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Python-Based Interactive Simulation in STEM E-LKPD to Increase Sustainability Awareness on Global Warming Material

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Abstract: This study aims to present the design and efficacy of an enhanced learning tool for digital platforms featuring interactive simulations to educate students about the complexities of global warming. This study utilized an experimental method involving 32 10th-grade high school students. The Python-assisted E-Learning Tool offers dynamic visualization and model interaction, allowing students to explore the causal relationship between human activities and climate change. By manipulating simulation parameters, students observed the impact of global temperature trends in real-time, which fostered a nuanced understanding of global warming. This allows them to observe the cause-and-effect relationship between human activities, greenhouse gas emissions, and environmental impact. Interactive simulations and applications enable students to experiment independently with physics concepts. Python underscores its suitability for education because of its extensive functionality and ease of use and because it encourages a hands-on and exploratory approach to learning complex STEM subjects such as global warming. This process is accompanied by structured instructional content, including data analysis, group discussion, and reflective assessment, to enhance cognitive engagement and promote ongoing practice. This study highlights the potential of integrating technology-based learning tools into the STEM curriculum to facilitate active exploration of global sustainability challenges.

Keywords: Python; STEM; Sustainability awarness

Introduction

Physics is an ever-evolving discipline with new discoveries that are often abstract and complex. Concepts such as quantum mechanics, general relativity, and quantum field theory often go beyond everyday experience and require complex mathematical models. Learning media can help visualize these concepts, so that students can understand difficult material better. Simulations and interactive applications allow students to experiment with physics concepts independently, reinforcing understanding through hands-on experience. Another subject that some people find challenging to understand is physics, particularly for students in Indonesia. This is because some students are not interested in learning more about the subject because it involves a lot of numbers, complicated calculations, and complex concepts (Fathurohman & Nur, 2022). The rapid advancements in technology have revolutionized the educational landscape, particularly in the fields of Science, Technology, Engineering, and Mathematics (STEM), where the integration of innovative tools and techniques has become paramount. With the increasing concern about global warming and its impact on the environment, it has become crucial to raise awarenessand educate students about sustainability (Parry & Metzger, 2023).

This Python-based interactive simulation Jupyter Notebook offers an engaging and hands-on approach to learning about global warming and its effects. Through

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interactive visualizations and real-time data simulations, students can explore the causes and consequences of global warming, fostering a deeper understanding of the issues at hand. Additionally, this tool facilitates active participation and problem-solving, empowering students to develop solutions for sustainable practices in their communities (Cao, 2020). Sustainability education is crucial because it integrates topics such as economic, environmental, and social systems, enabling learners to grasp the complexity of global warming (Samuelsson & Park, 2017). It can encourage a sense of stewardship, where individuals feel responsible for the condition of the planet and are motivated to pursue a sustainable future.

The E-LKPD concept is a modern approach to education, harmonizing with digital advancements and the growing need for interactive and technology-based learning materials (Rolipa et al., 2023; Wiyono, 2015). In this case, the selection of global warming materials can be used electronically (Aji et al., 2025). The importance of E-LKPDs in modern education can be outlined as follows: Accessibility: E-LKPDs make educational material more accessible to students, allowing them to engage with content anytime and anywhere. Interactivity: They offer interactive features that can enhance engagement and help students better understand complex concepts (Marlina et al., 2021; Yang & Baldwin, 2020), such as simulations, animations, and multimedia elements. Engagement: E-LKPDs can provide a more engaging learning experience through multimedia elements such as videos, diagrams, quizzes, and simulations (Khotami et al., 2023). Sustainability They align with sustainability goals by reducing the need for printed materials and enabling a more environmentally friendly approach to education (Sofiadin, 2020).

Global warming education encompasses various methods to teach about climate change and its impacts, and the effectiveness of these methods can vary based on how they are implemented and the audience they are targeted at (Aji et al., 2024). Here are some existing methods used to educate about global warming and general insights into their effectiveess. Purpose of the Study Introduction to the development of the E-LKPD STEM tool using Python. This interactive educational tool aims to enhance learning in STEM fields by providing a hands-on, engaging way to explore and understand complex scientific concepts such as global warming and sustainability.

