

## Green Technology Literacy and STEM Teaching Practice Needs of Primary School Teachers in The Context of Sustainable Education

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### Abstract

This study aims to identify the needs of primary school teachers regarding green technology literacy and the practice of STEM (Science, Technology, Engineering, Mathematics) teaching in the context of sustainable education. A descriptive qualitative approach was used, involving 10 teachers from four primary schools in Tangerang. Data were collected through in depth interviews, analysis of instructional documents, and field notes. The results show that teachers' understanding of green technology concepts remains general and is mostly limited to simple practices such as recycling and energy conservation. STEM teaching practices are unstructured and generally not explicitly integrated with sustainability issues. Teachers expressed the need for practical training, simple thematic teaching modules, and school policy support to implement contextual and environmentally oriented learning. These findings provide a foundation for the development of teacher training programs and green STEM based curricula at the primary education level.

**Keywords:** Green Technology Literacy, STEM Education, Primary School Teachers, Sustainable Education

### Introduction

The accelerating pace of climate change, the intensifying global energy crisis, and the ongoing degradation of natural ecosystems have placed unprecedented pressures on societies worldwide. These interconnected challenges highlight the urgent need for multidimensional responses, with the education sector emerging as one of the most critical arenas for cultivating long-term, sustainable solutions. Schools, particularly at the primary level, play a strategic role in shaping young learners' values, mindsets, and behaviours. As the foundation of early cognitive and character development, primary education offers a vital platform for instilling ecological awareness, responsible citizenship, and sustainable habits from an early age. Consequently, integrating Education for Sustainable Development (ESD) into primary school curricula has become a central agenda in global educational reform (UNESCO, 2020).

ESD is more than an environmental initiative; it represents a transformative approach that prepares learners to navigate complex social, economic, and ecological issues. It integrates action oriented learning, systems thinking, and values-based education to equip students with the competencies needed to participate in building a more sustainable future (Akinsemolu & Onyeaka, 2025). To effectively operationalize these principles in classroom practice, pedagogical models must be engaging, inquiry-driven, and closely linked to real-world contexts. One of the most relevant frameworks in this regard is STEM education encompassing Science, Technology, Engineering, and Mathematics. STEM enables students to understand scientific phenomena, engage in engineering design processes, and apply technological solutions to authentic problems (National Science Foundation, 2019).

When STEM principles are explicitly connected to sustainability issues, they evolve into the Green-STEM approach. Green-STEM Education emphasizes the integration of scientific inquiry and environmental values, empowering students not only to understand ecological challenges but also to design innovative, environmentally friendly solutions (Rantanen et al., 2024). At the primary level, this integration is particularly powerful, as it nurtures curiosity, critical thinking, environmental stewardship, and problem solving competence simultaneously.

Despite its potential, the implementation of Green-STEM in primary schools faces considerable challenges. One key obstacle is the limited level of teachers' green technology literacy. Many teachers understand environmental themes only at the surface level such as recycling, saving electricity, or cleaning school grounds without deeper comprehension of technological innovations, renewable energy systems, or resource-efficient processes (Suprpto et al., 2023). Pedagogically, many primary teachers also struggle to design interdisciplinary, project-based STEM lessons that embed sustainability concepts meaningfully. As Chatterjee and Gol (2024) note, the success of ESD

depends heavily on teachers' ability to integrate ecological, technological, and scientific perspectives into everyday instructional practices.

The selection of Tangerang Regency as the research site further underscores the importance of examining these challenges. As one of the rapidly developing regions in Indonesia, Tangerang has undergone significant industrialization, urban expansion, and demographic change. These transformations introduce environmental pressures from pollution to waste management issues that make sustainability-oriented education not only relevant but essential. Teachers in such contexts must be equipped to develop students' scientific reasoning, problem solving abilities, and ecological literacy concurrently.

