CHAPTER I
INTRODUCTION

1.1. Research Background

Coal remains the world's primary source of electricity and a significant contributor to CO_2 emissions, driving climate change (IEA, 2022). To tackle this pressing issue, the global community established the Paris Agreement, which aims to limit the increase in global temperatures to below 2 °C, with an aspirational goal of 1.5 °C above pre-industrial levels (Ruiz-Campillo, 2024). Among the nations committed to achieving these objectives is Indonesia, the fifth-largest coal producer globally (Reyseliani et al., 2024) and the fourth most populous country (Ordonez et al., 2022).

According to a statistical review of world energy by British Petroleum (BP) (2022), Indonesia's coal consumption grew by 5.3% annually between 2011 and 2021, contributing approximately 2% to the global increase in CO_2 emissions. As greenhouse gas levels increase, higher concentrations of CO_2 directly impact the rise of global temperatures, which accelerates climate change. The rise in coal usage is connected to Indonesia's increasing electricity consumption, which is driven by public behavior and growing energy demands. Data from the Central Statistics Agency (BPS), The consumption of electricity in Indonesia has increased from 1.10 MWh/capita in 2021 to 1.20 MWh/capita in 2022 (Badan Pusat Statistik, 2024). The impact of burning fossil fuels like coal contributes to environmental pollution by releasing toxic gases, damaging living organisms' health, and increasing global warming (Erdiwansyah et al., 2024). This emphasizes the importance of varying energy sources, focusing on renewable alternatives, to prevent energy shortages and maintain sustainable energy security.

Indonesia occupies significant potential for renewable energy, especially in solar energy, due to its tropical climate and equatorial location. Most regions in the country receive abundant sunlight, with an average daily solar radiation of approximately 4 kilowatt-hour per square meter (kWh/m^2) (Handayani & Ariyanti, 2012). Among renewable energy sources, solar energy stands out as the most promising and cost-effective solution to tackling climate change issues (Handayani & Ariyanti, 2012). Despite this potential, some research reveals that the renewable energy resources in Indonesia remain underutilized due to the lack of infrastructure and limited investment in solar energy projects (Aditya et al., 2025). Existing solar power installations are minimal compared to global standards, with an average annual addition of around 43 MW over the past five years. To achieve the national renewable energy target, this figure is projected to rise to approximately 4.68 GW per year between 2024 and 2030 to meet the national renewable energy targets (Octama et al., 2024). This falls significantly short of the 11–12 GW per year required to meet the 1.5°C climate target, underscoring the urgent need to accelerate solar energy development and reduce reliance on coal (IEA, 2022)

Maximizing solar energy reduces dependence on coal and aligns with global climate commitments, as emphasized in Sustainable Development Goal 13 (SDG 13). This SDG 13, namely Climate Action, urging nations to integrate climate mitigation measures into national policies, enhance adaptability, and minimize vulnerabilities to climate risks (Abbasi et al., 2024). Expanding the adoption of renewable energy are essential for addressing the challenges by climate change and the environmental impacts of fossil fuels. One key to advancing this goal is education, which is critical in supporting SDG 13.

Education serves as a crucial instrument for fostering environmental awareness and advancing climate action. It equips students with the knowledge, skills, values, and attitudes needed to address the climate crisis and empowers them to act as agents of change (UNESCO, 2023). Encouraging Indonesians, especially students, to take responsible and informed actions in response to the climate crisis. Education for Sustainable Development (ESD) provides a pathway to achieve climate action goals by embedding sustainability principles into educational practices. This approach integrates sustainability as a core element of the learning process, enhancing students' knowledge and inquiry while building their competencies in sustainability (Torsdottir, Olsson, Sinnes, et al., 2024). ESD also offers students a platform to engage in sustainability actions both in the present and the future (Torsdottir, Olsson, Sinnes, et al., 2024). However, the effectiveness of students' sustainability actions requires improvement. This is primarily attributed to gaps in competencies, such as a limited understanding of sustainability issues and a lack of motivation and confidence to act in their ability to drive meaningful change (Sass et al., 2020).

The competency of action refers to the competency of the individual or group that focuses on the solution to the sustainable development issues. (Sass et al., 2020). One of the behaviors that students are supposed to have is sustainable actions. While behavior may be habitual, actions require decision-making (Whitmarsh & Hampton, 2024). Previous research found a significant gap between strong awareness and concern about climate change and the limited real-life actions taken by people, especially in urban areas of Indonesia (Rahmani et al., 2021). A similar study also showed the same result among students in Indonesia (Ridwan, Kaniawati, et al., 2021) additionally, the same case is also occurring in Sweden and Saudi Arabia (Alsaati et al., 2020; Berglund, 2020). The ultimate learning objective is for students to be capable enough in sustainability action implementation to work without the constructed method (Torsdottir, Olsson, & Sinnes, 2024). Meanwhile, many students have not yet had enough hands-on learning experiences focusing on real-world action, making it difficult for them to apply their knowledge to sustainability challenges (Chen & Liu, 2020).

