

Transforming the School Environment as a Living Laboratory in Environmental Geography-Based Climate Change Mitigation

Diana¹, Kareendra putiraidyztha², Halim³, Armin Alamsyah⁴

^{1,2,3,4} Department of Geography Education, Faculty of Teacher Education and Educational Sciences, University of Muhammadiyah Mataram, Mataram City, Indonesia

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ABSTRAK

Penelitian ini mengkaji transformasi lingkungan sekolah sebagai laboratorium hidup dalam mitigasi perubahan iklim berbasis geografi lingkungan. Tujuan penelitian ini adalah untuk menganalisis bagaimana integrasi elemen lingkungan fisik, analisis spasial, dan perilaku manusia di lingkungan sekolah dapat berkontribusi terhadap mitigasi perubahan iklim pada skala lokal. Metode yang digunakan adalah pendekatan kualitatif deskriptif dengan studi literatur dan pendekatan konseptual. Data diperoleh dari jurnal ilmiah, buku, dan publikasi terkait geografi lingkungan, mitigasi perubahan iklim, serta pendidikan lingkungan. Hasil penelitian menunjukkan bahwa transformasi lingkungan sekolah melalui pengelolaan vegetasi, penataan ruang berkelanjutan, serta penerapan perilaku ramah lingkungan mampu menurunkan emisi karbon dan memperbaiki kondisi iklim mikro. Selain itu, pemanfaatan teknologi geospasial seperti Sistem Informasi Geografis (SIG) meningkatkan pemahaman siswa terhadap dinamika lingkungan. Transformasi ini tidak hanya meningkatkan kesadaran lingkungan, tetapi juga menjadikan sekolah sebagai agen aktif dalam mitigasi perubahan iklim. Studi ini menyoroti pentingnya mengintegrasikan Pendidikan, lingkungan, dan teknologi spasial dalam mengatasi tantangan lingkungan global di skala mikro

ABSTRACT

This study examines the transformation of school environments into living laboratories as an innovative approach to climate change mitigation based on environmental geography. The objective of this research is to analyze how the integration of physical environmental elements, spatial analysis, and human behavior within school settings can contribute to climate change mitigation at a local scale. This study employs a qualitative descriptive method with a conceptual and literature-based approach. Data were collected from scientific journals, books, and relevant publications related to environmental geography, climate change mitigation, and environmental education. The results indicate that transforming school environments through vegetation management, sustainable spatial planning, and environmentally friendly behavioral practices can significantly reduce carbon emissions and improve microclimate conditions. Furthermore, the use of geospatial technologies such as Geographic Information Systems (GIS) enhances students' understanding of spatial environmental dynamics. This transformation not only strengthens environmental awareness but also positions schools as active agents in climate change mitigation. The study highlights the importance of integrating education, environment, and spatial technology in addressing global environmental challenges at the micro level.

1. INTRODUCTION

The transformation of the school environment into a living laboratory is an innovative approach in environmental education that integrates contextual learning with real-world practices based on direct experience. This concept positions the school as a space for socio-ecological experimentation where interactions between humans and the environment can be

observed and developed in a sustainable manner. From an environmental geography perspective, this approach emphasizes the interconnection between human activities and environmental conditions as a dynamic system. Experience-based environmental education has proven effective in enhancing ecological awareness and fostering sustainable behavioral change (Ardoin et al., 2020; Salas-Zapata et al., 2021). Furthermore, the whole-school approach in sustainability education demonstrates that transforming the school environment can strengthen environmental literacy and collective climate change mitigation actions (Fakoya et al., 2023)

Various studies indicate that integrating climate change education into schools has a significant impact on increasing students' environmental awareness and behavior. Research by (Hutagalung & Sazali, 2024; Monroe et al., 2019) shows that systematically designed climate change education can enhance students' understanding and encourage knowledge-based mitigation actions. Furthermore, a study by Trott, (2021) found that hands-on learning experiences in the school environment contribute to increased student engagement with climate change issues. Additionally, research by Ojala, (2022) confirms that a contextual educational approach can foster pro-environmental attitudes and enhance students' adaptive responses to the climate crisis.