Given these considerations, there is a growing need to understand the specific competencies and support systems teachers require to implement Green-STEM effectively. This study aims to explore primary school teachers' needs regarding green technology literacy and STEM based pedagogical practices within the framework of sustainable education. By identifying these needs, the study contributes to the development of more targeted teacher training programs, relevant curricular materials, and supportive school policies that can strengthen the implementation of ESD in primary education.

## **Theoretical Review**

### **Education for Sustainable Development (ESD)**

Education for Sustainable Development (ESD) is an educational framework aimed at preparing learners to understand, address, and solve global challenges such as climate change, energy crises, poverty, social inequality, and environmental degradation. UNESCO (2021) defines ESD as "education that equips learners with systems thinking skills, ecological empathy, and the capacity to take action on sustainability issues."

This approach demands a transformation of educational paradigms from merely transferring knowledge to implementing transformative learning that integrates knowledge, values, and action. In the context of primary education, ESD serves to develop ecological awareness, critical thinking, and social responsibility from an early age (OECD, 2021). Children not only learn to recognize natural phenomena but also to understand the interconnections between science, technology, society, and the environment.

ESD encompasses five interrelated dimensions:

- a. Cognitive: understanding sustainability principles and systemic human–environment relationships;
- b. Affective: developing values and attitudes that support sustainability;
- c. Psychomotor: the ability to take real actions to protect the environment;
- d. Socio-Cultural: appreciation of local wisdom and cultural diversity;
- e. Transformational: the ability to reflect on and change behavior toward sustainable living.

In Indonesia, ESD aligns with the implementation of the *Profil Pelajar Pancasila*, which emphasizes character qualities such as faithfulness, critical reasoning, creativity, collaboration, and environmental stewardship (Kemdikbudristek, 2022). Therefore, the integration of sustainability values must be realized through contextual, active, and collaborative learning approaches, including the application of environmentally oriented STEM learning (Green-STEM).

### **Green Technology Literacy**

Green technology literacy is a key dimension of ESD that links scientific knowledge to ecological responsibility. This concept refers to an individual's ability to recognize, understand, and apply environmentally friendly technologies in daily life (Akinsemolu & Onyeaka, 2025).

Green technology literacy involves not only technological proficiency but also critical awareness of the social and ecological impacts of technology use. According to Akinsemolu and Onyeaka (2025), this literacy comprises three main dimensions:

- a. Cognitive: mastery of knowledge related to clean technologies, renewable energy, water conservation, waste management, and resource efficiency.
- b. Affective: the development of values and attitudes of environmental care, along with the belief that technology can be harnessed for ecological well-being.
- c. Behavioral: the ability and willingness to implement environmentally friendly practices in daily life at home, in school, and in the community.

Within primary education, green technology literacy serves as a bridge between science learning and environmental awareness. Teachers who possess adequate green technology literacy are better able to integrate sustainability concepts into science (IPA), mathematics, and IPAS lessons in concrete and contextual ways. Examples include teaching energy concepts using mini solar panel experiments, designing recycling projects using used materials, or utilizing local environmental data as learning resources.

Integrating green literacy also reinforces the implementation of the *Kurikulum Merdeka*, which emphasizes project-based learning (PjBL) to foster creativity, collaboration, and social responsibility among students. Thus, green technology literacy not only supports the achievement of scientific competencies but also contributes to the formation of character and a sustainable school culture.

### ***STEM Learning (Science, Technology, Engineering, Mathematics)***

STEM Education is an interdisciplinary learning approach that integrates science, technology, engineering, and mathematics to understand and solve real-world problems. The National Science Foundation (NSF, 2019) emphasizes that the main goal of STEM is to cultivate critical, innovative, collaborative, and solution-oriented thinking in learners.

At the primary school level, this approach encourages students to learn through experiments, inquiry, and hands-on projects rather than rote memorization of concepts. When linked with sustainability issues, STEM evolves into a new paradigm known as Green-STEM an application of STEM principles to support environmental action and sustainable development (Rantanen et al., 2024).

