

CHAPTER I

INTRODUCTION

A. Background

Climate change is presently the foremost issue, alongside the Covid-19 pandemic, prioritized by global leaders and institutions for resolution. Earth's climate has changed throughout history. Only the last 650,000 years have there been seven cycles of glacial forward and backward motion, with the sudden end of the last ice age some 11,700 years ago marking the start of the era of modern climate and human civilization. The current trend of global warming is very important because it is clearly related to human activities since the mid-20th century and continues at an unprecedented rate for thousands of years (Westerhold et al., 2020). The current state is that the planet's average surface temperature has increased by about 2.12 Fahrenheit or 1.18 Celsius since the late 19th century; a change driven in large part by increased emissions of carbon dioxide into the atmosphere and other human activities. Carbon dioxide emissions have increased since 1950 to the present, from 300 parts per million to 410 parts per million in the atmosphere (NOAA, 2021).

The things described above are environmental problems. Problems with the environment are among the most significant challenges that people all around the world, including those in Indonesia, are forced to contend with. (Joyce & Dzoga, 2011; Tati et al., 2017). The most significant and actual environmental issues that are occurring today and have an effect on the entire world are climate change and global warming (Djalante, 2019). On the other hand, the damage is increasingly being caused by the decreasing ability of nature's carrying capacity for life, it is caused by the inability of humans to develop an environmentally friendly social value system, as well as their lifestyle that is not in harmony with the environment. This condition will threaten the survival of living things and future life if allowed to continue. Research conducted by Roy et al., (2008) has clearly explained

problems related to the environment such as excessive use of fossil fuels and increased carbon emissions. The fact that the globe is currently experiencing a significant climate change is one of the most visible consequences that can be attributed to environmental issues. (Intergovernmental Panel on Climate Change, 2014).

Globally, the average earth surface temperature increase in 140 years was 0.850 C and sea levels rose as high as 225 mm, and the global concentration of carbon dioxide gas is currently the highest in 800,000 years (Dawson, 2015). The amount of CO₂ gas emissions is a crucial factor that determines the quality of the environment (Hdom, 2019), in this context, namely global warming and climate change. However, the total amount of CO₂ gas emissions in Indonesia is 1,9 Billion CO₂^e in 2023. Here are the trends in total CO₂ gas emissions over the past 20 years, from 2003 to 2023 (Jones et al., 2024), **Figure 1.1**. Discussions concerning environmental problems are intrinsically linked to the concept of low carbon. Yuan et al., (2011) elucidate that the concept of low carbon encompasses multiple interpretations, contingent upon the theoretical and pragmatic frameworks employed. Nonetheless, there is agreement that, despite varying interpretations of low carbon, the primary objective remains to “reduce Greenhouse Gas emissions, utilize low carbon energy, and assure economic development” (Yuan et al., 2011).

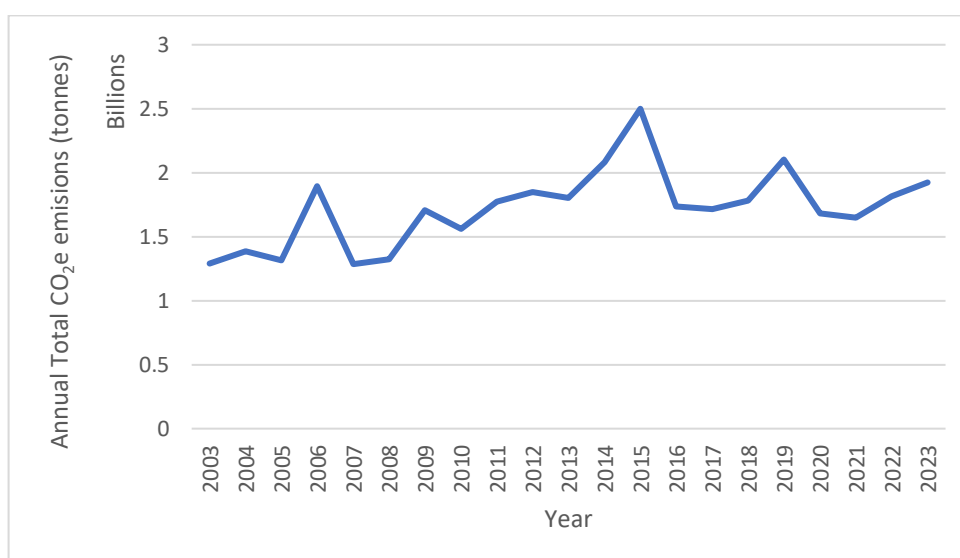


Figure 1.1. The Trend of CO₂ gas emissions in 2003-2023

Annisa Nurramadhani, 2025

DEVELOPMENT OF STEM-LCE (STEM-LOW CARBON EDUCATION) LEARNING PROGRAM TO CONSTRUCT PRE-SERVICE TEACHER'S 4C AND SUSTAINABILITY CONSCIOUSNESS

