frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 16 July 2025
DOI 10.3389/feduc.2025.1561574

OPEN ACCESS

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RECEIVED 16 January 2025
ACCEPTED 27 June 2025
PUBLISHED 16 July 2025

CITATION
Meekaew N and Saenkum D (2025) Bridging policy and practice in climate change education: evidence from Northeast Thailand. *Front. Educ.* 10:1561574. doi: 10.3389/feduc.2025.1561574

Bridging policy and practice in climate change education: evidence from Northeast Thailand

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Climate change presents significant challenges to vulnerable regions, yet educational systems often lack systematic approaches to climate change education (CCE), particularly in resource-constrained settings. While research has examined CCE implementation in developed countries, little is known about effective delivery in climate-vulnerable regions. This study investigates the implementation of CCE in Northeast Thailand, emphasizing the interaction among teacher training, institutional support, and resource accessibility in a developing context where climate impacts directly affect communities. The study employed a sequential explanatory mixed-methods approach, integrating quantitative survey data from 400 teachers with qualitative insights from semi-structured interviews and focus group discussions among 15 teachers and 5 school administrators. Data were analyzed using multiple regression analysis and thematic analysis to identify key predictors of CCE effectiveness and contextual implementation factors. Regression analysis revealed teacher training as the strongest predictor of effective CCE implementation, followed by institutional support and resource availability. The study showed significant differences between urban and rural areas, with 85% of rural schools reporting insufficient resources compared to 40% of urban institutions. Additionally, 60% of teachers reported actively incorporating climate-related topics into their teaching. These findings demonstrate that successful CCE implementation requires the alignment of targeted teacher professional development, supportive institutional frameworks, and equitable resource distribution. Based on these findings, the study recommends establishing regional CCE teacher training centers, implementing resource-sharing networks between urban and rural schools, and developing locally adaptive curricula. This research provides an evidence-based framework for strengthening climate education in developing contexts, offering practical insights for educational policymakers working in climate-vulnerable regions.

KEYWORDS

climate change, implementation barriers, teacher professional development, educational policy, resource constraints, Thailand

1 Introduction

Educational systems in developing countries face mounting pressure to address climate change impacts while struggling with resource constraints and systemic inequalities. Despite global recognition of education's role in climate resilience, significant implementation gaps persist in resource-limited settings, particularly affecting marginalized and rural communities (Reid, 2019; Bangay and Blum, 2010). These challenges reflect broader educational development issues in the Global South, where limited infrastructure, institutional capacity, and inadequate teacher preparation often hinder educational innovation and adaptation (Mónus, 2022; Nepraš et al., 2022).

While research has examined CCE implementation in developed countries, little is known about effective delivery in climate-vulnerable regions. For example, a study by Enke and Budke (2023) explored how geography curricula in Europe tackle climate change, highlighting various teaching methodologies and the integration of physical-geographical and socio-economic content in more developed contexts. However, the existing literature primarily reflects experiences from high-income countries, leaving significant gaps in understanding how resource-constrained educational systems can effectively implement CCE (Tulachom et al., 2015). This knowledge gap is particularly problematic since developing regions often face the most severe climate impacts, making effective climate education crucial for community resilience.

The successful implementation of CCE depends on the complex interplay between policy frameworks and practical implementation factors. Teachers, as primary implementers of educational initiatives, require comprehensive support systems to effectively translate climate education policies into classroom practice. However, in resource-constrained settings like Northeast Thailand, teachers often lack the necessary training, materials, and institutional backing to deliver effective climate education (Hung, 2022; Kelani, 2015). This challenge is particularly acute in rural areas, where educators must balance competing educational priorities while managing limited resources.

The intersection of educational development challenges and climate change vulnerabilities creates unique implementation barriers that remain understudied. These include limited institutional capacity for teacher training, resource allocation constraints, and challenges in adapting global educational frameworks to local contexts (UNESCO, 2021). Understanding these barriers is crucial for developing contextually appropriate educational interventions that can succeed within existing resource constraints (Ledley et al., 2017; Oliver and Adkins, 2020).

This study addresses these knowledge gaps by examining how educational development challenges shape CCE implementation in Northeast Thailand. The region exemplifies the educational development challenges facing climate-vulnerable areas, as one of Thailand's poorest regions experiencing severe climate vulnerabilities that intersect with existing socioeconomic disparities (Tammadid et al., 2023; Waqas et al., 2024). The region's educational system mirrors nationwide development patterns, where urban-rural inequalities significantly impact educational access and quality (Piyaman et al., 2017). Schools struggle with multiple implementation barriers, including inadequate resources, limited teacher professional development opportunities, and weak institutional support for climate-related curricula (Inpin et al., 2023).

A mixed-methods approach was chosen because the complex nature of CCE implementation requires both broad quantitative patterns to understand systemic trends and rich qualitative insights to capture contextual nuances and implementation experiences. The quantitative component identifies key implementation factors across a large sample. At the same time, the qualitative element provides depth in understanding how these factors operate in practice and how teachers navigate implementation challenges. Using this integrated approach, the study investigates three critical aspects of educational capacity: teacher preparation, institutional support mechanisms, and resource accessibility.

The research aims to (1) identify the determinants of effective CCE implementation in resource-constrained settings, (2) assess teacher preparedness and resource availability, and (3) develop evidence-based policy recommendations for enhancing climate education delivery in developing contexts. The findings contribute to understanding how developing regions can strengthen climate education despite resource constraints, offering practical insights for educational policymakers and practitioners working in similar contexts.

The study's focus on Northeast Thailand provides valuable insights into the challenges faced by developing regions in implementing specialized educational initiatives. By examining how local educational systems navigate resource constraints while attempting to address urgent climate challenges, this research offers lessons for other developing contexts struggling with similar educational development challenges. Through this investigation, we aim to bridge the gap between educational policy aspirations and practical implementation realities in climate change education.

2 Literature review

2.1 Theoretical framework and implementation challenges in resource-constrained settings

Climate Change Education (CCE) in developing countries requires theoretical frameworks that acknowledge both global pedagogical principles and local implementation realities. This study builds upon the synergistic interaction of constructivist learning theory, which emphasizes how students build climate knowledge through local experiences and cultural contexts (Gisore and Njurai, 2023); experiential learning theory, which turns resource constraints into pedagogical advantages by using direct environmental challenges as learning opportunities (Park et al., 2020); and transformative learning theory, which drives long-term behavioral change by encouraging critical examination of existing practices (Reilly et al., 2024; Leite, 2024).

