11) and floods in the past 5 years (experience 2, Q12, city floods have been frequently reported and highly concerning weather events in recent years). For media coverage, we used a multiple-choice question (Q13) about their information sources of climate change, and a selected option was scored 1. Seven options and an open option called "others" were classified into 3 categories. Offline media coverage included "Someone else, e.g., a friend, family member, work/class-mate"; "Traditional offline media, e.g., a book, magazine, newspaper"; and others. Online media coverage consisted of "Online news (app, website etc.)"; "Video sharing website, live streaming"; and "Social media, e.g., WeChat, Weibo". Finally, "Academic source (journal, website, post etc.)" and "Popular science channel" represented scientific media coverage. Notably, only 34 of the 3067 respondents selected "others", and only 7 of these specified an answer, such as "weather forecast", "documentary", or "reading material". Therefore, we simply classified this selection as offline media.

Climate literacy plays a pivotal role in shaping people's opinions about climate change and their support for climate policy. The measurement for concern about climate change is adapted from (Spence et al., 2012) and consists of three items that form a reliable scale (Q6-Q8, Cronbach's $\alpha = 0.819$). Two single items regarding policy priority (Q15) and acceptance of policy cost (Q16) were used to evaluate respondents' attitude toward climate policy (Ge and Lin, 2021). Value orientations (Q17-Q19) and trust (Q14) were introduced as covariates in the regression model to represent concern about climate change and policy acceptance. Value orientations consist of three subscales, i.e., egoism (Q17, $\alpha = 0.652$), altruism (Q18, $\alpha = 0.813$), and biospherism (Q19, $\alpha = 0.840$) (Shi et al., 2016; Stern et al., 1999). Respondents were asked to reveal their trust in the information provided by the authority, experts

(e.g., from universities and research institutions) and public media respectively. The trust in authority and experts were constructed to one dimension measure (α = 0.67) representing institutional trust.

4. Results

4.1. Climate literacy in China

Our sample of the Chinese public demonstrated a considerably high level of climate literacy across all scopes of one-dimensional measurements (Shi et al., 2016; Simpson et al., 2021). A total of 72.8% and 81.1% of our sample were well informed of global warming and its anthropogenic causes, respectively (Scope 1, Fig. 1). In an instrument with medium scalability ($H = 0.37$) and good reliability ($\rho = 0.750$), 73.2% of respondents correctly answered 6 out of 7 items, and only approximately 2.8% failed to obtain a score of no more than 2 (Scope 2, $M = 5.86$, $SD = 1.60$). For all 30 questions related to climate literacy, 47.4% of respondents received a score of 20 or above, while those who correctly answered no more than 12 items accounted for only 4.3% ($M = 19.15$, $SD = 3.55$). In addition, 4 items were answered correctly by over 85% of our respondents, with the highest rate at 90.7% (*"climate change will lead to an overall rise in sea level due to the melting of polar ice"*); another 4 items had a relatively low correct response rate (less than 30%, the lowest rate at only 14.9% (*"climate varies over space and time through man-made instead of natural processes"*)).

Scope 1 is a basic instrument for climate literacy assessment and consists of only two items[24]. As shown in Fig. 1, women have an overall better understanding of these two questions, which are more or less close to perception. The teenagers in our sample are significantly less knowledgeable than their adult counterparts, while senior citizens display a very high level of belief in climate change—e.g., all 20 people above 55 answered Item 6 correctly. Additionally, the 25–34 age group ($N = 1347$) shows a higher correct rate than its near group. Age also seems to be positively related to S1: while respondents who have only received compulsory education perform quite poorly on both questions and the correct answer rate for each question increases with education level, those with the highest education level demonstrate a slight decrease in the correct answer rate compared to those with a college level education, probably because the former are accustomed to thinking independently and are more skeptical.

Fig. 2 shows 3 of the subscales with acceptable scalability and reliability that are basic for scopes 3 and 4. It seems that the Chinese public is quite informed of the causes and human engagement dimensions of climate literacy, as many items were answered with a high correct rate, over 80%, probably because related information, e.g., on carbon emissions in industrial production and the role of international corporations in mitigation, are widely covered in the media. On the other hand, the respondents in our sample demonstrated certain misconceptions

