Development and validation of MACK-12: A short multidimensional climate knowledge scale

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Abstract

Accurate knowledge about climate change—including its causes, consequences, and solutions—plays a significant role in shaping people's pro-climate attitudes and behaviors. This knowledge influences voting behavior, policy support, personal lifestyle choices, and community-level actions, all contributing to society's collective response to climate change. However, few validated tools exist to assess people's climate knowledge, particularly short questionnaires suitable for large-scale studies of psychological constructs and behaviors related to the climate crisis. This research aimed to develop and validate a short, multidimensional climate knowledge scale—the Multidimensional Climate Knowledge Scale (MACK-12). In Study 1, we created and administered an initial set of 62 items to a representative sample of 2,000 adults in Quebec, Canada. These items covered various dimensions: greenhouse effect, causes and consequences of climate change, individual and collective solutions, and climate science. We selected twelve items with high psychometric quality for inclusion in the MACK-12, ensuring coverage of all targeted dimensions. We demonstrated the scale's validity and reliability using conventional metrics, including Cronbach's alpha and correlations between respondents' scores and education level. Study 2 confirmed MACK-12's test-retest reliability through a follow-up data collection (n = 500) two weeks later. Study 3 (n = 2,513) further demonstrated the scale's construct validity by showing that respondents' scores correlated with constructs known or expected to be associated with climate change knowledge (climate change denial, environmental concern, perceived urgency to act, and climate-friendly actions). This new climate knowledge scale can help researchers and decision-makers identify knowledge gaps among Quebecers and other populations worldwide, supporting more targeted communication strategies, policy design, and behavior-change campaigns to effectively engage the public in sustainable actions. The scale also offers valuable applications for

interdisciplinary research: it can be integrated into large-scale observational studies alongside other measures assessing relevant concepts, such as personal values or political orientation.

1. Introduction

Climate change's accelerating impacts are now felt worldwide, affecting ecosystems, economies, and human societies [1]. Addressing this global crisis requires both scientific and technological solutions and widespread public understanding and engagement. While scientists and policymakers are crucial for climate mitigation and adaptation, the attitudes and behaviors of the general public are equally vital for success. Research shows that accurate knowledge about climate change—its causes, consequences, and solutions—significantly shapes people's pro-climate attitudes and behaviors. This knowledge influences voting patterns, policy support, personal lifestyle choices, and community actions, all contributing to society's collective response to climate change [2,3].

Research by Winterich et al. [4] and Kurowski et al. [5] demonstrates that greater climate change knowledge correlates with increased pro-climate consumer behaviors. Studies also show that better understanding of climate change's causes and consequences leads to heightened concern and stronger support for climate-friendly policies [6–8]. Moreover, when people are well-informed about climate science, they are more likely to engage in environmental advocacy [9] and seek political involvement [10]. This body of evidence underscores the vital importance of climate education for laypeople.

However, many scholars caution against overemphasizing climate knowledge, noting that simply providing information about climate change is not enough to effectively engage the public [11–14]. While information plays an important role, engaging the public on climate change requires a multifaceted approach that addresses both psychological and structural barriers. Nevertheless, scholars agree that a baseline level of climate literacy among the public serves as a valuable tool in addressing climate change [15]. As Tobler et al. [16] explain, “climate-related knowledge

represents an important, yet not sufficient, prerequisite for people's willingness to accept climate protection measures or to change their behaviors." (p. 191).

Studying how well laypeople understand climate change is a crucial research priority. By identifying gaps between scientific consensus and public understanding, researchers can pinpoint misconceptions and areas where communication needs improvement [17,18]. When people lack accurate climate knowledge, they may be less likely to support essential policies and actions, hindering the implementation of effective climate strategies. Measuring public climate knowledge also helps shape more effective educational campaigns, media strategies, and outreach programs [19]. Yet experts continue to debate how best to assess climate knowledge—specifically, which concepts to measure and how to measure them.

1.1 Climate change knowledge: a multidimensional concept

According to Azevedo and Marques [20], climate literacy comprises three key elements: knowledge of climate science, the ability to access and evaluate climate information, and positive attitudes toward adaptation and mitigation strategies. This definition integrates both objective components (knowledge and skills) and subjective elements (attitudes), highlighting climate literacy's multidimensional nature. As Sato and Park [21] emphasize, "qualifying a person to be climate change literate should require a meticulous assessment of not one but multiple domains of climate change literacy." (pp. 11-12).

Regarding climate knowledge specifically (as distinct from skills or attitudes), existing assessment tools vary considerably in their scope and focus on different dimensions of climate literacy. Some tools emphasize the biophysical processes of climate change [e.g., 22], while others concentrate on specific causes [e.g., food practices, 23] and consequences [e.g., infectious diseases, 24].

In their comprehensive assessment of climate-related knowledge, Tobler et al. [16] identified four key dimensions. The first dimension, physical knowledge, encompasses scientific principles like the greenhouse effect and carbon dioxide's (CO_2) role. The second dimension focuses on knowledge about climate change and its causes, examining both its existence and human origins. The third dimension addresses knowledge of climate change consequences, including increased extreme weather events and melting polar ice caps. The fourth dimension covers action-related knowledge, which includes strategies and practices for reducing CO_2 emissions. Building on this framework, Taddicken et al. [25] added a fifth dimension—procedural knowledge—which examines how climate knowledge is developed and what scientific uncertainties exist.

As mentioned previously, most existing climate knowledge measurement tools only partially cover these five dimensions [21]. Moreover, the action knowledge dimension, when measured, typically focuses on individual behaviors. Many questionnaires, for instance, assess people's understanding of how personal actions affect CO_2 emissions [e.g., 26–28]. However, solutions to the climate crisis go well beyond individual actions. They include collective-level decisions such as urban planning, public transit implementation, and eco-taxation [29–31]. Despite this, climate knowledge measurement tools rarely assess this broader type of knowledge [21].

Moreover, while most assessment tools in the literature focus primarily on global climate change knowledge (e.g., how CO_2 emissions are raising Earth's temperature), understanding how populations comprehend local climate issues is equally important.

Firstly, different regions of the world experience climate change impacts in distinct ways. In northern regions like Scandinavia, for instance, accelerated melting of glaciers and permafrost contributes to rising sea levels and threatens coastal communities [32]. Meanwhile, Mediterranean countries face increasingly frequent and intense heat waves. In 2024, Greece, Spain, Portugal, France, and Morocco suffered extreme weather events that led to fatalities, widespread wildfires,

and public health emergencies [33]. Therefore, measurement tools that focus solely on global climate change consequences cannot assess whether people understand how climate change affects their local area. This limitation makes it impossible to determine if individuals truly comprehend the risks specific to their region.