The practical application of these integrated theories depends heavily on teacher preparation and institutional support, particularly in addressing infrastructure limitations and teacher preparation levels common in resource-constrained schools (DeCamp, 2024; Ferguson, 2022; Molthan-Hill et al., 2022). Problem-Based Learning (PBL) and Place-Based Education become particularly powerful when adapted to developing contexts, where strong connections to local environments can compensate for limited formal educational resources (Canlas and Kazakbaeva, 2023; Nusche et al., 2024).

However, the translation of CCE from policy to practice faces significant barriers in developing regions. Teachers serve as critical mediators between educational policies and classroom implementation, yet they often struggle with insufficient pre-service training, limited professional development opportunities,

and weak institutional support mechanisms (Hung, 2022; Kelani, 2015; Mbah et al., 2022). Research from Sub-Saharan Africa and Southeast Asia demonstrates how teachers must bridge sophisticated scientific concepts with local environmental realities while managing large class sizes and limited resources (Gugssa, 2023; Sedtha et al., 2023).

2.2 Global implementation patterns and development disparities

The global implementation of CCE reflects broader patterns of educational inequality between developed and developing nations. While international frameworks such as UNESCO's Education for Sustainable Development (ESD) promote universal climate education goals (Mochizuki and Bryan, 2015), implementation reveals significant North-South disparities in educational capacity and resources (Kioupi and Voulvoulis, 2019).

High-income countries like Finland and Sweden demonstrate successful integration of climate education into national curricula (Siponen et al., 2024; Yli-Panula et al., 2022), while developing nations face multiple implementation barriers including limited funding for teacher training, insufficient teacher preparation, weak institutional support systems, and difficulties adapting global frameworks to local contexts (Kelani, 2015; Læssøe and Mochizuki, 2015). Research from Sub-Saharan Africa illustrates how motivated teachers struggle with inadequate training and scarce teaching materials, patterns that emerge consistently across developing regions (Gugssa, 2023).

Innovative approaches such as transdisciplinary education have shown promise for enhancing climate change education by enabling knowledge exchange between students and scientific partners while completing research on real-world issues (Kubisch et al., 2022). Additionally, digital tools and science education apps may bridge gaps between scientific knowledge and public understanding, particularly in resource-limited settings (Moser and Dilling, 2019). Borg and Mayo (2023) advocate for transformative aesthetics in climate change education, emphasizing integration of science as part of addressing socio-ecological challenges through student agency and community action.

Critical factors for successful CCE implementation in developing contexts include contextualized teacher professional development, strong community engagement to compensate for formal institutional limitations (Nelson and Stroink, 2020), and addressing persistent challenges including assessment difficulties, competing educational priorities, and infrastructure gaps (Teixeira and Crawford, 2022; Waldron et al., 2020).

2.3 Thailand's policy framework and regional implementation challenges

Thailand has recognized CCE importance through its National Education Plan (2017–2036) and Climate Change Master Plan (2015–2050), aligning with global Sustainable Development Goals (Limsakul et al., 2024; Office of Natural Resources and Environmental Policy and Planning, 2015). Different government agencies have established complementary initiatives to operationalize these policies.

The Department of Climate Change and Environment introduced the Eco-School initiative (Environmental Education School for Sustainable Development), promoting environmental education through a Whole School Approach that integrates environmental considerations into policy, curriculum, campus management, and community engagement (Department of Environmental Quality Promotion, 2016). The Royal Initiative School Botanical Garden Project (RSPG) also fosters environmental consciousness through school-based botanical gardens, reflecting Thailand's comprehensive multi-agency approach to environmental education (Royal Speech Foundation Project, n.d.). Most recently, the Office of the Basic Education Commission has implemented the Green OBEC Environmental Education for Sustainable Development Project, providing systematic training and resources for teachers and educational personnel to enhance environmental management knowledge and sustainable development practices (Office of the Basic Education Commission, 2024). Despite these coordinated multi-faceted initiatives, implementation faces challenges due to unclear operational guidelines and lack of concrete long-term strategies, particularly concerning sustainability measures and inter-agency coordination. The integration of CCE into Thailand's educational system reveals significant urban-rural disparities. Urban schools generally have better resources and facilities, enabling more comprehensive implementation (Chankrajang and Muttarak, 2017), while rural schools face multiple barriers including limited teaching materials, inadequate infrastructure, and insufficient teacher training (Office of the Education Council Secretariat, 2019). Many educators lack specific preparation in climate science and environmental education pedagogy, particularly in rural areas with limited access to professional development.

Northeast Thailand (Isan) provides a critical case for examining how national CCE policies translate into practice within a climate-vulnerable context. The region experiences severe climate impacts including droughts, floods, and extreme temperatures (Babel et al., 2011), creating both urgency and opportunity for climate education. While these environmental challenges offer practical teaching examples, they also highlight implementation gaps between national policy aspirations and local capacity. The primary mechanism for implementing CCE has been through science and social studies curricula, supplemented by the Eco-School initiative, but unclear implementation guidelines and limited institutional support often result in climate-related topics remaining supplementary rather than core curriculum components (Buran and Jantakoon, 2024). Non-formal initiatives attempt to bridge implementation gaps but face challenges in reaching remote areas effectively (Kiatadisorn, 2023).

The intersection of national policy aspirations and regional implementation realities highlights the need for clearer implementation strategies and context-sensitive approaches to CCE, particularly in addressing stark urban-rural disparities that currently hinder effective delivery of climate change education in vulnerable regions.

TABLE 1 Climate indicators and extreme weather events in Northeast Thailand in 2015–2020.

Year	Average rainfall (mm)	Average temperature (°C)	Severe droughts (Incidents)	Flood incidents
2015	1,200	28.5	3	5
2016	1,100	28.7	2	7
2017	950	28.9	4	3
2018	1,400	29.2	1	8
2019	1,350	29.1	2	6
2020	1,250	29.3	3	5

Remark: Data for rainfall and temperature were obtained from the Thailand Meteorological Department's "Climatological Data for the Period 1981–2010" database (Thailand Meteorological Department, n.d.). Data for drought and flood incidents were compiled from the Office of the National Water Resources' "Annual Report on Water Resources Management 2021." (Office of the National Water Resources, 2021).

