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Research Paper

Mitigating Carbon Emissions in Maritime Operations: A Case Study of Bakungan Port

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Abstract

PT. Baramulti Suksessarana, Tbk. (PT. BSSR), a mining company in Batuah Village, Kutai Kartanegara, operates a port facility in Bakungan Village powered entirely by electricity supplied by PLN. This energy source drives the crusher unit, OLC, and BLC (identified as significant energy users in the port area) and supports additional activities, such as office operations and control rooms. PT BSSR, having joined the B20 movement that emphasizes "Energy, Sustainability & Climate," supports PT PLN's program targeting a reduction of 900 million tons of carbon emissions per year. Our research, therefore, centers on energy conservation and carbon emission reduction. PT BSSR inventoried all electrical energy-consuming units, compiled an electricity usage history, and created a baseline for consumption. A linear regression equation correlating energy consumption (kWh) with crushing product (MT) was derived from this baseline, establishing a benchmark for future conservation. We aimed to reduce the CO_2e/MT Ratio or Greenhouse Gas Emissions in the Bakungan Port area from 0.44086 kg CO_2e/MT to 0.3837 Kg CO_2e/MT. Initiatives included implementing sensor monitoring and CCTV to prevent large rock entry, minimizing electrical "Start-Stops," conducting regular inspections and maintenance, and executing other conservation programs. The research led to a successful reduction in Greenhouse Gas/Carbon Emissions by 0.025e/MT, equivalent to 101.11 Tons of CO_2e per year. This equates to a reduction of 0.169 kWh/MT or 680.689 kWh annually, yielding a cost saving of Rp 220.06/MT or a total of Rp 883,988,533 per year.

Keywords *Carbon Emissions, Maritime Operations, Bakungan Port, Energy Conservation, Electricity Consumption*

INTRODUCTION

Discussions on energy consumption and efficiency, coupled with monitoring and evaluating best practices and their implementation, can significantly contribute to achieving at least three Sustainable Development Goals (UNECLAC, 2016). The challenges of the greenhouse effect, melting glaciers, and ozone layer depletion have intensified in recent years, threatening humanity (Zeng et al., 2023). The concept of "Energy, Sustainability & Climate" encompasses:

a. **Energy:** This focuses on diverse sources, from fossil fuels to renewables, and emphasizes advanced production, storage, and distribution technologies.
b. **Sustainability**: This aims to meet current energy demands without jeopardizing the needs Of future generations. It involves efficient resource use, waste minimization, biodiversity protection, and fostering economic, environmental, and social harmony.
c. **Climate Change**: This concerns the repercussions of human actions, mainly greenhouse gas emissions, leading to global warming and subsequent climatic shifts.
d. **Adaptation and Mitigation:** These strategies counteract climate change impacts and Prepare societies for inevitable changes.
e. **Policies and Regulations**: These are crucial frameworks at various levels that support sustainable energy, emission reductions, ecosystem protection, and the implementation of

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green technology.

Our study on PT. BSSR targeted carbon emissions mitigation, emphasizing energy conservation and emission reduction. A significant correlation exists between port operation and energy efficiency (Iris et al., 2019), suggesting that enhanced efficiency can reduce energy consumption. The Bakungan port of PT BSSR primarily uses electricity, with units like the crusher, OLC, and BLC being the main consumers. Additionally, PT BSSR supports the B20 biodiesel blend initiative, aligning with the "Energy, Sustainability & Climate" philosophy, and contributes to PT PLN's goal of reducing 900 million tons of carbon annually. PT BSSR champions electricity conservation and emission reduction every year through its innovation event.

Recent literature has increasingly focused on carbon emission reduction at ports, especially from energy conservation and efficiency perspectives (Wang, B. et al., 2023; Alamoush et al., 2022). Much of the existing research focuses on optimizing port operations, reducing energy consumption, and exploring alternative transport solutions for reducing carbon emissions. However, scholarly investigations within the coal mining sector remain limited, with a primary focus on carbon emissions related to logistics and port operations (Hoang et al., 2022; Poulsen et al., 2022; Tang et.al., 2019).