Green-STEM learning is characterized by:

- a. Problem-Based Learning: students identify local environmental problems and design science- and technology-based solutions.
- b. Interdisciplinary and Contextual Integration: learning connects different subjects to real-world issues such as waste management or clean energy.
- c. Action-Oriented Outcomes: learning results in products or real actions, such as simple tools, energy experiments, or environmental campaigns.
- d. Collaborative and Reflective Processes: students work in groups, share ideas, and reflect on problem-solving processes.

Thus, the STEM approach serves as a key driver of ESD transformation in primary schools because it teaches students to think systemically, innovate, and act responsibly toward the environment. Teachers who master this approach are not only able to improve learning outcomes in science or mathematics but also cultivate an environmental mindset that forms the foundation of future sustainability literacy.

### ***Sustainable Teacher Competence***

In the paradigm of ESD, teachers act as change agents who guide learners toward ecological awareness and social responsibility. Chatterjee and Gol (2024) emphasize that the success of ESD depends on teachers' readiness and competence in understanding and applying sustainability values in the classroom.

Sustainable teacher competence comprises three main dimensions:

- a. Pedagogical Competence: the ability to design contextual, collaborative, and project-based learning to facilitate understanding of sustainability.
- b. Technological Competence: the ability to utilize digital technologies and environmentally oriented learning resources to enhance the effectiveness of instruction.
- c. Eco-pedagogical Competence: teachers' awareness of human–nature relationships and the ability to integrate ecological, social, and ethical issues into learning (OECD, 2021).

Developing sustainable teacher competence requires a holistic approach through training, mentoring, reflective practice, and strengthening teacher learning communities (Professional Learning Community/PLC). Teachers who possess sustainable competence not only teach academic concepts but also cultivate sustainable living values through role modelling and direct experience.

Within the *Kurikulum Merdeka* framework, the role of the teacher is expanded to that of a facilitator and learning innovator. Sustainable teachers actively contribute to building a green school culture that integrates classroom learning, school policies, and community participation.

Thus, sustainable teacher competence becomes a key variable linking green technology literacy, STEM instruction, and the goals of ESD. Teachers who are pedagogically, technologically, and eco-pedagogically competent are capable of actualizing sustainable education in primary school classrooms.

#### Conceptual Synthesis

Based on the theoretical review above, it can be concluded that:

- a. ESD provides the value framework and sustainability goals within education;
- b. Green technology literacy offers the knowledge content and ecological awareness;
- c. STEM learning serves as a concrete instructional method or strategy; and
- d. Sustainable teacher competence functions as the primary driver of implementation at the primary school level.

The interaction of these four concepts forms an integrative theoretical framework the Integrative Green-STEM Framework which positions teachers at the center of learning transformation toward sustainable primary education. This framework will serve as the analytical basis for the empirical study aimed at identifying primary school teachers' needs, readiness, and development strategies in the context of green technology literacy and STEM instruction.

#### Research Methodology

This study employed a descriptive qualitative approach with an interpretive design. The participants consisted of 10 primary school teachers from four schools in Tangerang Regency (two public schools and two private schools). Data were collected through in-depth interviews, analysis of instructional documents, and field notes.

Data analysis was conducted using thematic analysis (Braun & Clarke, 2006), which involved the following steps: (1) repeated reading of the data, (2) open coding, (3) categorizing codes into themes, (4) interpreting emerging patterns, and (5) drawing conclusions. The credibility and trustworthiness of the data were ensured through member checking, peer debriefing, and source triangulation (Lincoln & Guba, 1985).

#### Research Findings

This section presents the findings derived from in-depth interviews, analysis of instructional documents, and field observations involving ten primary school teachers in Tangerang Regency. The analytic process followed the principles of thematic analysis as outlined by Braun & Clarke (2006), which include coding, categorization, and theme abstraction.

