Volume 13 Number 01 (2026)

JURNAL REKAYASA SISTEM DAN INDUSTRI
e-ISSN: 2579-9142 p-ISSN: 2356-0843

https://journals.telkomuniversity.ac.id/jrsi

Performance Evaluation of the Pressing Process to Improve Electrical Energy Efficiency at PT ISM Bogasari Flour Mills Surabaya

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ARTICLE INFO

Article history:
Received 26-05-2026
Fixed 02-06-2026
Approved 15-07-2026

Keywords:
Productivity, Objective Matrix (OMAX), Energy Efficiency, Electrical Energy Consumption, Pelletizing

ABSTRACT

This study aims to evaluate the performance of the pressing process as an effort to improve electrical energy efficiency in the Pelletizing Division of PT ISM Bogasari Flour Mills Surabaya. The research problem is based on the unachieved Key Performance Indicator (KPI) target for the electrical energy consumption ratio of 17.5 kWh/ton, where the actual consumption in 2024 reached 18.705 kWh/ton. The study employs the Objective Matrix (OMAX) method to measure productivity levels based on several performance indicators covering labor, machinery, raw materials, and electrical energy. Research data were obtained from operational production data for the period of July to December 2024. The analysis results indicate that the pressing process accounts for the largest share of energy consumption at 81.23% of total electrical energy waste in the pelletizing process. The implementation of a corrective action in the form of a reprocess raw material pathway relayout was proven effective in improving press machine work effectiveness and reducing electrical energy consumption. The average OMAX productivity increased from 5.10 to 5.34, while the average electrical energy consumption decreased from 18.80 kWh/ton to 16.12 kWh/ton. Furthermore, the company's electrical energy consumption KPI target was successfully achieved following the implementation of the improvement.

1. Introduction

The Manufacturing industries are continuously required to improve their operational efficiency to remain sustainably competitive, particularly in terms of productivity, quality, and resource utilization [1], [2]. In the current era of industrial competition, manufacturing companies are expected not only to achieve high production output, but also to optimize the utilization of available resources efficiently and sustainably [3], [4]. One of the most critical resources in industrial operations is electrical energy, which significantly influences production costs, machine performance, and overall operational effectiveness. Therefore, improving energy efficiency has become an important strategic objective for manufacturing industries seeking to maintain long-term competitiveness and operational sustainability [5].

One of the primary challenges faced by manufacturing companies is the high level of electrical energy consumption in the production process. Inefficient use of electrical energy can increase operational costs and reduce the overall effectiveness of the production process. Electrical energy inefficiency may arise from several operational factors, including machine overloading, unstable material flow, ineffective production scheduling, suboptimal machine utilization, and excessive idle operation [2]. These conditions not only increase production costs but may also reduce equipment lifetime and negatively affect productivity performance. Therefore, evaluating production process performance is essential as a means of improving a company's operational efficiency [3].

PT Indofood Sukses Makmur Tbk - Bogasari Flour Mills Division is a wheat processing company that produces wheat flour as its primary product, along with by-products such as bran, pollard, and animal feed pellets. Pellet production is carried out in the Pelletizing Division, utilizing the residual outputs from the milling process as the main raw material [6]. The pellet production stages include raw material storage, the pressing process (pellet press), cooling, separation (separator), and transfer to storage silos. As one of the largest flour milling companies in Indonesia, maintaining operational efficiency within the Pelletizing Division is highly important because the

DOI: https://doi.org/10.25124/jrsi.v13i01.11176

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division contributes to the value-added utilization of by-products generated from the flour milling process. Efficient pellet production operations can directly support cost reduction, waste minimization, and production sustainability within the company [7].

Based on the operational performance evaluation of the Pelletizing Division during the period of July to December 2024, the company's Key Performance Indicator (KPI) target for the electrical energy consumption ratio per ton of pellet production had not been achieved. The established energy consumption target is 17.5 kWh/ton, whereas the actual consumption reached 18.705 kWh/ton. This condition indicates that the production process still experiences significant electrical energy inefficiency, which potentially increases operational expenses and decreases production effectiveness. Failure to achieve the established KPI target also reflects that existing operational controls and production resource utilization have not yet operated optimally.

