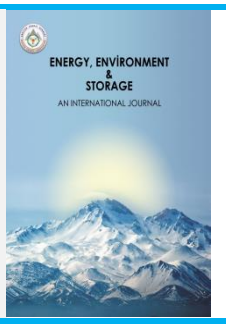
Energy, Environment and Storage

Journal Homepage: www.enenstrg.com



Integrating Climate Change Education: Opportunities, Challenges, And Innovative Approaches

Cincin Cintami[1*], Indriyani Rachman [1,2] ,Toru Matsumoto [2]

[1] *Department of Natural Science Education, School of Postgraduate Studies, Universitas Pakuan Bogor, 16143, Indonesia, ORCID: https://orcid.org/ 0009-0000-7040-1043*

[2] *Graduate Programs in Environmental Systems, Graduate School of Environmental Engineering, The University of Kitakyushu, Kitakyushu, 808-0135, Japan, ORCID: https://orcid.org/0000-0001-7511-6241*

[3] *Graduate Programs in Environmental Systems, Graduate School of Environmental Engineering, The University of Kitakyushu, Kitakyushu, 808-0135, Japan, ORCID: https://orcid.org/ 0000-0002-3191-2681*

ABSTRACT. Climate change is a global challenge that requires collective action, including through education. This study aims to explore the opportunities, challenges, principles, and approaches in climate change education through a systematic analysis of 10 scientific articles published in the last five years in Scopus-indexed journals. The findings indicate that the main opportunities for climate change education include student engagement as agents of change, the strategic role of teachers, supportive learning environments, curriculum integration, science education, and supportive government policies. However, significant challenges remain, such as improving teacher competency, material complexity, limited curriculum tools, collaboration between stakeholders, and gaps between student knowledge and skills. In addition, six main principles of climate change education implementation were found, including improving teacher competency, curriculum adjustment, cross-sector collaboration, student environmental awareness, providing knowledge related to climate change, and connecting learning with contextual issues. Student-based learning approaches, such as inquiry-based learning, problem-based learning, and project-based learning, have proven effective in delivering complex and contextual materials. This study provides contextual and applicable recommendations for education stakeholders in Indonesia, taking into account the unique social, cultural, and educational policy characteristics of Indonesia.

Keywords: Climate Change Education, Opportunities, Challenges, Learning Approaches, Systematic Literature Review

Article History: Received: 21.01.2025; Revised: 12.05.2025; Accepted: 16.05.2025; Available Online: 16.05.2025
Doi: https://doi.org/10.52924/QWFE3052

1. INTRODUCTION

Since ancient times, climate has been an important part of a civilization, humans and other living things must adapt to their living environment including climate. Climate change occurs globally but its impacts can be felt locally. Indications of climate change include changes in the pattern and intensity of various climate parameters such as air temperature, rainfall, wind, humidity, cloud cover and evaporation [1].

Climate change is the change in the pattern and intensity of climate elements in a certain period of time, usually on average 30 years [2]. Climate change can occur naturally, for example volcanic eruptions, El Nino and La Nina events, continental plate shifts, and solar activity. Climate change is also largely caused by human activities, especially the burning of traditional fuels, which results in the accumulation of greenhouse gases [3] such as increasing urbanization, deforestation, illegal peatland clearing, coastal reclamation, industrialization, and improper waste management [4].

Currently, climate change that is hitting the earth is increasingly worrying, increasing temperatures over time change weather patterns and disrupt the balance of nature. This poses many risks to humans and all other living things on Earth, hotter temperatures, more severe storms, increased droughts, increased ocean volume and temperature, species extinction, food shortages, increased health risks, and poverty [5].

Climate change is a shared responsibility of all human beings on planet earth. Education plays an important role in climate change, first building awareness in mitigation and prevention, second building adaptability, third encouraging a sustainable learning process [6]. Climate change education is education that aims to address and develop effective responses to climate change that helps students

*Corresponding author: bucincinkimia@gmail.com

understand the causes and consequences of climate change, prepares them to live with the impacts of climate change, and empowers them to take appropriate action to adopt a more sustainable lifestyle [7].

Climate change education has undergone significant changes over the past few decades. Many countries have expanded their curricula to include climate change and related topics such as sustainability, renewable energy, and environmental policy [8]. The Indonesian government itself in late August 2024 through the Education Standards, Curriculum, and Assessment Agency, Ministry of Education, Culture, Research, and Technology released the Climate Change Education Guide. The guide, which is intended for regional policy makers, school principals, and teachers, aims to provide an in-depth understanding of the issue of climate change, including its definition and impact on people's lives [9].

The Climate Change Education Guide is the first concrete result of a long planning process for the integration of climate change education into formal education in Indonesia that began in mid-2023 [10]. A little late compared to other countries, this guide also requires development related to content, implementation mechanisms, and outreach strategies so that it can be implemented optimally and effectively. A study of climate change education in Indonesia, namely in geography subjects at the senior high school level, shows that there are opportunities for students' climate change learning in the Basic Competencies in the geography curriculum [11]. However, the syllabus is not supported by materials/topics and learning activities that explicitly address climate change education.

This Systematic Literature Review aims to explore climate change education in various countries to obtain an overview of its implementation in schools so that it can be used as inspiration and adapted in Indonesia. This study will try to find answers from selected literature to the following questions, (1) What are the opportunities and challenges in implementing climate change education? (2) What are the principles in climate change education? (3) What is the right approach to use for climate change education in the classroom?

2. MATERIALS AND METHODS

2.1 Methodology

This study is a Systematic Literature Review (SLR) using the PRISMA (Reporting Items for Systematic Review and Meta-Analyses) method [12]. The process of making an SLR using the PRISMA approach consists of the steps of identification, screening, eligibility, study quality assessment, data extraction and analysis.