Method

This research uses an experimental method that provides Python-based interactive simulations in STEM E-LKPDs to increase sustainability awareness on global warming material for 10th-grade high school students (Murniati et al., 2023). Tools and Technologies Used Overview of Python, Jupyter Notebook, and any other relevant tools. Python and Jupyter Notebooks are the central tools used in the development of the E-LKPD STEM tool for enhancing global warming education: Python A versatile programming language that is widely used in scientific computing and data analysis. Its syntax is clear and readable, which makes it an excellent language for educational purposes, and it has a vast ecosystem of libraries for various applications, including numerical computations, data visualization, and machine learning (Pedregosa et al., 2011). Jupyter Notebook: An open-source web application that allows you to create and share documents that contain live code, equations, visualizations, and narrative text. It is particularly useful in an educational context because it supports interactive data visualization and the integration of explanatory content alongside the code, making it a valuable tool for exploratory and collaborative computational work (Ruiz-Sarmiento et al., 2021).

Other relevant tools that could be used in conjunction with Python and Jupyter Notebooks include: Matplotlib and Seaborn Libraries for creating static, animated, and interactive visualizations in Python (Waskom, 2021). Pandas An open-source data manipulation and analysis library designed to make data analysis in Python more streamlined and efficient. NumPy A library for Python that supports large, multi-dimensional arrays and matrices, along with a collection of mathematical functions to operate on these arrays. SciPy An ecosystem of software for mathematics, science, and engineering, which is built on the NumPy extensions and is designed to work with NumPy arrays. Scikit-learn A machine learning library for Python that features various classification, regression, and clustering algorithms. The choice of these tools, particularly Python and Jupyter Notebooks, underlines their suitability for educational purposes not only because of their wide-ranging functionality and ease of use but also because they encourage a hands-on, exploratory approach to learning complex STEM subjects like global warming.

How the material on global warming was structured the material on global warming within an educational context such as the E-LKPD STEM tool is typically structured to facilitate understanding and engagement (Aubrecht, 2018). While the specific structure may vary, an effective content design could include the following elements: Introduction to Concepts, begin with an introduction to basic concepts of global warming, such as greenhouse gases, the greenhouse effect, and how human activities contribute

to climate change (Ozdemir, 2023). Impact Analysis, explore the different impacts of global warming on various systems, such as weather patterns, ecosystems, sea levels, and human societies. Case Studies include real-life case studies that illustrate the effects of global warming in different regions of the world, showing the practical implications of climate change. Data Exploration, integrate data analysis sections where students can examine and interpret climate data, graphs, and models. Interactive Simulations, incorporate interactive simulations and models that allow students to manipulate variables and see the outcome on climate patterns. Problem-Solving Activities, engage students with problem-solving activities that challenge them to come up with solutions to mitigate the effects of global warming. Research Assignments, assign research topics related to global warming to encourage deeper investigation and understanding of the subject matter. Discussion and Reflection, Facilitate discussion and reflection activities to allow students to articulate their thoughts on the subject and how it relates to broader societal and ethical issues. Actionable Steps, outline actionable steps and best practices that individuals or communities can take to combat global warming. Assessment, end with assessment questions or projects that evaluate the students' understanding.

Result and Discussion

Climate Change Simulations: interactive simulation modeling that will be used in E-LKPD. Implementation Steps Using Python and Jupyter Notebook. Gather Data, import historical temperature data and emission datasets into the Jupyter Notebook using Python's data handling libraries like pandas (Rahman et al., 2020). Data Processing, use Python tools to process and prepare the data for visualization and modeling purposes. Develop Models, code the climate models in Python, incorporating the relevant climate science and calculating future temperature trends based on variables (Waskom, 2021). Create Interactive Elements, use libraries like ipywidgets to create interactive controls that users can manipulate. Visualization, plot the data and model outputs using visualization libraries such as Matplotlib, Seaborn, or Bokeh to create interactive and engaging graphs or maps (Sutchenkov & Tikhonov, 2020). User Interaction, Construct the notebook so that when users adjust the variables, the climate model recalculates and updates the visualizations in real-time (Pedregosa et al., 2011). Narrative and Guidance, include text cells with explanations and instructions to guide the users through the simulation, explaining the implications of their interactions with the model (Röber et al., 2021). Deployment, set up the notebook in a way that it can be easily shared and accessed, possibly through platforms like Binder or using JupyterHub for classroom settings (Lonsky et al., 2023). This type of simulation can be a powerful tool for educating students about the impact of human activity on global climatic trends and the importance of mitigation efforts in managing future climate change scenarios.