Table 1. Presents the KPIs of the Pelletizing Division.

Objective	Target		2024 Achievements	Notes
Steam consumption ratio / ton of pellet production	Max 36.0	Kg/Ton	35.30	*Achieved*
Pellet moisture quality hit rare	Min 99.0	%	100	*Achieved*
Pellet hardness quality hit rare	Min 99.0	%	100	*Achieved*
Press machine capacity vs design capacity	Min 85.0	%	91.67	*Achieved*
Electrical energy consumption ratio / ton of pellet production	Max 17.5	kwh/Ton	18,705	*Not Achieved*

This condition indicates inefficient use of electrical energy in the pellet production process, directly contributing to increased operational costs. Preliminary analysis further revealed that the pressing process accounts for the largest share of electrical energy consumption among all production stages, contributing 81.23% of the total energy waste in the pelletizing process. The pressing process is considered a critical stage because it involves high mechanical loads and continuous machine operation, resulting in substantial electrical energy demand. Consequently, inefficiencies occurring at this stage significantly affect the overall energy performance of the pellet production system.

Table 2.
Stratification of Electrical Energy Waste by Production Stage

Tahapan Proses	Pemborosan (kwh)	Daya (Kw)	%	% Kum
Pressing	1.125.321	2216	81,23	81,23
Cooling	89.909	177	6,49	87,72
Silo Machine	74.670	147	5,39	93,11
Separator	51.258	101	3,70	96,81
Pellet Transfer	28.954	57	2,09	98,90
Magnet separator	15.239	30	1,10	100,00
Total	1.385.351	2728	100,00	

In addition to the high energy consumption, the pellet production process also exhibits productivity fluctuations influenced by workforce utilization, machine effectiveness, raw material usage, and worker overtime. The high levels of overtime and varying machine capacity effectiveness indicate that the production process has not been operating optimally. Furthermore, unstable productivity conditions may indicate the presence of operational inefficiencies caused by imbalances between production capacity, machine loading, and material flow continuity [7]. If these issues are not properly identified and controlled, they may continuously reduce productivity performance and increase energy consumption within the production process. Therefore, a productivity measurement method is needed that is capable of comprehensively evaluating production performance across multiple key indicators.

One method suitable for this purpose is the Objective Matrix (OMAX). The OMAX method is a productivity measurement approach that integrates multiple productivity ratios into a weighted scoring matrix, enabling a comprehensive assessment of production performance achievement [8]. This method also helps companies identify productivity indicators with low performance, which can then serve as the basis for formulating process improvement recommendations. The advantage of the OMAX method lies in its ability to combine several productivity criteria simultaneously, such as labor productivity, machine productivity, raw material efficiency, and energy efficiency, into an integrated performance evaluation system. In addition, the weighted scoring system enables management to prioritize improvement efforts based on the relative importance of each productivity indicator.

Several previous studies have demonstrated the effectiveness of the OMAX method in evaluating productivity across various industrial sectors. Mukti et al. [9] showed that the OMAX method can effectively identify the root causes of productivity decline in a production department. Wahyuni and Setiawan [10] further demonstrated that low performance in electrical energy utilization is one of the primary factors affecting production process efficiency. Other studies also reported that OMAX is capable of supporting managerial decision-making by identifying dominant productivity factors and evaluating improvement effectiveness quantitatively. Existing studies have predominantly applied the OMAX method to evaluate overall productivity performance in manufacturing environments. However, limited attention has been given to the integration of productivity measurement and electrical energy efficiency assessment in pellet production systems, particularly at the pressing stage where energy consumption is highly concentrated. In addition, empirical evidence regarding the effectiveness of process-layout-based improvements in reducing energy intensity through OMAX evaluation remains scarce. Therefore, this study addresses this gap by examining the relationship between productivity performance, energy efficiency, and process improvement within an industrial pelletizing operation. In particular, research addressing energy inefficiency in the pressing stage as the dominant energy-consuming process has not been widely discussed. This condition indicates the existence of a research gap that requires further investigation.