2.2 The Review Method

Identificiation

Identification is the initial step by using various appropriate keywords in the process of searching for article sources as references. Based on the formulation of the research problem that has been previously determined, the author uses two main keywords, namely "Climate Change Education" and "Climate Change in School". This search process is carried out in three databases, namely ERIC, DOAJ, and Science Direct. In the three databases, a filter is set against the year of publication, namely the last five years (2020 to 2024). From the identification stage, 584 articles were obtained which will then go through the screening stage. 12 duplicate articles were obtained so that the remaining number is 572 articles. The identification results can be seen in table 1 of the following search series.

Table 1 Search Chain

Keywords	ERIC	DOAJ	Science Direct
Climate change education	24	83	99
Climate change in school	320	12	46
Number of searches	344	95	145

Screening

The screening stage uses inclusion and exclusion criteria consisting of several criteria shown in table 2.

Table 2 Inclusion and Exclusion Criteria

	Inclusion Criteria		Exclusion Criteria
1.	Year of publication from 2020 to 2024	1.	Year of publication before 2020
2.	International articles in English	2.	Article not in English
3.	Educational research	3.	Not educational research
4.	Articles published in journals	4.	Articles in the form of proceedings, Book Chapters, etc
5.	Published in international journals indexed by Scopus	5.	Published not in international journals indexed by Scopus

Inclusion criteria number 1 (year of publication) was applied directly when searching for articles in the database used (at the identification stage). So that 572 articles that entered the screening stage were articles that had passed the first inclusion criteria. At the screening stage, many articles were excluded because five inclusion criteria were applied as in table 2. The number of articles that were removed at the screening stage was 443, leaving 129 articles that would enter the next stage, namely eligibility.

Eligibility

All articles from the screening process will go through a second screening process, namely the eligibility process. This process is carried out to ensure that all selected articles are accurate and suitable for use. This process is carried out by referring to the article title and abstract to find the determining factors that can answer the research questions that have been set. If the determining factors cannot be found, then the next step will refer to the methodology, findings, and discussion sections of the article. From this process, 119 articles were removed and 10 articles remained to be included in the next process, namely quality assessment. The series of article selection processes from the beginning to the end can be seen in figure 1 Flow chart of the research article selection process.

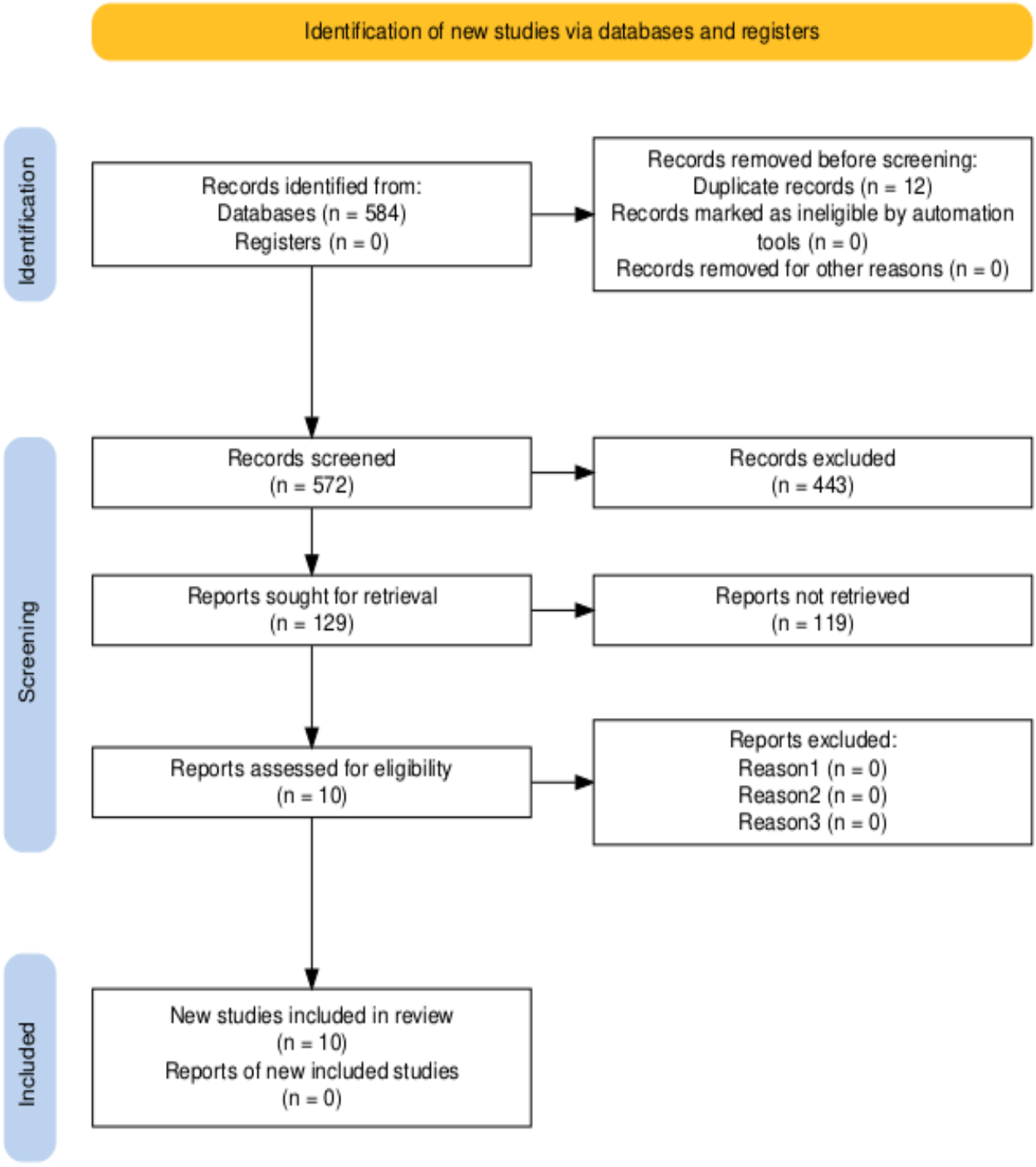


Fig. 1 Flow chart of the research article selection process

Selected articles that passed all stages of the PRISMA method can be seen in table 3.