3 Materials and methods

3.1 Research design

This study employs a sequential explanatory mixed-methods design to explore the determinants of climate change education (CCE) effectiveness and its challenges in Northeast Thailand. In this design, quantitative data collection and analysis were conducted first, followed by qualitative data collection and analysis to help explain and interpret the quantitative findings (Creswell, 2021). The quantitative phase prioritized collecting broad survey data from teachers to identify key predictors of effective CCE implementation. The subsequent qualitative phase, involving interviews and focus group discussions with teachers and school administrators, provided deeper insights into how these predictors operate in practice and how teachers navigate implementation challenges. This design enabled a comprehensive understanding of statistical patterns and contextual factors influencing CCE effectiveness.

3.2 Settings

Northeast Thailand, known as Isan, represents one of the country's most climate-vulnerable regions, making it an ideal setting for examining CCE implementation challenges in developing contexts. The region's semi-arid climate, heavy reliance on agriculture, and socioeconomic challenges create a context where climate impacts directly affect communities, providing both urgency and practical relevance for climate education initiatives. The region has experienced increasing climate variability over recent years, with rising temperatures and more frequent extreme weather events. Table 1 presents comprehensive climate data demonstrating these trends between 2015–2020, showing average annual rainfall ranging from 950 mm to 1,400 mm, steadily increasing temperatures from 28.5°C to 29.3°C, and persistent patterns of severe droughts (1–4 incidents annually) and floods (3–8 incidents annually).

This climate variability directly impacts the region's predominantly rain-fed agricultural sector, which forms the backbone of the local economy but remains highly sensitive to climate fluctuations. Erratic rainfall patterns have become a significant concern, with prolonged dry spells severely reducing crop yields and threatening food security, while heavy rainfall and floods damage infrastructure, homes, and farmlands, exacerbating poverty levels. Rising temperatures have compounded these challenges, contributing to heat stress on crops and livestock, creating not only environmental concerns but also significant socio-economic threats to local populations.

The educational landscape in Northeast Thailand reflects broader national patterns of urban-rural inequality while operating within Thailand's climate education policy framework. Operating within Thailand's established climate education policy framework, the region demonstrates significant implementation challenges despite national policy support. The region's educational system demonstrates significant disparities that directly impact CCE implementation capacity. Urban schools generally have better resources and facilities, enabling more comprehensive implementation of climate education programs (Chankrajang and Muttarak, 2017), while rural schools face multiple barriers, including limited teaching materials, inadequate infrastructure, and insufficient teacher training (Office of the Education Council Secretariat, 2019). Many educators lack specific preparation in climate science and environmental education pedagogy, particularly in rural areas with limited access to professional development. Teachers frequently report limited professional development opportunities focusing on climate science or sustainability education, creating gaps in their ability to equip students with knowledge and skills to adapt to changing climate conditions. Non-formal initiatives, including community workshops and awareness campaigns, attempt to bridge implementation gaps but face challenges in reaching remote areas effectively (Kiatadisorn, 2023).

Despite these challenges, Northeast Thailand offers significant potential for impactful climate change education. The region's strong community networks and reliance on traditional agricultural knowledge provide a foundation for localized educational strategies, while the direct experience of climate impacts provides authentic learning opportunities that many developed regions lack. Students can observe and analyze real environmental changes in their communities, from changing rainfall patterns affecting family farms to adaptation strategies employed by local farmers. This contextual richness offers unique pedagogical advantages for experiential and place-based learning approaches, though realizing this potential requires adequate teacher preparation and institutional support. The intersection of national policy aspirations and regional implementation realities highlights the need for clearer implementation strategies and context-sensitive approaches to CCE, particularly in addressing the stark urban-rural disparities that currently hinder effective delivery of climate change education in this climate-vulnerable region.

3.3 Population and sampling

The research focused on teachers working in Northeast Thailand's primary and secondary schools, a region where climate change education (CCE) holds particular significance due to its environmental vulnerabilities. The study population encompassed

educators from diverse teaching environments, reflecting the region's varied educational landscape. This diversity was essential for understanding how CCE implementation differs across different school contexts and geographical settings.

The sampling process followed a sequential mixed-methods design. For the quantitative phase, stratified random sampling was employed to ensure representative coverage of the region's educational diversity. Sample size was determined through power analysis ($\alpha = 0.05$, $\beta = 0.80$, medium effect size), indicating 400 teachers would provide adequate statistical power for regression analysis. Schools were stratified based on geographical location (urban or rural), school size according to official OTEPC classifications (small: ≤119 students, medium: 120–719 students, large: 720–1,679 students, extra-large: ≥1,680 students) (Office of the Teacher Civil Service and Educational Personnel Commission, 2024), and institutional affiliation (government institutions under OBEC, local administrative organizations, or private institutions).

Within each stratum, schools were randomly selected using random number generation, followed by random selection of teachers within selected schools. The final sample maintained proportional representation: 52% urban/48% rural schools, 30% small/40% medium/30% large schools, and 80% government/15% LAO/5% private institutions, closely reflecting the regional distribution of educational institutions in Northeast Thailand.

The qualitative phase employed a more targeted approach through purposive sampling, selecting 20 participants with specific expertise and experience in CCE implementation. This sample comprised 15 teachers and 5 school administrators, chosen based on their demonstrated involvement in climate-related education and professional development activities. The selection criteria emphasized participants' experience teaching climate-related content, engagement with CCE professional development programs, and proven track record in implementing climate education initiatives.

These qualitative participants contributed to the study through semi-structured interviews and focus group discussions. The smaller, more focused qualitative sample allowed for an in-depth exploration of CCE implementation experiences, challenges, and successes. The combination of teachers and administrators in the qualitative sample provided complementary perspectives on classroom-level implementation and institutional support mechanisms.

The mixed-methods sampling approach served multiple research objectives. The quantitative sample provided the breadth needed to understand regional patterns and relationships between variables. In contrast, the qualitative sample offered the depth required to understand the nuances of CCE implementation in different contexts. This complementarity between sampling approaches strengthened the study's ability to provide generalizable findings and rich, contextual insights into the challenges and opportunities of implementing climate change education in Northeast Thailand.