Table 3.
Comparative Analysis of Previous Studies and Research Gap Identification

Author	Industry	Method	Main Finding	Limitation
Mukti et al.	Manufacturing	OMAX	Productivity evaluation	No energy focus
Wahyuni & Setiawan	Manufacturing	OMAX	Productivity measurement	No improvement validation
Nathania & Desrianty	SCM	OMAX	Performance measurement	No energy efficiency analysis
This Study	Pelletizing	OMAX + Fishbone + Before-After	Energy efficiency improvement	-

Although the Objective Matrix (OMAX) method has been widely applied for productivity evaluation in manufacturing industries, its application for identifying electrical energy inefficiency in pellet production systems remains limited. Previous studies generally focused on overall productivity measurement without specifically integrating energy efficiency indicators as the primary performance objective. This study contributes by combining OMAX-based productivity assessment with energy-efficiency-oriented root cause analysis and corrective action evaluation in a pelletizing process. Furthermore, the study demonstrates how productivity measurement can be used not only as a monitoring tool but also as a decision-support mechanism for identifying dominant energy waste sources and evaluating the effectiveness of operational improvements in industrial practice.

Based on the issues described above, this study aims to evaluate the pellet production process performance in the Pelletizing Division using the Objective Matrix (OMAX) method, in order to determine the productivity level of the production process and identify the factors influencing low electrical energy efficiency in the pressing process. Furthermore, this study also seeks to analyze the root causes of energy inefficiency and evaluate the effectiveness of corrective actions implemented to improve electrical energy performance in the pelletizing process [7]. The findings of this study are expected to serve as a basis for formulating improvement recommendations to enhance operational efficiency in the pellet production process. This study contributes academically by extending the application of the OMAX method toward energy-efficiency-oriented productivity evaluation in pellet production systems. Practically, the study provides an industrial case demonstrating how productivity measurement, root cause analysis, and process-layout improvement can be integrated to reduce electrical energy consumption and improve operational performance. The findings may serve as a reference for manufacturing companies facing similar energy-efficiency challenges in machine-intensive production processes.

Unlike simulation-based studies, this research utilizes actual operational data and evaluates a real improvement implementation within an industrial production environment. Therefore, the findings provide practical evidence regarding the effectiveness of productivity measurement and energy-efficiency improvement in manufacturing operations.

2. Research methods

This study employs a quantitative approach using the Objective Matrix (OMAX) method to measure the productivity level of the pellet production process in the Pelletizing Division of Bogasari Flour Mills. The OMAX method was selected because it is capable of integrating multiple productivity ratios into a single weighted scoring matrix, thereby providing a comprehensive picture of production performance [11]. The quantitative approach was chosen because the study relies on numerical operational data to evaluate productivity performance and electrical energy efficiency objectively. Furthermore, the OMAX method enables the integration of several operational indicators into a unified productivity evaluation framework, allowing management to identify dominant factors influencing productivity decline and energy inefficiency [11].

The study was conducted over the period of July to December 2024, with the research object being the pellet production process on the Pelletizing Line. The research scope focused specifically on the pressing process because preliminary evaluation results indicated that this stage contributed the largest proportion of electrical energy consumption within the overall pellet production system. The research stages consisted of problem identification, data collection, productivity measurement using the OMAX method, root cause analysis, implementation of corrective actions, and comparative performance evaluation before and after improvement implementation.

2.1 Problem Identification

The problem identification stage was conducted to understand the actual conditions of the pellet production process in the Pelletizing Division. Identification was based on evaluation of the company's Key Performance Indicators (KPIs), direct field observation, and analysis of operational production data for the period of July to December 2024. At this stage, the researchers also analyzed operational constraints related to machine performance, material flow continuity, workforce utilization, and electrical energy consumption patterns occurring during the production process. Evaluation results confirmed that the electrical energy consumption ratio per ton of pellet production had not met the company's target of 17.5 kWh/ton, with actual consumption reaching 18.705 kWh/ton. This condition indicates the presence of electrical energy waste in the pellet production process. In addition, field observation revealed an imbalance in the reprocess material flow within the pellet press area, which caused an excessive workload on the pressing machines leading to increased energy consumption, higher workforce overtime, and reduced production process effectiveness. The identification stage also indicated that several operational activities were still performed without standardized control of machine loading and material distribution, resulting in unstable productivity achievement and fluctuating energy efficiency performance.