Secondly, greenhouse gas emissions patterns vary significantly across countries and regions. For example, some European countries—Portugal, France, and the UK—have much lower CO_2 emissions per capita than neighboring countries with comparable living standards, such as Germany, the Netherlands, and Belgium. This difference stems from their energy choices: Portugal, France, and the UK generate most of their electricity from nuclear and renewable sources, while Germany relies on fossil fuels for about half of its electricity production [34]. Significant differences also exist between regions within the same country. In Canada, greenhouse gas emissions in the province of Quebec (9.1 tons of CO_2 equivalent per capita in 2022) are substantially lower than in the province of Saskatchewan (64.4 tons of CO_2 equivalent per capita during the same year). This distinction also stems from their energy source: Quebec relies primarily on hydroelectricity, while Saskatchewan depends mainly on natural gas [35]. As a result, climate literacy assessment tools that focus solely on global causes or generic solutions cannot effectively measure whether people understand the most relevant actions for reducing emissions or adapting to climate change in their specific region.

1.2 Measuring climate change knowledge

Research on objective climate knowledge assessment features questionnaires of various lengths, from brief scales with fewer than five items [e.g., 36,37] to extensive ones with over 20 items [e.g., 22,25]. While comprehensive questionnaires yield rich insights into target audiences, their administration is resource-intensive. Shorter questionnaires present a practical solution but—

as noted earlier—often fail to cover all dimensions of climate knowledge. This creates a pressing need for concise yet multidimensional questionnaires that can effectively distinguish between varying levels of climate change knowledge at both global and local scales.

Existing climate knowledge scales show considerable variation in how they phrase and structure items [21]. While some questionnaires ask respondents to select correct answers from multiple choices [e.g., 5,22], others require them to evaluate statements [e.g., 16,38]. In the latter approach, respondents typically rate their agreement with claims on a scale from *strongly agree* to *strongly disagree* [e.g., 25,37]. This method, however, makes it difficult to separate objective knowledge from attitudes and beliefs [25]. Though some researchers have tried to address this by measuring awareness of expert consensus on climate change [e.g., 37], the challenge of distinguishing between actual knowledge and perceived expert consensus persists.

Researchers also often use true/false statements rather than agreement scales to better measure objective knowledge. These questionnaires frequently include an "I don't know" option to discourage random guessing [e.g., 7,39]. However, this approach has drawbacks—less confident respondents might select "I don't know" even when they know the answer, while less motivated participants might choose it as an easy way out [40]. To address this issue, researchers can ask respondents to rate their confidence in each answer, either through a separate question or as part of a Likert scale [e.g., 36,38].

Regardless of their length, item types, and response options, few climate knowledge questionnaires have undergone rigorous validation. Most are ad hoc instruments with unverified psychometric properties, and publications rarely include validation evidence for these measurement tools. Given the critical nature of climate change, using validated instruments is essential to ensure that climate-related research leads to interventions and policies based on accurate measurements of climate knowledge.

1.3 Aim of the research

Climate knowledge is frequently studied in relation to attitudes, beliefs, and behaviors, creating a need among researchers and practitioners for a concise, multidimensional, and reliable assessment tool. However, existing research lacks such an instrument. This article aims to address this gap by developing and validating a new instrument, the 12-item Multidimensional Assessment of Climate Knowledge-12 (MACK-12). Using Quebec (Canada)'s population as a case study, we developed the MACK-12 to be readily adaptable for assessing climate literacy in other populations.

With 8.9 million inhabitants, Quebec represents approximately one-quarter of Canada's total population [41]. Quebec is the only Canadian province where French is both the official and majority language. About 80% of Quebecers speak French as their first language, while most other Canadians have English as their first official language spoken [41]. This linguistic difference profoundly shapes the province's culture, education system, and public policies.

Quebec's distinct character is also evident in public attitudes toward climate change. A 2016 nationwide study showed that among all Canadian provinces, Quebec had the highest percentage of residents who believed climate change is human-caused and showed the strongest support for carbon pricing through emissions trading [42]. More recently, Champagne St-Arnaud et al. [43] found that 85% of Quebecers consider fighting climate change urgent, while only 14% deny its existence—demonstrating high public concern about the climate crisis. However, self-assessed climate literacy levels remain modest. In the same study, 39% of respondents reported being unable to explain "carbon emissions," while 21% could not explain "adaptation to climate change," among other concepts. Although these findings suggest limited climate knowledge, no objective assessment of climate literacy has been conducted for this population—making Quebec an ideal

case study for developing a valid and reliable tool that measures both global and local climate knowledge.

Using three distinct studies with large, representative samples of Quebec's population, we developed and validated the 12-item Multidimensional Assessment of Climate Knowledge-12 (MACK-12), confirming both its validity and reliability.

2. Study 1: Development of a short climate knowledge scale

Study 1 aimed to develop a concise climate knowledge scale by identifying the most suitable items. From an initial pool of 62 candidate items administered to a large sample, we selected 12 items with optimal psychometric properties. We then evaluated the validity and reliability of this shortened scale.

2.1. Materials and Methods

2.1.1. Items generation

Building on Taddicken et al. [25], who expanded upon Tobler et al.'s [16] study, we identified five dimensions of climate change knowledge for our scale: knowledge of the greenhouse effect, evolution and causes of climate change, consequences of climate change, carbon footprint of individual actions, and development and accessibility of climate science. We added a sixth dimension—collective solutions to climate change—which encompasses mitigation and adaptation strategies at the collective level (e.g., designing sustainable cities), following Sato and Park's [21] considerations for comprehensive climate literacy. Permissions were obtained from the authors of both questionnaires.

While addressing similar dimensions, our final set of items differs substantially from Taddicken et al.'s [25] questionnaire, with 84% of items being entirely new (see S1 File for the complete list of items). This divergence stems primarily from our addition of a "collective solutions

to climate change" subscale (subscale 5), which covers climate change mitigation and adaptation strategies. We also tailored our questionnaire to Quebec's specific climate, geographical location, ecosystems, infrastructure, and economic context. For example, we included the item: "In Quebec, the transportation sector is the largest emitter of greenhouse gases." Many questions drew from the 2024 technical report of the *Comité consultatif sur les changements climatiques*, an independent expert committee that advises Quebec's government on climate change mitigation and adaptation (comparable to the UK's *Climate Change Committee*) [44]. Additionally, we expanded our questionnaire beyond bioclimatic consequences to encompass a broader range of climate change impacts, including social, health, and economic effects.