3.4 Data collection

This study collected data through a sequential explanatory mixed-methods approach, combining quantitative surveys with qualitative interviews and focus groups. The research team gathered data directly from schools to ensure high response rates and data quality. The quantitative phase involved administering structured questionnaires to 400 teachers across Northeast Thailand. The questionnaire was developed based on an extensive literature review and validated through expert review and pilot testing. It comprised five sections using 5-point Likert scales (1 = strongly disagree to 5 = strongly agree): (1) teacher characteristics including demographic information, (2) Teacher knowledge of climate change with 15 items (e.g., "I understand the basic science of climate change"), (3) Teacher attitudes toward CCE with 15 items (e.g., "Climate change education is crucial for students' future"), (4) school ecosystem factors with 25 items (e.g., "My school provides adequate resources for teaching climate topics"), and (5) CCE effectiveness with 15 items (e.g., "I can effectively integrate climate topics into my lessons").

The qualitative phase collected data through two complementary methods involving 20 participants (15 teachers and 5 school administrators). First, semi-structured individual interviews (45–60 min each) explored teachers' personal experiences with CCE implementation, perceived barriers and enablers, resource utilization strategies, and professional development needs. Second, focus group discussions (90 min each) were conducted with subsets of these participants to examine institutional factors, community influences, resource management strategies, and policy implementation challenges. All interviews and focus groups were audio-recorded with participant consent and transcribed verbatim for analysis.

Quantitative and qualitative data collection took place between February to May 2024, with pilot testing conducted 1 month prior to ensure instrument reliability. All data collection procedures followed ethical guidelines approved by the Institutional Ethics Committee, with particular attention to participant confidentiality and informed consent.

3.5 Data analysis

The study employed an integrated mixed-methods analytical approach to examine the implementation of climate change education (CCE) in Northeast Thailand. By combining quantitative and qualitative analyses, we comprehensively understood the statistical relationships and the underlying contextual factors influencing CCE effectiveness.

The quantitative analysis proceeded through three systematic stages using SPSS version 28 software. First, we conducted descriptive statistical analysis to understand the basic patterns in our data, examining key variables such as teacher preparedness, institutional support, and attitudes toward CCE. This initial analysis helped us establish the fundamental characteristics of our study population and their relationship to CCE implementation.

Second, regression was analyzed to identify the strongest predictors of effective CCE implementation. This statistical modeling revealed how teacher knowledge, resource availability, and institutional support—influence CCE success. The regression analysis was particularly valuable in quantifying the relative importance of each factor.

To ensure the quality of our analysis, several validation measures were implemented. The Cronbach's alpha coefficient calculated across all questionnaire sections was 0.78, indicating acceptable internal consistency reliability. The study examined Variance Inflation Factors (VIF) and tolerance values to assess multicollinearity among predictor variables. All VIF values were below 5 (ranging from 1.24 to 2.31), and tolerance values were above 0.2 (ranging from 0.43 to 0.81), indicating no serious multicollinearity concerns among the predictor variables. Additionally, pilot testing was conducted with a smaller respondent group, using their feedback to refine the survey instrument and ensure its alignment with our research objectives. The pilot testing helped identify potential ambiguities in question wording and allowed us to make necessary adjustments before the primary data collection phase.

The qualitative analysis followed a structured thematic approach using ATLAS.ti software. A comprehensive coding framework was developed based on our research objectives and initial data review. This framework guided our detailed interview and focus group transcript analysis, allowing us to identify key themes related to CCE implementation barriers, innovative teaching practices, and institutional challenges.

The thematic analysis proceeded methodically through coding, pattern identification, and theme development. ATLAS.ti facilitated this process by helping us organize and categorize the data systematically, leading to the emergence of nuanced themes that captured the complexity of CCE implementation in schools.

Additionally, the study strengthened the credibility of our findings through methodological triangulation. This process systematically compared themes from our qualitative analysis with our quantitative results. For example, when teachers in interviews described challenges with resource limitations, we cross-referenced these accounts with our survey data about institutional support. Integrating different data sources provided a more complete and validated understanding of educators' challenges in implementing CCE.

4 Results

4.1 Descriptive statistics of participants

This study gathered data from 400 teachers across Northeast Thailand's primary and secondary schools, capturing a diverse cross-section of educators who shape climate change education (CCE) in the region. The demographic composition of our sample reveals important patterns that influence how CCE is implemented across different educational contexts.

The age distribution of participants reflects the generational diversity within Thailand's teaching workforce. The majority of teachers (58%) were in their career prime, aged 31–50, suggesting a sample with substantial teaching experience. Younger teachers under 30 constituted 25% of participants, bringing potentially newer pedagogical approaches to CCE, while 17% were over 50, contributing experienced perspectives to our understanding of climate education implementation.

Teaching experience among participants showed a balanced distribution that enriched our analysis of CCE implementation. The largest group (45%) had 11–20 years of experience, providing insights from educators who witnessed environmental education's evolution in Thailand. Those with less than 10 years' experience (32%) offered perspectives on newer approaches to climate education, while highly experienced teachers with over 20 years (23%) contributed valuable long-term views on educational change.

The gender composition of our sample (68% female, 32% male) mirrors the broader feminization of the teaching profession in Thailand, particularly at the primary level. This gender distribution provides an important context for understanding how CCE is implemented across different classroom settings.

Educational qualifications among participants reflected typical patterns in Thai teacher preparation, with most holding bachelor's degrees (72%). A significant proportion of master's degrees (25%) suggests substantial advanced training among some participants, while a small group (3%) held other qualifications. This distribution helps us understand the formal preparation teachers receive for implementing CCE.

The study achieved near-equal representation between urban (52%) and rural (48%) schools, allowing for meaningful comparisons of CCE implementation across different geographic contexts. Similarly, the balanced distribution across school sizes—small (30%), medium (40%), and large (30%)—enabled analysis of how institutional capacity affects climate education delivery.

A particularly notable finding emerged in CCE engagement levels, where 60% of teachers reported actively incorporating climate-related topics into their teaching. However, this engagement showed a clear urban-rural divide, with rural teachers reporting lower levels of CCE implementation. This disparity appears linked to specific challenges these teachers identified, particularly in accessing resources and training opportunities for climate education.