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Awareness to protect our planet has been seen from the efforts of the United Nations organization to make a sustainable development program (Sustainable Development Goals) or in general we know as SDGs. The sustainable development program has 17 goals, namely: 1) No poverty, 2) Zero hunger, 3) Good health and well-being, 4) Quality education, 5) Gender equality, 6) Clean water and Sanitation, 7) Affordable and Clean energy, 8) Decent work and Economic Growth, 9) Industry, Innovation, and Infrastructure, 10) Reduces inequality, 11) Sustainable city and Communities, 12) Responsible consumption and Production, 13) Climate action, 14) Life below water , 15) Life on Land, 16) Peace, justice, and Institutions, 17) Partnership for the goals (United Nations, 2015). The Sustainable Development Goals (SDGs), referred to as the Global Goals, were established by the United Nations in 2015 as a universal initiative to eradicate poverty, safeguard the planet, and guarantee that all individuals experience harmony and prosperity by 2030. Their seventeen interconnected Sustainable Development Goals acknowledge that efforts in one domain will influence results in another, and that development must harmonies social, economic, and environmental sustainability. Countries have committed to prioritizing progress for those who are lagging behind. The SDGs are designed to end poverty, hunger, AIDS, and discrimination against women and girls. Creativity, knowledge, technology and financial resources of the entire community are needed to achieve the SDGs in every context (United Nations Development Program, 2021).

One of the goals included in the sustainable development program is to protect the environment by reducing the amount of carbon emissions, so that climate change can drastically be suppressed. These activities have been carried out by the world community today, including Indonesia. This is to build public awareness and concern for the importance of protecting the environment and maintaining environmental sustainability which is important and must be done immediately. Awareness of low-carbon activities originates from the traditions, culture, and indigenous knowledge of the Indonesian populace, which have existed for millennia and continue to be preserved, albeit unrecognized by the people

themselves. As technology advances, traditional practices are increasingly diminished, resulting in the present generation's unfamiliarity with some customs.

Research on low carbon development has been conducted in Global North countries, including the UK (Roy et al., 2008; Whitmarsh et al., 2011) and Japan, as evidenced by studies by Shimada et al., (2007) and Su, (2009). Research in Indonesia remains scarce, despite the country emitting approximately 1,453 gigatons of carbon dioxide (GtCO₂) in 2012 (Dursin, 2018). Even though the government has initiated the Low Carbon Development Framework, issues stemming from insufficient public awareness regarding the use of low-carbon materials continue to prevail (Pangestu, 2018).

Prior investigations towards low carbon primarily originated from an economic perspective. This is further corroborated by the Indonesian government's low carbon initiative, specifically the Green Economy, as articulated by Low Carbon Development Indonesia (LCDI) and launched by BAPPENAS in conjunction with key ministries, including the Ministry of Environment, Ministry of Industry, Ministry of Agriculture, Ministry of Marine Affairs and Fisheries, Ministry of Energy and Mineral Resources, and Ministry of Finance (Low Carbon Development Indonesia (LCDI), 2021). LCDI's own programs cover the forestry and peatland sector, the agricultural sector, the coastal and marine sector, the energy sector, the transportation sector, and the waste management sector. This is understandable because the goal of low-carbon development is postulated to promote the economic development of the country (Yuan et al., 2011) especially in Indonesia. However, the discussion of low carbon within the LCDI framework has not yet entered the realm of education.

Nonetheless, a low-carbon development is also required from an educational standpoint. The application of the low carbon concept in education finds a solution to the main issue of how to change the mindset of students and society who are still accustomed to a high-emission lifestyle. One of the solution-oriented approaches is through the contextual and transformative integration of low-carbon education in learning, so that students not only understand the concept theoretically but also are able to relate it to their daily activities, such as waste

management, energy use, and food consumption. This change in mindset is very important because greenhouse gas emissions largely stem from the environmentally unfriendly habits of society. Through education that fosters critical and participatory awareness, students will grow as agents of change capable of spreading environmentally friendly habits to their surrounding communities. Therefore, the implementation of the low carbon concept in the classroom is not only relevant but also urgent as a strategic step in long-term climate change mitigation.