Our research seeks to fill this gap by examining carbon emissions, specifically in maritime operations. We catalogued all the units consuming electric energy, documented the electricity consumption history, set baseline energy consumption metrics, and developed a regression equation to correlate energy consumption with crushing product output. This work lays the foundation for future electricity conservation initiatives.

LITERATURE REVIEW

We aim to provide a comprehensive yet succinct background without delving into an extensive literature survey or summarizing results. The theoretical section is structured to augment, rather than reiterate, the foundational background established in the introduction, paving the way for further analysis. The calculations section symbolizes the pragmatic evolution from this theoretical base.

Carbon Emissions

Carbon emissions are primarily quantified at two levels: macroscopic and microscopic. Macroscopic computation employs carbon emission assessment methodologies from a conceptual interpretation vantage point, whereas microscopic computations offer estimates of carbon emissions based on varying emission origins. The microscopic approach dominates academic research (Yu et al., 2022).

Maritime Ports

Innovative technological interventions have emerged as pivotal to instilling sustainable practices and environmental stewardship within ports. These technologies herald a transition from fossil fuel-reliant, carbon-intensive port industries to low-carbon port paradigms, leveraging renewable energies, alternative fuels (e.g., LNG, hydrogen, biofuel), and enhanced energy distribution and monitoring frameworks (Iris & Lam, 2019).

Bakungan Port

Ports deploy various equipment assortments to facilitate operations. Port operations are inherently energy-intensive, underscoring the imperativeness of robust, sustainable, and resilient infrastructure poised to bolster future economic developments (UNECLAC, 2016). Infrastructure enhancements tailored for sustainability can amplify resource use efficiency and expedite the adoption of eco-friendly technologies and processes. Bakungan Port, specifically located in Desa Bakungan, Kabupaten Kutai Kartanegara, manifests substantial electricity consumption, especially in its stockpile activities, crushing, overline conveyor, and barge loader conveyor.

Energy Conservation

Energy management paradigms encapsulate energy demand forecasting, energy supply planning, and sophisticated energy management systems bridging demand and supply. A port's adeptness in energy management is contingent on accurate energy consumption measurements and forecasts. Furthermore, these systems necessitate a robust management strategy. Ports harness diverse energy components, including batteries, distributors, and converters. Emerging methodologies to bolster grid intelligence and innovative energy storage devices (e.g., flywheels, supercapacitors) can further enhance energy efficiency (Iris & Lam, 2019).

Electricity Consumption

Next-generation ports are anticipated to leverage automation, electrification, and sophisticated energy management systems (Iris et al., 2019). At Bakungan Port, energy is predominantly consumed in the form of electricity, highlighting the port's operational activities' electric consumption.

RESEARCH METHOD

The research methodology employed is quantitative and comprises the following steps:

1. Use the Pareto diagram to identify energy usage across various facilities at Port Bakungan, aiding in problem prioritization.
2. Create a scatter diagram to establish a baseline energy profile using data from the first four months of 2022, incorporating linear regression with crusher production data of 400,000 MT/month.
3. Draw comparisons between optimal energy usage and the company's achieved production.
4. Employ the SIPOC (Supplier, Input, Process, Output, Customer) method to provide a concise overview of the process's impact on customers, which assists in identifying problem areas and shaping the research title.
5. Utilize data tables from January to March 2022 to set the study's emission reduction targets (kg CO_2/ MT).
6. Analyze existing conditions using brainstorming and the Nominal Group Discussion technique. Out of 29 identified conditions comparing the actual with the ideal, nine met three criteria: they were primary concerns, relevant, and controllable.
7. Identify root causes using the Ishikawa or fishbone diagram, focusing on Man, Machine, Method, Material, and Environment.
8. Conduct problem verification using the scatter diagram method for the processes mentioned in point 7, determining the strength of their correlations. Fewer than nine conditions from point 6 were selected after this verification.
9. Plan corrective actions centred on dominant root causes and formulate an action plan using a check sheet consisting of the 5 W's and 2 H's: What, Where, How, Who, When, and How Much.
10. Implement actions and compare outcomes, analyzing data before and after the interventions.
11. Evaluate the results, showcasing evidence and data highlighting the research's

positive impacts, particularly significant effects on certain processes.