2.1.2. Generation of items and response options

Each subscale measured several subdimensions of climate knowledge. For example, subscale 3 included subdimensions about climate change's effects on ecosystems and its impact on food insecurity. Subscales 1, 2, and 5 each contained five subdimensions, subscales 3 and 4 each contained seven, and subscale 6 contained two subdimensions (see S1 File). We created two items per subdimension, resulting in 10 items each for subscales 1, 2, and 5; 14 items each for subscales 3 and 4; and 4 items for subscale 6. Since our questionnaire assumed the existence of climate change, we added an eleventh item to subscale 2: "Climate change is real." This item was included to help interpret results by identifying the proportion of climate change skeptics, and was therefore excluded from the knowledge assessment tool.

To help respondents focus on anthropogenic climate change rather than historical climatic variations, we provided the following definition at the beginning of each subscale: "In this questionnaire, 'climate change' refers to global climate changes that have occurred since

industrialization, not the natural climate fluctuations throughout Earth's history (such as glacial periods)." This definition was adapted fromTobler et al. [16].

The questionnaire focused on assessing factual knowledge about climate change, rather than attitudes, behaviors, or skills. We designed each item to have a clear true or false answer. Respondents rated their agreement with each statement using a five-point scale: 1) definitely false, 2) probably false, 3) I don't know, 4) probably true, 5) definitely true. This response format allowed us to evaluate both the accuracy of participants' knowledge and their confidence level in their answers [see 25].

To minimize response bias, we balanced each scale with an equal number of true and false statements. While most subscales had randomized items, subscale 1 maintained a fixed order so respondents would encounter the greenhouse effect's definition before its determinants and consequences. Following best practices in online surveying [e.g., 45], , we included two attention check questions—for example, asking participants to identify animals from a mixed list of animals and fruits.

Since French and English are the two most commonly spoken languages in Quebec, we developed the questionnaire in both languages. We first created the items in French, then used ChatGPT and Gemini for initial English translations, followed by manual editing to ensure accuracy.

2.1.3. Assessment of content and face validity

Content validity was assessed by a climate change expert with a Ph.D. in environmental science, who verified the accuracy of each statement and evaluated the questionnaire for any missing important themes [see, e.g., 46,47]. Based on her feedback, we replaced one item and made minor wording changes to six others. To assess face validity, we conducted cognitive interviews

with a diverse sample of 19 adults [see, e.g., 46,48]. The participants (6 women and 13 men; *M* age = 42 years, range: 21-65 years) represented various education levels (from high school to postdoctoral) and occupations (students, workers, retirees). They read the questionnaire in either French (n = 17) or English (n = 2) and provided feedback on the clarity of instructions, items, and response options. This process led to minor wording modifications in 20 items. When asked to describe what they thought each subscale measured, participants' interpretations aligned with the intended themes.

2.1.4. Participants and data collection

The questionnaire was administered through an online panel by Léger, a renowned Canadian market research and analytics company, between July 16, 2024, and July 26, 2024. In the instructions section of the questionnaire (see S2 File), respondents were asked to answer based solely on their own knowledge, without consulting external sources such as the Internet or other people.

Two thousand respondents (N = 2,000) aged 18 years or older completed the survey. None had participated in the cognitive interviews. Sociodemographic questions—covering age, sex, first language, education, region of residence, and presence of children in the household—enabled the creation of post-stratification weights to ensure a representative sample of Quebec's adult population. For optional questions used in data weighting, missing values were handled as follows: nine respondents (0.5%) who did not disclose children in their household were classified as living with children, six respondents (0.3%) who did not provide their education level were classified as having no university degree, and one respondent (0.1%) who did not indicate their first language was classified as a non-native French speaker. Table 1 presents the sample's sociodemographic characteristics using unweighted values. The study received approval from Université Laval's

Ethics Committee (2022-253 Phase IV / 10-05-2024). Participants received thorough instructions and provided written informed consent.

Table 1. Sociodemographic characteristics of the sample for each study.

	Study 1 (*n* = 2000)	Study 2 (*n* = 502)	Study 3 (*n* = 2513)
Questionnaire completion language			
French	1626 (81%)[a]	404 (81%)	2001 (80%)
English	374 (19%)	98 (20%)	512 (20%)
First language			
French	1671 (84%)	419 (84%)	2090 (83%)
English	212 (11%)	57 (11%)	286 (11%)
Other	116 (6%)	26 (5%)	137 (6%)
Preferred not to say	1 (0.1%)	0 (0%)	0 (0%)
Sex			
Female	1020 (51%)	233 (46%)	1295 (52%)
Male	980 (49%)	269 (54%)	1218 (49%)
Age group (years)			
18-34	473 (24%)	108 (22%)	588 (23%)
35-54	648 (32%)	157 (31%)	781 (31%)
55-74	776 (39%)	212 (42%)	884 (35%)
≥ 75	103 (5%)	25 (5%)	260 (10%)
Highest level of education completed			
Primary	18 (1%)	9 (2%)	25 (1%)
Highschool	492 (25%)	126 (25%)	549 (22%)
College	643 (32%)	165 (33%)	803 (32%)
University	841 (42%)	201 (40%)	1128 (45%)
Preferred not to say	6 (0.3%)	1 (0.2%)	8 (0.3%)

Values represent the unweighted number and percentage of respondents per category.

[a]Percentages may not always equal to 100% due to rounding.

2.1.5. Analysis

Response options were scored on a 5-point scale, ranging from "definitely false" (1) to "definitely true" (5). For false statements, we reversed the scale so that higher scores consistently indicated greater knowledge. Additionally, to calculate certain psychometric indices (item accuracy and discrimination index), we dichotomized responses into correct and incorrect answers. Responses of "definitely true" or "probably true" were scored as 1 (correct) when the statement was true, while "definitely false," "probably false," and "I don't know" were scored as 0 (incorrect).

We assessed item accuracy by calculating the percentage of respondents who identified each statement as definitely or probably true (with scores reversed for false statements). To be

included in the final scale, items needed an accuracy rate between 20% and 80%—thresholds commonly used to identify items with appropriate difficulty levels [see 47].

We aimed to include only items with high discriminating power in the final scale by assessing item discrimination in two ways [see 48]. First, we calculated an item discrimination index using the top and bottom 27% of the sample, based on overall accuracy across all items. For each item, we subtracted the accuracy of the lowest performers from that of the highest performers [see 49]. Items with a discrimination index of at least .30 were considered as suitable candidates for the final questionnaire [49]. After identifying potential items for the short scale, we assessed their discriminating power using the adapted item-total correlation—the correlation between each item and the total score on the short scale, excluding that item. Items with a weak Pearson item-total correlation ($r < .20$) were considered for removal [see 47].