TABLE 2 Teacher knowledge of climate change.

Knowledge level	Number of teachers (*n*)	Percentage (%)
High knowledge	160	40
Moderate knowledge	180	45
Low knowledge	60	15
Total	400	100

4.2 Teacher knowledge and attitudes toward climate change education

The analysis revealed complex relationships between teachers' knowledge, attitudes, and ability to implement effective climate change education (CCE). Understanding these relationships requires examining the quantitative patterns in our survey data and the rich contextual insights from our qualitative interviews.

The quantitative data in Table 2 provided a broad overview of varying teacher knowledge about climate change across the sample. Table 2 shows that 40% demonstrated high knowledge levels, 45% showing moderate understanding, and 15% indicating limited

TABLE 3 Teacher's perception on resource availability.

Resource availability	Number of teachers (*n*)	Percentage (%)
Sufficient resources	120	30
Limited resources	200	50
No resources	80	20
Total	400	100

knowledge of climate science and its educational applications. This numerical understanding of the prevalence of knowledge levels was crucial. Furthermore, the quantitative analysis revealed that teachers' knowledge levels significantly correlated with their confidence in teaching climate-related topics and their likelihood of incorporating CCE into their regular teaching practice, establishing what relationships exist across the larger teacher population.

Teachers' attitudes toward CCE were generally positive, with 75% strongly believing in its importance. However, the qualitative data provided contextual depth to these positive attitudes, revealing that their ability to act on them often faced institutional barriers. Our quantitative analysis identified a clear relationship between institutional support and teachers' motivation to implement CCE, with 30% of the sample reporting sufficient resources being significantly more likely to express positive attitudes. In contrast, teachers in schools with limited resources (50%) or no resources (20%) often expressed frustration despite their positive attitudes toward CCE.

The qualitative data helped explain these patterns through teachers' lived experiences and narratives, illustrating the mechanism behind the quantitative observations. For example, one teacher with high knowledge levels and positive attitudes explained: "I understand the importance of teaching about climate change, and I want to do more, but without proper teaching materials, it is challenging to translate this knowledge into effective lessons." (T-09). This sentiment was particularly common among rural teachers, who often demonstrated a strong commitment to CCE despite facing significant resource constraints.

The qualitative insights also showed how the relationship between knowledge, attitudes, and implementation appeared strongest when supported by institutional frameworks. One urban teacher said: "Having the knowledge and the school's support makes a huge difference. When our principal actively encourages climate education and provides resources, it reinforces our commitment to teaching these topics." (T-12). Conversely, teachers in less supportive environments often struggled to maintain their initial enthusiasm despite having strong knowledge and positive attitudes.

Additionally, qualitative analysis also revealed how teachers' attitudes toward CCE evolved with experience. Despite challenges, those who successfully integrated climate topics into their teaching often developed more positive attitudes over time. One rural teacher shared: "At first, I was uncertain about teaching climate change but seeing how students respond to local environmental examples has made me more confident and enthusiastic." (T-14).

These findings suggest that while teacher knowledge and positive attitudes are crucial foundations for effective CCE implementation, they must be supported by adequate resources and institutional backing to translate into successful teaching practices. This comprehensive understanding points to the need for comprehensive support systems that address teachers implementing CCE's intellectual and practical needs.

4.3 Institutional support and resource availability

The analysis revealed significant disparities in how schools support and resource climate change education (CCE) implementation across Northeast Thailand. The patterns we observed suggest that institutional support and resource availability are deeply interconnected, with each factor influencing the other in ways that ultimately affect teaching effectiveness. The mixed-methods approach allowed us to quantify these disparities and provide rich qualitative context to understand their impact.

The quantitative analysis in Table 3 showed a clear stratification of resource availability across schools. Among the 400 teachers surveyed, 30% reported having sufficient resources for effective CCE implementation, including teaching materials, digital tools, and curriculum support. However, half of the respondents (50%) indicated they worked with limited resources, while one-fifth (20%) reported a complete absence of teaching resources for climate education. This quantitative distribution reveals a concerning pattern of resource inequality that affects teachers' ability to deliver effective climate education.

The urban-rural divide emerged as a crucial factor in resource distribution. Urban schools generally demonstrated better resource availability, with 65% of urban teachers reporting at least moderate access to teaching materials and technological tools. In contrast, rural schools faced more severe resource constraints, with 85% of rural teachers reporting insufficient or no access to specialized CCE materials. This quantitative disparity manifests in several ways, which the qualitative data then richly illustrated:

Digital resources: urban schools typically had better access to computers, internet connectivity, and digital learning platforms, enabling teachers to incorporate diverse teaching methods. Rural teachers often lacked these basic technological tools, limiting their ability to access and share educational resources.

Teaching materials: while urban schools frequently had dedicated budgets for environmental education materials, rural teachers often resorted to creating their own resources. As one rural teacher explained: "We make do with what we have—using local newspapers, collecting environmental samples, and creating our worksheets. It is time-consuming but necessary because we have no budget for proper materials." (T-03). One urban teacher clearly articulated the impact of adequate resources on teaching effectiveness: "When we have proper teaching materials, students are more engaged and I can demonstrate concepts effectively" (T-11). This contrasts sharply with the resource constraints described by rural teachers.

Professional development: the availability of institutional support for teacher training showed similar patterns of inequality. Urban teachers reported more frequent access to professional development opportunities, while rural teachers

often missed crucial training sessions due to distance and resource constraints.

Administrative support: this extended beyond material resources, with institutional backing varying significantly across schools. Those demonstrating strong administrative support exhibited several key characteristics that enhanced CCE implementation: they allocated dedicated time for climate education planning and implementation, provided regular opportunities for teacher collaboration, ensured clear integration of climate topics into curriculum planning, and maintained active engagement with community environmental initiatives. These administrative support elements created an enabling environment for effective climate education delivery.

These findings point to a complex relationship between resource availability and institutional support. While some schools with limited resources demonstrated strong institutional commitment to CCE through creative problem-solving and community engagement, the qualitative data revealed that lacking basic teaching materials and professional development opportunities often undermined these efforts. As one administrator noted: "We want to prioritize environmental education, but without adequate resources, our teachers can only do so much." (A-02). This statement underscores the practical limitations imposed by the quantitative resource shortages.