FINDINGS AND DISCUSSION

Researchers conducted an identification study to investigate the magnitude of electrical energy consumption in the Port Bakungan area. The researchers segmented the port into 14 distinct zones that consume electricity. These zones include the Crusher, OLC (Over Land Conveyor), BLC (Barge Loading Conveyor), Old Office, MCC (Motor Control Center) 1 & 2, New Office, Fuel Room, Workshop, Lower Office, Weighing Area, Purchasing, MCC BLC (Motor Control Center of Barge Loading Conveyor). Among these identified zones, the Crusher, OLC, and BLC, when combined, accounted for a significant 94.03% or approximately 5,164.95 kWh/day of the total electricity consumption. As such, these three locations have been designated as the focal areas for the research scope.

The above research data and calculations are grounded on information from the International Energy Agency (IEA, 2006). The IEA is a global organization that fosters energy cooperation among its member countries. It offers a plethora of data and reports related to energy, encompassing insights on production, consumption, pricing, and global energy trends. In 2006, the IEA released various reports, statistical data, analyses, and projections on energy supply, renewable energies, energy efficiency, pollution & and emissions, energy security, and energy technology. From these resources, it was determined that the Emission factor stands at 770.74 gr CO_2/kWh.

To determine the benchmark for ideal electrical energy consumption at Port Bakungan, in line with the Crusher production of 400,000 MT/month, the scatter diagram provided a linear regression distribution represented by the equation:

$$Y = 0.4464(400{,}000) + 634.17$$

Thus,

$$Y = 197{,}585.10 \text{ kWh or } 0.49 \text{ kWh/MT, with an } R^2 \text{ value of } 0.9532.$$

Where,
Y = Energy Consumption
X = Crushing Production (400,000 MT/month)
M = Constant (0.4464)
C = Baseline Load (634.17)

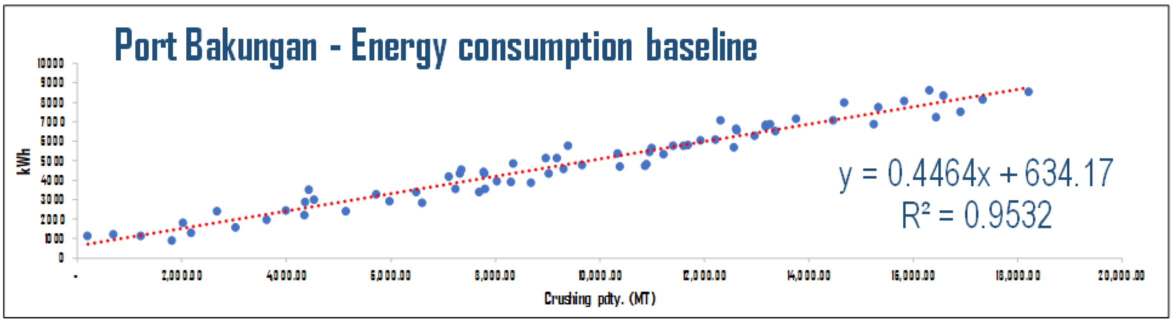

Figure 1. Data from January 1 to April 2022 - Baseline Energy Consumption

For the period spanning January to March 2022, Port Bakungan's energy consumption totalled 415,600 kWh, which incurred a billing amount of IDR 1,032,661,395. This resulted in a financial deficit of IDR 498,822,956 due to the failure to meet the minimum energy threshold set by PLN. Given this scenario, the research aimed to identify avenues for electrical energy conservation with the overarching objective of curbing greenhouse gas (GHG) emissions.

Upon juxtaposing the Crusher's production data with GHG emissions (in terms of CO2 equivalent) and drawing from the established electrical energy baseline, we derived the following insights:

Table 1. Discrepancies or Gaps Based on the Electrical Energy Baseline

Condition	**kWh/MT**	**IDR/MT**	**CO_2e/MT**	Second/**MT**	Hour/**MT**
Ideal	0.49	614.69	0.3877	3.64	13.49
Actual (Jan-Mar '23)	0.62	670.26	0.4086	3.86	14.28