As mentioned previously, this project's main objective was to create a short, multidimensional climate knowledge questionnaire. Therefore, We selected 12 items for the final scale that met our established criteria, with two items representing each of the six climate dimensions. This number strikes an optimal balance between assessment specificity and administration efficiency. We chose items from each dimension to represent different subdimensions of climate knowledge, with one exception: in subscale 6, no items from one of the two subdimensions met our discrimination criteria. We maintained an approximately equal distribution of true and false items. With 12 items and response options ranging from 1 to 5, the final questionnaire scores could range from 12 to 60.

We used Cronbach's alpha to assess the internal consistency of the final scale, with a minimal threshold of 0.7 indicating adequate reliability [see 48]. To assess construct validity of the short version, we examined the Pearson correlation between scores on the 12-item short scale and the complete 62-item scale. We also analyzed how scores varied by education level—a known

correlate of climate change knowledge [21]. We conducted a one-way ANOVA comparing three education levels: primary/secondary school (combined due to few primary-only respondents, see Table 1), college, and university. For significant main effects, we used Bonferroni-corrected pairwise comparisons to identify specific differences between groups. Based on previous research [16,25,50], we hypothesized that higher education levels would correspond with higher scores.

Only complete questionnaires were retained, as post-stratification weights maintained the generalizability of the results. All analyses used sample weights to ensure sample representativeness. We conducted analyses using IBM SPSS Statistics 27 with an alpha level of .05, interpreting correlation strengths according to Cohen's [51] conventions.

2.2. Results

The mean accuracy across all 62 items (using dichotomous scoring) was 60.3% (*SD* = 17.9%), with individual item accuracy ranging from 9.0% to 89.0%. Participants performed better on true items (*M* = 71.2%, *SD* = 21.9%) than false items (*M* = 50.0%, *SD* = 19.8%). When asked about the reality of climate change, 92.1% of respondents identified it as true—75.2% selecting "definitely true" and 16.9% "probably true." Only 4.5% selected "I don't know," while 3.5% identified it as false (1.3% "definitely false" and 2.2% "probably false"). To maintain population representativeness, we included all respondents in our analyses, regardless of their beliefs about climate change.

Four items had a correct response rate below 20% (items 2.2, 4.13, 4.14, and 5.4; see S1 File), while 14 items had a correct response rate above 80% (items 1.8, 1.9, 2.7, 3.2, 3.3, 3.6, 3.13, 4.2, 4.5, 4.12, 5.2, 5.3, 5.8, and 5.10). Additionally, eleven items (1.3, 1.6, 1.10, 2.2, 2.6, 3.4, 3.11, 3.12, 4.13, 4.14, and 5.4) showed a discrimination index below 0.3. Since four of these items were

already eliminated based on the accuracy criterion, we retained 37 candidate items for the short questionnaire.

The final scale retained twelve items that assessed diverse climate knowledge subdimensions (see Table 2 for the complete list of items and their psychometric properties). This short questionnaire comprised five true and seven false statements. All items demonstrated adequate corrected item-total correlation with other items in the reduced questionnaire (all $r \geq .219$). The final questionnaire yielded a Cronbach's alpha of .765. We found a strong positive correlation between respondents' scores on the short scale and their scores on the complete 62-item climate knowledge assessment, $r = .900$, $p < .001$.

347 **Table 2. Items included in the MACK-12, associated item-level statistics, and overall accuracy achieved in each study.**

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Item	Study 1			Study 2			Study 3		
	Accuracy (%) *M* (± *SD*)	**Discrimi-nation index[b]**	**Corrected item-total correlation**	**Accuracy (%) *M* (± *SD*)**	**Discrimi-nation index[b]**	**Corrected item-total correlation**	**Accuracy (%) *M* (± *SD*)**	**Discrimi-nation index[c]**	**Corrected item-total correlation**
Subscale 1									
a. Carbon dioxide (CO_2) is a greenhouse gas. (T)[a]	66.2 (± 47.3)	.449	.333	69.9 (± 45.9)	.415	.394	75.0 (± 43.3)	.521	.375
b. The more the amount of greenhouse gases increases in the atmosphere, the more the Earth is able to absorb them. (F)	71.9 (± 45.0)	.618	.518	72.7 (± 44.6)	.603	.529	73.2 (± 44.3)	.694	.504
Subscale 2									
c. Experts estimate that the current decade is the warmest the Earth has experienced in the past 100,000 years. (T)	63.7 (± 48.1)	.435	.347	69.4 (± 46.1)	.431	.409	72.7 (± 44.5)	.514	.376
d. Climate change is primarily caused by natural phenomena (such as volcanic eruptions). (F)	68.9 (± 46.3)	.648	.551	65.6 (± 47.6)	.674	.640	67.5 (± 46.8)	.740	.550
Subscale 3									
e. An increase of just a few degrees in the Earth's temperature will have very mild effects on the climate. (F)	65.7 (± 47.5)	.678	.536	66.4 (± 47.3)	.663	.546	66.2 (± 47.3)	.764	.509
f. In Quebec, a warmer climate will generally promote more abundant and higher-quality crops. (F)	56.0 (± 49.7)	.542	.408	51.8 (± 50.0)	.575	.393	47.6 (± 50.0)	.583	.373
Subscale 4									
g. The production of 1 kg of wheat generates as much greenhouse gas as the	48.0 (± 50.0)	.626	.377	45.0 (± 49.8)	.663	.384	47.3 (± 49.9)	.647	.379

production of 1 kg of beef. (F)									
h. In Quebec, the transportation sector is the largest emitter of greenhouse gases. (T)	56.3 (± 49.6)	.401	.219	61.0 (± 48.8)	.421	.224	53.8 (± 49.9)	.418	.104
Subscale 5									
i. To combat climate change, the priority is to offset the greenhouse gas emissions we produce (e.g., by planting trees) rather than reducing emissions at the source. (F)	39.2 (± 48.8)	.671	.355	37.7 (± 48.5)	.582	.340	44.7 (± 49.7)	.702	.385
j. Creating cities where all services (grocery store, library, etc.) are accessible by foot or bike within 15 minutes is a way to combat the climate crisis. (T)	78.8 (± 40.9)	.523	.493	81.5 (± 38.8)	.493	.456	69.5 (± 46.0)	.528	.356
Subscale 6									
k. Comments found on social media are generally trustworthy sources for information about climate change. (F)	74.8 (± 43.5)	.485	.323	74.2 (± 43.8)	.577	.432	73.4 (± 44.2)	.550	.373
l. The most credible source of information on climate science is the Intergovernmental Panel on Climate Change (IPCC). (T)	42.4 (± 49.4)	.390	.353	44.2 (± 49.7)	.320	.284	53.8 (± 49.9)	.603	.381
All subscales									
Mean score on the short questionnaire	61.0 (± 24.3)			61.8 (± 24.4)			62.1 (± 24.2)		

[a](T) and (F) at the end of each item indicate whether the item is true or false, respectively.