A significant difficulty in implementing low-carbon programs in education is the widespread lack of information regarding the low-carbon issue itself (Moloney et al., 2010). Especially in Indonesia, approximately 68% of students lack comprehension of the concept and significance of low carbon education. The students believe they have not been adequately introduced to the notion of low carbon education in the classroom. The remaining 32% of students acknowledge that their understanding of the low carbon education idea is limited to pollution (Nurramadhani et al., 2022). Not only students who lack of low-carbon education concept, but also the teachers in Indonesia have the same condition. The teacher was unaware that they were already familiar with the low-carbon education concept. Low-carbon education encompasses environmental education subjects including the greenhouse effect, energy conservation, and renewable energy. These topics and activities have been previously incorporated into Indonesian educational curricula. Those that have been implemented in teaching and learning throughout all educational levels, from elementary to higher education (Nurramadhani et al., 2024c). In fact, understanding the low-carbon education concept is very important in the field of education to shape the mindset and perspective of society towards current environmental issues.

In addition, initial research findings on preservice teacher, which show that 21st-century skills (critical thinking skills, creativity, collaboration skills, and communication skills) still need improvement among students. Students' critical thinking skills still need improvement (58%). Their creativity is also in the needs improvement category, with a score of 67.3%. The most important aspects to

consider are originality (40%) and the product's value (65%) (Nurramadhani et al., 2024d). Collaboration skills is already quite good according to the criteria (79.6%) generally, however, there are some aspects that need attention, multiple inquiry (67.8%) and peer interaction (76.3%) (Nurramadhani et al., 2024a). Oral communication skills is also quite good (75.6%), but there are some aspects where students still struggle, the conclusion (50%) and organization (73.3%). Students still find difficulties to present their study results in a structured manner, with evidence, and to draw appropriate conclusions (Nurramadhani et al., 2023). Meanwhile, students' sustainability consciousness is still low at 51.3%, with the aspect that needs improvement being sustainability behavior (48%). This is very important to improve because these skills are needed to solve real-world environmental problems, and understanding carbon emissions is also necessary to change individual mindsets and lifestyles, which will have a positive impact on the environment.

Indeed, this is an opportunity for education can play an important role in raising public understanding. Educating the public about the environment is the most effective way to overcome today's environmental problems (Srbinovski, 2019). Education is also only able to facilitate the process of planting and developing literacy, communication skills, collaboration, creativity, and critical thinking related to the environment in the younger generation. This process must be carried out as early as possible and applied at all levels of education from lower education to higher education (Aquarini et al., 2017). So that, in the work-face, the community is trained to apply those skills in realizing environmentally friendly work (green jobs). Learning material about the environment, especially the greenhouse effect, global warming, and climate change, must be carried out through all scientific fields including education. The current environmental conditions and the challenges in the future that are increasingly severe require a paradigm shift in education. Current issues and problems related to the environment such as sustainable development or sustainability, the relationship and balance between science and society must be an integral part of the substance and content taught in education (Trna & Trnova, 2015). Thus, teaching materials about energy,

greenhouse gases, CO₂ gas emissions, climate change, to how calculate the carbon emissions footprints conversions which is the core substance of low carbon education. Only in this way can we prepare future generations to focus on the environmental challenges they will face in the future.

Research has been conducted on low carbon education within the educational context. The study conducted by Roy et al., (2008) seeks to establish a low-carbon education model within a higher education context. Comparable research undertaken by Dongfeng (2010) regarding the implementation of low-carbon education within the university context. Additional studies have been conducted at secondary educational institutions, including Junior High School and Senior High School (Çelikler & Aksan, 2016; De Leeuw et al., 2015; Ho et al., 2017; Shealy et al., 2017). This study employs the term environmental issues more frequently than low-carbon issues. In general, this research aims to provide students with understanding, skills, and attitudes about low-carbon issues that provide an understanding of awareness in acting in the environmental activity by applying those principles. Teaching about nature through education and environmental science is essentially an effort to foster generations so that they have knowledge, awareness, attitudes, and responsibility for the sustainability of nature and the environment. The ultimate goal is to maintain environmental balance so that it can support the sustainability of human life today and in the future. Global warming and climate change, which are the main global environmental problems today, require the education to pay more attention to have an effort to reduce carbon emissions (low carbon development). So, it is natural that education today must be transformed or at least integrated with low carbon education as a form of contribution to realizing low carbon development and sustainable development.