Table 3 Selected Articles

Title	Year/Author	Methodology	Findings
1 A Climate Change and Sustainability Education Movement: Networks, Open Schooling, and the 'CARE- KNOW-DO' Framework	2023 Alexandra Okada, and Peter Gray	Method : Delphi Subject : 27 Experts Instrument : Questionnaire	1. Climate Change Education needs to be integrated at all levels of education, from formal to informal education 2. The CARE-KNOW-DO framework provides a basis for guiding students in understanding and addressing environmental issues 3. Cross-disciplinary Learning enhances a holistic understanding of climate change
2 Climate change education implementation : the voices of policymakers, professional development providers, and teachers in five countries	2024 Orit Ben Zvi Assaraf, Vaille Dawson, Efrat Eilam, Tuba Gokpinar, Daphne Goldman, Nofar Naugauker, Gusti Agung Paramitha Eka Putri, Agung Wijaya Subiantoro, Sakari Tolppanen, Peta White, Helen Widdop Quinton & Justin Dillon	Method : Qualitative Subjects : 36 participants from 5 countries Instrument : Interview	1. Climate change education needs to be more explicitly integrated into school curricula with approaches that support active learning. 2. While there is support for incorporating CCE, there are still significant challenges to be overcome to ensure effective implementation.
3 Inquiry-Based Learning on Climate Change in Upper Secondary Education: A Design-Based Approach	2022 Sebastian Brumann, Ulrike Ohl and Johannes Schulz	Method : Design Based Research Subjects : 34 teachers and 433 students Instruments : Modules, Observation Sheets	Inquiry Based Learning is a promising approach to climate change education especially in strengthening climate literacy and scientific skills.
4 "Stickier" learning through gameplay: An e□ective approach to climate change education	2021 S. Pfirman, T. O'Garra, E. Bachrach Simon, J. Brunacini, D. Reckien, J. J. Lee & E. Lukasiewicz	Method : experimental Subjects : 41 adults from Greater Boston Instruments : questionnaire, illustrated article, EcoChains: Arctic Crisis cards	1. The EcoChains game was as effective as the article in increasing short-term knowledge about climate change, but more effective in long-term knowledge retention 2. Participants who played the game also reported higher levels of engagement, greater enjoyment, and were more likely to recommend the game to others compared to those who read the article.
5 Using inquiry-based dialogues to explore controversialclimate change issues with secondary students: Anexample from Norway	2022 Lisa Steffensen , Marit Johnsen-Høines and Kjellrun Hiis Hauge	Method : Qualitative Subjects : 4 classes of Norwegian secondary school students Instruments : Audio-video recordings	Inquiry-based dialogue strengthens student engagement in democratic issues and supports real-world issue-based learning.

Title	Year/Author	Methodology	Findings
6 Climate Change Education Challenges from Two Different Perspectives of Change Agents: Perceptions of School Students and Pre-Service Teachers	2022 Veronika Winter, Johanna Kranz, and Andrea Möller	Method : Qualitative Subjects : 80 grade 12 students and 18 pre-service teachers in Austria Instruments : Questionnaire and document analysis	1. Both students and Prospective Teachers feel inadequately prepared to act as agents of change regarding climate change 2. The topic of Climate Change does not receive sufficient attention in the curriculum 3. There are systemic challenges that educational institutions must face to support teacher professional development in the field of CCE.
7 Science Education for Sustainability: Strengthening Children's Science Engagement through Climate Change Learning and Action	2020 Carlie D. Trott, and Andrea E. Weinberg	Methods : mixed-methods Subjects : 55 children aged 10-12 years from the Mountain West, USA Instrument : questionnaire	The program successfully broadened children's understanding of science and strengthened their engagement with sustainability themes. Children became more confident, actively engaged in science classes, and were able to connect science to real-world action.
8 Teaching Atmospheric Hazards in the Climate Change Context—Environmental Didactic Proposals in the Mediterranean Region for Secondary Schools	2021 Álvaro-Francisco Morote, Jorge Olcina, and María Hernández	Method : curriculum analysis Subjects : students at Secondary Education (ages 12-16 years) and Baccalaureate (ages 17-18 years) in Spain Instruments : Qualitative analysis	1. Data-based approaches such as graphical analysis of rainfall and drought trends have been shown to improve student understanding 2. Project-based materials, including fieldwork and climate modeling, help students understand the relationship between natural phenomena and human activities
9 Identifying gaps in climate change education - a casestudy in Austrian schools	2023 Eva Feldbacher, Manuela Waberera, Lena Campostrinib and GabrieleWeigelhofer	Method : case study Subjects : 113 secondary school students (aged 13–17 years) in Austria Instrument : online survey	Climate education needs to be overhauled to improve students' understanding of the complex human-climate relationships. An interdisciplinary approach is needed to help students understand dynamic system interactions and encourage pro-environmental action.
10 'Don't Say It's Going to Be Okay': How International Educators Embrace Transformative Education to Support Their Students Navigating Our Global Climate Emergency	2021 Jeremy Jimenez and Laura Moorhead	Method : qualitative Subject : seven educators and staff Instrument : semi-structured interview	This research suggests that sustainability education should be approached with a transformational approach, where students are encouraged to think independently and develop actions based on their own understanding. Educators strive to create learning environments that support long-term advocacy for environmental and social justice issues.

Study Quality Assessment

The selected articles in the eligibility process amounting to 10 articles need to be evaluated for quality to ensure that only relevant, valid, and high-quality articles are used in further analysis. Before the assessment is carried out, an assessment rubric is first prepared as a reference in assessing the quality of the article as can be seen in table 4.