[b]Discrimination indices for each item in Studies 1 and 2 were calculated based on accuracy across the initial set of 62 items.

[c]For Study 3, discrimination indices for each item were calculated based on accuracy across the 12 items of the final questionnaire.

Table 3 shows the distribution of responses on the 5-point Likert scale, providing insight into respondents' certainty about their answers. Among the three items that less than half the sample answered correctly (items g and l; see Table 3), two showed low accuracy primarily because respondents indicated they did not know the answer. For these items, when excluding "don't know" responses, only 11% of respondents gave incorrect answers. The third poorly performed item (item i) showed a different pattern, with a higher proportion of incorrect responses. Even after excluding the 24% who reported not knowing the answer, more than one-third of respondents incorrectly endorsed the false statement that offsetting greenhouse gas emissions should take priority over reducing emissions at source. Some items generated more confident and accurate responses—for five of the 12 items (a, b, e, j, and k), at least one-third of respondents were certain of their correct true/false answers.

363 **Table 3. Distribution of responses on the MACK-12 according to the response scale (dichotomous or Likert) in Study 1.**

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Item	Dichotomous scale	Likert scale (number and % of respondents)				
	Accuracy (%) *M* (± *SD*)	**Definitely false**	**Probably false**	**I don't know**	**Probably true**	**Definitely true**
Subscale 1						
a. Carbon dioxide (CO_2) is a greenhouse gas. (T)[a]	66.2 (± 47.3)	65 (3%)[b]	138 (7%)	472 (24%)	**660 (33%)**	**664 (33%)**
b. The more the amount of greenhouse gases increases in the atmosphere, the more the Earth is able to absorb them. (F)	71.9 (± 45.0)	**801 (40%)**	**637 (32%)**	353 (18%)	160 (8%)	49 (2%)
Subscale 2						
c. Experts estimate that the current decade is the warmest the Earth has experienced in the past 100,000 years. (T)	63.7 (± 48.1)	64 (3%)	148 (7%)	513 (26%)	**811 (41%)**	**464 (23%)**
d. Climate change is primarily caused by natural phenomena (such as volcanic eruptions). (F)	68.9 (± 46.3)	**640 (32%)**	**737 (37%)**	330 (17%)	230 (12%)	62 (3%)
Subscale 3						
e. An increase of just a few degrees in the Earth's temperature will have very mild effects on the climate. (F)	65.7 (± 47.5)	**700 (35%)**	**613 (31%)**	269 (13%)	295 (15%)	123 (6%)
f. In Quebec, a warmer climate will generally promote more abundant and higher-quality crops. (F)	56.0 (± 49.7)	**415 (21%)**	**704 (35%)**	438 (22%)	373 (19%)	70 (3%)
Subscale 4						
g. The production of 1 kg of wheat generates as much greenhouse gas as the production of 1 kg of beef. (F)	48.0 (± 50.0)	**447 (22%)**	**514 (26%)**	811 (41%)	186 (9%)	42 (2%)
h. In Quebec, the transportation sector is the largest emitter of greenhouse gases. (T)	56.3 (± 49.6)	60 (3%)	273 (14%)	542 (27%)	**860 (43%)**	**266 (13%)**
Subscale 5						
i. To combat climate change, the priority is to offset the greenhouse gas emissions we produce (e.g., by planting trees) rather than reducing emissions at the source. (F)	39.2 (± 48.8)	**352 (18%)**	**432 (22%)**	479 (24%)	506 (25%)	230 (12%)
j. Creating cities where all services (grocery store, library, etc.) are	78.8	73	96	254	**805**	**772**

accessible by foot or bike within 15 minutes is a way to combat the climate crisis. (T)	(± 40.9)	(4%)	(5%)	(13%)	**(40%)**	**(39%)**
Subscale 6						
k. Comments found on social media are generally trustworthy sources for information about climate change. (F)	74.8 (± 43.5)	**937 (47%)**	**558 (28%)**	284 (14%)	186 (9%)	35 (2%)
l. The most credible source of information on climate science is the Intergovernmental Panel on Climate Change (IPCC). (T)	42.4 (± 49.4)	84 (4%)	134 (7%)	933 (47%)	**636 (32%)**	**213 (11%)**

Correct responses on the Likert scale are indicated in bold.

[a](T) and (F) at the end of each item indicate whether the item is true or false, respectively.

[b]Percentages may not always equal to 100% due to rounding.

Mean (± *SD*) scores on the short questionnaire (out of 60) were 43.1 (± 6.3), 44.1 (± 6.9), and 46.1 (± 6.8) for respondents with primary/secondary, college, and university education, respectively. An ANOVA revealed a small but statistically significant main effect of education level, $F(2, 2068) = 34.41$, $p < .001$, $\eta^2 = .032$. Bonferroni-corrected pairwise comparisons showed that questionnaire scores increased significantly with each education level (all $p \leq .02$).1).

2.3. Discussion

Starting with 62 items designed to measure climate knowledge, we selected 12 items to create the short Multidimensional Assessment of Climate Knowledge Scale (MACK-12). The scale demonstrates reliability through satisfactory internal consistency. Its validity is supported by two findings: first, the strong correlation between MACK-12 scores and scores from the complete item set; second, the positive relationship between MACK-12 scores and education levels—a pattern consistent with previous climate knowledge research [e.g., 16,26].

More than half of respondents correctly answered items about the greenhouse effect, the evolution and causes of climate change, and climate change consequences (subscales 1, 2, and 3). There was greater variation in response accuracy for items about individual actions' impact, collective solutions, and climate science accessibility (subscales 4, 5, and 6). For example, while over 75% of respondents recognized active transportation as a solution to the climate crisis, only slightly more than half knew that transportation is Quebec's largest source of greenhouse gas emissions. This finding underscores the importance of increasing public awareness about how goods and passenger transport affect the climate.