This will be achieved if the understanding, awareness, and consciousness of students and the community about low carbon is much better. Starting with curiosity about environmental issues, especially carbon pollution, then understanding the principles of low carbon education, then awareness arises and the application of low carbon principles in everyday life. Efforts to realize an understanding of low carbon in education have also been carried out by researchers

such as the development of low carbon education-based programs on universities (Lee et al., 2010; Mishra, 2018; C. Xiong et al., 2015), lower education and higher education (Mahat et al., 2020; Phang et al., 2016). Carrying out online learning or blended learning as a form of reducing carbon footprint caused by student traffic from where they live to college and the trail of students who are less responsible for the college's environment (Roy et al., 2008; Versteijlen et al., 2017; Zhou & Hu, 2021). Development of teaching materials such as printed or digital textbooks based on low carbon education for students at schools or college (Amin et al., 2018; Hudha et al., 2020; Ichsan et al., 2020; Permanasari et al., 2020). There is also the development of an evaluation set based on the context of low carbon education (Nan et al., 2013). In addition, in the learning process there are also those who develop a low carbon model (environmental education) (Weng et al., 2018) and the HEADS (Higher Education Accelerating Development Sustainability) approach in low-carbon technology to form a low-carbon society (Horan et al., 2019).

Nevertheless, research on low carbon education in Indonesia is still a few and is still at the initiation stage, especially in higher education. This is proven by the bibliometric study derived from Scopus articles, Indonesia ranks fourteenth, following Sweden, Austria, France, Greece, and Iran, with 14 publications over the past decade (Nurramadhani et al., 2024b).

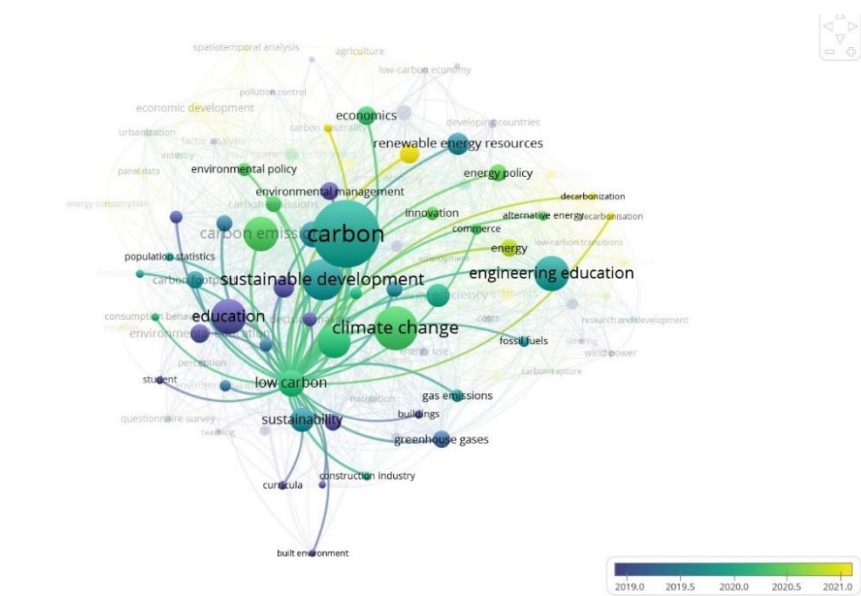


Figure 1.2. The Overlay of Low-Carbon Education Publication by Year

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DEVELOPMENT OF STEM-LCE (STEM-LOW CARBON EDUCATION) LEARNING PROGRAM TO CONSTRUCT PRE-SERVICE TEACHER'S 4C AND SUSTAINABILITY CONSCIOUSNESS

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Low carbon has strong relation with education, climate change, sustainable development, sustainability, and engineering education (**Figure 1.2**). It means that low-carbon education is a part of sustainable development and needs students' sustainability consciousness. It also could be implemented together with engineering education. The low carbon dot has green colour that indicate its publication still recently researched and still need explored (2020-2021). So, it is needed to be explicitly taught as material in learning so that students could more understood pertaining low-carbon education concept.

It demonstrates that there remains insufficient focus and attention on integrating low carbon initiatives within the educational sector, particularly within curriculum. The advancement of low carbon initiatives in Indonesia remains concentrated on the economy, marine and fishery sectors, agricultural industry, and trade market, rather than the educational sector (Low Carbon Development Indonesia (LCDI), 2021). Empowerment of educational potential to develop low carbon education begins with preparing prospective educators who understand and focus on current environmental problems, namely global warming and climate change. Higher education has great potential and ability to provide positive changes to a community and even society (Etse & Ingley, 2016), including 21st century skills that will later be applied to the work-face anywhere and anytime. Higher education institutions that have teaching faculties and educational sciences, function to prepare pre-service teachers, have a strong influence in shaping personal mentality, skills, society, and leaders which are critical points for realizing a sustainable society order (Broman et al., 2017). Teaching pre-service teachers about the substance of low-carbon education (education with minimal carbon emissions) such as global warming, climate change, energy efficiency, fuel and CO₂ emissions, food consumption, waste management, clean energy, to calculate carbon emissions footprints is an important thing to do to produce pre-service teachers who are competent in educating students to be wise in using energy, contribute to reducing emissions, are ready to face environmental challenges, and are responsible for maintaining their sustainability. The more pre-service teachers learn about environmental issues and conditions, the higher their attention and conscious to the