Table 4 Study Quality Assessment [13]

No	Item	Answer
1	Was the article refereed?	Yes/No
2	Were the aim(s) of the study clearly stated?	Yes/No/Partially
3	Were the study participants or observational units adequately described? For example, students' programming experience, year of study etc	Yes/No/Partially
4	Were the data collections carried out very well? For example, discussion of procedures used for collection, and how the study setting may have influenced the data collected?	Yes/No/Partially
5	Were potential confounders adequately controlled for in the analysis?	Yes/No/Partially
6	Were the approach to and formulation of the analysis well conveyed? For example, description of the form of the original data, rationale for choice of method/tool/package?	Yes/No/Partially
7	Were the findings credible? For example, the study was methodologically explained so that we can trust the findings; findings/conclusions are resonant with other knowledge and experience?	Yes/No/Partially

The article quality assessment answers are converted into a score of 0 for no, 0.5 for partially, and 1 for yes. Then the total score of the article assessment results is interpreted to determine the eligibility of the article as the quality score in table 5. Articles with fair, good, and very good quality will then be included in the analysis stage.

Table 5 Quality Score [13]

Score	Quality Scale
< 2	Very Poor
2-2.5	Poor
3-4.5	Fair
5-6	Good
>6	Very Good

Of the ten articles assessed, five articles showed a score of 7 which means they have very good quality, namely articles number 1,2,3,4, and 6. Three articles showed a score of 6.5, namely articles number 7, 9, and 10 with quality still classified as very good. One article, namely article number 5, showed a score of 6 and is still classified as very good quality. The article with the lowest score is article number 8 with a score of 5.5 and is classified as good quality. The quality assessment of the ten selected articles can be seen in table 6 Article Quality Assessment on the next page.

Data Extraction and Analysis

All articles that enter the eligibility stage have article quality that is worthy of entering the next stage, namely data extraction and analysis. The data extraction process focuses on three main parts of the article, namely the abstract, research results, and research discussion. The extracted data is then analyzed to find answers to the research questions that have been created.

3. RESULT AND DISCUSSION

To answer the research questions, coding was carried out on themes related to the research questions, namely challenges, opportunities, principles and approaches.

Opportunities and challenges in implementing climate change education

Opportunities are situations or conditions that can provide benefits if utilized effectively. Identifying opportunities and then taking steps to exploit them is a very important thing to do. The first opportunity for implementing climate change education is the learning environment found in six SLR articles but with different mentions. Four articles directly mention the word learning environment as an opportunity in implementing climate change education and two other articles mention collaboration between stakeholders and organizations [14], political environment, and media [15]. The learning environment is all conditions that can influence the subjects involved in the teaching and learning process, namely teachers and students. The learning environment can be a physical environment such as a place and facilities for learning or non-physical such as support from the family.

The next opportunity for climate change implementation is students and teachers. Both have strategic roles in implementing climate change education. Students are the main subjects who receive knowledge and develop skills, students are also the next generation who have the potential to become agents of change. Teachers are also seen as agents of change who are as important as students as multipliers of knowledge and action [16]. In climate change education it is found that the reality of classroom teaching depends almost exclusively on the teacher's ability to convey this knowledge [15]. Teachers as facilitators do have the opportunity to convey knowledge about the impacts of climate change and mitigation and adaptation measures through innovative approaches that are relevant to students' daily lives.

Table 6 Article Quality Assessment

No	Item	Article Score									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	Was the article refereed?	1	1	1	1	1	1	1	1	1	1
2	Were the aim(s) of the study clearly stated?	1	1	1	1	1	1	1	1	1	1
3	Were the study participants or observational units adequately described? For example, students' programming experience, year of study etc	1	1	1	1	0,5	1	1	0,5	0,5	1
4	Were the data collections carried out very well? For example, discussion of procedures used for collection, and how the study setting may have influenced the data collected?	1	1	1	1	0,5	1	0,5	0	1	0,5
5	Were potential confounders adequately controlled for in the analysis?	1	1	1	1	1	1	1	1	1	1
6	Were the approach to and formulation of the analysis well conveyed? For example, description of the form of the original data, rationale for choice of method/tool/package?	1	1	1	1	1	1	1	1	1	1
7	Were the findings credible? For example, the study was methodologically explained so that we can trust the findings; findings/conclusions are resonant with other knowledge and experience?	1	1	1	1	1	1	1	1	1	1
	Total Score	7	7	7	7	6	7	6,5	5,5	6,5	6,5
	Quality Scale	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Good	Very Good	Very Good

Other opportunities are government, curriculum, and science education. The government as a policy maker for the implementation of climate change education, the curriculum as the main guideline for climate change education, and science education as the main basis for understanding the concept of climate change. The government is a policy-making stakeholder [14], government leadership in education includes support for climate change education, professional development, and provision of resources [17].

Challenges, on the other hand, refer to obstacles or barriers faced in achieving goals or taking advantage of existing opportunities. Challenges can arise from a variety of sources, such as changes in the economic environment, legal or regulatory barriers, intense competition, changes in consumer trends or preferences, or internal organizational issues. Challenges must be overcome or confronted in order to optimize existing opportunities. The first challenge identified in the SLR article is teacher competence which includes mastery of the material broadly and deeply (professional competence) and the ability to manage learning to achieve learning objectives (pedagogical competence) [18]. Teachers who do not have a science background and are unable to understand how to address climate change [15], as well as teachers with a science background who have difficulty in project learning, especially connecting learning with action [17], are challenges that must both be faced.

The next challenge that is widely identified is the context of climate change material, which is complex material with a multi-layered topic nature [16] and is related to many fields [19]. In addition, the explanation of climate change material in school textbooks is not well focused and often uses messages that are too powerful and sensational, which is found to be the next challenge [15]. Furthermore, the challenge of climate change education is in the form of appropriate curriculum tools. The curriculum is a set of plans and arrangements regarding objectives, content, and learning materials as well as methods used as guidelines for organizing learning activities to achieve certain educational goals [20]. The curriculum is indeed designed by involving all parties such as students, parents, society, industry, and policy makers. However, the national curriculum is first determined by the government by setting educational standards that aim to provide equal quality education. As in England, the curriculum has been previously determined, is fixed, and is not related to current issues [14]. Including the issue of climate change which has not been integrated into the independent curriculum implemented in Indonesia and other countries such as Austria, teachers are often faced with difficult decisions about where and how long the topic of climate change can be integrated into teaching [16].