The data reflect the actual conditions of teachers' understanding and practices in integrating green technology concepts and the STEM (Science, Technology, Engineering, and Mathematics) approach into primary school learning processes.

The findings of this study are presented in two main forms:

- a. Quantitative descriptive data, consisting of frequency tables and percentages derived from interview and observation results categorized into five major dimensions of teacher competence; and
- b. Qualitative narrative data, consisting of direct quotations and contextual interpretations that enrich and reinforce the meaning behind the numerical data.

This analysis aims to identify the *real needs* of teachers in developing Green-STEM competencies as part of the implementation of Education for Sustainable Development (ESD) at the primary school level.

The findings are grouped into five key dimensions of teacher development:

- a. Conceptual needs related to green technology literacy,
- b. Pedagogical needs in implementing STEM instruction,
- c. Needs for contextual learning resources and media,
- d. System-support needs at the school level, and
- e. Professional development needs through training and learning communities.

These five dimensions form the foundation for designing a Green-STEM Teacher Competency Framework, which serves not only as a conceptual model but also as an operational guideline for future teacher training policies and curriculum development at the primary education level.

Table 1. Research Findings

Aspect	Findings
Conceptual Needs	Teachers have a limited understanding of green technology, often restricted to basic ideas such as “saving electricity” or “planting trees.” Few understand concepts such as renewable energy, circular economy, or environmentally friendly technology design. <i>“Green technology is like recycling and saving energy, but I don’t yet know how to explain solar energy or industrial waste to primary students.”</i> (Teacher A) Teachers require strengthened conceptual literacy that explains the relationship between technology, the environment, and foundational learning.
Pedagogical Needs	Teachers have implemented simple projects such as science experiments, but they have not yet understood STEM as an integrative thinking framework. <i>“We often do experiments, but we didn’t know they could be developed into STEM projects.”</i> (Teacher D) They need practical training and applicable Green-STEM lesson plan guides tailored for primary students.
Learning Resource Needs	Most teachers experience limitations in teaching media and experimental tools. <i>“If we had modules and simple tools for energy or recycling, students would be more engaged.”</i> (Teacher B) Teachers hope for digital modules, learning videos, and interactive media relevant to the local environmental context.
System Support	A major constraint is the absence of school policies explicitly supporting green STEM learning programs. Teachers also noted limitations related to time, infrastructure, and principal support. <i>“Environmental programs at school depend on teachers’ enthusiasm; they are not yet formal policies.”</i> (Teacher E)
Professional Strengthening	All teachers emphasized the need for continuous training and STEM–environment learning communities. <i>“If possible, training should not be purely theoretical. We need hands-on mentoring.”</i> (Teacher I) They also expect collaboration between schools, universities, and local governments in integrated Green-STEM training.

Teachers’ Understanding of Green Technology Concepts

Table 2. Findings for Each Investigated Aspect

Understanding Aspect	Description of Field Findings	Teacher Frequency (n = 10)	Percentage (%)
Knowledge of general concepts (energy saving, recycling)	Mention examples of everyday environmentally friendly behaviors	9	90%
Understanding innovation-based green technology principles (renewable energy, energy efficiency)	Able to explain simple scientific concepts (solar panels, composters, biogas)	3	30%
Ability to connect green technology concepts to science/IPAS instruction	Integrate sustainability topics into lesson plans or learning activities	2	20%
Lack of specific understanding of green technology concepts	Only aware of “saving electricity and proper waste disposal”	5	50%

The findings show that primary school teachers possess a basic awareness of green practices, but their understanding of green technology remains largely superficial and moral practical rather than scientific. Most teachers (90%) can identify general environmentally friendly behaviors such as saving energy or recycling. However, only a small number demonstrate an understanding of innovation-based green technologies; just 30% can explain simple scientific concepts like solar panels, composters, or biogas. The ability to integrate green technology concepts into science or IPAS learning is even more limited, with only 20% incorporating sustainability topics

into lesson plans or classroom activities. Half of the teachers (50%) exhibit a narrow understanding, limited to ideas such as “saving electricity” and basic waste disposal. Overall, the findings indicate that teachers’ conceptual literacy in green technology especially in areas requiring scientific explanation or classroom application remains low, highlighting the need for strengthened training and instructional support.