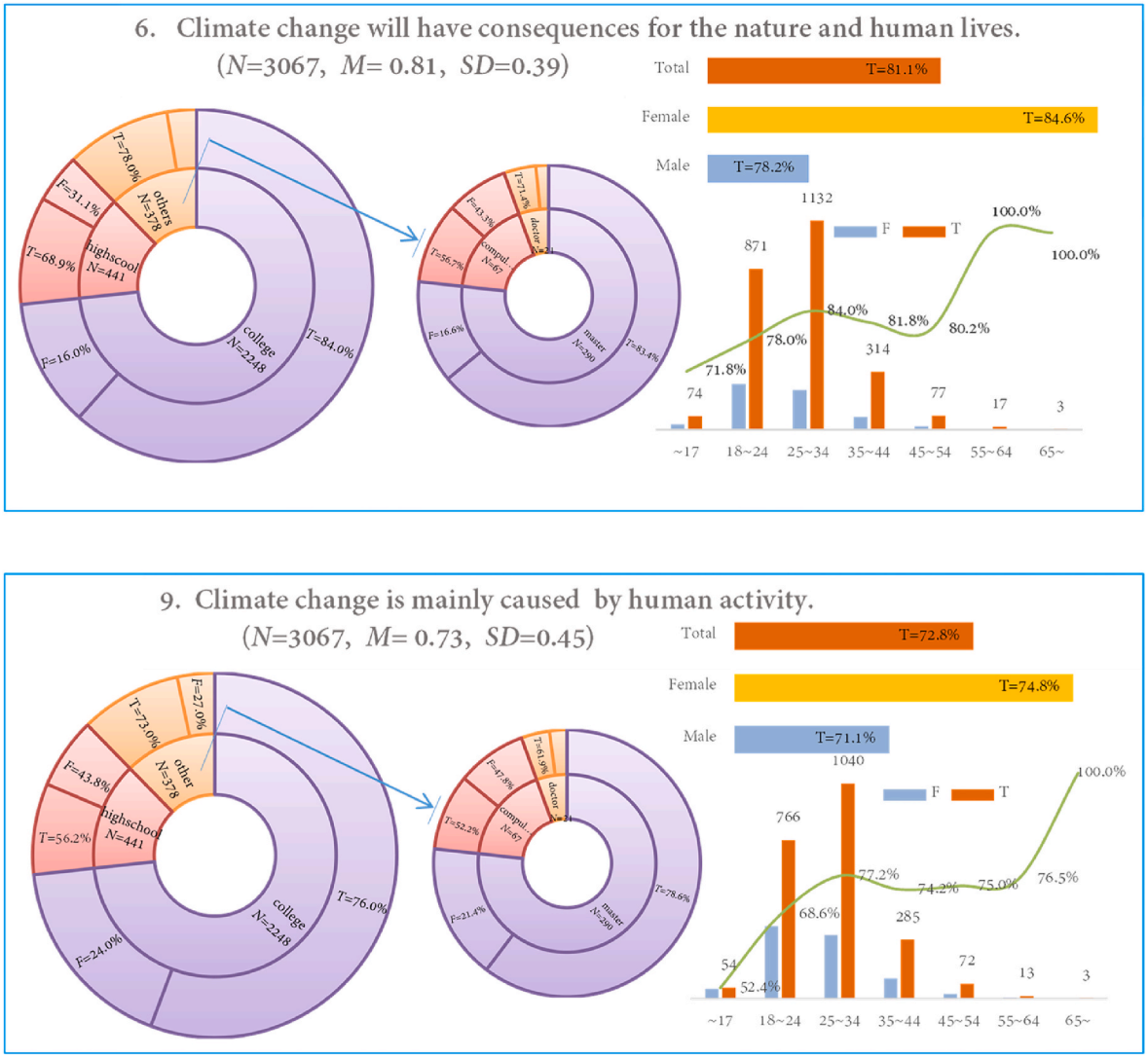

Fig. 1. Two basic items for literacy measurement (Scope 1).

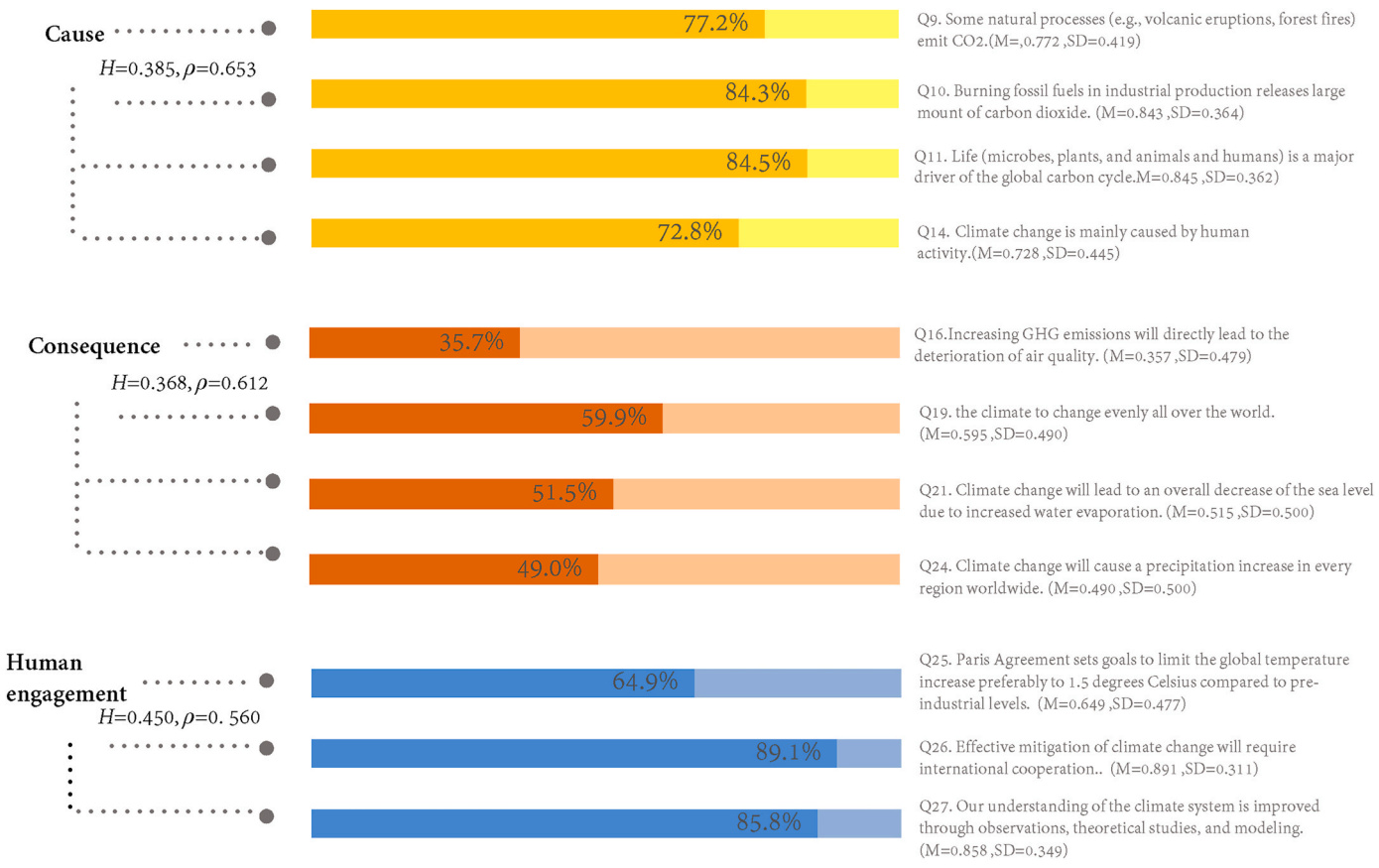

Fig. 2. Constructs for three presentative sub-dimensions of climate literacy.

regarding "green belief", and they tended to struggle with consequence-related questions; only approximately half our sample knew the right answers to these (Fleming et al., 2021).

4.2. Measurements and predictors of climate literacy

We provided 5 scopes of one-dimensional measurement instruments for climate literacy and compared their differentiated implications and applicability. Table S2 compares the regression results with these constructs as the dependent variables. Across all these instruments, people with stronger climate-related beliefs and perceptions tend to be more climate literate, while those who are psychologically distant from climate change are less so. Education has been found to significantly increase respondents' climate literacy, as does online media exposure. The influence of other determinants, however, is not always consistent among different measurements. Gender (male = 0, female = 1) seems to be slightly negatively associated with climate literacy, especially in some complex constructs (S3~S5). Notably, although the two items forming S1 are positively correlated with gender (Fig. 1), their relation changes when controlling for other variables. Age has a small and inconsistent influence on climate literacy. This inconsistent impact is even more obvious when it comes to wage: it has a negative impact on S1 and S2 yet a positive one on S5, which are all statistically significant. Climate-related experience seems to have a very small and negative impact on climate literacy; only the experience of city floods, instead of general climate experience, is statistically significant in some scopes.

Table 1 lists the detailed regression results of 4 subscales, providing some information on the inconsistencies across the different measurements. The impact of income on the subdimensions of climate literacy displays remarkable discrepancies: people with a lower income report a

Table 1
Determinants of climate literacy across different subscales (SS).