The combined quantitative and qualitative data suggests that addressing these disparities requires a multifaceted approach considering material resources and institutional support structures. Successful CCE implementation depends not only on the availability of teaching materials but also on creating supportive institutional environments that enable teachers to utilize these resources effectively.

4.4 Determinants of effective CCE implementation

Prior to regression analysis, correlations among study variables were examined. Table 4 presents descriptive statistics and correlations among the six variables included in the analysis.

The correlation analysis revealed that CCE effectiveness showed the strongest relationships with teacher training ($r = 0.52$, $p < 0.01$) and institutional support ($r = 0.48$, $p < 0.01$), followed by moderate correlations with resource availability ($r = 0.38$, $p < 0.01$) and teacher knowledge ($r = 0.31$, $p < 0.01$). Class size showed a weak negative correlation with CCE effectiveness ($r = -0.18$, $p < 0.01$).

To identify the strongest predictors of CCE implementation, multiple regression analysis was conducted. The analysis shown in Table 5 identified three key factors that significantly predict climate change education's successful implementation. Both the statistical evidence from the quantitative analysis and teachers' lived experiences captured through qualitative interviews supported these findings. The regression analysis revealed a clear hierarchy of influence among these predictors, while qualitative data helped explain how these factors work in practice.

Teacher training emerged as the strongest predictor of effective CCE implementation ($\beta = 0.34$, $p < 0.01$). This robust statistical relationship suggests that for every standard deviation increase in teacher training, CCE effectiveness increased by 0.34 standard deviations, holding other factors constant. The qualitative data helped explain why this relationship is so strong. Teachers consistently described how specialized training transformed their teaching practice, particularly when it combined theoretical knowledge with practical application. As one experienced teacher explained: "After attending a workshop on climate change, I finally felt confident discussing environmental issues in class. The practical examples they shared were beneficial." (T-15). This confidence translated into more innovative teaching approaches and better student engagement. Another teacher also emphasized the local relevance aspect: "Training helped me understand not just what to teach, but how to make it relevant to our local conditions" (T-08). This sentiment reinforces how effective training programs must connect global climate science with local environmental realities.

Institutional support showed the second strongest influence ($\beta = 0.29$, $p < 0.05$), demonstrating how school-level backing shapes CCE implementation. The statistical relationship indicates that stronger institutional support significantly enhances teaching effectiveness, even after accounting for other factors. Teachers' narratives from the qualitative sample illuminated how this support manifests in daily practice and what consequences its absence entails. Those with strong administrative backing described feeling empowered to experiment with new teaching methods and seek additional resources. However, the absence of such support often led to diminished effort and enthusiasm. As one teacher noted: "My principal is more focused on test scores than environmental education. Without their backing, it is hard to prioritize climate topics." (T-07). This qualitative insight provided a crucial layer of understanding to the quantitative correlation.

Resource availability emerged as the third significant predictor ($\beta = 0.21$, $p < 0.05$). While its statistical influence was smaller than teacher training or institutional support, qualitative data revealed its importance in enabling effective implementation. Teachers consistently described how access to appropriate materials and tools shaped their ability to deliver engaging lessons. However, this relationship showed important geographic variations, with rural teachers facing challenges in accessing resources despite their motivation to teach climate topics effectively.

These three predictors work together synergistically. Our integrated analysis suggests that while each factor independently influences CCE implementation, their combined effect is particularly powerful. For example, teachers who received comprehensive training were better able to utilize available resources effectively, but this effect was amplified when they also had strong institutional support. This interaction between predictors helps explain why some schools achieve more successful CCE implementation than others, even with similar resource levels.

The geographic disparities in these predictors warrant particular attention. Rural teachers consistently reported less access to all three enabling factors—training opportunities, institutional support, and teaching resources. This compound disadvantage helps explain the urban-rural gap in CCE implementation effectiveness, suggesting that policy interventions must simultaneously address all three factors to achieve meaningful improvement in rural schools.

TABLE 4 Descriptive statistics and correlations among study variables.

Variable	M	SD	1	2	3	4	5	6
1. CCE effectiveness	3.42	0.78	–					
2. Teacher training	2.86	0.92	0.52**	–				
3. Institutional support	3.15	0.85	0.48**	0.41**	–			
4. Resource availability	2.73	0.96	0.38**	0.33**	0.56**	–		
5. Teacher knowledge	3.68	0.72	0.31**	0.45**	0.28**	0.24**	–	
6. Class size	35.2	8.4	−0.18**	−0.15**	−0.22**	−0.28**	−0.08	–

N = 400. **$p < 0.01$, $p < 0.05$. Variables 1–5 measured on 5-point Likert scales. Class Size = average number of students.

TABLE 5 Regression analysis of predictors of effective CCE implementation with supporting qualitative insights.

Variable	Standardized coefficient (β)	Significance (*p*-value)	Supporting qualitative evidence	Participant ID
Teacher training	0.34	<0.01	"After attending a workshop on climate change, I finally felt confident discussing environmental issues in class. The practical examples they shared were beneficial."	T-15
			"Training helped me understand not just what to teach, but how to make it relevant to our local conditions."	T-08
Institutional Support	0.29	<0.05	"Having the knowledge and the school's support makes a huge difference. When our principal actively encourages climate education and provides resources, it reinforces our commitment."	T-12
			"My principal is more focused on test scores than environmental education. Without their backing, it is hard to prioritize climate topics."	T-07
Resource availability	0.21	<0.05	"We make do with what we have—using local newspapers, collecting environmental samples, and creating our worksheets. It is time-consuming but necessary because we have no budget for proper materials."	T-03
			"When we have proper teaching materials, students are more engaged and I can demonstrate concepts effectively."	T-11
Teacher knowledge	0.15	0.07	"I understand the importance of teaching about climate change, and I want to do more, but without proper teaching materials, it is challenging to translate this knowledge into effective lessons."	T-09
Class size	−0.10	0.15	"With 45 students in my class, it's difficult to do hands-on climate activities that would be more effective."	T-06

Model $R^2 = 0.42$, $F(5,394) = 58.7$, $p < 0.001$. Participant IDs: T = Teacher, A = Administrator. All quotes represent themes that emerged across multiple participants.