#### Implementation of STEM Learning in Primary Schools

Table 3. Description of Research Findings for Each Indicator

Implementation Indicator	Description of Activities	Frequency (n)	Percentage (%)
Implementation of simple science experiments (Science/Mathematics)	Examples: water experiments, plant observations, magnets	8	80%
Integration of two or more STEM disciplines	Science–Mathematics or simple Science–Technology integration	3	30%
Implementation of environmentally based problem-solving projects	Examples: waste recycling, hydroponics, mini gardens	4	40%
Authentic assessment of projects (rubrics, presentations, reflection)	Assessing both process and product	2	20%
No systematic STEM implementation	Teaching remains conventional (lectures, textbooks)	5	50%

The findings indicate that while teachers have begun to introduce STEM-related activities, the implementation remains basic and largely unstructured. Most teachers (80%) have conducted simple science experiments such as water investigations, plant observations, or magnet activities showing an initial effort to promote hands on learning. However, only 30% have integrated two or more STEM disciplines in a single lesson, typically combining Science and Mathematics or simple Science Technology tasks. Environmentally oriented, problem based projects are implemented by 40% of teachers, with examples such as recycling projects, hydroponics, or creating mini gardens. Authentic assessment practices such as using rubrics, student presentations, or reflective evaluations are rarely applied, with only 20% of teachers assessing both process and product.

Additionally, half of the teachers (50%) have never implemented STEM systematically and continue to rely on conventional instructional approaches, such as lectures and textbook-based teaching. Overall, STEM implementation at the primary level remains partial, incidental, and not yet aligned with a structured STEM pedagogy, indicating the need for improved teacher training, clearer instructional models, and stronger support systems.

#### Teacher Training Needs in Green-STEM

Table 4. Development Needs Identified for Future Research

Type of Development Need	Teacher Frequency (n)	Percentage (%)	Additional Notes (Interview Quotes)
Green technology literacy training	9	90%	“We want to learn how to explain clean energy to primary students.”
Project-based STEM instructional design training	8	80%	“We need examples of lesson plans or projects that we can use directly.”
Provision of thematic modules & environmental teaching media	7	70%	“If we had modules and simple tools, students would definitely be more engaged.”
Support for facilities (experimental tools, practice space)	6	60%	“Our school has very limited experimental tools.”

Type of Development Need	Teacher Frequency (n)	Percentage (%)	Additional Notes (Interview Quotes)
Strengthening school policies (green policy)	5	50%	“The school has no specific environmental program; it depends on the teachers.”

The results reveal strong demand among primary school teachers for professional development related to Green STEM. The most urgent need is green technology literacy training, with 90% of teachers expressing the desire to better understand and explain concepts such as clean energy to young learners. This reflects a significant conceptual gap in teachers’ scientific understanding of sustainability technologies. The second major need is training in project-based STEM instructional design (80%). Teachers reported the need for practical examples of lesson plans and ready-to-use project templates that align with sustainability themes. In terms of learning resources, 70% of teachers indicated the need for thematic modules and environmental teaching media, such as simple experiment kits and digital materials to support classroom activities.

Additionally, 60% require improved facilities, noting the scarcity of experimental tools and practice spaces in their schools. Finally, half of the teachers (50%) emphasized the need for stronger school-level policies that formally support environmental programs and Green STEM initiatives, as current efforts often rely solely on teacher motivation. Overall, the findings indicate that teachers need comprehensive support conceptual, pedagogical, resource-based, infrastructural, and policy-driven to effectively implement Green-STEM learning in primary schools.