To enhance real-world action, students need to identify real-world problems. One of the skills that can help students adapt to real-world problems is engineering design skills (Santana & De Deus Lopes, 2020). Students in Indonesia must develop a variety of competencies to meet the challenges of the 21st century, including critical thinking, effective communication, teamwork, and problem-solving abilities. Engineering design skills stand out as a crucial competency that directly impacts a nation’s global competitiveness. As the World Economic Forum (WEF) reports, Indonesia's global competitiveness index declined from 34th place in 2014 to 37th place in 2015, lower than ASEAN neighbors like Singapore, Malaysia, and Thailand (World Economic Forum, 2015). This can happen due to the lack of engineering skills among students, which are important to fostering economic growth and innovation. Earlier studies also claimed that younger students do not have the skills to design and plan approaches to solving engineering-based problems (English et al., 2017). This weakness is related to the Engineering Design Process (EDP) as a new trend in science education reform while many science teachers are poorly informed about the use of EDP in science learning (Winarno et al., 2020). Meanwhile previous study reveals that in developed countries, strong engineering skills in secondary education help build a skilled workforce that can take on important jobs, ensuring the country stays competitive in the global market (Onsomu et al., 2010). Therefore, enhancing engineering design skills in Indonesian students is crucial to improving the nation's competitiveness on the global stage.

Design itself is a combination of design thinking processes and skills, which become a way to find new solutions for human needs by using tools and generating thoughts that depend on active problem solving and the ability of the person to create effective changes (Ergül & Çalış, 2021). It is human-centered and action-oriented, emphasizing five key stages: empathizing, defining, ideating, prototyping, and testing (Ergin, 2024). The engineering design process itself involves decision-making in which basic sciences, mathematics, and engineering science are applied to meet the objective of the issues (Jin, 2015). Furthermore, to address global competition, developed countries are enhancing the competitiveness of their citizens through education based on STEM.

The STEM approach integrates Science (S), Technology (T), Engineering (E), and Mathematics (M) to equip students with the skills to apply integrated STEM knowledge in solving real-world challenges (Chien et al., 2023). STEM education follows specific phases, beginning with problem formulation, considering technological solutions, designing future technologies, producing technological products, testing these products, and refining them through improved designs (Widodo, 2021). However, in secondary schools, the aspects of technology and engineering are often overlooked in STEM education (K. Y. Lin et al., 2021).

This issue arises partly because the Engineering Design Process (EDP) is rarely implemented at the secondary level (Margot & Kettler, 2019). Incorporating STEM education can help students develop engineering skills essential for designing systems or components that meet specific needs (Rusmana et al., 2021). Integrating Education for Sustainable Development (ESD) with STEM, or ESD-STEM, presents an innovative teaching-learning approach that enhances students' engineering design skills while fostering sustainability action.

Implementing ESD-STEM learning through solar cell projects offers students the opportunity to improve both their engineering design skills and their competencies in sustainability action. Solar energy itself is a renewable resource with significant potential in Indonesia (Laksana et al., 2021), which can reduce carbon emissions, addressing the climate change crisis (Kakran et al., 2024).The solar cell project, linked to renewable energy, allows students to explore the causes and impacts of climate change, understand the types of renewable energy, and optimize their use to develop innovative solutions. By engaging in these projects, students strengthen their competencies in sustainability action and engineering design skills, empowering them to contribute to climate change solutions.

However, the research on applying engineering design skills is occurring more in higher education, and the Engineering Design Process (EDP) is rarely implemented in secondary schools (Winarno et al., 2020), even though it has great potential to help students develop critical thinking skills (habit of mind) and engage in hands-on learning through activities like designing and building projects (Abdurrahman et al., 2023). At the same time, research on how students can take meaningful action to address sustainability challenges is still very limited (Sinakou et al., 2022), it is because the ESD-related topics primarily focus on environmental issues and the identification of the underlying causes (Eliyawati et al., 2022).

Previous research involving ESD-STEM learning shows improvement in students' sustainability actions towards environmental issues. The implementation of ESD-STEM learning which has been implemented require students to work on real-world problems of sustainability such as waste to energy project by making biogas (Solihat et al., 2024) which gives improvement of students' actions toward environmental issues, another research is in interdisciplinary STEM course that applied on children's attitudes of learning and engineering design skills (Chiang et al., 2022) which shows the improvement on engineering design skills using interdisciplinary STEM in grade four elementary school, study of integrating STEM-PBL with the Engineering Design Process (EDP) in renewable energy learning units which show a significant improvement in students thinking skills and their ability to design through applied technology and engineered activities which encourages active involvement in every EDP process, enhancing both mind-on and hands-on activities and crucial for developing engineering design skills (Abdurrahman et al., 2023), moreover, study also reveals that hands-on learning by making project in renewable energy in this case wind and solar project significantly enhances students' project design skills and emphasizing the importance of sustainability and environmental awareness (Rizki et al., 2024). In other words, ESD-STEM learning, which has been implemented, can affect students' sustainability actions and their engineering design skills.