	SS1-cause	SS2a-consequence	SS2b-consequence	SS3-engagement	SS4-general
gender	0.0001	−0.016	0.012	−0.118***	−0.342***
age	0.009	0.044	0.021	−0.007	−0.005
education	0.167***	0.03	0.173***	0.121***	0.233***
wage	−0.061***	0.03	−0.058***	0.042***	0.097***
belief	0.255***	−0.034*	0.167***	0.103***	0.129***
perception	0.217***	−0.071**	0.173***	0.125***	0.065*
psych-distance	−0.082***	−0.01	−0.066***	−0.027***	−0.045***
experience 1	−0.01	−0.005	−0.002	−0.015	0.005
experience 2	−0.044***	0.013	−0.007	−0.013	0.006
media1_offline	0.157***	−0.307***	0.095***	0.122***	0.081**
media2_science	0.033	−0.077**	0.076***	0.025	0.131***
media3_online	0.201***	−0.177***	0.162***	0.046***	0.011
R^2	0.34	0.066	0.289	0.125	0.078

$N = 3067$. The construct of each subscale could be found at SI. *p < 0.1, **p < 0.05, ***p < 0.01.

high level of cause and consequence (SS2b)-related climate literacy, while those who earn more tend to be more literate in the human engagement and general knowledge subdimensions. The final positive regression coefficient from S5 seems to indicate that the latter two subscales have a relatively high influence. The gender difference in climate literacy follows a similar pattern: men perform better on human engagement and general knowledge, although no such difference is found in the cause and consequence subscales. Across all the subscales, only flood experience has a small and negative impact, but only on the subscale cause.

Other interesting clues can be found in the differences across the subscales. For example, in the one-dimensional measurements, online sources are the most important media that influence climate literacy, while the results of the subscales reveal more: the cause and consequence (SS2a) subdimension is consistent with one-dimensional measurements, while online media has a very small and insignificant effect on general knowledge. On the other hand, offline and science media play a major role in human engagement and general knowledge subscales, respectively. Last and most importantly, two parallel measurements of consequences display totally different characteristics. SS2a (H = 0.368, $\rho = 0.612$) is built on less common items and has a poor model fit ($R^2 =$ 6.6%), while SS2b (H = 0.283, $\rho = 0.579$) is based on common items and fits the regression well ($R^2 = 28.6\%$). Belief, risk perception and all three types of media coverage are negatively associated with SS2a, which is not only different from SS2b but also from all other subscales. This is hardly intuitive; hence, we provide some possible explanations for it in the Discussion section below. Fig. S1 further illustrates the relations between the subscales and confirms the distinctness of SS2a. Interestingly, although SS2a is negatively correlated with all other scales, it shows a very small positive correlation with general knowledge ($r =$ 0.046, $P = 0.012$). Meanwhile, the cause is central among the subdimensions of climate literacy, with a relatively strong positive correlation with the consequence (SS2b, $r = 0.630$, $P = 0.000$) and a medium relationship with human engagement ($r = 0.450$, $P = 0.000$). General knowledge has a weaker relationship with the other scales, but it has a near medium correlation with human engagement.

The most important predictors of climate literacy are located in the subjective aspects. Table S3 further elaborates the explained variance contributions of each independent variable to climate literacy. Belief is the most important predictor among all the independent variables (ΔR^2, 12.4%–23.9%) in our model. SES has an overall small explanatory power in the model, where education accounts for a considerable share of explained variances (ΔR^2, 2.1–3.2%). Surprisingly, climate-related experience has little influence and accounts for only approximately 0.1% of the explained variance; it adds little to the predictive power of the model across all dimensions, and the change in R^2 is only significant in the subscale cause. In addition, media coverage has a relatively wide range of explained variances across the five measurements. In particular, it accounts for only 0.2% of the explained variance in the model with S3 as the dependent variable—the impact of media coverage seems to have been muted in S3 since its components, i.e., SS1, SS2a and SS3, all have a much higher explanatory power (Table S4). Meanwhile, as a variant of S3, S4 does not display this phenomenon. From this perspective, although built on subscales of optimal scalability and reliability, S3 is less useful as an instrument for climate literacy.

Accordingly, we recommend S2($H = 0.37$, $\rho = 0.75$) as the one-dimensional measurement of climate literacy for the following reasons: (a) It has better reliability and scalability than the other instruments. (b) It has only 7 items yet covers all 4 subdimensions, rendering it both representative of climate literacy and easily referenced for related research. (c) The regression model shows that S2 has a relatively better model fit.

4.3. The role of climate literacy in response to climate change

This section examines the impact of climate literacy (S2, $H = 0.37$, $\rho = 0.75$) on concern about climate change and attitude toward climate-related policy when controlling for SES, experiences, media coverage, trust and values. Table 2 lists the results of the hierarchical regression on concern about climate change. Climate literacy is the most important predictor and accounts for a very large share of explained variances (9.9%), followed by climate experience (5.4%); both are positively related to concern about climate change. SES makes up 3.2% of explained variances, which is not a low level (Driscoll, 2019). Women and elderly individuals show greater concern, while education and wages seem to demonstrate no significant relation with the outcome variable. More scientific and online media exposure leads to more concern, and trust in climate information, especially institutional trust, largely strengthens this effect. Regarding the influence of values, egoism and biospheric value are significantly related to concern about climate change, although in opposite directions, while altruism shows no significant direct effect. Specifically, self-centered people are less likely to worry about the climate, while those with a higher biospheric value show more concern.

Based on the above hierarchical regression results, we also included interactions among climate literacy and experience, institutional trust, and 3 values, confirming the moderating role of climate literacy through *post hoc* probing. As shown in Fig. 3 (left), when institutional trust increases, concern among respondents with more climate literacy rises more strongly than among less literate respondents. A climate literate person may understand more of the information from these institutions and thus display a greater climate change concern. This result thus confirms the positive relation between trust and climate change concern, which is more consistent with recent evidence than the traditional institutional trust hypothesis (Xiao and McCright, 2015). A possible reason for this is that today, people have more concern about climate change than they used to, which could be attributed to the publicity and popularization of climate change driven by institutions. Further analysis indicates that only when institutional trust is higher than a specific level can the mediation effect of climate literacy be significant (Fig. S1); the turning point from the simple slope thus indicates that the mediating effect would be weakened. Fig. 3 (right) also reveals an interesting discrepancy between people with different levels of climate literacy: in the group with higher climate literacy, altruism seems to be positively related to concern; in the less literate group, the relation between altruism and concern changes to a negative one. In addition, climate literacy can also mediate the effect of climate experience on climate change concern: it seems that climate experience is more related to concern when people are less literate, while this effect is very limited (Fig. S2).

We further tested the mediating role of climate literacy in predicting concern about climate change. Table S5 shows that while offline media coverage has no significant direct effect, its indirect effect is much larger and statistically significant, which means that more offline media exposure results in increased concern about climate change through the mediation of climate literacy. Online media coverage has almost equal direct and indirect impacts on concern about climate change. In our empirical results, climate literacy was also found to mediate the influence of values on concern. A full mediation effect of climate literacy on altruism was identified, and a partial mediation path was found when the independent variable was biospheric value.