The dominant needs identified relate to strengthening teachers' capacity in two main areas:

- (1) conceptual knowledge of green technology, and
- (2) project-based STEM pedagogical practices.

Support systems and learning resources are also considered critical.

#### Synthesis of Field Findings: Five Dimensions of Teacher Development Needs

Table 5. Competency Dimensions

Competency Dimension	Specific Aspects Identified	Percentage of Teachers Needing Development	Development Priority (Scale 1–5)
Conceptual	Understanding green technology, renewable energy, resource efficiency	90%	5
Pedagogical	Designing project-based and inquiry-based STEM learning	80%	5
Learning Resources	Use of simple experimental tools and digital environmental media	70%	4
System Support	Green school policies and learning facilities	60%	3
Professional	Training, mentoring, and sustainable teacher communities	90%	5

The analysis of field data identifies five key dimensions that define teachers’ developmental needs for effective Green STEM implementation in primary schools. The conceptual dimension emerges as one of the highest priorities, with 90% of teachers needing stronger understanding of green technology, renewable energy, and resource efficiency. This highlights a fundamental knowledge gap that must be addressed to support sustainability based instruction. The pedagogical dimension is equally critical (80%; priority level 5), reflecting teachers’ need for skills in designing interdisciplinary, project-based, and inquiry-driven STEM learning experiences.

Without these competencies, the translation of sustainability concepts into classroom practice remains limited. In terms of learning resources, 70% of teachers require access to simple experimental tools and digital environmental media to support hands-on and contextual learning (priority level 4). This underscores the importance of resource availability in enabling effective

STEM instruction. The system support dimension (60%; priority level 3) indicates that institutional structures such as green school policies, leadership support, and adequate facilities must be strengthened to create a conducive environment for Green-STEM adoption. Finally, the professional dimension, also rated as a top priority (90%; priority level 5), points to the need for sustained training, mentoring, and active participation in teacher learning communities.

Continuous professional development is essential for maintaining teacher readiness and encouraging reflective, long-term engagement with sustainability issues. Overall, these five dimensions form an integrated framework that highlights where capacity-building efforts should be directed to empower teachers as effective agents of green and sustainable education.

**Radar Chart: Green-STEM Teacher Competency Needs Profile**

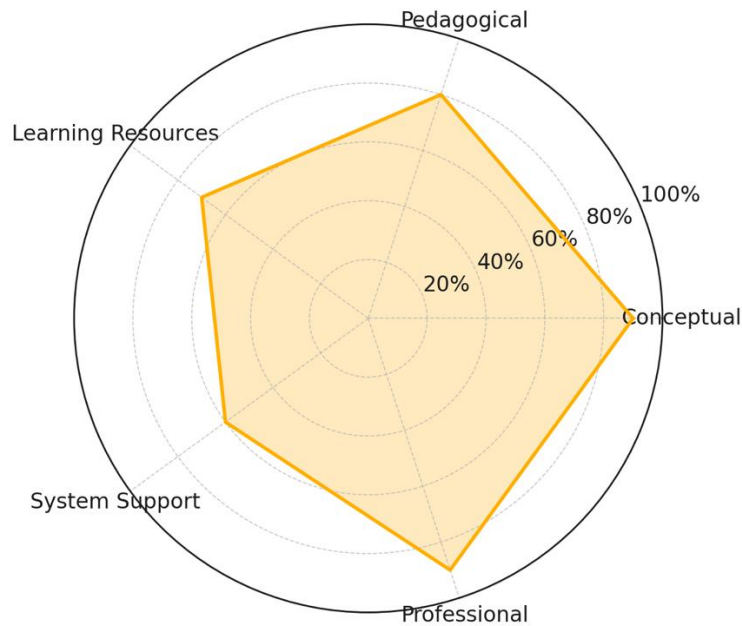


Fig 1. Radart chart of Green-STEM teacher competency

### Discussion

The findings of this study reveal that primary school teachers' understanding and mastery of green technology concepts and STEM learning remain at a practical level rather than conceptual or integrative. Teachers demonstrate strong ecological awareness such as conserving energy, planting trees, and engaging in recycling activities yet they have not fully grasped how scientific and technological principles can be used to develop sustainability-oriented solutions in the classroom.