The next challenge for climate change education is collaboration between government, business, civil society and the education sector to foster a science-literate society [14]. And the last challenge is the reality of climate change education in the field where climate change is in a transition phase characterized by appearing explicitly in core subjects [17], as well as other realities in the form of gaps between knowledge and skills [19]. Higher education does not always mean or directly increase pro-environmental behavior.

Principles in climate change education

Six principles were found in the implementation of climate change education based on the analyzed SLR articles. The first is improving teacher competency such as teaching skills, teacher confidence [14], developing competency in handling complex climate change topics [21], teacher training programs that should focus more on the professional development of teachers in the field of climate science [16], and provide innovative and modern learning media, for example with digital learning formats that suit young people's preferences and everyday life [19]. The second principle is commitment and cooperation between all parties, namely universities, schools, companies, policy makers, and the wider community as well as cooperation between students with stakeholders and organizations [14], government leadership to support climate change education, especially in teacher professional development and the provision of resources [17], and the commitment of all parties to address climate change [22].

The third principle is the adjustment of the curriculum and teaching tools, adjustments can be in the form of contextualizing the curriculum, changing the curriculum from frightening to full of hope, and making the national benchmarks that have been determined useful [14]. Other adjustments include integrating climate change education with clear guidelines on how to integrate the topic into various subjects [16], as well as restructuring science education by positioning students as important actors for sustainability in the context of science education [23].

The fourth principle is to foster students' environmental awareness, increase high climate awareness at all levels and increase students' interest in nature. Raising students' awareness of the environment is done through education that focuses not only on increasing knowledge but also on action [23], the gap between knowledge and action is seen as an obstacle to successful adaptation to climate change and is particularly visible in young population groups [19]. Increasing climate awareness is done by giving students the competence to identify issues and responsible actions to keep the earth a habitable planet for everyone. While increasing students' interest in nature is done through curriculum adjustments that have been implemented [14].

The fifth principle is to provide knowledge about climate change, especially to clarify the meaning of climate change education. There is still a lot of confusion about what affects the climate and what does not, and how education can promote climate change [14]. Providing knowledge can be in the form of complementing young people's experiences of climate change through direct experiments, field trips, and demonstrations of impacts in the environment [19]. Young people need to have good knowledge about climate change and human influence on

climate in order to consciously decide on pro-environmental actions [19].

The final principle is that climate change education must be comprehensive and contextual, comprehensive means covering more than just scientific topics to connect them to issues related to economics, society, values, and social justice [14]. Contextual means connected to relevant issues [14], covering real-world problems [24], community-oriented and not limited to the school environment alone but offering unique opportunities to involve various community actors and unite them to pursue common goals [16]. Science and climate change need to be seen as important and relevant to life, in the classroom science topics are often seen as unrelated to real-world issues [23].

The right approach to use for climate change education in the classroom

The learning approach is a starting point or a point of view towards the learning process, in learning the main variables involved are teachers and students so that the approach to learning is generally divided into two, namely the teacher-oriented approach and the student-oriented approach [25]. In the SLR article, it was found that several appropriate approaches to implementing climate change education that place students as learning subjects who are actively involved in learning are student-oriented approaches. No climate change learning approaches were found using teacher-oriented approaches. The student-oriented approach is based on constructivism theory, which emphasizes that students construct their own knowledge through active interaction with the environment and learning experiences. In constructivism, the role of the teacher is as a facilitator who supports the process of student exploration and reflection so that learning becomes meaningful and contextual [26].

When viewed from the material, the learning approach is also divided into two, namely the contextual approach and the thematic approach. The contextual approach is an approach that helps students see the meaning of their learning by connecting it to the context of everyday life, while the thematic approach is learning in which the material to be learned by students is presented in the form of topics or themes that are considered relevant [25]. Thematic approach can be a single discipline or multidisciplinary approach. In the SLR article, the thematic approach that is suitable for application in climate change education is a multidisciplinary approach, and for the contextual approach, it is found in the SLR article as one of the recommended learning approaches.

Learning approaches that have been proven to be effective in climate change education were found in nine SLR articles, the first of which was the interdisciplinary and transdisciplinary approach. Although the main scientific aspects of climate change are in the disciplines of biology, chemistry, ecology and environmental science, there are other issues such as natural history, sociology and the politics of climate change which fall within the scope of social studies subjects which must be improved through interdisciplinary and transdisciplinary approaches [14]. Both interdisciplinary and transdisciplinary approaches are approaches that use two or more disciplines. The difference is that in the interdisciplinary approach, problem analysis is carried out in parallel, while the transdisciplinary approach offers a specific approach and even basic assumptions for understanding the complex issues being faced [27]. One form of interdisciplinary approach that combines science, technology, engineering, and mathematics is STEM, which is also recommended as a learning approach that provides students with the opportunity to see how the science they are studying is important for their lives and other living things and to spread knowledge to the surrounding environment [23].

The next approach is the contextual approach, climate change is the main real-life scenario. In line with the contextual approach, another suggested approach is the phenomenon-based learning approach which is a holistic approach that encourages students to learn a phenomenon as a complete intensity in a real context [28]. The phenomenon-based approach is also in line with the cross-curricular approach, namely an interdisciplinary approach for all ages (5–25) and levels of education (from elementary school to higher education) [14]. The holistic approach is found in the SLR article as the right approach to use in implementing climate change education [16], the holistic approach aims to help students understand the interconnectedness between various aspects of themselves and their world, so that students can grow intellectually, emotionally, and socially [29]. Next, an inclusive approach was found, which is an education system that provides opportunities for all students who have disabilities and have the potential for intelligence and/or special talents to participate in education or learning in an educational environment together with students in general [30].