Other research highlights the importance of schools as spaces for practical application in climate change mitigation through environment-based activities. (Nome et al., 2023; Voytenko, 2020) found that the living lab approach in educational institutions can foster innovation and sustainable behavioral change through active community participation. (Bulkeley, 2021; Trencher et al., 2014) also found that the living lab concept is effective in integrating academic learning with real-world solutions to environmental problems. Khoiruman et al., (2024) emphasize that experience-based learning in real-world settings can enhance sustainability competencies and environmental problem-solving skills (Brundiars, 2021).

In the context of school culture, research indicates that the development of environmental habits and values has a significant impact on the success of climate change mitigation. A study by (Afdhal et al., 2024; Ridha et al., 2025) demonstrates that a whole-school approach can bring about systemic changes in environmental behavior. Furthermore, research by emphasizes the importance of the participation of the entire school community in building a culture of sustainability. Additionally, research by Iman et al., (2025) reveals that integrating environmental values into daily school activities can sustainably strengthen students' ecological awareness.

From an environmental geography perspective, various studies indicate that spatial and contextual approaches are crucial for understanding human-environment interactions. Berglund & Gericke, (2022) emphasize that geography education plays a strategic role in developing spatial thinking skills and environmental awareness. Furthermore, research by Bednarz et al., (2022) using a systems approach demonstrates that understanding cause-and-effect relationships within environmental systems can enhance the effectiveness of climate change mitigation. Additionally, (Meadows, 2008; Oktavianus et al., 2023) emphasizes that environment-based education must bridge theory with real-world practice to bring about significant behavioral change.

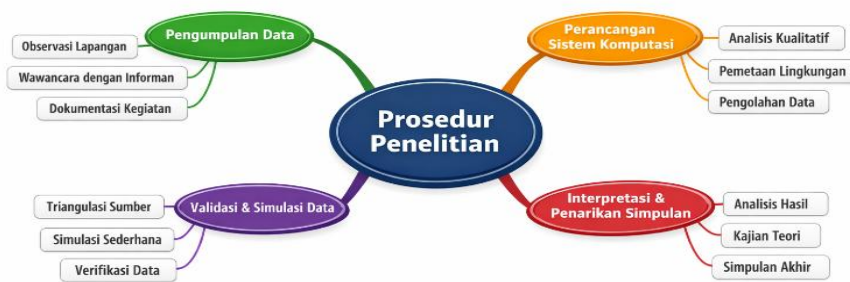
Although various studies have demonstrated the effectiveness of environmental education and the living laboratory approach, most studies remain fragmented and have not comprehensively integrated the concepts of the living laboratory, climate change mitigation, and environmental geography within the school context. Many studies focus on specific aspects of the curriculum or programs, but have not yet treated the school environment as a holistic and sustainable learning system. Furthermore, studies that simultaneously link social, ecological, and spatial dimensions remain limited, necessitating a more holistic approach.

Based on this, this study offers a novel approach by integrating the concept of transforming the school environment into a living laboratory with an environmental geography approach in efforts to mitigate climate change. This study emphasizes not only the learning aspect but also systemic changes and the overall behavior of the school community. Thus, the objective of this study is to analyze how the school environment can be transformed into an effective living laboratory to support climate change mitigation based on environmental geography.

2. METHOD

This study employs a qualitative approach with a descriptive-exploratory design combined with environmental geography-based analysis. This approach was chosen because it can provide an in-depth description of the process of transforming the school environment into a living laboratory for climate change mitigation. Additionally, this study integrates a simple spatial approach to understand the interactions between school community activities and the school's physical environment. This method is relevant for examining socio-ecological phenomena holistically, particularly in the context of environmental education and behavioral change (Creswell, 2014; Yin, 2018). Thus, the study focuses not only on outcomes but also on the transformation processes occurring within the school environment.