environment and the greater their ability to teach about the environment (Saribas et al., 2017).

However, the reality shows that some university in Indonesia has not been integrate low-carbon education concept explicitly in environmental learning. In higher education, environmental learning has been mandated as a requisite subject across all faculties or academic programs. The preliminary identification findings of environmental education courses at a state university in Central Java indicate that students in the scientific education program enroll in these courses during their third semester for 2 credits. The examined content pertains to the ways in which science might benefit the environment. For instance, the capacity to assess fundamental concepts about global and local environmental challenges and identify pertinent projects, as well as the ability to properly analyze options for climate change mitigation, and so forth. The learning employs a case-based methodology and collaborative project work. Likewise, a science education program at a public university in Makassar has instituted an environmental education course in the second semester, including 2 credits. Like the preceding university, environmental education courses are delivered with a broad framework that highlights only the influence of science on the environment and strategies for its preservation.

Likewise in learning activities, especially in faculty courses related to the environment, science, technology, and society (SETS). SETS is a course that implemented and included in the Faculty of Teacher Training and Education at one of private university in Bogor. Based on the review of syllabus and lesson plan document, in the SETS learning, topics related to the integrated environment have been implemented, but have not applied specifically related and explicit to low carbon education concepts. The approach implemented in SETS learning activities has not been fully integrated towards activities yet. This make students still do not understand what low carbon is related to carbon emissions. Thus, the achievement of knowledge, skills, and attitudes of pre-service teacher regarding the environment also has not been optimal such as critical thinking, creativity, collaboration, communication, and sustainability consciousness. So, it needs a learning process which integrate with low-carbon education explicitly and could improve students'

21st century skills. For that improvement, it also needs the appropriate approach that cultivate 4c's skills and sustainability consciousness. The approach that which trains students as problem solvers, providing solutions through unique projects that can address current environmental issues. One of the approaches which could be implemented in learning with low-carbon concept explicitly is STEM approach.

SETS courses are highly relevant for implementation in the STEM-LCE learning program because the topics covered in SETS courses are closely related to the low-carbon education (LCE) framework. The topics covered in that lecture are multidisciplinary, requiring the solution of real-world environmental problems from various scientific perspectives. One appropriate learning approach is STEM. The STEM approach is very suitable for implementation in the SETS course because the characteristics of the SETS course are multidisciplinary knowledge, and STEM trains problem-solving from various scientific perspectives. Thus, critical thinking skills, creativity, collaboration, and communication will be well accommodated, as will sustainability consciousness.

STEM is one of the models of education used in the era of the industrial revolution 4.0 and society 5.0 recently as an effective method, model, and approach. STEM is also considered as one of the contemporary science learning revolutions (Wu & Anderson, 2015). Some schools in Indonesia or most around the world have implemented a learning approach in Science, Technology, Engineering, and Mathematics (STEM) approach that introduces students to learning process in solving problems and providing solutions based on everyday life. Contextual problem solving are two main things in STEM approach. Real-world context-based learning assumes that everyday situations familiar to the students can be investigated and that STEM concepts relevant to these problems can be explored and used to explain situations.

In STEM approach, students look for solutions to real-life problems. Analysis of bibliometric data concerning keywords in STEM learning and environmental education indicates that the STEM learning approach has not yet been explicitly observed to directly intersect with low-carbon education (LCE), as research in this area remains limited. Low-carbon education (LCE) is essential to

sustainable educational growth; thus, its implementation in learning can incorporate the STEM approach and the project-based learning model. The dots for STEM education and sustainability in education are green, and the dot for higher education is yellow, indicating that this research is relatively new and requires further exploration, especially in higher education (**Figure 1.3**).

