

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This sub-chapter contains conclusions from the results obtained and recommendations for future research.

6.1 Conclusions

Based on the results of the analysis in the previous chapter, the following conclusions can be obtained.

1. Crane operational costs in this study are incurred each time the crane operates. The calculated operational cost components include crane fuel costs, preventive maintenance costs, labor costs, non-preventive maintenance costs, the cost of using electronic devices to support crane operations, and, in cases after electrification, depreciation costs from the electrification installation are added. In the pre-electrification condition, the total operational cost was Rp5.556.517.285,38, while in the post-electrification condition, it decreased to Rp4.659.131.371,80. This total cost represents the annual operational cost when lifting the same load unit, namely 1.260.466 tons. The cost difference mainly occurs in the fuel cost component and preventive maintenance costs, where both decreased after electrification, resulting in a lower total cost. The decrease in fuel costs occurs because fuel prices increase yearly following market values, while electricity rates remain stable due to the company's contract with PLN. The decrease in generator preventive maintenance costs is due to the reduced frequency of replacement of several components after the system switched to electricity. Because the generator is no longer used as the main energy source, the generator operation is limited to routine warm-up only. The installation cost of Rp944.395.212,92 is added to the operational costs after electrification for the next 25 years. Based on the calculation results, the net savings in the first year still reached Rp897.385.913,58. The savings of Rp897 million are equivalent to approximately 59 days of daily energy costs

before electrification. This means the company can only finance approximately 2 months of operations without increasing the financial burden. According to the company, the budget from these savings will be allocated for other things, such as investment or procurement of new equipment or repair of facilities at this port and other branches. Based on these results, crane electrification can be considered feasible to continue from an operational cost aspect. This statement is supported by the sensitivity analysis results for scenarios 1 and 3. Scenario 1 shows that electricity consumption costs remain stable, as even a significant increase in electricity tariffs does not increase the total cost beyond the operational costs when using diesel. Scenario 3 sensitivity analysis results show that operational costs after electrification remain lower when the electricity supply is suboptimal and the crane uses the generator again for several hours.

2. Carbon emission calculations were conducted to assess whether electrification activities also provide advantages regarding environmental impact. Carbon emissions before and after electrification were calculated by considering all activities during crane operations that could produce emissions from fuel use, supporting electronic devices during operational activities, and emissions generated during maintenance activities. Based on the calculation results, total carbon emissions before electrification were 1,045,600.51 kg CO_{2e}, while after electrification decreased to 855.558,91 kg CO_{2e}, or a net emission reduction of 225.863,88 kg CO_{2e}. With a transport load of 1.2 million tons, emission intensity decreased from 0,861 kg CO_{2e}/ton to 0,673 kg CO_{2e}/ton. This is due to the large value of the diesel emission factor. Diesel produces 2,68 kg CO₂ per liter, while electricity produces 0,52 kg CO₂ per kWh. Although there are additional emissions from generator warm-up activities after electrification, total emissions remain lower. The company also remains below the environmental emission limit set by NOAA (2025) of 400 ppm CO₂ per year. Thus, crane

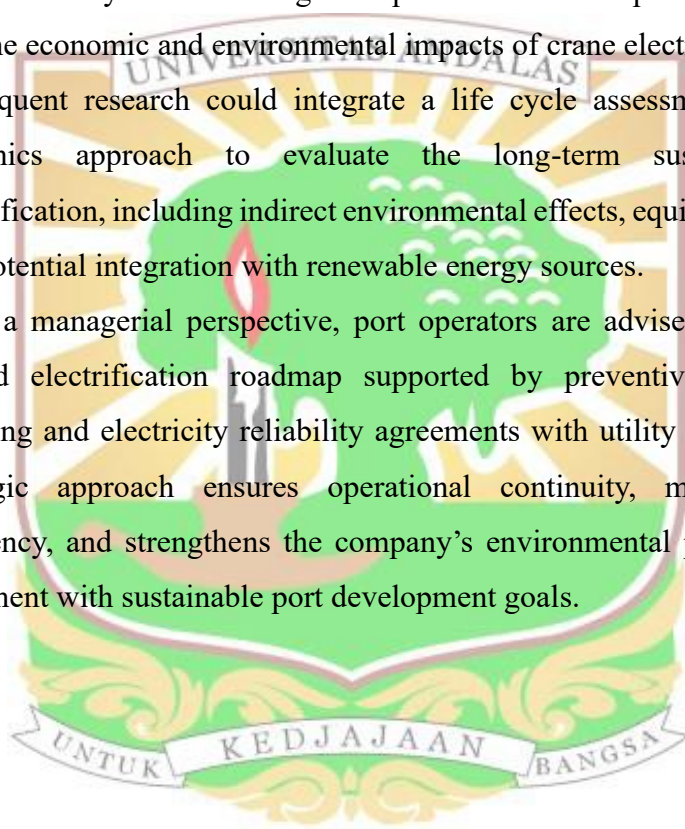
electrification provides significant environmental efficiency without exceeding the emission threshold.

3. Following the cost and emission analysis, an alternative selection stage was conducted to determine the port's most efficient electricity support strategy for crane operations. This step was taken because the company needed to ensure that the transition from a diesel to an electric system could run smoothly without disrupting 24-hour loading and unloading activities. Based on discussions with the utility manager, the company identified four alternative actions: (A1) providing a generator as a backup power source, (A2) replacing the cranes in stages, (A3) replacing the cranes altogether, and (A4) securing an electricity supply guarantee contract with PLN. The criteria and sub-criteria used in selecting these alternatives refer to Justin (2021) and are adapted to actual conditions in the field. The four main criteria are investment costs, system reliability, implementation practicality, and long-term operational costs. These criteria are broken down into six sub-criteria: guaranteed energy continuity, response to disruptions, replacement duration, impact on operations during implementation, energy consumption, and system maintenance costs. The assessment was conducted using the Analytical Hierarchy Process (AHP) method to obtain the weight and priority of each alternative. The results show that A1 (generator backup) is the best alternative with a score of 0,37590, followed by A3 (simultaneous replacement), A4 (PLN contract), and A2 (phased replacement). This order reflects the company's focus on system reliability and long-term efficiency, not just initial costs. These results align with the company's actual conditions. They are proven stable based on a sensitivity analysis, where the weights of the two highest criteria do not change the order of the alternatives.

6.2 Recommendations

Based on the conclusions and findings of this study, several recommendations are proposed to guide future research and provide practical insights for managerial decision-making related to crane electrification as follows:

1. Future studies are encouraged to expand the analysis by incorporating a broader range of operational scenarios. This would enhance the generalizability of the findings and provide more comprehensive insights into the economic and environmental impacts of crane electrification.
2. Subsequent research could integrate a life cycle assessment or system dynamics approach to evaluate the long-term sustainability of electrification, including indirect environmental effects, equipment lifespan, and potential integration with renewable energy sources.
3. From a managerial perspective, port operators are advised to develop a phased electrification roadmap supported by preventive maintenance planning and electricity reliability agreements with utility providers. This strategic approach ensures operational continuity, maximizes cost efficiency, and strengthens the company's environmental performance in alignment with sustainable port development goals.



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