The table illustrates that teacher training had the highest standardized coefficient ($\beta = 0.34$). Teachers also identified resource availability as a crucial enabler or barrier. While 30% of teachers reported sufficient resources, the remaining 70% struggled to deliver engaging lessons due to inadequate materials. One rural teacher shared: "We have to rely on printed handouts or create our materials because no official resources are available." (T-16).

While class size and teacher knowledge did not emerge as statistically significant predictors of CCE implementation in our regression model, qualitative insights revealed that these factors still present practical challenges for some teachers. For instance, one teacher noted the difficulties imposed by large classes: "With 45 students in my class, it's difficult to do hands-on climate activities that would be more effective" (T-06). This suggests that while these factors may not predict overall implementation success across the broader sample, they can still create meaningful barriers in specific classroom contexts.

In summary, the integrated findings, as presented in Table 6, highlight the multifaceted challenges and opportunities in implementing climate change education in Northeast Thailand. To consolidate these insights, Table 6 provides an integrated summary of the key quantitative and qualitative findings, synthesizing how themes such as teacher training, institutional support, and resource availability converge to shape the effectiveness of climate education implementation.

5 Discussion

The integrated findings from this study, summarized in Table 6, provide valuable insights into the systemic and contextual challenges of implementing Climate Change Education (CCE) in resource-constrained settings. By offering broad statistical patterns and rich contextual narratives, our mixed-methods approach enabled a comprehensive understanding of these challenges. These findings point to three critical areas requiring focused policy attention: teacher professional development, institutional support frameworks, and resource distribution, particularly in addressing urban-rural disparities. The implications of these findings offer

TABLE 6 Integration of quantitative findings and qualitative findings with participant transcripts.

Theme	Quantitative findings	Qualitative insights	Supporting evidence	Integration
Teacher training	Strongest predictor ($\beta = 0.34$, $p < 0.01$); 60% of teachers actively incorporating CCE after training	Teachers highlighted that workshops combining theory and practical application increased their confidence and teaching effectiveness.	See Supplementary material A.1 (T-15, T-08, T-14)	Training impacts not only technical knowledge but also teachers' confidence and classroom innovation, making it a cornerstone for CCE success.
Institutional Support	Second strongest predictor ($\beta = 0.29$, $p < 0.05$); Schools with formal climate plans showed 40% higher implementation	Teachers in supportive schools reported motivation to integrate CCE, while those lacking support described diminished enthusiasm.	See Supplementary material A.2 (T-12, T-07, A-03)	Institutional support amplifies the effectiveness of trained teachers, emphasizing the need for administrative alignment with CCE objectives.
Resource availability	70% limited/no resources; 85% rural vs. 40% urban inadequate resources; Significant predictor ($\beta = 0.21$, $p < 0.05$)	Rural teachers creatively used local materials but expressed frustration over inadequate resources and unequal distribution.	See Supplementary material A.3 (T-03, T-11, T-13)	Resource shortages disproportionately hinder rural schools, necessitating targeted resource allocation policies to bridge urban-rural gaps.
Urban-rural disparities	Rural schools: 85% inadequate resources, 60% limited PD access; Urban: 40% inadequate resources, 20% limited PD	Rural teachers innovated under constraints but faced compounding disadvantages due to isolation and infrastructure gaps.	See Supplementary material A.4 (T-05, T-04, A-01)	The systemic inequalities that undermine rural CCE implementation, requiring multi-level interventions for equitable access to training and resources.
Knowledge-implementation gap	40% high knowledge but implementation varied by support; Knowledge non-significant predictor ($\beta = 0.15$, $p = 0.07$)	Teachers with strong knowledge still struggled to implement CCE due to institutional and resource barriers.	See Supplementary material A.5 (T-09, T-06, T-10)	Knowledge alone is insufficient; systemic support must complement teacher expertise to achieve effective CCE outcomes.
Community engagement	Schools with community partnerships: 35% higher student engagement; 55% reported family involvement improved outcomes	Local connections transform CCE from academic exercise to lived family knowledge	See Supplementary material A.6 (T-11, T-15, T-12)	Community integration enhances relevance and creates reinforcement beyond classroom settings

Quantitative findings based on analysis of 400-teacher survey. Qualitative insights from 15 teacher interviews and 3 focus groups (February to May 2024). Complete participant transcripts and thematic analysis provided in Supplementary material.

concrete policy recommendations aimed at strengthening CCE implementation and ensuring its sustainability in the long term.

Teacher training emerged as the strongest predictor of effective CCE implementation ($\beta = 0.34$, $p < 0.01$), emphasizing the crucial role of professional development in bridging the gap between policy expectations and classroom practice. The regression model explained 42% of variance in CCE implementation effectiveness ($R^2 = 0.42$), indicating substantial explanatory power for the identified predictors and suggesting that teacher training, institutional support, and resource availability account for nearly half of the variation in implementation success. This result aligns with the literature that underscores the importance of specialized teacher training, particularly in resource-constrained regions where teachers often lack formal preparation in environmental education (Gisore and Njurai, 2023; Hung, 2022). Current training programs focus on generic content, but the qualitative data consistently revealed that teachers in vulnerable regions need specialized training that directly connects climate science with local environmental realities to feel confident and effective. For instance, in Northeast Thailand, where challenges such as droughts and floods are prevalent, professional development should include localized training that emphasizes practical application. Based on this compelling evidence, we recommend the establishment of regional CCE teacher training centers catering specifically to teachers in these regions. These centers should provide specialized training on climate science and its local implications, ideally linked to universities, NGOs, and community-based organizations working on climate change adaptation. Additionally, establishing regional teacher networks would facilitate ongoing knowledge-sharing between experienced and novice educators, reinforcing the importance of professional learning communities. Furthermore, education authorities should collaborate with local environmental experts and organizations to develop area-specific training materials that reflect immediate environmental challenges and practical solutions, ensuring CCE is perceived as an immediate and relevant issue in line with place-based education models (Park et al., 2020). The importance of teacher training as the key to effective CCE implementation is further emphasized by the converging evidence from both statistical analysis and the detailed accounts of teachers' experiences, demonstrating that specialized and context-sensitive professional development is essential.