Use of Simulation: Introductory Material, start by reading the introductory material which explains the basics of global warming and the purpose of the simulation. Running Code Cells, run each code cell sequentially by pressing the 'Run' button or using the Shift + Enter shortcut. Interaction with Simulation Input Data, enter data or parameters required by the simulation, such as carbon emission levels, temperature changes, or other factors relevant to global warming. Result Observation, observe the results displayed in the form of graphs, tables or other visualizations. Note the changes that occur based on the input provided, variable Exploration: Change input variables and rerun the simulation to see how changing parameters affects the results. It helps students understand the cause-and-effect relationships in the global warming phenomenon; Discussion and Analysis, group Discussion, students are divided into groups to discuss the results obtained from the simulation. They compare the results of the different scenarios they have tried, Data Analysis, students analyze the resulting data to draw conclusions about the impact of various factors on global warming. Guiding Questions, use the guiding questions that have been prepared in the E-LKPD to help students think critically about the data they obtain and how it relates to the concept of sustainability. Assessment and Reflection, quiz or test, give a quiz or test to measure student understanding after using the simulation. This can be done through online learning platforms or in person, Individual Reflection, students write reflections about what they learned, how the simulation helped their understanding, and what actions they can take to improve sustainability in everyday life. Feedback, collect feedback from students regarding their experiences using E-LKPD and interactive simulations. This helps in improving the material for future use. By following this procedure, students can utilize the interactive simulation in E-LKPD to gain a deeper understanding of global warming and increase their awareness of the importance of sustainability.

The results from the interactive simulation in the E-LKPD demonstrate that students were able to develop a deeper understanding of the complex relationship between human activities, greenhouse gas emissions, and global climate change. The simulations allowed students to explore different scenarios and observe the impact of changing variables on global temperature trends. This aligns with previous research that has

shown the effectiveness of interactive digital tools in engaging students with environmental and sustainability issues.

The findings suggest that incorporating such simulation-based learning experiences into STEM curricula can be a powerful way to increase students' awareness of sustainability challenges and empower them to take action. By giving students the opportunity to manipulate the parameters of the simulation, they gain a more nuanced appreciation for the multifaceted nature of global warming and the need for a multifaceted approach to addressing it.

Components of the Simulation

Emission Scenarios : Allow users to select or input various scenarios of greenhouse gas emissions, ranging from 'business as usual' to aggressive emission reductions, Variable Manipulation, provide sliders or input boxes where users can adjust variables such as CO_2 concentration, albedo effect, solar radiation, and other factors that impact global temperatures (Volkmann & Fraunhofer, 2023), Visualization Outputs, Show the results of the simulation through dynamic graphs, charts, or even global maps that illustrate temperature changes under different scenarios (Rahman et al., 2020).

Visualization Outputs

Global average temperature trend an interactive simulation modeling global average temperature trends would typically aim to demonstrate how different variables can influence the Earth's climate over time (Figure 1a).