The data sources in this study consist of primary and secondary data. Primary data were obtained through direct observation of the school environment, in-depth interviews with the school community (students, teachers, and school staff), and documentation of environment-based activities. Meanwhile, secondary data were obtained from school documents, policies related to environmental education, and scientific literature relevant to the research topic. The types of data collected include qualitative data in the form of narratives, behaviors, and environmental practices, as well as simple quantitative data such as participation rates and the frequency of environmental activities. Data classification was conducted based on ecological, social, and educational aspects to facilitate analysis within the framework of environmental geography (Miles et al., 2014; Sugiyono, 20



Gambar 1. Prosedur Penelitian

The research procedure was conducted in several main stages. The first stage involved data collection, which included observing the physical conditions of the school environment, identifying eco-friendly activities, and conducting interviews with key informants. The second stage is the design of a simple computational system, namely data processing using qualitative analysis techniques (data reduction, categorization, and presentation) as well as simple mapping to identify patterns of human-environment interaction. The third stage is data validation and simulation, which is carried out through triangulation of sources and methods to ensure data validity, as well as simple simulations to project the impact of environmental activities on climate change mitigation. The fourth stage involves data interpretation and drawing conclusions, achieved by linking the analysis results to concepts of environmental geography and the living laboratory theory.

Next, the interpretation process was conducted comprehensively by integrating field findings and theoretical reviews. The analysis focused on how the school environment can function as a living laboratory in shaping climate change mitigation behaviors. Conclusions are drawn inductively by considering the interrelationships between social, ecological, and educational aspects. To ensure the validity of the research results, data triangulation and member checking techniques are employed, thereby ensuring the findings are scientifically accountable (Lincoln &

Guba, 1985). Through these steps, this study aims to provide a systematic and in-depth understanding of school environment transformation grounded in environmental geography.

3. RESULT AND DISCUSSION

Result

The research findings indicate that the transformation of the school environment into a living laboratory has begun to be implemented through various environment-based activities involving the entire school community. Field observations reveal the integration of learning activities with real-world practices such as waste management, greening initiatives, and energy conservation. The school's physical environment is utilized as a contextual learning medium, so that students not only understand the concept of climate change theoretically but also directly experience mitigation practices. This demonstrates that an experience-based approach can strengthen the connection between knowledge and action within the context of environmental education.

In addition, the interview results indicate an increase in ecological awareness among students and teachers following the implementation of the living laboratory concept. Students demonstrated behavioral changes such as disposing of trash properly, reducing the use of single-use plastics, and actively participating in environmental activities. Teachers also began integrating climate change issues into the cross-curricular learning process. These changes reflect that the living laboratory approach impacts not only cognitive aspects but also affective and psychomotor aspects in fostering an environmentally conscious character.

From a systemic and management perspective, the research findings indicate that the success of school environmental transformation is significantly influenced by policy support and school culture. Schools with structured environmental programs, such as Adiwiyata schools or similar initiatives, tend to be more successful in implementing these concepts. Furthermore, the active involvement of the entire school community, including the principal and educational staff, is a key factor in creating an environment that supports sustainable practices. This indicates that school environmental transformation requires a systemic approach that focuses not only on individuals but also on organizational structures.

Furthermore, an environmental geography-based analysis reveals significant patterns of interaction between human activities and the physical environmental conditions of the school. Activities such as greening and waste management have been shown to improve the quality of the school environment, such as increasing green open spaces and environmental cleanliness. Additionally, a simple mapping of environmental activities indicates that areas frequently used for practical activities exhibit higher levels of environmental awareness compared to other areas. This reinforces the notion that a spatial approach in environmental geography can help identify patterns and the effectiveness of environmental interventions in schools.

However, this study also identified several challenges in implementing the living laboratory concept, such as limited facilities and infrastructure, a lack of training for teachers, and the absence of strong integration into the formal curriculum. Additionally, some activities remain sporadic and lack systematic continuity. Therefore, strengthening strategies are needed through curriculum integration, human resource capacity building, and more comprehensive policy support. Overall, the results of this study indicate that transforming the school environment into a living laboratory holds great potential for supporting climate change mitigation, but requires planned and sustainable management to achieve optimal impact.