Fig. 4 displays the determinants of climate literacy for policy priority and acceptance of climate cost when controlling for climate literacy and concern. Regression models seem to match policy priority ($R^2 = 26.7\%$) better than policy acceptance ($R^2 = 11.5\%$). More importantly, the two models demonstrate some disparities concerning how people's policy preferences are shaped. The most prominent difference comes from climate literacy and biospheric value: more climate literacy or biospheric value leads to a higher level of priority for climate policy but less acceptance of cost for climate policy. In addition, age, gender and online media coverage are all negatively associated with policy acceptance but exert no significant impact on policy priority.

Table 2
Concern about climate change: the hierarchical regression result.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Gender	0.137***	0.142***	0.115***	0.106***	0.094***	0.083***
Age	0.078***	0.073***	0.057***	0.057***	0.063***	0.061***
Education	0.056***	0.062***	0.010	0.007	0.003	0.005
Wage	0.030	0.008	0.026	0.023	0.015	0.019
Experience1		0.237***	0.197***	0.188***	0.185***	0.185***
Experience2		−0.011	0.011	0.008	0.005	0.010
Literacy			0.323***	0.293***	0.235***	0.194***
Media1_offline				0.011	0.006	0.006
Media2_science				0.095***	0.082***	0.080***
Media3_online				0.062***	0.047***	0.032*
Institutional trust					0.182***	0.147***
Media trust					0.005	0.019
Egoism						−0.051***
Altruism						0.011
Biospherism						0.133***
R^2	3.2%	8.6%	18.6%	20.0%	22.8%	24.1%
ΔR^2	3.2%	5.4%	9.9%	1.4%	2.8%	1.3%
ΔF	25.6***	90.4***	373.7***	17.7***	56.0***	17.5***

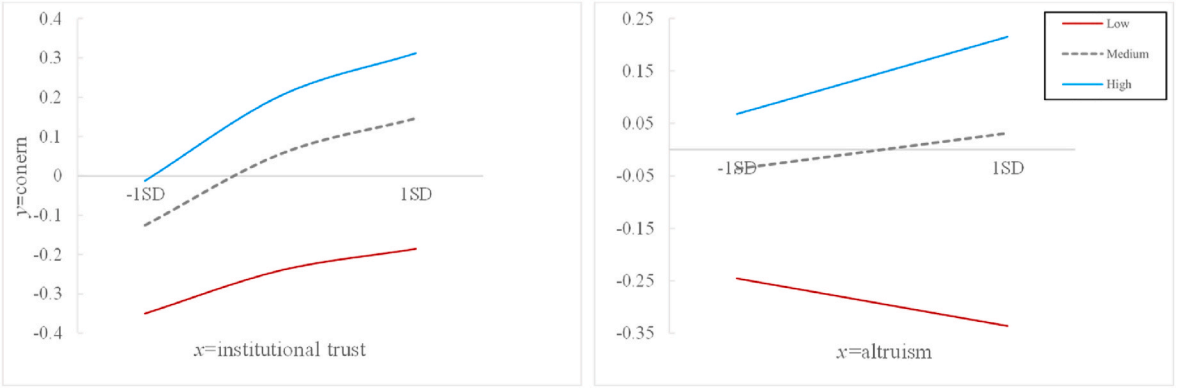

Fig. 3. The moderation role of climate literacy.

The model of policy acceptance (as the outcome variable) could have many practical implications and merits further attention. Women and the elderly are less likely to pay for a climate policy, but the negative impacts of climate literacy, online media coverage and biospheric value are hardly intuitive, as discussed in the next section. Additionally, the opposite effect of online media exposure and media trust on policy acceptance reveals a possible fact, i.e., our respondents tend to distrust information about climate policy in online media. This could also be partially confirmed in the model of policy priority (although the regression coefficients lack statistical meaning).

In addition to these differences, there are some factors that affect these two outcome variables about climate policy in the same direction. For example, a greater concern about climate change will result in a high level of both policy acceptance and policy priority. Similarly, scientific media exposure, institutional trust and egoism all contribute to the positive attitude toward climate policy.

The indirect effects of climate literacy on climate policy, mediated by concern about climate change are presented in Table S6. These results show that while concern can partially mediate the effect of climate literacy on climate policy, the direct effect is still major and accounts for a very large share (near 90%). Notably, although climate literacy is negatively associated with policy acceptance in the main regression model, it can increase the acceptance of climate policy through the mediation of concern, which is more intuitive than the direct effect.

We also analyzed two groups of mediation models to test the mediating effect of climate literacy on policy acceptance and policy priority. As shown in Table 3, media coverage can exert a significant indirect effect on climate policy, mediated by climate literacy. Offline media exposure has both positive direct and indirect impacts on policy priorities, while online media can affect people's policy preferences only through the mediating effect of climate literacy; in other words, climate literacy fully mediates the impact of online media coverage on policy priorities. Regarding the role of media in policy acceptance, offline media exposure is completely mediated by climate literacy and has both direct and indirect negative impacts on the outcome variable, while online media exposure has only a small and indirect effect. In addition, we included interactions between climate literacy and other independent variables in two models of climate policy and confirmed only very weak differences between high and low levels of climate literacy. When the outcome variable is policy acceptance, none of the interactions are statistically significant. Therefore, the moderating role of climate literacy on climate policy is likely negligible.

5. Discussion

As we have pointed out above, climate literacy may be formative instead of responsive. Some of our results provide support for this claim. For example, consequence (b) (SS2b) has poorer scalability and reliability but is more reasonable and fits better in some models than consequence (a) which is better scaled (Table 1). Moreover, it may convey some unrevealed information about the consequence dimension of climate literacy. The Chinese public knows much about the general consequences of climate change (consequence (b)), but they seem to be confused about the more specific and negative consequences (consequence (a)). The latter could be of vital importance, considering some of the unexpected results in our regression models: most factors that have

