CHAPTER V
CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The research findings in this study indicate that the implementation on ESD-STEM learning on solar cell project has a positive impact on students' engineering design skill and their sustainability action to support Sustainable Development Goal 13 (climate action). There are two core results of the research based on the research questions.

First, the implementation of ESD-STEM learning on solar cell project significantly enhanced the engineering design skills of students in the experimental class, with a score of 88.4, indicating that students' engineering design skills are in very good performance better than previous study that only showing score of 75 indicating in "Fair" performance. The students showed a great improvement in many phases of the design process, such as identifying problems related to fossil fuel dependence, developing innovative renewable energy solutions, constructing prototypes, and communicating their products effectively. This improvement was largely supported by active group collaboration, prior knowledge in robotics possessed by some members, and intensive discussions throughout the project stages. These findings highlight that integrating ESD principles into STEM learning successfully equips students' engineering design skills in addressing real-world energy issues.

Second, the hypothesis test has been carried out and shows that the implementation of ESD-STEM learning on solar cell project had a positive impact on students' sustainability actions. Although the pre-test scores indicated differences in initial ability between the experimental and control classes, the gain score analysis revealed a greater increase in the experimental class (0.90) compared to the control class (0.72). Statistical testing further confirmed that this difference was significant ($p < 0.05$), demonstrating that the ESD-STEM approach was more effective than the regular teacher's regular model following inquiry applied in the

control class. The hands-on experience of creating solar energy solutions encouraged students to relate classroom concepts to daily practices, which in turn fostered a stronger sense of responsibility and proactive behaviour toward mitigating climate change. In comparison, students in the control class showed only limited improvement, which was influenced by the different stages in project activities and direct engagement with real-life energy problems.

5.2. Recommendation

The implementation of ESD-STEM learning on solar cell project still requires habituation and consistent practice. Students are recommended to actively participate in school activities, for example, student organizations or extracurricular programs, that involve the ESD-STEM principles. At the same time, teachers and schools are encouraged to collaborate in fostering this habituation by participating in training programs to deepen the understanding of ESD-STEM learning and its implementation in schools. Over time, ESD-STEM learning can provide students with meaningful project experiences that enhance their engineering skills and raise their sustainable action.

Furthermore, it is recommended for future research to assess students' initial skills, involving in prior knowledge in engineering levels. This research can ensure that the distribution of abilities within each student is more balanced. Future research may also integrate more advanced technological tools, such as IoT-based energy monitoring integrated with the land used condition, to enhance students' experiences and further connect project outcomes with real-world applications.

Last, curriculum developers and teachers are encouraged to incorporate ESD-STEM projects more widely into other science content. Providing structured guidance, clear learning materials, and continuous mentoring will maximize the effectiveness of ESD-STEM learning, in fostering students' technical skills and sustainable behaviours aligned with climate action goals (SDG 13) or Other SDGs aspects.