Upon analyzing the current conditions, 29 circumstances were identified that resulted in greenhouse gas emissions (CO_2e/MT) surpassing the ideal values. Using the Ishikawa diagram for data processing, nine dominant conditions were discerned as the root causes necessitating rectification. Further validation through the scatter diagram, commonly referred to as the dispersion diagram, determined the cause-effect relationships. From this, it was ascertained that only five conditions have a strong correlation leading to the persistently high greenhouse gas emissions at Port Bakungan. The specific five conditions are as follows:

Table 2. Determination of Problem Verification

No	**Actual condition**	**Ideal Condition**	**Executed Programs**	**R^2 value (Correlation)**	**Remark**
1.	There is no duty officer on standby in the crusher area to observe the boulder material entering the hopper (MAN)	There is an officer on guard at the crusher area to observe the boulder entering the hopper then pressing the emergency stop button so that the boulder does not enter the crusher	There is an allocation of a team to keep the boulder from entering the Crusher	$R^2 = 0.9519$	STRONG CORRELATION
2.	There is an incident of v-belt slip/break as a result of the boulder material entering the crusher (MACHINE)	There is no boulder material that enters the crusher, to reduce the load on the drive motor and the belt	DATA – The cause of unscheduled maintenance started with boulder material entering the crusher resulting in damage or abnormal conditions	$R^2= 0.7679$	STRONG CORRELATION
3.	There is an incident where the chain feeder is problematic (needs to be adjusted) as a result of boulder material entering the crusher – (MACHINE)	No boulder material enters the crusher; if there are indications of boulder material, stop crushing immediately and break the boulder before entering the crusher		$R^2 = 0.7596$	STRONG CORRELATION

		in the crusher unit		
4.	There are 5 driving motors with a total power of 282.5 kW and there is an incident of a crusher stop due to unscheduled maintenance and boulder – (MACHINE)	The motor works continuously with stable energy use		$R^2 = 0.9519$	STRONG CORRELATION
5.	There is no baseline energy data as a reference for performance measurement (METHOD)	An energy baseline is available to measure energy-saving performance	DATA-Baseline Energy	$R^2 = 0.9532$	STRONG CORRELATION

Implementation

Enhance Hopper and Crusher productivity by:

1. Introducing specialized tools such as the Dozer and Wheel Loader to ensure continuous coal supply, eliminating hopper downtime.

- Maximizing dozer efficiency with direct dozing and optimal dumping proximity to the hopper.
- Installing sensors and CCTV to prevent boulders, which can halt production, from entering the Hopper and Crusher.
- Appointing a dedicated dumpman to guide dump truck operations, ensuring optimal Crusher operation hours and increased crushing productivity.

Table 3. Achievement of Ideal Crusher Operational Hours and crushing Productivity

1. Achievement of Ideal Crusher Operational Hours			
Parameter		**Jan- April 22**	**Mei – Jun 2022**
Working Hours (hours)		987.10	593.5
Crushing Prod (MT)		796,459	693,299
Crushing Productivity (MT/h)		806.86	1,168.15
Ideal Working Hours (Hours)		13.49	
Actual Working Hours (hours)		14.441	3.77
Ratio (s/MT) Ideal		3.64	
Ratio (s/MT) Actual		3.90	3.72
2. Increased Crushing Productivity			
Before			
Period	**Plan**	**Actual**	**Achievement (%)**
January 22	850	547	64 %
February 22	1,000	931	93 %
March 22	1,000	928	93 %
After			
Periode	**Plan**	**Actual**	**Achievement (%)**
May 22	1,000	1,110	111 %
June 22	1,000	1,220	122 %

From the table above, it has been tested that with the research and implementation carried out, there was an increase in the crushing productivity value from 806.86 MT/h to 1,168.15 MT/h, and there was an optimization of the crusher operating hours, which was originally 3.9 s/MT to 3.72 s/MT or equivalent with an optimization of 2,084 minutes or 34.73 hours in May to June 2022 production.

2. Establish and assess optimal Crusher operational hours and conduct systematic inspections and preventative measures to minimize shutdowns and maintenance time caused by boulders.