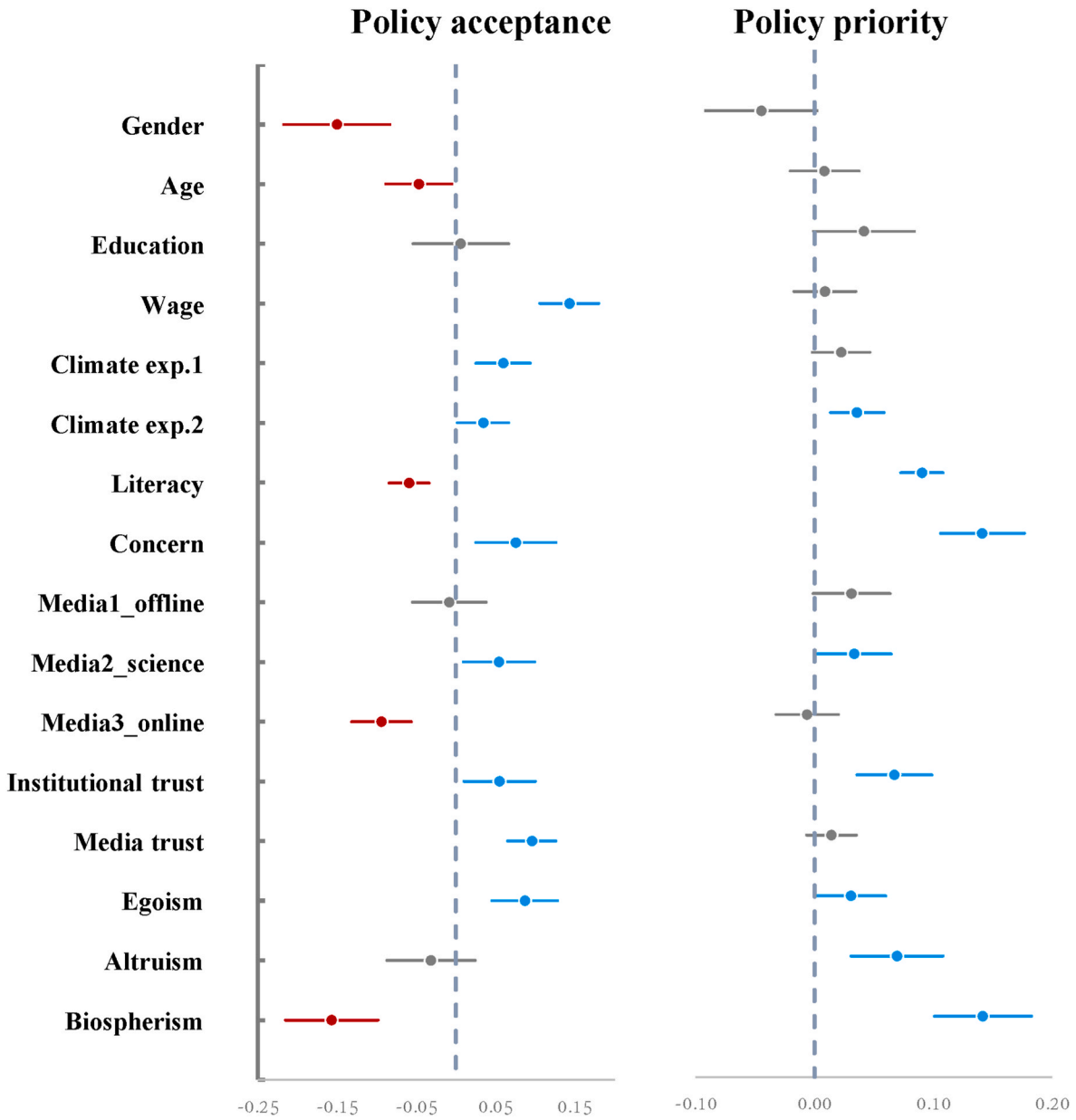

Fig. 4. Determinants of altitude about climate policy. The bars indicate the significant level at 95%.

positive impacts on other subscales of climate literacy seem to be significantly and negatively associated with the consequence (a). A similar discrepancy between consequences and other scales has been reported in (Shi et al., 2015), who show that result-related knowledge has a negative relationship with people's willingness to change their behavior, suggesting that the "items were too catastrophic". In our sample, consequence-related items are mostly neutral; thus, we argue that the uniqueness of the consequence scale may be a result of its own features *per se* rather than its specific measuring items. In addition, even misconceptions of some climate knowledge could result in a positive climate response; only the influence would be nuanced (Fleming et al., 2021). This is partly confirmed in our results: two measures of consequence affect concern and policy acceptance in the same direction, but they exert an opposite influence on policy priority (Table S7).

One possible explanation for the uniqueness of consequence (a) is the denial or mute effect due to the cognitive and psychologically distant facts about climate change (Scruggs and Benegal, 2012). Table S4 shows that the majority of the explained variance in consequence (a) comes from media exposure, where media exposure has a negative relation with consequences. Today's media coverage of climate change tends to be too general and similar and lacks more detailed facts; overexposure to this information could possibly lead to reduced belief in the uncommon consequences that are seldom covered in public media (Haltinner and Sarathchandra, 2018). Science media coverage has a much smaller effect than offline and online sources because it has a richer coverage of consequences. Notably, more credible support for our argument would require the coefficient of science media coverage to be positive; given the very small effect of science media and some missing factors or unknown effects, we believe this explanation is reasonable.

5.1. Factors related to people's response to climate change

Climate literacy is positively associated with climate concern and policy priority and is their first predictor. It is also one of the most important determinants of policy acceptance, although this relationship is negative. Climate experience, scientific media exposure and institutional trust consistently affect all outcome variables, which indicates that they are the most important factors policy-makers should consider,

Table 3
The mediating role of climate literacy on climate policy.

DV = policy priority				
IV=media(offline)	**Estimate**	**95% CI Lower**	**95% CI Upper**	**p-value**
Indirect	0.015	0.008	0.020	0.000
Direct	0.031	0.002	0.060	0.000
Total	0.046	0.015	0.080	0.000
IV=media(online)	**Estimate**	**95% CI Lower**	**95% CI Upper**	**p-value**
Indirect	0.019	0.013	0.030	0.000
Direct	−0.006	−0.029	0.020	0.600
Total	0.013	−0.007	0.040	0.280
DV = policy acceptance				
IV=media(offline)	**Estimate**	**95% CI Lower**	**95% CI Upper**	**p-value**
Indirect	−0.010	−0.016	−0.010	0.000
Direct	−0.009	−0.059	0.040	0.780
Total	−0.019	−0.067	0.030	0.480
IV=media(online)	**Estimate**	**95% CI Lower**	**95% CI Upper**	**p-value**
Indirect	−0.013	−0.020	−0.010	0.000
Direct	−0.094	−0.133	−0.050	0.000
Total	−0.106	−0.144	−0.060	0.000

irrespective of the possible complex interactions or unknown mechanisms among the variables. Although online and offline media coverage have no direct effect (95% significant level) on the concern about climate change, they can both have indirect impacts through the mediation of climate literacy whose size is larger than that of direct influence (Table S5). Similarly, online and offline media coverage could also significantly affect policy priority and acceptance of cost for climate policy through indirect effects, although some direct paths may not be effective (Table 3). This confirms the importance of media coverage for climate policy and entails the need for greater focus on its role in policy-making and climate communication.