2.2 Data Collection

The data used in this study consist of primary and secondary data. Primary data were obtained through direct observation of pellet production activities, interviews with production operators and supervisors, and documentation of operational conditions in the Pelletizing Division. Observations were conducted to understand the production flow, machine utilization conditions, and reprocess material handling activities in the production area. Interviews were conducted to obtain information regarding operational constraints, machine operating conditions, production scheduling practices, and production control procedures implemented by the company. Secondary data were obtained from the company's operational reports for the period of July to December 2024, covering pellet production output, electrical energy consumption, raw material usage, workforce numbers, overtime hours, and press machine capacity effectiveness. These data served as the basis for calculating productivity ratios using the OMAX method [11]. The collected data were validated through cross-checking between operational reports and field observations to ensure data consistency and reliability before being processed in the productivity analysis stage.

Table 4.
Research Data Sources

Data Types	Data source
Production Output	Production Reports
Electrical Energy Consumption	Energy Usage Data
Raw Material Usage	Production Data
Workforce Count	Production Manpower Data
Overtime Hours	Production Overtime Data
Machine Performance Effectiveness	Production Performance Data

2.3 Data Processing (OMAX Method)

Data processing was performed using the Objective Matrix (OMAX) method to measure the productivity level of the pellet production process. The processing stages began with the determination of productivity criteria based on indicators that influence production performance. The productivity ratios used in this study are: labor productivity ratio (R1), effective working hours ratio (R2), raw material productivity ratio (R3), machine productivity ratio (R4), and electrical energy efficiency ratio (R5). These productivity ratios were selected because they represent the primary operational resources affecting production performance, namely labor, time utilization, raw material efficiency, machine effectiveness, and electrical energy consumption.

The productivity ratios used in this study are calculated as follows:

2.3.1 Labor Productivity Ratio (R1)

$$\frac{TotalProductionOutput(ton)}{NumberofWorkers(person)}$$

This ratio measures the ability of the workforce to produce pellet output during the production period. Higher ratio values indicate better labor productivity performance.

2.3.2 Effective Working Hours Ratio (R2)

$$\frac{TotalProductionOutput(ton)}{EffectiveWorkingHours(hour)}$$

This ratio evaluates the effectiveness of working time utilization during production operations.

2.3.3 Raw Material Productivity Ratio (R3)

$$\frac{TotalProductionOutput(ton)}{RawMaterialUsed(ton)}$$

This ratio reflects the efficiency of converting raw materials into finished pellet products.

2.3.4 Machine Productivity Ratio (R4)

$$\frac{TotalProductionOutput(ton)}{MachineOperatingHours(hour)}$$

This ratio measures the production capability of machines during operating hours and indicates the effectiveness of machine utilization.

2.3.5 Electrical Energy Efficiency Ratio (R5)

$$\frac{TotalProductionOutput(ton)}{ElectricalEnergyConsumed(kWh)}$$

This ratio represents the efficiency of electrical energy utilization in producing pellet output. Higher ratio values indicate better electrical energy efficiency performance.

The actual values of each productivity ratio were then calculated using the operational data collected during the study period. The ratio values were subsequently converted into OMAX performance levels on a scale of 0 to 10, based on the company's target values, historical averages, and actual achievements. Performance levels were determined using three anchor points: Level 10 represents the best recorded performance, Level 3 represents the average performance, and Level 0 represents the worst recorded performance. Intermediate levels were determined through linear interpolation.

2.3.6 Linear Interpolation for Performance Level

$$\text{Level(x)} = \text{Level(a)} + \frac{(\text{X} - \text{Value(a)})}{(\text{Value(b)} - \text{Value(a)})} \text{x}(\text{Level(b)} - \text{Level(a)})$$

where:
X : actual ratio value;
Value(a), Value(b) : lower and upper anchor values;
Level(a), Level(b) : corresponding lower and upper performance levels.