While individuals generally understood the limitations of social media as a source of climate change information, they struggled to identify reliable sources. Only 42% correctly identified the Intergovernmental Panel on Climate Change (IPCC) as the most credible source of

climate science information. The high number of "don't know" responses suggests that this low recognition stems from lack of awareness rather than distrust in the organization.

Fewer than half of respondents recognized that wheat production generates fewer greenhouse gases than beef production of equal weight, aligning with previous studies that show limited public awareness of food's environmental impact [23,52]. Most respondents also failed to understand that reducing greenhouse gas emissions at the source is more effective than offsetting them after production. This misconception may be reinforced by the proliferation of companies offering carbon credit purchases to consumers, leading some to believe that offsetting emissions is as effective as preventing them.

3. Study 2: Assessment of test-retest reliability

In Study 1, we developed a short, multidimensional scale to assess climate change knowledge (MACK-12). Multiple psychometric indices confirmed the scale's validity and reliability. Study 2 evaluated the test-retest reliability of the scale—determining whether our measure of climate change knowledge remained stable over time [see 48]. For this purpose, we recruited a subsample of Study 1 respondents to complete the questionnaire again. The methodology for Study 2 followed that of Study 1, with exceptions noted below.

3.1. Method

3.1.1. Participants and data collection

Two weeks after Study 1, a second data collection was conducted (August 8-9, 2024). Five hundred and two respondents completed the same 62-item questionnaire. Their sociodemographic characteristics are presented in Table 1. The study received approval from Université Laval's Ethics Committee (2022-253 Phase IV / 10-05-2024). Participants received thorough instructions and provided written informed consent.

3.1.2. Analysis

We used Pearson correlation to assess test-retest reliability of the MACK-12 by examining the correlation between scores (out of 60) achieved on the 12 selected items at each data collection time point. As in Study 1, we also examined item accuracy, discrimination index, corrected item-total correlation, and Cronbach's alpha to assess the scale's validity and reliability. All analyses were performed using post-stratification weights calculated for the subsample of 502 respondents.

3.2. Results and discussion

Table 2 presents item-level statistics for each MACK-12 item and mean accuracy across all items. Overall accuracy showed strong consistency between Studies 1 and 2, with only a 0.8% mean difference. Individual item performance was also highly comparable across both studies, with the maximum difference for any single item being 5.7%. This consistency suggests participants did not search for answers between their first and second questionnaire completions. Though one item slightly exceeded our 80% accuracy threshold, we retained it due to its minimal deviation (1.5% above threshold) and strong discriminating power.

As with Study 1, all 12 items of the short scale showed a high discrimination index ($\geq .320$) and adequate corrected item-total correlations with other items (all $r \geq .224$). Cronbach's alpha was .782, demonstrating adequate internal consistency [47]. A strong positive correlation emerged between the total scores on the MACK-12 from the first and second data collections, $r = .814$, $p < .001$, confirming strong test-retest reliability. These results from Study 2 further support the conclusion that the short multidimensional scale is a reliable tool for assessing climate knowledge.

4. Study 3: Validation in a new sample

Studies 1 and 2 focused on developing and evaluating the psychometric properties of the MACK-12, a short climate knowledge scale. In Study 3, we further assessed the scale's construct

438 validity by examining how questionnaire scores related to measures known or expected to correlate
439 with climate change knowledge. Unless otherwise specified, Study 3 used the same methods as
440 Study 1.

441 # 4.1. Method

442 ## 4.1.1. Participants and data collection

443 A new sample of 2,513 respondents completed the questionnaire between September 17,
444 2024, and October 12, 2024 (see Table 1 for their sociodemographic characteristics). Instead of
445 completing all 62 items from the initial pool, participants only answered the short climate
446 knowledge questionnaire. The MACK-12 was included in the 2024 online questionnaire of the
447 *Baromètre de l'action climatique*, an annual large-scale survey that assesses climate-related beliefs,
448 attitudes, and behaviors among Quebec's adult population [53]. The study received approval from
449 Université Laval's Ethics Committee (2022-253 Phase IV / 10-05-2024). Participants received
450 thorough instructions and provided written informed consent.

451 ## 4.1.2. Measures and analysis

452 We analyzed how scores on the MACK-12 correlated with measures of climate change
453 denial, environmental concern, perceived urgency of climate action in Quebec, and individual
454 climate-mitigation behaviors. Table 4 lists the items for each domain.

455 **Table 4. Distribution of climate-related beliefs, attitudes, and behaviors and their correlation with climate knowledge.**

456

	Fully agree	Strongly agree	Somewhat agree	Somewhat disagree	Strongly disagree	Fully disagree	I don't know/I prefer not to answer	Correlation with climate knowledge score (r_s)
Climate change denial								
Climate change is not scientifically proven.	88 (3%)[a]	77 (3%)	160 (6%)	463 (18%)	470 (19%)	1075 (43%)	181 (7%)	-.623***
Environmental concern								
I see myself as someone who is very concerned about environmental issues in general.	258 (10%)	343 (14%)	1071 (43%)	537 (21%)	121 (5%)	83 (3%)	100 (4%)	.226***
Perceived urgency to act against climate change								
Urgent action is needed in Quebec to fight climate change	686 (27%)	580 (23%)	792 (32%)	167 (7%)	67 (3%)	109 (4%)	112 (4%)	.454***

	I am currently doing this	Intention to do so within 1 year	No intention of doing so	Impossible in my situation	I don't know/ I prefer not to answer	Correlation with climate knowledge score (r_s)
Specific actions taken to limit one's climate footprint (composite score)						
Choose local products as much as possible	1544 (61%)	367 (15%)	329 (13%)	116 (5%)	158 (6%)	.306***
Minimize the use of gasoline-powered vehicles	1203 (48%)	333 (13%)	441 (18%)	425 (17%)	112 (4%)	
Minimize food waste	2128 (85%)	224 (9%)	89 (4%)	29 (1%)	44 (2%)	
Recycle	2328 (93%)	66 (3%)	66 (3%)	31 (1%)	22 (1%)	
Compost	1502 (60%)	309 (12%)	397 (16%)	228 (9%)	77 (3%)	
Choose reusable rather than disposable products	1867 (74%)	309 (12%)	193 (8%)	37 (1%)	107 (4%)	

Minimize meat consumption	981 (39%)	269 (11%)	1058 (42%)	93 (4%)	112 (4%)
Minimize consumption of animal products (eggs, milk, etc.) other than meat	586 (23%)	231 (9%)	1421 (57%)	138 (6%)	137 (5%)
Minimize energy consumption at home	1903 (76%)	265 (11%)	194 (8%)	63 (3%)	87 (3%)
Minimize air travel	1509 (60%)	121 (5%)	548 (22%)	153 (6%)	182 (7%)
Buy only what I need	1867 (74%)	351 (14%)	165 (7%)	31 (1%)	99 (4%)
Buy second-hand (used) products	1396 (56%)	269 (11%)	620 (25%)	52 (2%)	176 (7%)

Values represent the weighted number and percentage of respondents who selected each response option, except for the Correlation with climate knowledge score column, which represents Spearman's rank-order correlation between each environmental disposition variable and the score (out of 60) on the MACK-12.