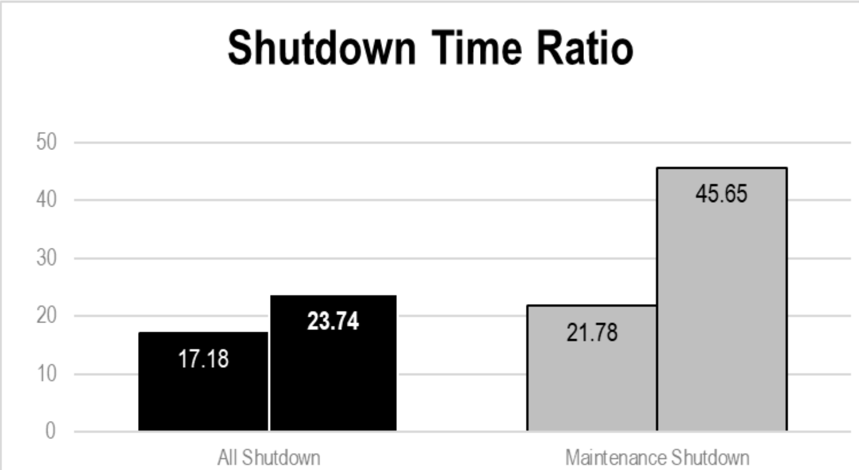

Figure 2. Shutdown Time Ratio

The displayed graph indicates a rise in shutdown maintenance events, increasing the duration from 17.18 minutes to 23.74 minutes (a 38% hike). Specifically, scheduled maintenance shutdowns extended the gap between events from 21.78 minutes to 45.65 minutes, marking a 110% performance boost.

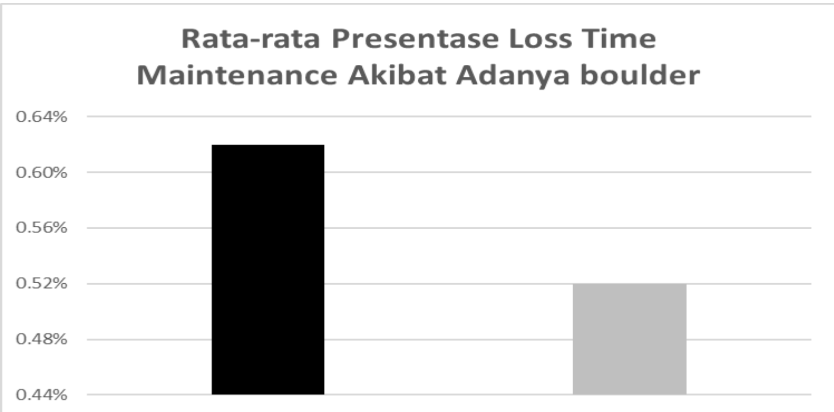

Figure 3. Average percentage of Loss Time Maintenance due to boulder

With the CCTV monitoring system, sensors and dumpman, the average loss time due to boulders has decreased from 0.62% to 0.52% or, in general, decreased by 15%.

3. Compile and analyze the use of electrical energy consumed to produce a reduction in greenhouse gas emissions.

Table 4. Reduction of Greenhouse Gas Emissions

Year	Month	Crushing Pdty	CO_2e (Ton)	Energy Consumption (kWh)	Cost of Energy (IDR)	Ratio		
						Kg CO_2e/MT	kWhe/MT	IDR/MT
	January	173,276.72	65.70	85,248	109,949,288	0.3792	0.492	634.53
	February	301,755.98	122.85	159,392	205,447,349	0.4071	0.528	680.84
	March	321,426.48	131.77	170,960	218,441,507	0.4099	0.532	679.60
	Q1-2022	623,182.46	254.62	415,600	533,838,144	0.4086	0.667	856.63
	April	Prepared						
	May	314,174.00	122.05	157,536	202,483,065	0.3885	0.5040	644.49
	June	379,125.48	143.85	186,640	236,415,838	0.3794	0.4923	623.58
2022	July	339,758.00	138.03	179,088	229,763,104	0.4063	0.5271	676.26
	August	392,576.00	150.46	195,216	251,740,512	0.3833	0.4973	641.25
	Sept	308,826.00	125.50	162,832	210,107,100	0.4064	0.5273	680.34
	Oct	379,091.00	142.79	185,264	236,214,522	0.3767	0.4887	623.11
	Nov	342,074.00	126.40	164,000	208,018,835	0.3695	0.4794	608.11
	Dec	412,296.00	150,49	195,248	250,891,314	0.3650	0.4736	608.52
	May-Dec	2,867,920.00	1,099.57	1,426,640	1,825,634,290	0.3834	0.497	636.57
						0.025	**0.169**	**220.06**

From the results of the data that has been calculated, a decrease in the value of the ratio of CO_2e/MT or greenhouse gas emissions from 0.4086 to 0.3834 is obtained or a decrease of 0.025 kgCO_2e/MT with a percentage level of 106%.