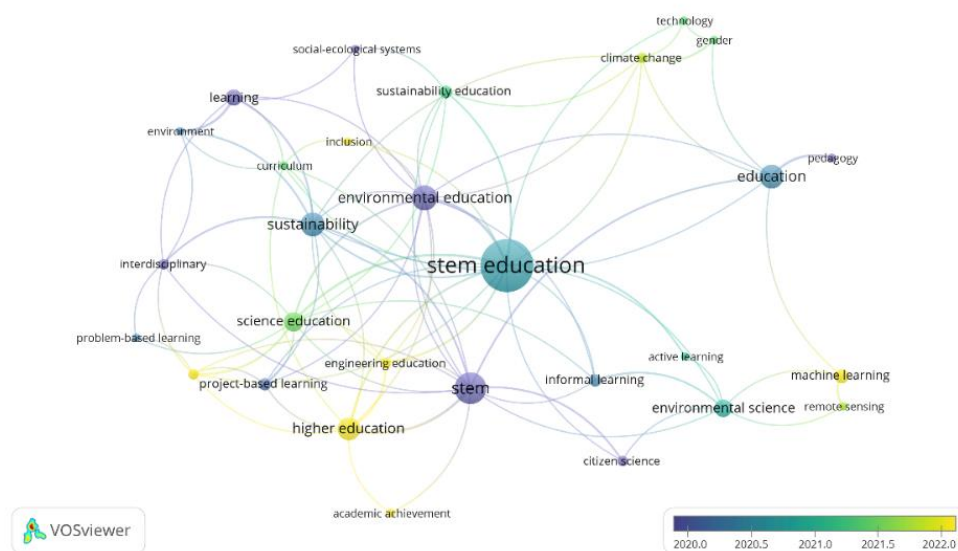


Figure 1.3. The Overlay of STEM Learning Publication by Year

The implementation of the STEM approach remains essential in higher education, particularly in educational-focused study programs. Students, as future educators, must acquire 21st-century talents; therefore, it is essential to comprehend strategies that might cultivate these skills for use in their future classrooms. Likewise, comprehending the significance of the low-carbon idea in environmental education and its interrelation with other disciplines is essential. The integration of STEM approach with the engineering design process systematically prepares students to progress carefully, learn from errors, and engage in design and redesign, resulting in optimal, innovative, and advantageous products.

The problems encountered in real life are interdisciplinary and cannot be limited to the knowledge and skills of a particular discipline. Therefore, to solve these problems pertaining low-carbon problems needs students that has interdisciplinary approach of knowledge and skills from various disciplines

according to their nature (Wang, 2012), such as critical thinking skills, creativity, communication skills, and collaborative skills. The issue of low carbon integrated with the environment is a real problem that requires someone with critical thinking skills to identify the root of the problem, creativity to find innovative solutions to the problem, skilled communication to realize those innovative solutions, and proficient collaboration skills to make the solutions more comprehensive from the perspective of other fields of study and implementable in the real world. If these four skills are well-developed, it is hoped that sustainability consciousness as a concrete action to encourages individuals and communities to prioritize save the environment by implementing a low-carbon lifestyle, sustainable practices in society, which are vital for long-term survival and development will also be realized (Pisters et al., 2019; Sukirwan et al., 2024; J. Williams & Parkman, 2003). This research offers a new contribution by demonstrating how a contextually designed STEM approach oriented towards environmental issues can simultaneously develop critical thinking, collaboration, communication, and creativity skills (4Cs) while also enhancing students' sustainability consciousness. The interrelation of the three is based on the urgent need to prepare future teachers who not only master the content of science and technology but also possess awareness of the social-environmental impacts of learning practices, thereby capable of shaping a generation that is adaptive to the challenges of climate change and sustainable development.

In a line with constructivism learning theory, "learning" is easier for humans to understand because humans build and develop knowledge based on experiences that have been passed. With this also human life becomes more dynamic. In the context of STEM education, constructivist theory is an important approach that emphasizes that students actively build knowledge through experiences and interactions with their environment. Constructivist learning theory plays a central role in the STEM learning approach by emphasizing the importance of active student engagement in building knowledge through direct and contextual experiences (Admawati et al., 2018). This model relies on discussions and group activities in the classroom to build a shared understanding. Project-based and

STEM approaches can significantly enhance students' critical thinking skills in learning (Alawi & Soh, 2019). Constructivist theory encourages active, contextual, and collaborative STEM learning, and has been proven to support the development of conceptual understanding, critical thinking skills, creativity, communication, collaboration, and scientific attitudes among students (Admawati et al., 2018; Mafugu et al., 2024). In addition, STEM learning can be said that it is very important for students to develop their 21st century skills such as problem solving, innovation, critical thinking, creativity, communication, and collaboration (Sari et al., 2020). Aligned with low-carbon education which has a real context in the form of issues and concepts based on real everyday life in the students' environment. So, the STEM approach is appropriate in low-carbon learning that is implemented in the classroom.