Although climate change concern is positively related to both climate policy priority and the acceptance of cost, simply focusing on concern may not lead to the desired outcomes. We have found that many factors have contrary effects on concern and attitude toward policy support. For example, online media coverage similarly provides divergent evidence: more exposure leads to increased concern but decreased policy support. Egoism entails fewer worries about climate change but a positive attitude toward climate policy, which is less difficult to explain than other contrasts. Egoistic persons are usually self-interest oriented and thus relatively more rational; for them, concern might have undesirable negative psychological impacts, but climate policy is desirable for mitigating climate change.

Multiple influencing factors demonstrated opposite effects on the two policy variables, and the transition from a preference for policy to a willingness to pay for them is not simple. Although the correlation between policy priority and acceptance is positive, the effect size is very weak ($r = 0.066$, $P = 0.000$) and much smaller than expected. Admittedly, a person who prefers a climate policy does not necessarily have to support the implementation of this policy if the cost is unacceptable. However, this logic is not sufficient to explain why the two key predictors, i.e., climate literacy and biospheric value, have completely opposite effects on the outcome variables. Specifically, it is difficult to interpret the regression results for policy acceptance. One possible explanation is that a literate person understands more about the complex measures needed to respond to climate change and thus agrees less with individual policies (Di Giusto et al., 2018). However, this logic cannot be applied to the negative effects of biospheric values and other factors. We argue that this might be attributed to an enlarged gap between subjectivity (policy priority) and reality (acceptance), which leads to a mute or denial effect (Scruggs and Benegal, 2012; Smith and Mayer, 2018) that resembles our proposed explanation for the disparity between consequences (a) and (b). The Chinese public generally believes that their government can take proper measures to address global climate change (Wang and Zhou, 2020), but they may seldom consider or be less informed about the costs of these climate actions or policies. Besides, the uniqueness in the model of policy acceptance could also be attributed to economic issues that can probably shift the public's priorities regarding their climate opinions (Brulle et al., 2012; Scruggs and Benegal, 2012). Finally, these discrepancies among two pairs of variables (policy, consequence) seem to point to a framing problem caused by the general vs. specific, common vs. uncommon, or subjective vs. realistic, which could produce quite different results and implications.

5.2. Policy implications

Promoting climate literacy has great significance for enhancing citizens' engagement with climate change given the identified pivotal roles (direct and indirect) of climate literacy on concern and policy support above. Education is positively associated with every dimension of climate literacy, but our results indicate that subjective aspects such as belief, perception and psychological distance seem to be more related to climate literacy. Hence, when educating the public, a perception and detail-based strategy may work better. Meanwhile, more emphasis should be placed on the popularization of consequences because this plays a pivotal role in predicting the outcome variables; while the respondents in our sample seemed to be quite confused to some results-related knowledge. Physical knowledge has no significant effect on people's response to climate change; thus, if there are constraints or trade-offs between content (e.g., in course design), this content can be marked as a lower priority.

Climate-related experience, scientific media and institutional trust have a significant and consistent influence on all the outcome variables. This is important for practical purposes because the opposite effects of the factors and interactions among variables can potentially lead to complex and unexpected situations. Strategies based on casual agents with consistent impacts on key outcome variables in the chain from perception to response to climate change can avoid these drawbacks. Therefore, the focus of climate communication and policy should be on climate experience, scientific media coverage and institutional trust; increasing the levels of these three is more likely to increase public concern as well as policy support. In addition, these should be integrated and made full use of to create multilevel science–policy interfaces (Eroglu and Erbil, 2022). For example, considering the possible interactive relationship between institutional trust and other variables when disseminate real and specific climate experiences in the mass media (Smith and Mayer, 2018). The Chinese public generally shows a high level of institutional trust; thus, government departments and academic institutions should post more climate-related information and knowledge. Organizing climate-related activities or designing citizen science programs are also possible methods (Brüggemann et al., 2017; Dean et al., 2018) that can effectively utilize these positive factors to boost public climate engagement.

Scientific media has fuller coverage and more detailed facts about climate change; thus, it plays a more prominent and consistent role in concern and policy support and can provide guidance for an enhanced role of other media sources. Although online and offline media exposure has fewer effects on outcome variables, their significant indirect effects have been identified in our study. Accordingly, all means of media coverage are of vital importance for people's responses to climate change. However, overexposure to general information about climate change may cause some undesirable results due to denial; for example, online media coverage in our sample had a weak negative relation with policy support. Therefore, the mass media can make greater contributions to climate change communication through the adjustment of content, e.g., reducing general and meaningless reports or clickbait headlines while covering more facts (preferably detail and experience-based) about climate change.

Two policy variables display considerable disparities: when people must pay for a climate policy, compared to their prioritizing a policy, the

effect of some determinants changed direction. This means that although the Chinese public generally attribute a high priority to climate policy (Wang and Zhou, 2020), they are not yet ready to bear its cost. People tend to want companies to bear the cost instead of themselves, i.e., indirect cost is preferred to direct cost (Douenne and Fabre, 2020). Our results seem to be consistent with this claim and indicate that China should not implement a climate policy that consumers must pay for in the current environment. However, consumers may inevitably bear the costs of climate change; it is also important to inform the public and publicize climate policies that more economic and regional factors could be considered (He et al., 2023; Yu et al., 2013).

6. Conclusions

This work investigated climate literacy in almost all provinces in China. A total of 72.8% and 81.1% of our sample were well informed about global warming and its anthropogenic causes, respectively, and 47.4% of respondents correctly answered at least 20 of the 30 items. The Chinese public is thus generally literate regarding the cause and public engagement dimensions of climate literacy but has polarized knowledge about the climate-related consequences. Education and media coverage are significantly associated with climate literacy, while climate experience has little to no effect on climate literacy. Some climate-related perception variables, like belief and psychological distance contribute the largest explained variance to climate literacy.

We also examined the effect of climate literacy on the concern about climate change and climate policy support, and found that climate literacy plays a pivotal role in people's responses to climate change. It is the strongest predictor for concern and policy preference, and it has significant mediation and moderation effects on some important variables. In particular, climate literacy largely strengthens the impact of media coverage on both concern and support for climate policy. Our results do not support concern-centric climate communications: concern has a very small effect on climate policy acceptance, while many important factors have opposite impacts on concern and policy support. Thus, more attention should be given to specific and contextual factors. On the other hand, climate experience, scientific media exposure and institutional trust all have consistent positive effects on the outcome variables, which means that a targeted policy and climate communication strategy should be directed toward them.

Finally, our results have identified a somewhat unpredicted contrast between two measures of consequences as well as two policy variables. These could be partly attributed to the framing problem, i.e., general vs. specific, common vs. uncommon, and subjective vs. realistic. However, this requires further exploration and calls for greater focus on the nuances of contextual factors.