This condition reflects a gap between environmental awareness and teachers' scientific technological literacy. These findings reinforce Suprpto et al. (2023), who argue that primary teachers in Indonesia tend to emphasize moral actions or environmentally friendly attitudes without strengthening conceptual, experimental, and scientific aspects. Consequently, the integration of science and sustainability values in learning has not been optimal.

In addition, limited systemic support from schools whether in the form of policies, facilities, or professional development weakens teachers' capacity to develop Green-STEM-based learning. Yet Chatterjee and Gol (2024) assert that the success of sustainable education depends on the synergy of teacher competence, institutional support, and a strong green school culture.

### Implications for Teacher Competence and Sustainable Education

The results of this study confirm the relevance of eco-pedagogical competence theory (Akinsemolu & Onyeaka, 2025), which emphasizes that teachers act as both educators and socio-ecological change agents. This means teachers are not only required to master teaching content but also to embed sustainability values through active, reflective, and context-based learning.

Based on the empirical findings, five key dimensions of teacher competence needed for implementing Green-STEM based sustainable education were identified:

**Conceptual Dimension:**

This includes teachers' literacy regarding sustainability principles, green technology, and their connections to the science and IPAS curriculum. Teachers need to understand concepts such as renewable energy, recycling, and circular economy, and be able to relate these concepts to primary-level instructional content.

**Pedagogical Dimension:**

This highlights the ability to design and implement interdisciplinary, project-based, and inquiry-based learning. Teachers must master STEM instructional stages that are contextual and relevant to students' local environmental issues.

**Learning Resource Dimension:**

This relates to teachers' ability to develop and utilize simple instructional media, experimental tools, and digital learning resources that support sustainability content.

**System Support Dimension:**

This involves school policies, leadership from principals, learning facilities, and collaboration with external stakeholders such as government agencies, universities, NGOs, or environmental communities.

**Professional Dimension:**

This encompasses teachers' motivation and participation in continuous training, professional learning communities (PLC), and their willingness to develop themselves as reflective practitioners in sustainability contexts.

Together, these five dimensions form a sustainable teacher development ecosystem, enabling teachers to become key drivers of green education transformation at the primary school level.

**Implications for School Policy and Practice**

These findings provide a foundation for strengthening environmentally oriented school policies (green school policy). Schools need to build a support system that not only emphasizes ceremonial environmental activities but also facilitates the integration of sustainability values into classroom instruction.

This can be achieved through:

- a. Establishing green school policies based on curriculum integration, whereby sustainability values are embedded across all subjects;
- b. Enhancing teacher capacity through micro-credential training or in-service workshops on Green-STEM; and
- c. Providing basic facilities, such as eco-lab corners, educational gardens, or primary-level green science programs.

These policies align with Indonesia's national education agenda, which emphasizes strengthening the *Profil Pelajar Pancasila* and SDG 4 (Quality Education) as well as SDG 13 (Climate Action) through adaptive and contextually relevant curricula (Kemdikbudristek, 2022).

**Implications for Model Development and Future Research**

The Green-STEM Teacher Competency Framework resulting from this study serves not only as a descriptive model but also as a theoretical and operational foundation for developing quantitative instruments and teacher training programs.

Several directions for future research include:

a. Development of Quantitative Instruments

Future researchers may develop measurement instruments (questionnaires or rubrics) based on the five competency dimensions identified. These instruments may be used to:

- 1) Measure primary teachers' green technology literacy,
- 2) Analyze teachers' readiness to implement Green-STEM learning, and
- 3) Assess the effectiveness of sustainability-based teacher training programs.