Simultaneously, studies show that many students continue to struggle with applying 4cs' skills in real-world problem-solving contexts. Students' critical thinking skills still need improvement (58%). Their creativity is also in the needs improvement category, with a score of 67.3%. The most important aspects to consider are originality (40%) and the product's value (65%) (Nurramadhani et al., 2024d). Collaboration skills is already quite good according to the criteria (79.6%) generally, however, there are some aspects that need attention, multiple inquiry (67.8%) and peer interaction (76.3%) (Nurramadhani et al., 2024a). Oral communication skills is also quite good (75.6%), but there are some aspects where students still struggle, the conclusion (50%) and organization (73.3%). Students still find difficulties to present their study results in a structured manner, with evidence, and to draw appropriate conclusions (Nurramadhani et al., 2023). Meanwhile, students' sustainability consciousness is still low at 51.3%, with the aspect that needs improvement being sustainability behavior (48%). Traditional subject-based instruction often fails to provide meaningful opportunities to connect knowledge across disciplines or address authentic environmental challenges. This calls for a transformative educational learning program that combines the strengths of STEM approach with the goals of low carbon education (LCE) to develop both cognitive and affective dimensions of student learning.

In response to this gap, the development of a STEM-LCE learning program is proposed by the study titled **Development of STEM-LCE (STEM-Low Carbon Education) Learning Program to Construct Pre-Service Teachers' 4C and Sustainability Consciousness**. This program aims not only to cultivate the 4Cs but also to embed sustainability consciousness through interdisciplinary, scientific inquiry, engineering design process integrated with low carbon concepts. By linking scientific and technological understanding with real-world environmental issues, STEM-LCE is expected to empower students with the knowledge, skills, and values necessary for promoting sustainable lifestyles and addressing environmental problems. The novelty of this research lies in the development of a STEM-LCE (Science, Technology, Engineering, Mathematics–Low Carbon Education) learning program that uniquely integrates low carbon education concept through STEM approach in learning. The innovative framework and learning process, by scientific inquiry and engineering design process which contextual learning and multidiscipline knowledge. To explicitly integrate learning with the low-carbon education concept and implement it with a STEM approach, it not only requires an appropriate learning process but also suitable teaching materials. Like modules, student worksheets that are appropriate for the topic, and evaluations, as well as the media used in the learning process, must also be suitable, so that students' critical thinking skills, creativity, collaboration, communication, and sustainability consciousness can develop optimally. Therefore, the development of a program that can cover those aspects is needed. The development learning programs which integrate the STEM approach with LCE concept that are able to develop students' 4c and sustainability consciousness. A learning program development with an approach to science, technology, engineering, mathematics, integrate with low carbon education concept to overcome environmental problems in terms of education which is trained for pre-service teacher who will later become teacher at school who give this knowledge, attitude, and behaviour pertaining low-carbon issues to their students, and also become givers of enlightenment, understanding, and role models of their students both lower and higher education. Thus, this research is expected to provide significance in the field of education,

particularly in environmental education, science, sustainable education, and 21st-century student skills as well as sustainability consciousness.

B. Research Problem

The research problem to be stated and becoming the initial foundation that determines the direction and focus of the entire research process. The research problem is “How is the developed of STEM-LCE learning program can be able to construct pre-service teacher’s 4c and sustainability consciousness”.

C. Research Objectives

Every single research has their own objective. Research objective becomes the direction and guideline in the overall research activities, helping researchers to stay focused on the topic being studied, and not to stray from the defined research problem. This research objective is to develop and produce STEM-LCE learning program which are able to construct pre-service teacher’s 4c (critical thinking skills, creativity, collaboration skills, communication skills) and sustainability consciousness.

D. Research Questions

Research questions based on research problem and research objective are able to described as well as:

1. How is the characteristic of STEM-LCE learning program that has been developed?
2. How can STEM-LCE learning program is able to improves pre-service teacher’s critical thinking skills?
3. How can STEM-LCE learning program is able to improves pre-service teacher’s creativity?
4. How can STEM-LCE learning program is able to improves pre-service teacher’s collaboration skills?
5. How can STEM-LCE learning program is able to improves pre-service teacher’s communication skills?