In addition to teacher training, institutional support is pivotal in CCE implementation. The quantitative analysis found that institutional support significantly influenced CCE implementation ($\beta = 0.29$, $p < 0.05$), showing its broad impact across the surveyed schools. The study also found that schools with formal climate action plans were more successful in incorporating climate change into their curricula and activities. This finding supports the literature emphasizing the need to systematically integrate CCE into school policies (UNESCO, 2021). Schools with clear guidelines

and institutional backing are better equipped to implement climate education effectively. Therefore, we recommend that national policies should mandate the development of formal climate action plans in schools. These plans should be integrated into school policies and explicitly outline specific steps for incorporating climate change into curricula, extracurricular activities, and school management. Schools with formal climate action plans are more likely to engage with climate education holistically, involving not only the curriculum but also campus management, energy use, waste management, and community engagement.

To support these efforts, education authorities at both national and local levels should provide technical support and resources for schools to develop and implement their climate action plans. This could include giving clear guidelines, training programs for administrators, and resources for student involvement in school-wide environmental initiatives. The role of administrative support in fostering an enabling environment for CCE is well-documented in the literature, where schools with strong institutional support demonstrated more significant success in integrating climate change into school life (Leite, 2024). Our study's combination of quantitative correlation and qualitative explanation strengthens this argument for robust institutional backing.

The study also revealed significant disparities between urban and rural schools, creating a "compound disadvantage" for rural institutions. Rural schools face compound disadvantages in resources, professional development access, and institutional support, aligning with broader patterns of rural educational inequality (Piyaman et al., 2017). To address these disparities, we strongly recommend targeted funding to ensure that rural schools have the necessary resources, including teaching materials, digital tools, and climate-specific curricula. Technology infrastructure development, particularly internet connectivity and digital tools, is especially crucial in these underserved areas. The importance of bridging the digital divide in education is widely discussed in literature, and this study reaffirms the need for better technological infrastructure in rural schools.

Public-private partnerships can play a key role in alleviating these disparities by providing schools with access to resources, technologies, and expertise. For example, businesses focused on sustainability could collaborate with schools to develop educational tools, sponsor climate education programs, or fund renewable energy projects. These partnerships are particularly crucial in rural areas with more pronounced resource limitations. Additionally, creating resource-sharing networks between urban and rural schools could help ensure that rural schools have access to materials and training opportunities, thereby promoting greater equity in CCE delivery.

The successful implementation of CCE policies requires careful coordination across different governance levels. While national policies can set clear guidelines and standards for CCE, local authorities must have the flexibility to adapt these frameworks to meet the specific needs of their communities. The findings of this study align with the literature on contextualized education policies, which argue for the importance of adapting national frameworks to local conditions (Mbah et al., 2022). For example, regions with distinct climate challenges, such as Northeast Thailand, should be allowed to tailor the curriculum and teaching methods to address their unique environmental issues, such as droughts, floods, and extreme temperatures. This emphasis on localized adaptation is particularly informed by our qualitative insights into the specific environmental realities teachers and communities face in Northeast Thailand. Therefore, we recommend that national CCE policies include provisions for regional flexibility and local curriculum adaptation.

Regular monitoring and evaluation mechanisms should be established to track the progress of CCE implementation, providing feedback that helps refine strategies and interventions. These mechanisms can further enhance the effectiveness of CCE policies, which would assess the implementation of climate change education and its impact on student engagement, climate literacy, and local community resilience. The literature emphasizes the importance of monitoring and adapting policies to ensure they remain relevant and effective in addressing evolving environmental and educational challenges (Gisore and Njurai, 2023). We recommend that education authorities establish robust monitoring and evaluation systems specifically for CCE, using quantitative implementation metrics and qualitative assessments of impact and challenges to inform ongoing policy adjustments.

As CCE continues to evolve, further research is needed to assess the long-term effectiveness of policy interventions and the sustainability of CCE programs. Longitudinal studies can provide valuable insights into the lasting impact of CCE on students' environmental behaviors and attitudes, helping policymakers understand the long-term benefits of investing in climate change education. Additionally, research should explore innovative approaches to resource distribution, particularly in rural areas, where digital tools and online learning platforms could offer scalable solutions. This focus on digital solutions for rural education has been identified in the literature as a promising avenue for overcoming resource limitations in remote regions (Waldron et al., 2020). Such future research could further build upon the quantitative baseline data provided by our study and explore in greater depth the qualitative experiences of implementing these new solutions.

6 Limitations

This study has several limitations that should be considered. The cross-sectional design prevents causal inferences about the relationships between teacher training and CCE implementation effectiveness. At the same time, reliance on self-reported measures may introduce social desirability bias and standard method variance. The absence of classroom observations and direct assessments of student learning outcomes limits validation of teacher-reported implementation effectiveness. Additionally, the qualitative sample was purposively selected for participants with demonstrated CCE expertise, potentially providing an optimistic representation of implementation possibilities compared to the broader teacher population.

Findings from Northeast Thailand may have limited generalizability to other developing contexts due to unique cultural, educational, and climate-related factors specific to this region. The study examined current implementation practices without assessing long-term sustainability or measuring actual student learning outcomes related to climate education. Despite

these limitations, this study contributes valuable evidence-based insights into climate change education implementation in resource-constrained, climate-vulnerable contexts.

Data availability statement

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

Ethics statement

The studies involving humans were approved by the Ethics Committee of Khon Kaen University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

NM: Conceptualization, Funding acquisition, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. DS: Data curation, Investigation, Writing – original draft.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This work was supported by Khon Kaen University under the 2023 Fundamental Funds.

Acknowledgments

The authors sincerely thank the Faculty of Education, Khon Kaen University, for providing valuable academic support throughout this research. This study would not have been possible without the generous cooperation of teachers, school administrators, and education officials across Northeast Thailand, whose participation and insights were instrumental in understanding the implementation of climate change education in the region.

Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Gen AI was used in the creation of this manuscript. While preparing this work, the author(s) used Claude 3.5 Sonnet to improve language clarity and enhance the overall readability of the manuscript. After using this tool, the author(s) reviewed and edited the content as needed and took full responsibility for the content of the publication.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1561574/full#supplementary-material

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