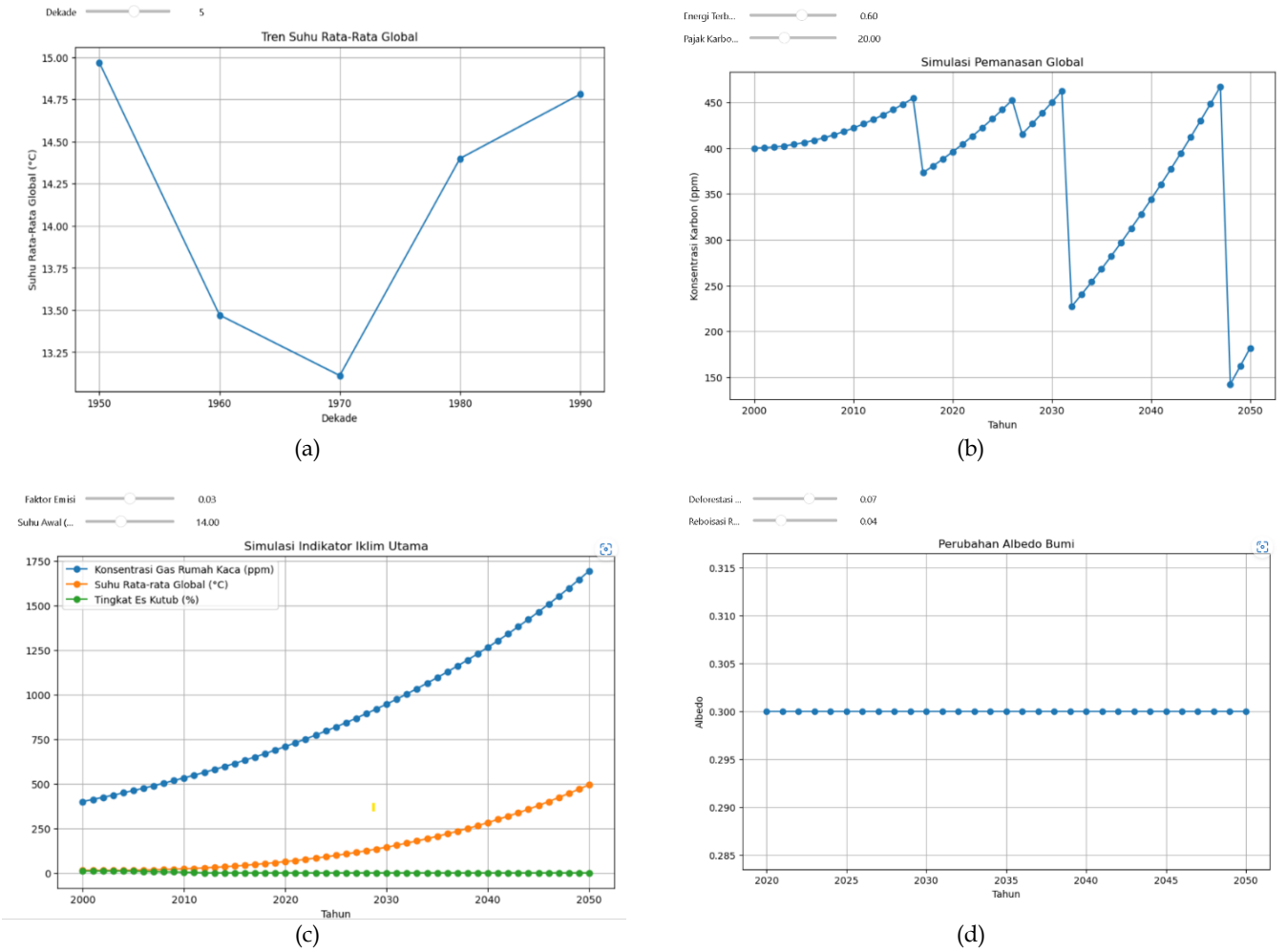

Figure 1. (a) Visualization Displays Global Average Temperature Trend; (b) Visualization Displays of Global Warming Similation (c)Visualization Displays simulation of main climate indicators; and (d) Visualization Displays Albedo change simulation

Global warming similation A global warming simulation is an interactive tool designed to help users understand the mechanisms of climate change and the potential impacts of different levels of greenhouse gas emissions on the Earth's temperature and climate systems (Figure 1b).

Simulation of main climate indicators, a simulation that allows users to explore the effects of various climate change factors, such as CO_2 levels, solar output, and volcanic activity, on key climate indicators like global temperature, sea level, and precipitation patterns (Cortázar et al., 2021) (Figure 1c).

Albedo change simulation, another valuable interactive simulation could focus on changes in the Earth's albedo, or reflectivity, and how this can affect the absorption of solar radiation and contribute to global warming (Sieber et al., 2019), (Figure 1d).

Biogeochemical cycle simulation (carbon), an interactive model that simulates the complex biogeochemical cycles, such as the carbon, water, and nutrient cycles, to demonstrate how human activities can disrupt these natural processes and lead to climate change (Teemueangsa et al., 2021), (Figure 2a).