6. How can STEM-LCE learning program is able to improves pre-service teacher's sustainability consciousness?

E. Operational Definitions

1. 21st century skills consist of 4C included critical thinking skills, creativity, collaborative skills, and communication skills. The term 'critical thinking' refers to a type of introspective thinking geared towards the examination and evaluation of existing communication, information, and arguments, particularly through the application of logic and reason. The instrument that is used to measure these skills is essay test based on critical thinking skills' ACER (Australian Council for Educational Research) framework which consist of three domains of critical thinking such as construct knowledge, evaluate reasoning, and decisions making. The data of critical thinking skills are taken by essay test which is given to the subject before and after learning program implementation.
2. Creativity is an intellectual characteristic an aptitude creating or potentially producing a definite product that is original and has societal or personal worth, planned with a certain aim in mind, employing provided information. Creativity including the creative thinking skills and creativity product. Creative thinking skills involves several aspects, such as fluency, flexibility, and originality, while creativity product in this instrument consists of technical product and science knowledge. The instruments used are creative thinking skills essay test and creativity product rubric. One item in essay test for only assess one aspect of creative thinking skills. It is given to the subject before and after learning program implementation. While, the product creativity assesses for the product that is produced in each topic.
3. Collaborative skills necessitate the formation of partnerships and the agreement on the nature of the ideas or hypotheses to be explored, as well as the team's approach. Then the collaborating students must make observations and seek information. It appears evident that successful collaborative skills are dependent on the social abilities of the participants. It may be more useful to

define the many sorts of social skills that are used when two or more people work together to solve an issue. So, in this research collaborative skills focus on social domain (participation, perspective taking, and social regulation). The collaboration skills data are taken by rubric adopted from collaborative problem-solving framework of (Griffin, 2015) through observation in each group of students. This data are taken in every discussion for each topic.

4. Communication skills are one of the skills included in the 21st Century Skills and even one of the skills that a person must have. Communication itself is the basic principle of a learning process, when someone has a very high understanding of knowledge but he cannot communicate what is in his mind or he cannot convey his ideas both orally and in writing, then it will hinder his process in learning and facing the challenges that are present following the demands of the 21st century. In this research, communication skills would be assessed from students communicate their work only on their presentation activity (oral communication). The rubric for both of assessment are adopted from Baltimore University with three main domains, i.e. opinion, gesture, and multimedia skills. Each main domains have different aspect, consist of organization, delivery, conclusion, eye contact, responsiveness, multimedia skills). The communication data are taken when subject present their project.
5. Sustainability consciousness is defined as integration between awareness, experiences, which focus on three basic concepts of environmental consciousness, for instance knowledge, attitude, and behaviour which broad to the three pillars of sustainable development, such as economic, social, and environment. Consciousness is defined as experience, exemplified by our observations and experiences. The instrument that is used to measure sustainability consciousness is sustainability consciousness questionnaire based on low carbon education which is adopted from Gericke, et.al. (2018). Sustainable consciousness data are taken before and after STEM-LCE learning program is implemented.

F. Research Benefits

This research is very important to be implemented by lecturers in environment-based education by integrating the low-carbon education concept using the STEM approach to enhance the 4Cs skills and sustainability consciousness of pre-service teachers. Here are the benefits of the STEM-LCE learning program development research from various aspects. The results of this study are expected to be useful in the following ways:

1. Theoretical Benefits

This research contributes to the development of theoretical studies in the field of science education and environmental education, particularly the integration of the STEM approach with the principles of low-carbon education (LCE). By constructing a conceptual framework that combines the reinforcement of the 4Cs (Critical thinking, Creativity, Collaboration, Communication) and sustainability awareness, this research expands the perspective of transdisciplinary learning based on sustainability, and enriches the literature in pre-service teacher education in the 21st century.

2. Policy Benefits

The findings from this research can serve as a basis for policy recommendations for higher education institutions and relevant ministries in designing teacher education curricula or education curricula that are adaptive to the challenges of climate change and sustainable development. The developed STEM-LCE program can serve as a model in formulating teacher education policies based on green competencies and environmental awareness.

3. Practical Benefits

Practically, this research provides concrete guidance in the form of a STEM-LCE learning program design that can be applied by lecturers or facilitators in courses for pre-service teachers. The materials, approaches, and activities developed in this program can be directly used to develop 4C skills and instill sustainability consciousness in students, thereby producing pre-service teachers

who are ready to implement learning relevant to contemporary environmental issues.

4. Benefits of Social Action

This research encourages the formation of change agents among pre-service teachers who not only possess 21st-century competencies but also sensitivity to social and environmental issues. By building sustainability consciousness through education, this research contributes to collective efforts in creating a society that is more carbon-conscious, environmentally caring, and empowered to face the global ecological crisis collaboratively and solution-oriented. It means the students and society could be gathered as low-carbon society.