The next important learning approach to be implemented is the socio-scientific approach and the emotional approach to climate change. The socio-scientific approach is a learning approach that is oriented towards the context of science and its relationship to social life in society [31], the emotional approach is an intensive approach between teachers and students like counseling guidance that involves interactive and interpersonal communication in opening up problems faced by students in the scope of school and society. The similarity between the two is bringing the social life of society into the context of learning [32].

In addition to the suggested approaches to climate change implementation, these SLR articles also found four recommended learning models to be used with these approaches. Learning models are procedures or steps in the learning process that can be used as a reference to achieve learning objectives [25]. The first is inquiry based learning which involves students in interdisciplinary and intergenerational inquiry projects, designed not only to provide scientific literacy, but also to influence the behavioral dimension by promoting participants' intention to act [33]. Next is problem based learning which is an active learning strategy that has been proven successful in

increasing knowledge and influencing attitudes [19]. The project based learning model is also suggested in the SLR article although implementing this project-based science curriculum is challenging in the context of standardized tests, time allocation, large number of students, and difficulty in giving individual grades [23]. The last is the games based learning model as a new didactic method that suits today's student profile and is a more interesting educational method [15]. The game-based approach in the SLR article was also found to be more interesting than the conventional approach [34].

4. DISCUSSION

The SLR studies analyzed included 10 articles published in the last five years in Scopus-indexed scientific journals, which provide a comprehensive overview of the opportunities, challenges, principles, and learning approaches relevant to climate change education. The main focus of this discussion is to integrate these global findings with social, cultural, and educational policy conditions in Indonesia, so that it can provide applicable and contextual recommendations for educational stakeholders in the country. This approach is important considering the unique characteristics of Indonesian education which requires adaptation strategies that are not only based on scientific evidence, but also consider local dynamics and the specific needs of students and teachers in various regions.

Climate change education in Indonesia has six main opportunities that can be utilized effectively based on SLR findings. First, students act as active subjects and agents of change, allowing them to be directly involved in environmental learning and action, thereby increasing social awareness and responsibility. Second, teachers function as facilitators and agents of change who are important in guiding students to understand climate change issues contextually and applicatively. Third, a learning environment that supports contextual learning, both inside and outside the classroom, provides opportunities for students to relate climate change concepts to real experiences around them. Fourth, science education is the main basis for understanding the scientific mechanisms of climate change, so strengthening science material is very necessary. Fifth, the curriculum as the main guideline must be integrated with climate change issues systematically so that learning becomes focused and relevant. Finally, the role of the government as a policy maker and support provider is crucial in providing resources, teacher training, and policies that support the implementation of climate change education as a whole. Synergistically utilizing these opportunities can strengthen the effectiveness of climate change education in Indonesia, for example by developing contextual teacher training programs and involving local communities in environmental learning activities.

The implementation of climate change education in Indonesia faces a number of significant challenges that need to be addressed in order to be effective and sustainable. First, improving teacher competency both in terms of professionalism and pedagogy, because teachers must be able to deliver complex climate change material in a contextual and interesting way for students. Second, the multidisciplinary and complex nature of climate change material demands an integrative and interdisciplinary learning approach, thus requiring the development of appropriate teaching tools. Third, the limited curriculum tools that accommodate climate change issues systematically are still an obstacle, so better adjustments and integration are needed in the national curriculum. Fourth, the lack of effective synergy and cooperation between the government and schools hinders the provision of adequate policy support, training, and resources. Finally, there is a gap between students' theoretical knowledge and the practical skills needed to deal with climate change issues in real terms, which requires a more applicable and experience-based learning model. To address these challenges, practical recommendations include the development of sustainable and contextual teacher training, curriculum revisions that integrate climate change education holistically, and increased collaboration across stakeholders, including the government, schools, and communities. This approach is expected to strengthen teacher capacity and the relevance of learning, while creating an educational ecosystem that supports the transformation of knowledge into real action in mitigating and adapting to climate change in Indonesia.

The principles of implementing climate change education found in this literature study emphasize six important aspects that must be the basis for implementation in Indonesia. First, continuous strengthening of teacher competencies is crucial so that teachers are able to deliver complex climate change material with an effective and contextual pedagogical approach. Second, commitment and collaboration across stakeholders, including schools, universities, government, and communities, are needed to create a supportive and sustainable learning ecosystem. Third, adjustments to the curriculum and teaching materials must be relevant to the local context and actual climate change issues so that learning becomes meaningful for students. Fourth, fostering environmental awareness and pro-environmental attitudes in students is the main focus for forming behaviors that support climate change mitigation and adaptation. Fifth, the delivery of climate change knowledge must be linked to local contextual issues so that students can understand the real impacts and relevance of the material in everyday life. Finally, the integration of related issues such as sustainability and environmental conservation in learning enriches students' understanding holistically. Consistent application of these principles will strengthen the effectiveness of climate change education in Indonesia and support the creation of a generation that is aware of and responsible for the environment

The most appropriate learning approach for climate change education in Indonesia is a student-centered learning approach, which places students as active subjects in the learning process. In addition, contextual and thematic approaches that integrate various disciplines in an interdisciplinary and transdisciplinary manner are very relevant to addressing the complexity of climate change material involving scientific, social, and environmental aspects. Cross-curriculum, phenomenon-based, holistic, socio-scientific, emotional, inclusive, and

STEM approaches can also enrich students' learning experiences by linking learning materials to real situations and local needs. Active learning models such as inquiry-based learning, problem-based learning, project-based learning, STEM, and game-based learning are highly recommended because they encourage engagement, collaboration, and the development of critical and creative thinking skills. Each of these approaches and models must be adapted to the cultural context and resources in Indonesia so that their implementation is effective and sustainable.

5. CONCLUSION

This literature review study successfully identified relevant opportunities, challenges, principles, and approaches in implementing climate change education based on an analysis of 10 articles published in the last five years. These findings emphasize the importance of a strategic and integrated approach in utilizing existing opportunities, such as actively involving students as agents of change, improving teacher competency, creating a supportive learning environment, integrating science education, developing a relevant curriculum, and optimizing the role of the government in supporting the implementation of climate change education. Climate change education requires a collective commitment from all parties, including educators, policy makers, and the wider community, to ensure the creation of a generation that is able to face the challenges of climate change with adequate knowledge, awareness, and skills.