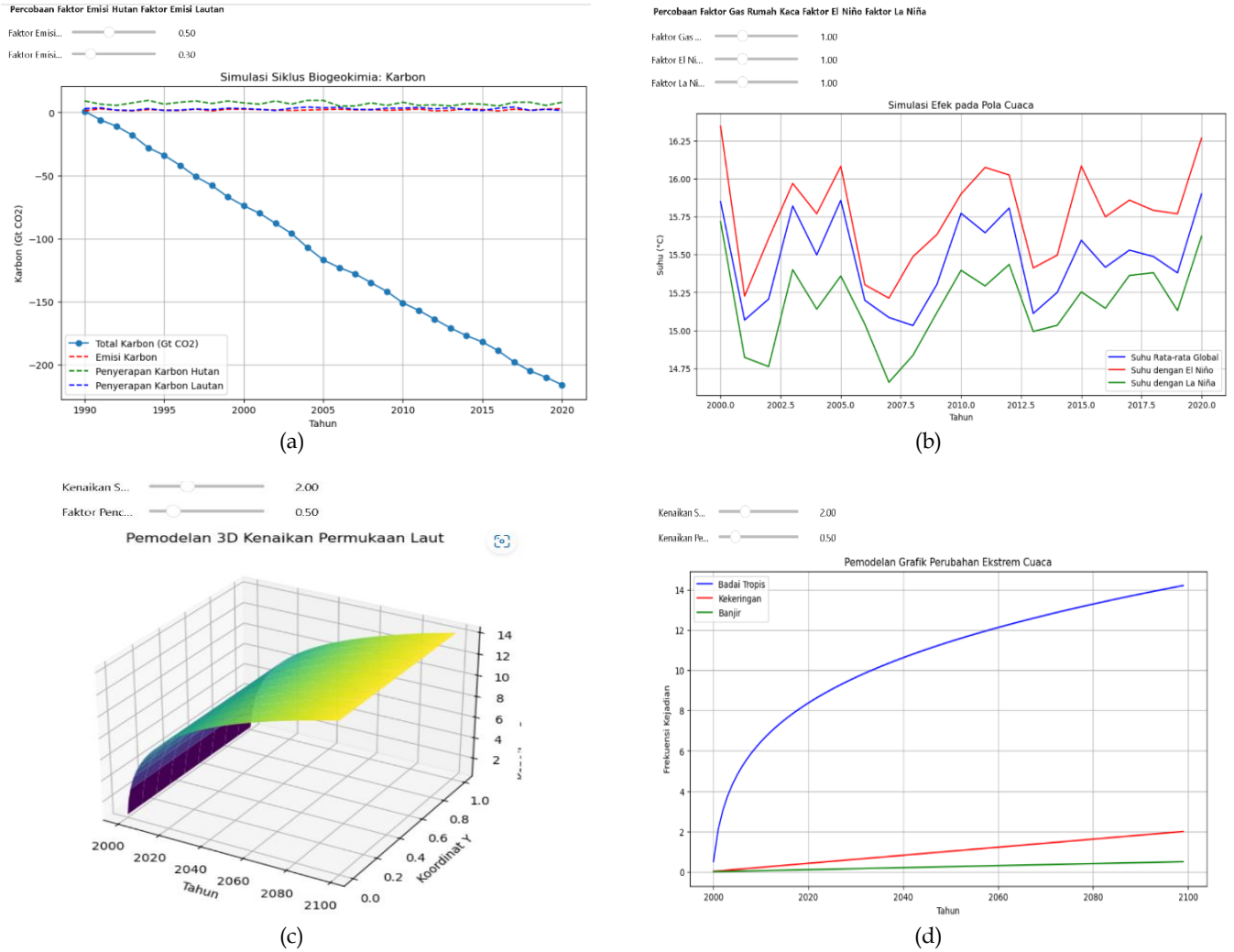

Figure 2. (a) Visualization Displays biogeochemical cycle simulation (carbon); (b) Visualization Displays Simulating the effects of weather patterns (El-Nino and La Nina); (c)Visualization Displays 3D modeling of Coral Reef Damage; and (d) (d) Visualization Displays Graphic modeling of extreme weather changes

Simulating the effects of weather patterns (El-Nino and La Nina), a simulation that allows users to experiment with different weather patterns, such as changes in wind, precipitation, and temperature, and observe how these changes can impact local and global climates (Clarke et al., 2022), (Figure 2b).