Instrument validation may be conducted using Confirmatory Factor Analysis (CFA) or Structural Equation Modeling (SEM) to verify relationships among variables.

b. Research and Development (R&D)

The model may also serve as a basis for designing educational or training products, such as:

- 1) Green-STEM Training Modules for Primary Teachers,

- 2) Guidelines for Integrating Sustainability Values into the Science/IPAS Curriculum,
- 3) Environmentally Friendly STEM Learning Toolkits for Primary Schools, and
- 4) A Green School Model Based on Teacher Learning Communities (Green-STEM PLC).

The development process may follow R&D models such as Borg & Gall or ADDIE, including expert validation, limited trials, and effectiveness testing to evaluate improvements in teacher competence.

c. Comparative or Longitudinal Research

Future studies may compare Green-STEM implementation across different regions for example, urban areas such as Tangerang versus rural areas to explore variations in readiness and challenges faced by teachers. Likewise, longitudinal studies may measure changes in teacher competence before and after participating in Green-STEM based training programs.

### Theoretical and Practical Synthesis

Based on the findings and literature review, the following conclusions can be drawn:

- a. Green technology literacy forms the conceptual foundation that cultivates teachers' awareness and understanding of sustainability.
- b. STEM learning serves as a pedagogical strategy that concretizes sustainability values within learning practice.
- c. Sustainable teacher competence is both an outcome and a driving force behind ESD implementation at the primary school level.

These three components exist within the broader framework of Education for Sustainable Development (ESD), which functions as the overarching value system and educational goal. Their integration produces the Green-STEM Teacher Competency Framework, which may serve as a national reference for teacher training, school curriculum development, and sustainability-based primary education policy.

### Conclusion

Primary school teachers in Tangerang Regency demonstrate strong enthusiasm for implementing environmentally oriented learning; however, they still require strengthened conceptual understanding, pedagogical skills, and systemic support.

This study identifies five key variables of teacher development needs that form the foundation of the proposed Green-STEM model:

1. Literacy in green technology concepts,
2. STEM pedagogical skills,
3. Contextual learning resources,
4. Institutional support, and
5. Continuous professional development.

This model can serve as both a theoretical and empirical basis for future quantitative studies aimed at developing measurement instruments and Green-STEM training programs for primary school teachers.

### REFERENCES

- Akinsemolu, A. A., & Onyeaka, H. (2025). *Education for sustainable development: Integrating green pedagogy and teacher competencies for climate action*. *Sustainability Education Journal*, 17(2), 45–61.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.
- Chatterjee, S., & Gol, S. (2024). Building teacher capacity for sustainability through green-STEM integration: Challenges and perspectives. *International Journal of Science Education*, 46(3), 312–330.
- Cordaro, R., Mak, A., & Philips, J. (2022). Designing digital learning environments for environmental literacy in primary education. *Journal of Environmental Education Research*, 28(4), 425–443.
- Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). Sage Publications.
- Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.

- National Science Foundation (NSF). (2019). *STEM education strategic plan: Charting a course for success*.
- OECD. (2021). *Teachers and leaders in schools: Teaching for the future*. OECD Publishing.
- Rantanen, M., Hakkarainen, K., & Lehtonen, T. (2024). Green-STEM in primary classrooms: Developing inquiry and sustainability literacy. *European Journal of STEM Education*, 9(1), 25–42.
- Suprpto, N., Zainuddin, M., & Wahyuni, D. (2023). Teachers' readiness in implementing STEM-based science education in Indonesian primary schools. *Jurnal Pendidikan IPA Indonesia*, 12(3), 421–435.
- UNESCO. (2020). *Education for Sustainable Development: A roadmap*. UNESCO Publishing.
- UNESCO. (2021). *Reimagining our futures together: A new social contract for education*. UNESCO Publishing.