Discussion

School environment transformation is a comprehensive and gradual process of change within the educational ecosystem to adapt to the demands of the times, technology, and students' character development needs. This transformation targets not only physical aspects (buildings and facilities) but also culture, teaching methods, and interactions among all members of the school community (Kadir et al., 2024). The following are the main pillars of school environment transformation: Cultural and Character Transformation with a Positive Climate, which involves creating a safe, comfortable, inclusive, and enjoyable environment so that students can develop optimally Behavioral Change, which emphasizes shifting students' attitudes toward a more

positive and adaptive mindset and Green School, which encourages schools to become agents of environmental change by implementing sustainability values, such as waste management and energy efficiency (Liu et al., 2026; Salas-Zapata et al., 2021).

Learning and Curriculum Transformation, such as Differentiated Instruction, involves shifting from a one-size-fits all model to one tailored to the individual needs of students. Innovation Labs, where teachers are given the space to ethically explore new teaching methods and technologies. Digital Transformation and Facilities, such as School (Fakoya et al., 2023; Lutri Bunga Lestari et al., 2025). Digitization the integration of digital technology into administration, communication, and the teaching-learning process to improve the quality of educational services and (Firmansyah et al., 2025; Octavia et al., 2022). Facility Revitalization, which involves updating infrastructure and supporting facilities like laboratories and libraries to make them more modern and conducive to learning (Koniyo et al., 2025; Zaidi et al., 2021). This transformation requires collaboration among the three pillars of education: schools (principals & teachers), students, and parents. The principal plays a key role in setting the vision and managing resources to bring about this change (Khoiruman et al., 2024)

The transformation of the school environment is achieved through the management of green open spaces, the planting of vegetation, and sustainable waste management (Pendidikan et al., 2023; Waskitho Try, 2024). This physical environment serves as a hands-on learning environment for students to understand the phenomenon of climate change. A Living Lab (LL) is a real world environment where research, innovative products, or services are tested and developed in collaboration with everyday participants in a collaborative setting (Opoku & Aluko, 2021). LLs can involve public, private, and community stakeholders working together to address real life challenges, create change, and ensure that solutions (Bulkeley, 2021; Voytenko, 2020) are practical and user centered. For example, LL researchers can collaborate with communities and councils to understand local practices, then experiment and jointly develop products or platforms for use after the project is completed (Nome et al., 2023).

Over the past decade, the Living Labs (LL) methodology has emerged across Europe as a key approach to conducting research on the ecological transition practices aimed at moving toward more sustainable ways of living, working, and producing in the face of the climate crisis (Hopkins 2008) and conservation in policy (Dadan Kurniawan, 2026). Living labs offer the possibility of connecting researchers and citizens, engaging them in collective action to identify shared needs, developing collaborative methods to address these needs, and sharing methods for broader implementation (Puerari et al. 2018). Living labs can also be seen as a means to expand citizens' capacity to engage in processes of change and enhance civic resilience (Hong et al., 2020; Karvánková et al., 2025)

Many programs encourage the involvement of various stakeholders in testing ideas and collaboration mechanisms within a laboratory setting. The framework for such laboratories is not determined solely by academic research projects. A laboratory can be initiated by groups of practitioners seeking alternatives, civil society organizations that recognize the importance of collaboration, or by local public administrations where the need for mediation is acknowledged. Furthermore, the European Union's ambition through the (Bulkeley, 2021; Rahman et al., 2025). Research and Innovation Program (Smart and Climate Neutral Cities Mission) places high hopes on pilot cities to demonstrate results through collaboration with academics, local communities, and the private sector in a spiral of innovation. Transforming the school environment into a living lab is a strategic and holistic approach to addressing educational challenges in the era of climate change and technological development (Brundiers, 2021; Wals et al., 2014). This transformation focuses not only on physical renewal but also encompasses cultural and behavioral changes, learning systems, and the integrated use of digital technology. By creating a green, inclusive, and innovative environment, schools can become real spaces for students to learn contextually through direct experience, thereby fostering ecological awareness, 21st-century skills, and adaptive character (Caughy et al., 2022; Stevenson & Peterson, 2021).