[a]Percentages may not always equal to 100% due to rounding.

***$p < .001$

For items measuring climate change denial, environmental concern, and perceived urgency to act against climate change, response options ranged from 1 (fully agree) to 6 (fully disagree). Responses were reverse coded so that higher scores represented greater agreement. For items about specific climate footprint-reducing actions, response options were: 1) I am currently doing this (3 points), 2) I intend to do so within 1 year (2 points), 3) I have no intention of doing so (1 point), and 4) It is impossible in my situation (1 point). The scores from these 12 action-specific items were combined into a composite score. For all validation items (attitudes, beliefs, and behavior-related variables), participants could select "don't know" or "prefer not to answer." These responses were excluded from analyses, resulting in varying sample sizes across analyses (see Table 4).

We used Spearman's rank-order correlation to examine the relationship between MACK-12 scores (out of 60) and all previously mentioned variables. Following Study 1's approach, we conducted a three-level one-way ANOVA to assess whether climate knowledge varied by education level.

4.2. Results

Table 2 presents the statistics for each MACK-12 item and the mean accuracy across all items. Item accuracy ranged from 44.7% (SD = 49.7%) to 75.0% (SD = 43.3%). Overall accuracy was consistent with findings from Studies 1 and 2. Participants' confidence levels in their responses were similar to those in Study 1 (see S3 Table). All items demonstrated strong discrimination (index $\geq$ .418) based on overall MACK-12 accuracy. Most items showed satisfactory corrected item-total correlation ($r \geq .356$), with one exception: the item regarding Quebec's transportation sector as the largest greenhouse gas emitter (r = .104). The questionnaire achieved a Cronbach's alpha of .755.

Table 4 presents the distribution of participants' responses to attitudes, beliefs, and behavior-related variables, along with Spearman's rank-order correlation coefficients between these variables and MACK-12 performance. The correlational analyses revealed several significant relationships: a strong negative correlation between climate change knowledge and agreement that climate change is scientifically proven; a small-to-moderate positive association between knowledge and environmental concern; a moderate-to-strong positive relationship between knowledge scores and perceived urgency to address climate change in Quebec; and a moderate positive correlation between climate knowledge and participants' reported climate-friendly actions, as measured by the composite climate footprint variable.

Mean (± *SD*) climate knowledge scores (out of 60) were 43.0 (± 6.4), 44.3 (± 6.8), and 45.8 (± 7.0) for respondents with primary/secondary, college, and university education, respectively. The analysis revealed a small effect of education level on climate knowledge, $F(2, 2459) = 32.03$, $p < .001$, $\eta^2 = .025$, with scores differing significantly between all education groups (all $p < .001$).

4.3. Discussion

Psychometric analysis of the MACK-12 demonstrated adequate internal consistency, with Cronbach's alpha values aligning with those from Studies 1 and 2. The strong positive correlation between education level and questionnaire performance provided additional evidence of construct validity. Further validation came from the observed relationships between MACK-12 scores and participants' environmental attitudes, beliefs, and behaviors.

Climate change denial had the strongest correlation with climate knowledge scores. As expected from previous research demonstrating a link between climate knowledge and climate change skepticism [16,54], we found a negative relationship. This strong correlation, however,

suggests a challenge in distinguishing between knowledge and beliefs. While respondents may understand the scientific consensus on climate change, their lack of trust in this consensus may influence how they answer knowledge-based questions.

The moderate-strong positive relationship between climate knowledge and perceived urgency to act against climate change in Quebec aligns with Shi et al.'s [7] findings, which link understanding of climate change causes to acceptance of climate-friendly policies. Individuals with higher knowledge levels demonstrate greater awareness of both the climate crisis's severity and the urgent need for mitigation actions.

Our findings revealed a moderate association between climate knowledge and respondents' efforts to reduce their climate footprint. This aligns with several studies demonstrating links between knowledge and pro-climate behavior or behavioral intentions [5,23,26]. However, social desirability bias in self-reported pro-climate actions might have inflated this relationship [see 55].

Consistent with findings from Bostrom et al. [6] and Tobler et al. [16], concern about environmental problems correlated positively with climate change knowledge—though this correlation was the weakest among all tested variables related to attitudes, beliefs, and behaviors. This suggests that people may be highly concerned about the climate crisis (e.g., due to increasingly frequent extreme weather events worldwide) without necessarily possessing comprehensive knowledge about climate change's various dimensions. The relationship might have been stronger had our questions focused specifically on climate change concerns rather than environmental concerns in general.

Although the questionnaire demonstrated adequate reliability and validity, one item—about the transportation sector being Quebec's largest greenhouse gas emitter—did not meet the predetermined item-total correlation threshold ($r \geq .20$) in Study 3. Further analysis showed this was the only item where respondents with university or college degrees scored lower (53% and

52%, respectively) than those with primary or secondary education (57%). This unexpected pattern may be explained by workers in the transportation sector (truck drivers, bus drivers, and mechanics) having greater awareness of their industry's significant role in greenhouse gas emissions. Since these transportation careers typically don't require post-secondary education, this could explain why performance on this item correlates poorly with overall questionnaire scores—despite climate knowledge generally increasing with education level. We maintain that this item remains relevant for assessing climate change knowledge in Quebec's population and should be retained in the questionnaire.

5. General Discussion

This study aimed to develop and validate the MACK-12, a brief multidimensional scale for assessing climate change knowledge that also provides insights into climate literacy levels among Quebec adults. In Study 1, we selected twelve items from an initial pool of 62, using three criteria: accuracy, discrimination index, and corrected item-total correlation. These items span six knowledge dimensions: the greenhouse effect, evolution and causes of climate change, consequences of climate change, carbon footprint of individual actions, collective climate solutions, and development and accessibility of climate science. Study 2 confirmed the MACK-12's test-retest reliability, while Study 3 validated the scale by demonstrating correlations between overall scores and environmental attitudes, beliefs, and behaviors.