However, significant challenges remain, including lack of teacher training, the complexity of climate change materials, limited curriculum tools, and the need for closer collaboration between government and educational institutions. Student-centered, interdisciplinary, and phenomenon-based learning approaches provide great opportunities to create more meaningful learning experiences. Active learning models such as inquiry-based learning, problem-based learning, project-based learning and game-based learning have also proven effective, although they require thorough preparation.

To support the development of climate change education, several strategic steps are needed in future research. First, in-depth contextual studies need to be conducted through case studies in various regions to explore the implementation of climate change education according to local challenges and needs. Second, cross-disciplinary collaboration must be strengthened by involving various fields of science to develop more holistic learning materials and approaches. Third, further research is needed to evaluate the effectiveness of climate change education in the long term, especially in measuring its impact on changes in student and community behavior. Fourth, policy and curriculum development are important focuses, where in-depth studies are needed to understand how education policies can support the integration of climate change education into the national curriculum systematically. Finally, innovation in learning models must continue to be developed, including exploring the effectiveness of new approaches, such as the integration of digital technology, to increase student engagement in understanding climate change issues.

The implementation of climate change education in Indonesia needs to be carried out through strategic steps that are adaptive and contextual according to local characteristics. First, the active role of students and teachers must be maximized by placing students as directly involved learning subjects and teachers as facilitators who support contextual learning. The development of relevant and sustainable teacher training is essential to improve professional and pedagogical competence in delivering complex climate change material. Furthermore, teaching materials and tools must be adapted to local conditions and systematically integrated into the national curriculum so that learning becomes relevant and meaningful for students. Close cooperation between the government, schools, and other stakeholders needs to be improved to support the provision of adequate resources, policies, and training. In addition, climate change education must be integrated into various subjects and extracurricular activities, and utilize formal and non-formal learning environments to provide contextual and applicable learning experiences. This adaptive and contextual approach is the key to the successful implementation of climate change education in Indonesia, allowing this program to run effectively and sustainably according to diverse local needs and challenges.

ACKNOWLEDGMENTS

We would like to thank the Science Education Study Program of the Postgraduate School of Pakuan University, for their support so that this systematic literature review can be implemented. We would also like to thank Graduate Programs in Environmental Systems, Graduate School of Environmental Engineering, The University of Kitakyushu, Kitakyushu, Japan.

REFERENCES

[1] A. S. dkk. Pratikto, *Konsep Implementasi Adaptasi Sektoral Perubahan Iklim*. Jakarta: Pusat Penelitian dan PengembanganBadan Meteorologi, Klimatologi, dan Geofisika, 2014.

[2] E. Aldrian and M. Budiman, *Adaptasi dan mitigasi perubahan iklim di Indonesia*, no. 2. 2011. [Online]. Available: https://www.researchgate.net/profile/Edvin_Aldrian/publication/309721670_Adaptasi_dan_Mitigasi_Perubahan_Iklim_di_Indonesia/links/581ec39c08aea429b295db6b.pdf

[3] S. Olaleru, J. Kirui, F. Elegbeleye, and T. Aniyikaiye, "Green Technology Solution to Global Climate Change Mitigation," *Energy, Environ. Storage*, vol. 1, no. 1, 2021, doi: 10.52924/dnrm8834.

[4] J. F. Arwan, L. Dewi, and D. Wahyudin, "Urgensi Pendidikan Berbasis Perubahan Iklim Untuk Pembangunan Berkelanjutan," *J. Pendidik. Lingkung. dan Pembang. Berkelanjutan*, vol. 22, no. 2, pp. 23–38, 2022.

[5] Perserikatan Bangsa - Bangsa Indonesia, "Penyebab Dan Dampak Perubahan Iklim." [Online]. Available: https://indonesia.un.org/id/175273-penyebab-dan-dampak-perubahan-iklim#Suhu_yang

[6] B. Standar, D. A. N. A. Pendidikan, K. Pendidikan, D. A. N. Teknologi, and R. Indonesia, *Panduan Implementasi untuk Satuan Pendidikan*. 2024.

[7] UNESCO, *Putting Climate Change Education into Practice*. 2015.

[8]"The Importance of Climate Change Education," 2023, [Online]. Available: https://bigrededucation.com/the-importance-of-climate-change-education/

[9] K. Tang, "Apa yang perlu ditingkatkan dari panduan pendidikan perubahan iklim?" [Online]. Available: https://theconversation.com/apa-yang-perlu-ditingkatkan-dari-panduan-pendidikan-perubahan-iklim-239317

[10] K. Tang, "Climate change education in Indonesia's formal education: a policy analysis," *npj Clim. Action*, vol. 3, no. 1, pp. 1–11, 2024, doi: 10.1038/s44168-024-00143-z.

[11] S. Sofiyan, F. I. Aksa, and S. Saiman, "An analysis climate change of the curriculum in Indonesia," *J. Phys. Conf. Ser.*, vol. 1321, no. 2, 2019, doi: 10.1088/1742-6596/1321/2/022121.

[12] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, "Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement," *Int. J. Surg.*, vol. 8, no. 5, pp. 336–341, 2010, doi: 10.1016/j.ijsu.2010.02.007.

[13] N. Salleh, E. Mendes, and J. C. Grundy, "Empirical studies of pair programming for CS/SE teaching in higher education: A systematic literature review," *IEEE Trans. Softw. Eng.*, vol. 37, no. 4, pp. 509–525, 2011, doi: 10.1109/TSE.2010.59.

[14] A. Okada and P. Gray, "A Climate Change and Sustainability Education Movement: Networks, Open Schooling, and the 'CARE-KNOW-DO' Framework," *Sustain.*, vol. 15, no. 3, 2023, doi: 10.3390/su15032356.