3D modeling of Coral Reef Damage, a 3D interactive visualization that depicts the effects of rising ocean temperatures and acidification on coral reef ecosystems, allowing users to see the deterioration of these vital habitats over time (Figure 2c).

Graphic modeling of extreme weather changes :an interactive graphic model that illustrates the increasing frequency and intensity of extreme weather events, such as hurricanes, droughts, and floods, as a result of climate change change (Clarke et al., 2022) (Figure 2d).

Integration of satellite data and temperature observations, an interactive tool that incorporates real-time satellite data and temperature observations to provide a dynamic visualization of global temperature trends and climate anomalies over time (Jones et al., 2022) (Figure 3).

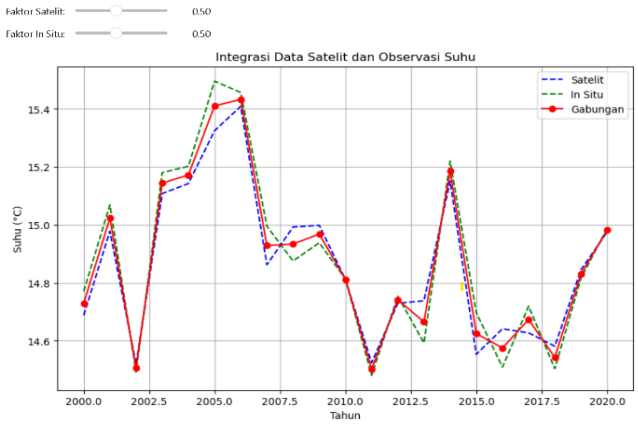

Figure 3. Visualization Displays integration of satellite data and temperature observations

Simulation of ice melting in the polar ice caps, an interactive simulation that models the melting of the polar ice caps and the resulting changes in sea levels, sea ice cover, and ecosystem impacts (Röber et al., 2021) (Figure 4).

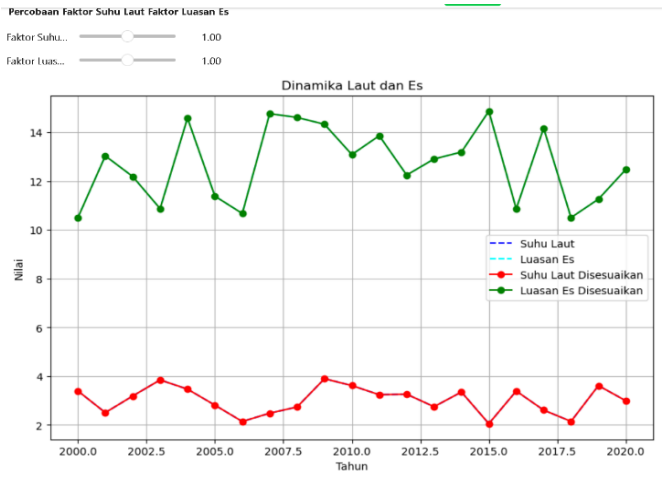

Figure 4. Visualization simulation of ice melting in the polar ice caps

Simulation of atmospheric physics models, an interactive simulation that allows users to explore the complex atmospheric physics and dynamics that drive climate change, such as the greenhouse effect, atmospheric circulation patterns, and the role of greenhouse gases (Steiner et al., 2021) (Figure 5).

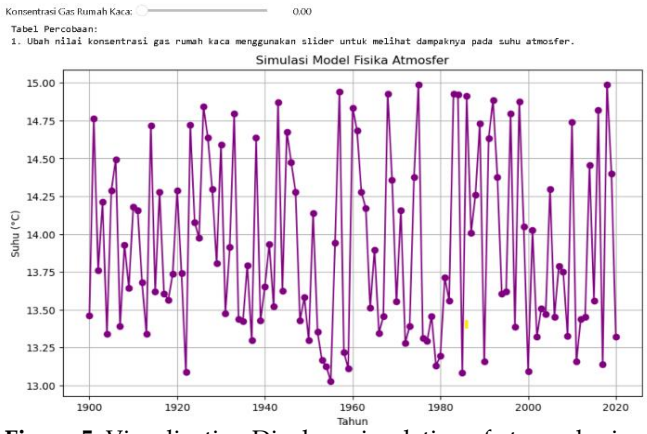

Figure 5. Visualization Displays simulation of atmospheric physics models

Simulation of renewable energy use and impact, an interactive simulation that models the potential impact of increased adoption of renewable energy sources, such as solar, wind, and hydropower, on reducing greenhouse gas emissions and mitigating the effects of climate change (Nyanga, 2020) (Figure 6).