5.1. Multidimensional climate knowledge scale

Across all three studies, the MACK-12 demonstrated its effectiveness as a tool for measuring climate change knowledge. The scale provided consistent estimates of Quebec residents' knowledge levels in both test-retest measurements of the same individuals and assessments of two

different representative population samples. Additionally, the questionnaire showed satisfactory internal consistency throughout all three data collections.

While the MACK-12 measures six distinct dimensions, each item correlated positively with the combined score of the other 11 items. The MACK-12 scores also showed strong correlation with the initial 62-item questionnaire. In line with previous research on climate knowledge, the short scale demonstrated positive associations with respondents' education level [e.g., 16,25,50]. Further validating the questionnaire, results showed expected correlations: negative relationships with climate change denial [e.g., 54] and positive correlations with environmental concern [e.g., 16], perceived urgency to act on climate change [e.g., 7], and engagement in climate-friendly behaviors [e.g., 26]. These consistent relationships confirm that the questionnaire effectively measures overall climate change knowledge.

5.2. Climate knowledge in the province of Quebec

Based on the three studies, Quebec residents demonstrated an intermediate level of climate change knowledge, with a mean accuracy of 62% on the MACK-12. This finding is consistent with climate change knowledge levels reported in other Western countries, including the United States [22], Switzerland [16], and Germany [25].

In line with several studies showing gaps in public knowledge about the environmental impact of food products [e.g., 23,52,56], respondents showed the highest uncertainty when comparing greenhouse gas emissions between wheat and beef production. With the bio-food sector responsible for nearly 20% of greenhouse gas emissions in Quebec [57], enhancing public knowledge about the climate impact of dietary choices offers a significant opportunity for climate action.

In addition, more than two-thirds of respondents were not confident in identifying the IPCC as the most reliable source of climate change information. This highlights the need to raise awareness about the organization's vital role in advancing scientific knowledge, especially given the prevalence of climate disinformation [58,59]. The study also revealed that respondents' most common misconception was about carbon offsetting—specifically, whether compensating for greenhouse gas emissions is preferable to reducing them at the source. This finding aligns with research on compensatory green beliefs, which describes the mistaken idea that climate-friendly actions can offset the carbon emissions from environmentally harmful behaviors [60].

5.3. Implications for practice and research

To our knowledge, MACK-12 is the first validated tool to assess climate change knowledge among residents of the province of Quebec, Canada. In this part of the world where temperatures increase faster than the global average [61] and where key climate-friendly behaviors like public transit and active transportation remain uncommon [53], having an objective measure of citizens' climate knowledge is crucial for promoting effective mitigation and adaptation practices.

The MACK-12 scale helps researchers and decision-makers identify knowledge gaps, misconceptions, and awareness levels among Quebecers. This information supports targeted communication strategies, policy design, and behavior-change campaigns to effectively engage the public in sustainable actions. Additionally, the scale serves as a formative tool to highlight and discuss common climate misconceptions with key stakeholders, including decision-makers, educators, and professionals in climate-affected sectors (e.g., agriculture, healthcare, engineering). Future research could adapt and validate the scale for children and adolescents, helping identify knowledge gaps and inform targeted educational initiatives.

The scale enables rapid identification of climate knowledge gaps, offering valuable applications across interdisciplinary research in climate communication, education, and policy analysis. Researchers can incorporate it into large-scale observational studies alongside other measures of relevant concepts, such as personal values or political orientation [e.g., 22]. Additionally, the scale serves as a useful tool for experimental research. For example, researchers could examine how climate change knowledge moderates the effectiveness of various behavioral interventions, such as the influence of eco-labels on consumer choices.

While our scale was developed specifically for assessing climate change knowledge in Quebec, it can be adapted for other populations. Because some items address Quebec-specific climate issues, they would need to be modified for different contexts, and any adapted version would require validation. This adaptation process can be simplified by using our comprehensive initial item pool (see S1 File) and following our outlined methods to verify if the same 12 items (with appropriate adjustments) remain suitable. Cross-national validation of the questionnaire would enable meaningful comparisons of climate change knowledge across populations and help explain regional differences.

5.4. Strengths and limitations

This study's key strength lies in our methodological approach. We built upon previously validated questionnaires [16,25] to identify core climate knowledge domains, while enhancing their scope with new items and an important additional dimension—collective solutions to climate change. The questionnaire's scientific accuracy was validated by a climate change expert, and its clarity was confirmed through pre-testing with laypersons across different age groups and backgrounds. Moreover, our use of post-stratification weights allowed us to generate a representative portrait of climate knowledge across Quebec's population.

Unlike a dichotomous response scale, our Likert scale offered a more nuanced measure of respondents' confidence in their answers. We minimized guessing by including an "I don't know" option and maintaining an equal number of true and false statements. Furthermore, choosing a true/false format instead of an agree/disagree scale ensured we were measuring knowledge rather than attitudes [see 25].

This research has some limitations. While the MACK-12 is a valid measure of general climate change knowledge, its compact design means it cannot assess all climate knowledge domains comprehensively (e.g., knowledge of climate change's many potential consequences). Yet this brevity is also a strength—the scale can be readily integrated into broader studies of climate-related orientations (e.g., attitudes, behaviors) to effectively differentiate between individuals with varying levels of climate change knowledge.

Although a small proportion of respondents denied the reality of climate change, we retained these participants to maintain population representativeness. We acknowledge that these participants may have exhibited atypical response patterns. This highlights the inherent challenge of measuring climate knowledge independently from individual perceptions or beliefs [see also 21,37].

6. Conclusion

Studies examining the relationship between climate change knowledge and related dispositions (e.g., attitudes, beliefs, actions) typically rely on self-reported data. However, self-assessed knowledge is prone to biases, including overconfidence [50] and social desirability [55]. Objective measurements are therefore essential to accurately measure individuals' climate knowledge—especially since this knowledge is crucial for behavioral change and public support of climate-friendly policies [4,7,62,63]. Our study advances the field by developing the MACK-

642 12, a brief, multidimensional tool that can be easily incorporated into broader studies of related
643 characteristics such as political orientation or individualism [e.g., 22]. This new scale can also help
644 researchers evaluate the effectiveness of educational interventions aimed at enhancing climate
645 change knowledge.

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Supporting information

S1 File. The subscales and subdimensions assessed by the 62-item questionnaire.

S2 File. The 62-item questionnaire administered to participants in Study 1.

S3 Table. Distribution of responses on the MACK-12 according to the response scale (dichotomous or Likert) in Study 3.