[15] Á. F. Morote, J. Olcina, and M. Hernández, "Teaching Atmospheric Hazards in the Climate Change Context—Environmental Didactic Proposals in the Mediterranean Region for Secondary Schools," *Environ. - MDPI*, vol. 9, no. 2, 2022, doi: 10.3390/environments9020029.

[16] V. Winter, J. Kranz, and A. Möller, "Climate Change Education Challenges from Two Different Perspectives of Change Agents: Perceptions of School Students and Pre-Service Teachers," *Sustain.*, vol. 14, no. 10, 2022, doi: 10.3390/su14106081.

[17] O. Ben Zvi Assaraf *et al.*, "Climate change education implementation: the voices of policymakers, professional development providers, and teachers in five countries," *Int. J. Sci. Educ.*, pp. 1–23, 2024, doi: 10.1080/09500693.2024.2314572.

[18] Tim Penulis, *Panduan Operasional Model Kompetensi Guru*. Direktorat Jenderal Guru dan Tenaga Kependidikan, Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi Republik Indonesia, 2023. [Online]. Available: https://gtk.kemdikbud.go.id/read-news/panduan-operasional-model-kompetensi-guru-2023

[19] E. Feldbacher, M. Waberer, L. Campostrini, and G. Weigelhofer, "Identifying gaps in climate change education - a case study in Austrian schools," *Int. Res. Geogr. Environ. Educ.*, vol. 33, no. 2, pp. 109–124, 2024, doi: 10.1080/10382046.2023.2214042.

[20] Kemendikbud, "Kurikulum Pada Pendidikan Anak Usia Dini, Jenjang Pendidikan Dasar, Dan Jenjang Pendidikan Menengah," *Permendikbud Ristek Nomor 12 Tahun 2024*, pp. 1–26, 2024.

[21] S. Brumann, U. Ohl, and J. Schulz, "Inquiry-Based Learning on Climate Change in Upper Secondary Education: A Design-Based Approach," *Sustain.*, vol. 14, no. 6, 2022, doi: 10.3390/su14063544.

[22] J. Jimenez and L. Moorhead, "'Don't Say It's Going to Be Okay': How International Educators Embrace Transformative Education to Support Their Students Navigating Our Global Climate Emergency," *Educ. Sci.*, vol. 11, no. 10, 2021, doi: 10.3390/educsci11100593.

[23] C. D. Trott and A. E. Weinberg, "Science Education for Sustainability: Strengthening Children's Science Engagement through Climate Change Learning and Action," *Sustainability*, vol. 12, no. 16, p. 6400, 2020, doi: 10.3390/su12166400.

[24] L. Steffensen, M. Johnsen-Høines, and K. H. Hauge, "Using inquiry-based dialogues to explore controversial climate change issues with secondary students: An example from Norway," *Educ. Philos. Theory*, vol. 55, no. 10, pp. 1181–1192, 2023, doi: 10.1080/00131857.2022.2144221.

[25] B. and R. Adolf, *Model dan Pendekatan Pembelajaran*. Indramayu: Penerbit Adab, 2022.

[26] P. P. Indonesia, "Pedagogi Konstruktivisme Dalam Praksis Pendidikan Indonesia Euis Nurhidayati 1," *Int. J. Educ. Couns.*, vol. 1, no. 1, pp. 1–14, 2017.

[27] Batmang, "Pendekatan Transdisipliner (Suatu Alternatif Pemecahan Masalah Pendidikan)," *Al-TA'DIB*, vol. 9, no. 2, p. 48, 2016, [Online]. Available: http://ejournal.iainkendari.ac.id/al-tadib/article/view/512

[28] N. M. Andriani, I. M. Tegeh, and I. M. Suarjana, "Pembelajaran Berbasis Phenomenon Based Learning untuk Mengatasi Fenomena Learning Loss Siswa Sekolah Dasar," *J. Imiah Pendidik. dan Pembelajaran*, vol. 6, no. 3, pp. 488–502, 2023, doi: 10.23887/jipp.v6i3.57502.

[29] dan R. T. Arsinta, Aulia., Rahman, Abdur., "Pembelajaran Holistik, Kontekstual dan Futuristik," vol. 5, pp. 378–397, 2024.

[30] A. Farah *et al.*, "Panduan Pendidikan Inklusif," *Kepala Pus. Kurikulum dan Pembelajaran Badan Standar, Kurikulum, dan Asesmen Pendidik. Kementeri.*

Pendidik. Kementeri. Pendidikan, Kebudayaan, Riset, dan Teknol., p. 3, 2022, [Online]. Available: https://kurikulum.kemdikbud.go.id/wp-content/uploads/2022/08/Panduan-Pelaksanaan-Pendidikan-Inklusif.pdf

[31] J. V Tumangkeng, "Penggunaan Pendekatan Sosiosaintifik Dalam Pengembangan Dan Implementasi Rancangan Tugas Tematik Banjir Pada Siswa Charm Sains," *J. Pendidik. Fis.*, vol. 3, no. 3, pp. 143–151, 2022.

[32] Y. M. Monalisa, Y. Andika, and D. Savitri, "Pendekatan emosional guru terhadap siswa dalam film Monsieur Lazhar dan film Ia Cour de Babel," *French Teaching, Linguist. Lit. Cult.*, vol. 1, no. 2, pp. 87–94, 2022.

[33] K. K. C. Cheung, "A Structural Model of Future-Oriented Climate Change Optimism in Science Education: PISA Evidence from Countries with Top Environmental Protection Index," *Res. Sci. Educ.*, vol. 54, no. 5, pp. 845–865, 2024, doi: 10.1007/s11165-024-10164-7.

[34] S. Pfirman *et al.*, "'Stickier' learning through gameplay: An effective approach to climate change education," *J. Geosci. Educ.*, vol. 69, no. 2, pp. 192–206, 2021, doi: 10.1080/10899995.2020.1858266.