Through the living lab approach, schools are no longer merely places for the transfer of knowledge, but also become hubs for collaboration among various stakeholders teachers, students, parents, the community, and external parties in designing and testing solutions to real-

world problems, particularly those related to environmental sustainability (Kirschner et al., 2006; Song et al., 2025). This approach strengthens the active involvement of the school community in the learning process while enhancing collective capacity to address global challenges such as the climate crisis. Thus, the success of transforming the school environment into a living lab depends heavily on synergy among educational elements, visionary leadership, and a shared commitment to continuous innovation and adaptation. This transformation is not merely a short term change but a long-term investment in shaping an environmentally conscious, creative generation capable of making tangible contributions to sustainable development (Baniata et al., 2024; Erlangga & Fajarwati, 2025).

The activities of the school community including students, teachers, and staff play a crucial role as agents of change in climate change mitigation efforts through character development and concrete actions in daily life (Rohmatin & Sudarwanto, 2025). Schools can serve as social laboratories that foster an eco-friendly culture, thereby creating a collective impact in reducing greenhouse gas emissions. In practice, this role is realized through various aspects, one of which is energy and resource management (Waskitho Try, 2024). School community members can develop the habit of using electricity efficiently, such as turning off lights, air conditioners, and electronic devices when not in use, as well as practicing water conservation by using water wisely to reduce the energy required for its treatment and distribution (Song et al., 2025).

In addition, the application of the 3R principles (Reduce, Reuse, Recycle) is an important part of eco-friendly behavior at school. Waste reduction can be achieved by minimizing the use of single-use plastics and reducing food waste in the cafeteria (Brundiers, 2021). On the other hand, recycling activities can be implemented through waste sorting and the reuse of used items to create useful products (Trott, 2021). This behavior not only reduces the volume of waste but also instills awareness of the importance of sustainable waste management. The role of the school community is also evident in the implementation of green transportation and mobility. Students, teachers, and staff can be encouraged to use public transportation, walk, or bike to school to reduce exhaust emissions. Additionally, efforts to preserve the biotic environment can be carried out through school greening activities, such as planting and maintaining plants that serve as natural carbon sinks (Brundiers, 2021). A green school culture can also be strengthened by integrating environmental values into the curriculum and extracurricular activities.

Furthermore, collective advocacy and education are integral components of climate change mitigation within the school environment. Students can play an active role in conducting environmental campaigns among their peers and families, thereby raising public awareness of climate change issues (Opoku & Aluko, 2021). Teachers also play a crucial role as role models in practicing eco-friendly behaviors and guiding students in understanding the risks of climate change and mitigation measures. Thus, the synergy of the entire school community in adopting sustainable practices will create an educational environment that not only supports learning but also makes a tangible contribution to environmental conservation (Sudirman et al., 2025).

School communities play a vital role in climate change mitigation efforts, particularly because the school environment serves as both a learning space and a setting for character development. Everyday habits such as energy conservation for example, turning off lights and electronic devices when not in use can significantly reduce energy consumption and carbon emissions. Additionally, reducing the use of single-use plastics by bringing one's own water bottles and food containers also helps minimize environmental pollution. These simple efforts, when undertaken collectively by the entire school community, will have a broader impact on environmental sustainability (Rohmatin & Sudarwanto, 2025).

Proper waste management is also an important part of eco-friendly practices in schools. Practices such as sorting organic and inorganic waste, recycling, and reusing used items can reduce the volume of waste that ends up in landfills (Wong et al., 2023). Additionally, activities such as school waste banks or creative recycling programs not only help reduce waste but also raise environmental awareness among students. Environmental education implemented through these concrete actions has proven effective in fostering sustainable habits from an early age (Bednarz et al., 2022).