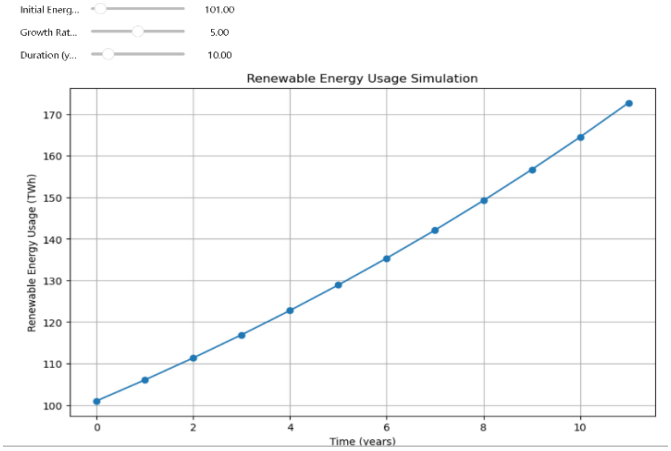

Figure 6. Visualization Displays Simulation of renewable energy use and impact

The simulations provided students with the opportunity to explore different scenarios and observe the direct impact of changing variables on global temperature trends. These findings are consistent with previous research indicating the effectiveness of interactive digital tools in captivating students' interest in environmental and sustainability issues (Cervenec et al., 2022). The results strongly suggest that integrating simulation-based learning experiences into STEM curricula can significantly enhance students' awareness of sustainability challenges and empower them to take proactive measures (Muslim et al., 2020). By allowing students to manipulate the parameters of the simulation, they develop a more nuanced appreciation for the multifaceted nature of global warming and the need for a comprehensive approach to addressing it.

However, it is important to acknowledge the limitations and challenges encountered during the study. One potential limitation is the sample size and demographic characteristics of the participants. As the current study focused on a specific population of STEM students, the findings may not extend to other educational contexts or age groups. Additionally, while the interactive simulation facilitated the exploration of global warming dynamics, the translation of this knowledge into real-world sustainable behaviors remains an open question, warranting further investigation (Jones et al., 2022). To enhance the interactive simulation tool in E-LKPD, future improvements might include expanding the range of scenarios and variables that students can manipulate. This could provide a more comprehensive exploration of the complexities of global warming and sustainability, enabling students to investigate a wider array of factors and potential solutions.

Furthermore, comparative studies could be conducted to evaluate the effectiveness of different types of interactive simulations in increasing sustainability awareness. For example, comparing the impact of Python-based simulations with those developed in other programming languages or platforms could provide valuable insights into the most effective approaches for engaging students in sustainability education (Lonsky et al., 2023). It is essential that educators and researchers continue to explore innovative methods, such as interactive simulations, to foster sustainability awareness among students.

Conclusion

According to the research that has been conducted, such Simulations allow students to explore various scenarios and observe the direct impact of changing variables on global temperature trends. The results strongly suggest that integrating simulation-based learning experiences into the STEM curriculum can significantly increase students' awareness of sustainability challenges and empower them to take proactive action. However, it is essential to acknowledge the limitations and challenges faced during the study. One possible limitation is the sample size and demographic characteristics of the participants. The current study focused on a specific population of STEM students, so the findings may not apply to other educational contexts or age groups. Future enhancements include expanding the range of scenarios and variables that students can manipulate to enhance the interactive simulation tool in the E-LKPD. This could provide a more comprehensive exploration of the complexities of global warming and sustainability, allowing students to investigate a broader range of factors and potential solutions. In addition, integrating real-time data or projections into the simulation could better connect the learning experience to the real-world implications of climate change. Access to current data and forecasts on greenhouse gas emissions, temperature trends, and other relevant factors can deepen students' understanding of the urgency of addressing sustainability challenges.

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This article was written by two authors, namely L. L., L. M., and A. F. All authors worked together in carrying out each stage of the article writing.

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Conflicts of Interest

The authors declare no conflict of interest.

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