Benefit Opportunity:

From the calculations obtained, 0.025 kgCO_2e/MT is equivalent to 101.11 Ton CO_2e/year, and 0.169 kWh/MT is equivalent to 680,689 kWh/year, and for 220.06 IDR/MT it produces 883,988,533 IDR/year.

CONCLUSIONS

From the conclusions of the study, the following insights were obtained:

1. The company has become a coal mining contributor in East Kalimantan, engaging with the G20 or B20 hosted in Indonesia in 2022 concerning energy and carbon issues.
2. There has been a reduction in greenhouse gas emissions amounting to 0.025 Kg CO_2e/MT, equivalent to 101.11 Ton CO_2e/Year.
3. Crushing Productivity has increased from 806.86 MT/h to 1,168.15 MT/h.
4. There has been an improvement in the ratio of crusher shutdown time, with occurrences increasing from one incident every 21.78 minutes to one incident every 45.65 minutes, reflecting a performance enhancement of 110%.
5. There has been a decrease in the ratio of electrical energy usage by 0.169 kWh/MT, equivalent to 680,689 kWh/Year.
6. The benefit opportunity realized is IDR 883,988,533/Year, meaning this research has facilitated significant cost reduction for the company.

Further Research

Based on the electricity bills issued by the company, it appears that significant costs have been incurred. The company has been paying the minimum bill threshold without actual electricity consumption, resulting in a variance of IDR 1,567,900,457 in 2022.

Table 5. Costs incurred due to excessive bills from PLN

Period	Billed based on actual usage				Variances
	Used expense bill (IDR)	PPJ 3% (IDR)	Total	Actual invoice from PLN	
January 22	106,746,882	3,202,406	109,949,288	340,206,153	230,256,865
February 22	199,463,445	5,983,903	205,447,349	346,675,552	141,228,203
March 22	212,079,133	6,362,374	218,441,507	345,779,395	127,337,888
April 22	217,768,275	6,533,048	224,301,323	345,472,141	121,170,818
May 22	196,585,500	5,897,565	202,483,065	344,960,052	142,476,987
June 22	229,529,940	6,885,898	236,415,838	344,925,913	108,510,075
July 22	223,707,975	6,692,129	229,763,104	347,341,269	117,578,165
August 22	224,408,265	7,332,248	251,740,512	349,952,925	98,212,413
September 22	203,987,475	6,119,624	210,107,100	347,204,711	137,097,611
October 22	229,334,487	6,880,035	236,214,522	346,376,833	110,162,311
November 22	201,960,034	6,058,801	208,018,835	343,713,967	135,695,132
December 22	243,583,800	7,307,514	250,891,314	349,065,303	98,173,989
					1,567,900,457

The ideas for future research based on our original theme:

1. Optimized Energy Use: "Strategies for Energy Consumption Reduction at the Port: A Focus on 2022 Energy Baseline Post-Improvement."
2. Sustainable Energy Transition: "Transitioning to Renewable Energy at the Port: Analyzing the 2022 Energy Baseline Post-Improvement."
3. Technology's Role: "Impact of Technological Innovations on Energy Expenditure and Cost/MT Ratio of Coal at the Port."
4. Behavioural Impact: "Behavioral Influences on Port Energy Consumption Patterns: Insights from 2022 Post-Improvement."
5. Energy Cost Audit: "Identifying Further Cost Reductions through an Energy Audit of the Port Using the 2022 Energy Baseline."
6. Economic Analysis: "Economic Analysis of Energy Consumption Trends at the Port Based on 2022 Energy Baseline."
7. Environmental Benefits: "Benefits of Reduced Energy Consumption at the Port: An

Environmental Impact Assessment Using the 2022 Baseline."

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