Linear interpolation was applied to determine intermediate performance levels between the established anchor points, enabling a more proportional and objective productivity scoring process.

2.3.7 *Total Productivity Score*

$$\text{Total Productivity} = \sum_{i=1}^{n} (\text{Level(i) x W(i)})$$

Where: Level(i) = performance level of ratio i; W(i) = weight of ratio i (in decimal); n = number of productivity criteria.

2.3.8 *Productivity Index (PI)*

$$\text{PI} = \frac{\text{Total Productivity(t)} - \text{Total Productivity(t}-1)}{\text{Total Productivity(t}-1)} \text{ x } 100\%$$

The next stage involved assigning weights to each productivity ratio according to its relative importance to the pellet production process. Weights were used to determine the contribution of each ratio to the company's total productivity score, calculated by multiplying each ratio's performance level by its corresponding weight.

The productivity measurement results were then analyzed using a traffic light system to classify productivity performance into three categories: green (good), yellow (moderate), and red (poor). Productivity ratios with the lowest performance were subsequently analyzed further to identify the root causes and develop process improvement recommendations. Furthermore, root cause analysis was conducted using the fishbone (Ishikawa) diagram approach based on the 4M+1E factors, consisting of Man, Machine, Method, Material, and Environment. This analysis was intended to identify the dominant factors contributing to low electrical energy efficiency in the pressing process and to formulate appropriate corrective actions for performance improvement.

3. Results and Discussion

3.1 *Problem Identification*

Productivity measurement in the pelletizing pressing process was conducted using the Objective Matrix (OMAX) method based on operational data from July to December 2024. Five productivity criteria were established: labor productivity (R1), effective working hours productivity (R2), raw material productivity (R3), machine productivity (R4), and electrical energy efficiency (R5). The actual ratio values for each period are presented in Table 4. The labor productivity ratio (R1) showed an average of 1,358.91 ton/person, with the highest value occurring in December and the lowest in November. The effective working hours ratio (R2) averaged 59.65 ton/hour, also exhibiting its peak in December. Raw material productivity (R3) remained constant at 0.97 ton/ton throughout all observation periods, indicating highly stable and efficient material conversion. Machine productivity (R4) averaged 8.82 ton/hour, while the electrical energy efficiency ratio (R5) averaged 0.0533 ton/kWh and showed a notable decline in December signaling a reduction in energy efficiency during the high-production month.

Table 5.
Actual Productivity Ratio Values (July–December 2024)

Ratio	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24
R1 – Labor Productivity (ton/person)	1,308.22	1,451.78	1,176.67	1,307.67	1,133.33	1,775.78
R2 – Effective Working Hours (ton/hour)	54.51	62.82	55.16	54.49	51.00	79.91
R3 – Raw Material Productivity (ton/ton)	0.97	0.97	0.97	0.97	0.97	0.97
R4 – Machine Productivity (ton/hour)	8.33	8.99	9.01	8.68	8.32	9.60
R5 – Energy Efficiency (ton/kWh)	0.0539	0.0533	0.0542	0.0541	0.0541	0.0499

The fluctuation in productivity ratios indicates that the pellet production process had not yet achieved stable operational performance during the observation period. The increase in labor productivity and machine productivity in December 2024 was primarily influenced by higher production output and increased machine utilization. However, this improvement was not accompanied by efficient electrical energy utilization, as indicated by the decline in the R5 ratio. This condition suggests that production capacity expansion without proper control of machine loading and material flow can lead to higher electrical energy consumption per unit output [11]. In addition, the consistently stable raw material productivity ratio (R3) demonstrates that the raw material conversion process was relatively efficient and did not significantly contribute to productivity decline. Therefore, the main operational issue was more closely associated with machine performance effectiveness and electrical energy utilization in the pressing process.

3.2 *OMAX Scale Level Determination*

The OMAX scoring scale ranges from 0 to 10, with three anchor points: Level 10 (best performance), Level 3 (average performance), and Level 0 (worst performance). Intermediate levels were obtained through linear interpolation. The consolidated scale levels for all five ratios are summarized in Table 5.