CRediT authorship contribution statement

Wu-Lin Pan: Conceptualization, Methodology, Writing – original draft. **Ruguo Fan:** Writing – review & editing, Supervision. **Wei Pan:** Conceptualization, Writing – review & editing, Supervision. **Xinyu Ma:** Methodology, Investigation. **Cheng Hu:** Investigation, Writing – original draft. **Piao Fu:** Investigation. **Jingyi Su:** Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

This study is supported by the National Natural Science Foundation of China (NSFC) (Grant no.71871169, U1933120 and J2024015) and fund for building world-class universities (disciplines) of Renmin University of China Project No. KYGJC2021005. W-L Pan would also thank the financial support provided by the China Scholarship Council (CSC).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2023.136874.

References

Alenda, J.M., 2021. Climate change literacy in Africa: the main role of experiences. Int. J. Environ. Stud. Ahead-Of-Print 1–17.
Anyanwu, R., Grange, L.L., 2017. The influence of teacher variables on climate change science literacy of Geography teachers in the Western Cape, South Africa. Int. Res. Geogr. Environ. Educ. 26, 193–206.
Arıkan, G., Günay, D., 2021. Public attitudes towards climate change: a cross-country analysis. Br. J. Polit. Int. Relat. 23, 158–174.
Aruta, J.J.B.R., 2022. Science literacy promotes energy conservation behaviors in Filipino youth via climate change knowledge efficacy: evidence from PISA 2018. Aust. J. Environ. Educ. 1–12.
Azevedo, J., Marques, M., 2017. Climate literacy: a systematic review and model integration. Int. J. Glob. Warming 12, 414.
Bergquist, M., Nilsson, A., Harring, N., Jagers, S.C., 2022. Meta-analyses of fifteen determinants of public opinion about climate change taxes and laws. Nat. Clim. Change 12, 235.
Brüggemann, M., De Silva-Schmidt, F., Hoppe, I., Arlt, D., Schmitt, J.B., 2017. The appeasement effect of a United Nations climate summit on the German public. Nat. Clim. Change 7, 783–787.
Brulle, R.J., Carmichael, J., Jenkins, J.C., 2012. Shifting public opinion on climate change: an empirical assessment of factors influencing concern over climate change in the U.S., 2002–2010. Climatic Change 114, 169–188.
Burke, S.E.L., Sanson, A.V., Van Hoorn, J., 2018. The psychological effects of climate change on children. Curr. Psychiat. Rep. 20.
Capstick, S., Whitmarsh, L., Poortinga, W., Pidgeon, N., Upham, P., 2015. International trends in public perceptions of climate change over the past quarter century. WIREs Clim. Change 6, 35–61.
Chen, F., Dai, S., Zhu, Y., Xu, H., 2020. Will concerns for ski tourism promote pro-environmental behaviour? An implication of protection motivation theory. Int. J. Tour. Res. 22, 303–313.
Clifford, K.R., Travis, W.R., 2018. Knowing climate as a social-ecological-atmospheric construct. Global Environ. Change 49, 1–9.
Cooper, O., Keeley, A., Merenlender, A., 2019. Curriculum gaps for adult climate literacy. Conserv. Sci. Pract. 1.
Crawley, S., Coffé, H., Chapman, R., 2020. Public opinion on climate change: belief and concern, issue salience and support for government action. Br. J. Polit. Int. Relat. 22, 102–121.
Curran, P.G., 2016. Methods for the detection of carelessly invalid responses in survey data. J. Exp. Soc. Psychol. 66, 4–19.
Dean, A.J., Church, E.K., Loder, J., Fielding, K.S., Wilson, K.A., 2018. How do marine and coastal citizen science experiences foster environmental engagement? J. Environ. Manag. 213, 409–416.
Di Giusto, B., Lavallee, J.P., Yu, T., 2018. Towards an East Asian model of climate change awareness: a questionnaire study among university students in Taiwan. PLoS One 13.
Dienes, C., 2015. Actions and intentions to pay for climate change mitigation: environmental concern and the role of economic factors. Ecol. Econ. 109, 122–129.
Douenne, T., Fabre, A., 2020. French attitudes on climate change, carbon taxation and other climate policies. Ecol. Econ. 169, 106496.
Drews, S., Van den Bergh, J.C.J.M., 2016. What explains public support for climate policies? A review of empirical and experimental studies. Clim. Pol. 16, 855–876.
Drews, S., Savin, I., van den Bergh, J.C.J.M., Villamayor-Tomás, S., 2022. Climate concern and policy acceptance before and after COVID-19. Ecol. Econ. 199, 107507.
Driscoll, D., 2019. Assessing Sociodemographic Predictors of Climate Change Concern, 1994–2016. Soc. Sci. Q.
Eroglu, M., Erbil, A.O., 2022. Appraising science-policy interfaces in local climate change policymaking: revealing policymakers' insights from Izmir Development Agency, Turkey. Environ. Sci. Pol. 127, 48–56.
Fernbach, P.M., Light, N., Scott, S.E., Inbar, Y., Rozin, P., 2019. Extreme opponents of genetically modified foods know the least but think they know the most. Nat. Human Behav. 3, 251–256.
Fleming, W., Hayes, A.L., Crosman, K.M., Bostrom, A., 2021. Indiscriminate, irrelevant, and sometimes wrong: causal misconceptions about climate change. Risk Anal. 41, 157–178.
Ge, J., Lin, B., 2021. Impact of public support and government's policy on climate change in China. J. Environ. Manag. 294, 112983.
Goldberg, M.H., Gustafson, A., Ballew, M.T., Rosenthal, S.A., Leiserowitz, A., 2021. Identifying the most important predictors of support for climate policy in the United States. Behav. Publ. Pol. 5, 480–502.