The living laboratory approach is an effective strategy for naturally fostering behavioral change among the school community. Through this approach, the school serves as a real-world laboratory where students can learn directly from experience such as planting trees, managing the school garden, or observing the impacts of energy use (Berglund & Gericke, 2022). This experience-based learning not only enhances students' understanding of climate change issues but also fosters attitudes and behaviors that are more environmentally conscious. Thus, schools serve not only as venues for knowledge transfer but also as agents of change in addressing the challenges of global climate change (Frisk & Larson, 2021).

The contributions of the school community to climate change mitigation at the local level are reflected in daily practices that directly impact emission reduction and environmental quality improvement. Students, teachers, and school staff serve as agents of change through simple yet sustainable actions, such as 3R-based waste management (reduce, reuse, recycle), electricity conservation, and the reduction of single-use plastic. In this context, schools function as effective social spaces for fostering collective, environmentally friendly habits. These behaviors, though carried out on a micro-scale, have a significant cumulative contribution to climate change mitigation, especially when implemented consistently and involving the entire school community.

In addition to individual efforts, the contributions of the school community are also evident through collaborative, environment-focused activities, such as greening programs, the creation of school gardens, and the management of a waste bank. These activities not only contribute to carbon sequestration and waste reduction but also strengthen collective awareness of the importance of maintaining environmental balance. The active involvement of the school community in these activities reflects a shift from mere knowledge to tangible action. From an environmental geography perspective, these activities demonstrate a positive interaction between humans and space, where the school environment is utilized as a living laboratory to develop local solutions to global problems.

Furthermore, the role of the school community in climate change mitigation is also strengthened through the development of a culture and values centered on environmental sustainability. Integrating climate change issues into the curriculum and school policies fosters an environment that systematically supports eco-friendly behavior. However, the effectiveness of these contributions depends heavily on consistent implementation, policy support, and the availability of supporting resources. Therefore, it is necessary to strengthen the capacity of the school community through continuous education and participatory approaches so that the resulting contributions are not temporary but become part of a sustainable school culture in supporting climate change mitigation at the local level. From an environmental geography perspective, these contributions demonstrate that the micro-scale plays a crucial role in global mitigation.

4. CONCLUSION

Based on the discussion presented, it can be concluded that transforming the school environment into a living laboratory is a strategic approach capable of integrating physical, cultural, educational, and technological aspects into a single sustainable educational system. This transformation is not only focused on facility upgrades but also on character development and behavioral changes among school community members toward more adaptive and environmentally conscious attitudes. Through the implementation of the green school concept, differentiated learning, and the use of digital technology, the school environment can function as a contextual learning space that encourages students to understand and directly engage in climate change mitigation efforts.

Furthermore, the active role of the school community as agents of change is key to the success of climate change mitigation at the local level. Everyday practices such as 3R-based waste management, energy conservation, greening initiatives, and eco-friendly mobility demonstrate that simple contributions can have a significant impact when carried out collectively and sustainably. The living laboratory approach strengthens this engagement through hands-on experiences and collaboration among stakeholders. Therefore, policy support, human resource

capacity building, and a shared commitment are necessary to ensure that the transformation of the school environment is not temporary but becomes a sustainable culture that tangibly supports climate change mitigation.

Suggestions

Based on the study's findings, it is recommended that schools implement environmental transformation more systematically by integrating the concept of a living laboratory into the curriculum, learning activities, and the overall school culture. Schools need to strengthen collaboration among principals, teachers, students, and parents, as well as establish partnerships with external stakeholders such as the government and environmental organizations to support sustainability programs. Additionally, enhancing teachers' capacity through environmental education training and providing supporting facilities such as waste management systems, green open spaces, and eco-friendly technologies is crucial. Through these measures, it is hoped that school environmental transformation can proceed consistently and sustainably, making a tangible contribution to climate change mitigation at the local level.

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