However, research in Indonesia still shows limited studies that investigate the integration of ESD-STEM learning through solar cell projects in enhancing students' engineering design skills and sustainability actions, particularly in the context of renewable energy and climate action. The novelty of this study lies in the development of an ESD-STEM learning model on renewable energy, implemented through a solar cell project and aligned with SDG 13, specifically designed for secondary school students. This learning design aims not only to demonstrate students' engineering design skills but also to foster their sustainability actions by emphasizing the importance of renewable energy in addressing climate change.

According to the background, Renewable energy as the chosen topic is intentional, as it provides foundational knowledge for addressing real-world environmental challenges stemming from climate issues. Through this topic, students can explore the causes and effects of climate problems from the energy used while learning strategies to address them effectively. Therefore, the title of this study is *"ESD-STEM Learning on Solar Cell Project to Enhance Students' Engineering Design Skills and Sustainability Action in Supporting Climate Action."*

1.2. Research Problem

Based on the research background, the main problem addressed in this study is: "How Does ESD-STEM Learning on Solar Cell Project enhance students' engineering design skills and sustainability actions in supporting Climate Action" From this research problem, the study seeks to explore the following questions:

1) How does students' engineering design skills after participate in ESD-STEM learning on Solar Cells Project?
2) How does students' engagement in ESD-STEM learning on Solar Cells Project impact their sustainability actions?

1.3. Operational Definition

a. ESD-STEM Learning on Solar Cell Project

The ESD-STEM Learning Solar Cell Project is a hands-on, practical activity where students are tasked with designing, creating, testing, and refining a project to optimize solar cell performance. By creating designs that align the solar cell with sunlight based on their position, students aim to maximize electricity production. This project provides an experiential learning opportunity, enhancing students' engineering design skills while promoting climate action through a deeper understanding and of renewable energy within the ESD-STEM learning.

The project adopts an open project, allowing students to develop ideas independently. A potential outcome of this research includes the implementation of technology such as Arduino Uno, servomotors, and LDR sensors to create a system capable of automatically detecting sunlight. For students with lower engineering skills, the project may focus on simpler tasks, such as determining the optimal layout for solar cells.

b. Engineering Design Skill (EDS)

In this research, engineering design skills refers to the ability to apply engineering principles and processes, including problem identification, idea generation, design, prototyping, testing, and re-design process. Based on the context, it refers to students' capacity to develop technological solutions for sustainability issues through the design and creation of solar cell projects. This student's engineering design skill was assessed using the Performance-Based Evaluation Rubric (PBER). This PBER assessed students' EDS based on four phases, which are problem identification, solution, implementation, and process management phases. The data is analyzed using rule of Purwanto (2008).

c. Sustainability Action

In this research, sustainability action is a concrete action and behavior taken by students in using energy to support environmental sustainability and address climate change. This includes efforts to reduce carbon emissions, adopt renewable energy solutions, and make informed decisions related to climate action aligned with Sustainable Development Goal 13 (SDG 13). The students' sustainability actions was assessed using a questionnaire based on the Environmental Citizenship Questionnaire (ECQ) rubric. Tha data is analyzed using SPSS IBM, through several test including, normality test (pre-test, post-test, gain score), and Mann-Witney U test for testing the hypothesis.

1.4. Research Objectives

The following objectives of this research, based on the problem that has been proposed, are:

a. To increase students' engineering design skills through the ESD-STEM learning on the Solar Cell project in Supporting Climate Action.
b. To increase students' sustainability action through ESD-STEM learning on the Solar Cell project in Supporting Climate Action.

1.5. Research Benefit

The findings of this research are valuable for students, by helping them to develop their engineering design skills and sustainability actions. Students will have a meaningful and innovative experiential learning opportunity by engaging in the project. Furthermore, this research presents teachers with a novel approach to teaching STEM in renewable energy topics, which will enhance students' engineering design skill and their sustainability actions. The integration of Education for Sustainable Development (ESD) into the curriculum will supports the creation of an educational environment focusing on renewable energy. The results of this study offer additional resources and data, making it a valuable reference for scholars with similar interests. Additionally, researchers might utilize the research findings as a guide for additional research. It is crucial to critically assess the research's advantages and disadvantages to maximize the outcomes in this field.

1.6. Scope of Research

This research examines the implementation of ESD-STEM learning through a solar cell project in enhancing students' engineering design skills and sustainability actions in supporting climate action (SDGs 13) with renewable energy as a topic. This research was implemented to determine the effect of implementing ESD-STEM learning on students' engineering design skills and sustainability action. Students should make a project to optimize the sun capture in the innovation of solar cells used to prevent climate change by following the STEM stages in an experimental class. The research itself employs a quasi-experimental method with both quantitative and qualitative data analysis. Students' engineering design skills are assessed using a modified engineering design skill rubric, while their sustainability actions are measured through a questionnaire of ECQ using a 1-4 Likert scale. The study was conducted at one of public Junior High School in Bandung, involving two groups, an experimental class and a control class in grade 8 with a total of 69 students. The learning activities were aligned with the Merdeka

Curriculum as the main reference. For analyzing the data, the quantitative and qualitative analyses were used to interpret the result of the learning model using SPSS and Excel for the quantitative analysis, while interviews and observations were used for the qualitative analysis.