Hall, M.P., Lewis, Jr., N, A., Ellsworth, P.C., 2018. Believing in climate change, but not behaving sustainably: evidence from a one-year longitudinal study. J. Environ. Psychol. 56, 55–62.
Haltinner, K., Sarathchandra, D., 2018. Climate change skepticism as a psychological coping strategy. Sociol. Compass 12, e12586.
Hannibal, B., Vedlitz, A., 2018. Social capital, knowledge, and the environment: the effect of interpersonal communication on climate change knowledge and policy preferences. Sociol. Spectrum 38, 277–293.
Hart, P.S., Nisbet, E.C., Myers, T.A., 2015. Public attention to science and political news and support for climate change mitigation. Nat. Clim. Change 5, 541–545.
He, K., Mi, Z., Zhang, J., Li, J., Coffman, D.M., 2023. The polarizing trend of regional CO2 emissions in China and its implications. Environ. Sci. Technol. 57 (11), 4406–4414, 2023.
Jakučionytė-Skodienė, M., Liobikienė, G., 2022. The changes in climate change concern, responsibility assumption and impact on climate-friendly behaviour in EU from the Paris agreement until 2019. Environ. Manag. 69, 1–16.
Kahan, D.M., 2015. Climate-science communication and the measurement problem. Polit. Psychol. 36, 1–43.
Kahan, D.M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L.L., Braman, D., Mandel, G., 2012. The polarizing impact of science literacy and numeracy on perceived climate change risks. Nat. Clim. Change 2, 732–735.
Klapp, J., Bouvier-Brown, N.C., 2021. Climate literacy among undergraduate students who study science in Los Angeles. Int. J. Sustain. High Educ. 22, 1707–1727.
Kuthe, A., Körfgen, A., Stötter, J., Keller, L., 2020. Strengthening their climate change literacy: a case study addressing the weaknesses in young people's climate change awareness. Appl. Environ. Educ. Commun. Int. J. 19, 375–388.
Lee, T.M., Markowitz, E.M., Howe, P.D., Ko, C., Leiserowitz, A.A., 2015. Predictors of public climate change awareness and risk perception around the world. Nat. Clim. Change 5, 1014–1020.
Leiserowitz, A.M.J.W., 2020. Knowledge of Climate Change across Global Warming ' S Six Americas. Yale Program on Climate Change Communication, New Haven, CT.
Lewandowsky, S., Gignac, G.E., Vaughan, S., 2013. The pivotal role of perceived scientific consensus in acceptance of science. Nat. Clim. Change 3, 399–404.
Liu, S., Varma, K., Roehrig, G., 2014a. In: Dalbotten, D., Roehrig, G., Hamilton, P. (Eds.), Climate Literacy and Scientific Reasoning. John Wiley & Sons, Inc, Hoboken, NJ, pp. 31–40.
Liu, Z., Smith, Jr., W, J., Safi, A.S., 2014b. Rancher and farmer perceptions of climate change in Nevada, USA. Climatic Change 122, 313–327.
Maran, D.A., Begotti, T., 2021. Media exposure to climate change, anxiety, and efficacy beliefs in a sample of Italian university students. Int. J. Env. Res. Publ. Health vol. 18.
McBride, S.E., Hammond, M.D., Sibley, C.G., Milfont, T.L., 2021. Longitudinal relations between climate change concern and psychological wellbeing. J. Environ. Psychol. 78, 101713.
McCright, A.M., 2010. The effects of gender on climate change knowledge and concern in the American public. Popul. Environ. 32, 66–87.
Milfont, T.L., 2012. The interplay between knowledge, perceived efficacy, and concern about global warming and climate change: a one-year longitudinal study. Risk Anal. 32, 1003–1020.
Niepold, F., Herring, D., McConville, D., 2008. The role of narrative and geospatial visualization in fostering climate literate citizens. Phys. Geogr. 29, 529–544.
Poortinga, W., Whitmarsh, L., Steg, L., Böhm, G., Fisher, S., 2019. Climate change perceptions and their individual-level determinants: a cross-European analysis. Global Environ. Change 55, 25–35.
Powers, S.E., DeWaters, J.E., Dhaniyala, S., 2021. Climate literacy—imperative competencies for tomorrow's engineers. Sustain. Basel 13, 9684.
Rhodes, E., Axsen, J., Jaccard, M., 2014. Does effective climate policy require well-informed citizen support? Glob. Environ. Chang. 29, 92–104.
Sambrook, K., Konstantinidis, E., Russell, S., Okan, Y., 2021. The role of personal experience and prior beliefs in shaping climate change perceptions: a narrative review. Front. Psychol. 12.
Schuldt, J.P., Eiseman, D.L., Hoffmann, M.P., 2020. Public concern about climate change impacts on food choices: the interplay of knowledge and politics. Agr. Hum. Values 37, 885–893.
Scruggs, L., Benegal, S., 2012. Declining public concern about climate change: can we blame the great recession? Global Environ. Change 22, 505–515.
Shi, J., Visschers, V.H.M., Siegrist, M., 2015. Public perception of climate change: the importance of knowledge and cultural worldviews. Risk Anal. 35, 2183–2201.
Shi, J., Visschers, V.H.M., Siegrist, M., Arvai, J., 2016. Knowledge as a driver of public perceptions about climate change reassessed. Nat. Clim. Change 6, 759–762.
Shwom, R., Isenhour, C., Jordan, R.C., McCright, A.M., Robinson, J.M., 2017. Integrating the social sciences to enhance climate literacy. Front. Ecol. Environ. 15, 377–384.
Simpson, N.P., Andrews, T.M., Krönke, M., Lennard, C., Odoulami, R.C., Ouweneel, B., Steynor, A., Trisos, C.H., 2021. Climate change literacy in Africa. Nat. Clim. Change 11, 937–944.
Singh, P., K, D., Mathur, A., 2019. Climate literacy and individual consumption behavior: an evaluation of the Indian experience. Eur. J. Sustain. Dev. 8, 187.
Smith, E.K., Mayer, A., 2018. A social trap for the climate? Collective action, trust and climate change risk perception in 35 countries. Glob. Environ. Chang. 49, 140–153.
Spence, A., Poortinga, W., Pidgeon, N., 2012. The psychological distance of climate change. Risk Anal. 32, 957–972.
Stern, P.C., Dietz, T., Abel, T., Guagnano, G.A., Kalof, L., 1999. A value-belief-norm theory of support for social movements: the case of environmentalism. Hum. Ecol. Rev. 6, 81–97.
Stevenson, K.T., Nils Peterson, M., Bondell, H.D., 2018. Developing a model of climate change behavior among adolescents. Climatic Change 151, 589–603.
Stoutenborough, J.W., Vedlitz, A., 2014. The effect of perceived and assessed knowledge of climate change on public policy concerns: an empirical comparison. Environ. Sci. Pol. 37, 23–33.
UN, SDG Goal 13.
USGCRP, 2009. Climate Literacy: the Essential Principles of Climate Science. US Global Change Research Program.
Van Boven, L., Sherman, D.K., 2021. Elite influence on public attitudes about climate policy. Curr. Opin. Behav. Sci. 42, 83–88.
van Schuur, W.H., 2003. Mokken scale analysis: between the guttman scale and parametric item response theory. Polit. Anal. 11, 139–163.
Wang, B., Zhou, Q., 2020. Climate change in the Chinese mind: an overview of public perceptions at macro and micro levels. WIREs Clim. Change 11.
Wu, J., Otsuka, Y., 2021. Exploring the climate literacy of high school students for better climate change education. Int. J. Glob. Warming 23, 151–168.
Xiao, C., McCright, A.M., 2015. Gender differences in environmental concern: revisiting the institutional trust hypothesis in the USA. Environ. Behav. 47, 17–37.
Yang, L., Liao, W., Liu, C., Zhang, N., Zhong, S., Huang, C., 2018. Associations between knowledge of the causes and perceived impacts of climate change: A cross-sectional survey of medical, public health and nursing students in universities in China. Int. J. Environ. Res. Publ. Health vol. 15, 2650.
Yu, H., Wang, B., Zhang, Y., Wang, S., Wei, Y., 2013. Public perception of climate change in China: results from the questionnaire survey. Nat. Hazards 69, 459–472.