CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

In this study, a life cycle assessment (LCA) technique was performed to evaluate energy efficiency and environmental performance of biodiesel produced from freshwater microalgae *Scenedesmus armatus*. The LCA commercial software named SimaPro version 7.1 was employed with Cumulative Energy Demand and CML 2 baseline 2000 method. The energy efficiency is expressed in terms of net energy ratio (NER) which is defined as a ratio of energy output to energy input. Various environmental impact categories were evaluated, focusing on global warming potential (GWP as kg CO_2 equivalent). Additionally, the results were compared to conventional diesel and biodiesel from other feedstocks.

5.1 Summary of Life Cycle Energy Analysis

In this analysis, the system boundary covered the entire life cycle of microalgae-based biodiesel which was divided into four distinct steps: cultivation, harvesting, oil extraction, and transesterification. Based on a functional unit of 1 MJ biodiesel, NER was found to be 0.34 and 0.19 for mass allocation and energy allocation, respectively. The main bottleneck of the microalgae-to-biodiesel production lies in the energy intensive process of cultivation. Therefore, the huge energy demand in cultivation process is the main challenge that has to overcome in order to make the value chain of microalgae-to-biodiesel feasible and practical. The results from sensitivity analysis showed that the proposed improvement in biomass concentration is the most effective scenario.

5.2 Summary of Life Cycle Impact Assessment

As stated earlier, global warming potential (GWP) has been focused in this study. In addition, other impact categories including abiotic depletion, ozone layer depletion, human toxicity, photochemical oxidation, acidification, and eutrophication have been concerned. The impact assessment results indicated that producing biodiesel from microalgae as a replacement of fossil diesel contributes to the reduction of global warming potential, mainly due to the CO_2 uptake via photosynthesis during biomass agriculture. Microalgae can fix up to 25 % of net greenhouse gas emissions (kg CO_2 equivalent). It can be concluded that most of the impacts are mainly driven by energy consumption and chemicals usage. Moreover, sensitivity analysis showed that the application of different allocation methods affects the LCA outcomes. Impacts are larger by switching from mass to energy allocation in all impact categories.

5.3 Recommendations

1. An appropriate method for biomass production should be selected in order to reduce the energy consumption during the cultivation process.
2. Microalgae with high lipid content should be used to produce biodiesel in order to increase the overall yield.
3. Biodiesel production process should be combined with biogas production process by utilizing the remaining biomass after lipid extraction to produce biogas in order to increase the energy efficiency.
4. Wastewater or culture media should be recycled in order to reduce the nutrient requirement during the cultivation process.