Table 6.
Recapitulation of OMAX Scale Levels per Rasio

Level	R1 (ton/person)	R2 (ton/hour)	R3 (ton/ton)	R4 (ton/hour)	R5 (ton/kWh)
10	1,775.78	79.91	0.97	9.60	0.0542
9	1,716.23	77.02	0.97	9.49	0.0541
8	1,656.67	74.12	0.97	9.38	0.0539
7	1,597.12	71.23	0.97	9.27	0.0538
6	1,537.57	68.33	0.97	9.16	0.0537
5	1,478.01	65.44	0.97	9.04	0.0535
4	1,418.46	62.54	0.97	8.93	0.0534
3	1,358.91	59.65	0.97	8.82	0.0532
2	1,283.72	56.77	0.97	8.65	0.0521
1	1,208.52	53.88	0.97	8.49	0.0510
0	1,133.33	51.00	0.97	8.32	0.0499

Source: Authors' processed data, 2026

The determination of OMAX scale levels enables each productivity indicator to be evaluated proportionally according to its operational performance. By converting actual ratio values into standardized performance levels, the OMAX method facilitates comparative analysis among productivity indicators despite differences in measurement units. The results indicate that the productivity indicators possessed different performance distributions throughout the observation period. The electrical energy efficiency ratio (R5) exhibited a relatively narrow numerical range but showed substantial differences in performance levels due to its high sensitivity to changes in energy consumption. Meanwhile, the raw material productivity ratio (R3) remained constant because the material conversion process operated under relatively stable production conditions. The use of linear interpolation also provided a more objective scoring mechanism because intermediate performance values could be determined proportionally between the best and worst operational conditions. Consequently, the OMAX evaluation process became more accurate in representing actual production performance conditions.

3.3 Weighting of Productivity Criteria

Each productivity ratio was assigned a weight reflecting its relative importance to the primary research problem, determined through expert judgement based on actual operational conditions. The energy efficiency ratio (R5) received the highest weight of 35% due to its direct relevance to the company's unmet KPI target of 17.5 kWh/ton. Machine productivity (R4) received 25%, raw material productivity (R3) 20%, effective working hours (R2) 15%, and labor productivity (R1) 5%. The full weight distribution is presented in Table 7.

The weighting process was conducted using expert judgment involving three experts from the Pelletizing Division, consisting of the Production Manager, Production Supervisor, and Senior Process Engineer, each having more than five years of experience in pellet production operations. The experts were asked to evaluate the relative importance of each productivity criterion based on its impact on operational performance and the company's strategic objectives. The final weights were determined through consensus discussions and validation against the company's key performance indicators. The electrical energy efficiency ratio (R5) received the highest weight (35%) because electrical energy consumption was the only KPI that failed to achieve the company's target during the observation period and represented the primary operational problem addressed in this study.

Table 7.
Productivity Criteria Weighting

No.	Productivity Criteria	Code	Weight (%)
1	Labor Productivity	R1	5
2	Effective Working Hours Productivity	R2	15
3	Raw Material Productivity	R3	20
4	Machine Productivity	R4	25
5	Electrical Energy Efficiency	R5	35
	Total		**100**

Source: Authors' processed data, 2026

The weighting results demonstrate that electrical energy efficiency was considered the most critical productivity criterion in this study. This prioritization was justified because electrical energy consumption represented the primary operational issue identified during the preliminary evaluation stage. Furthermore, electrical energy costs constitute a significant component of operational expenses in machine-intensive manufacturing industries. Machine productivity (R4) was assigned the second-highest weight because machine effectiveness directly influences production capacity, operational continuity, and electrical energy utilization. In contrast, labor productivity received the lowest weight because labor-related issues were considered less dominant compared to machine and energy-related operational problems.

3.4 OMAX Matrix and Productivity Index

The actual ratio values for each month were matched to the closest OMAX scale level, and contribution values were calculated by multiplying the level by its respective weight. The Productivity Index (PI) measures the percentage change in total productivity between consecutive periods:

$$PI = [(Total\ Productivity\ t - Total\ Productivity\ t{-}1) / Total\ Productivity\ t{-}1] \times 100\%$$

The complete OMAX matrix results are presented in Table 7. Note: December 2024 results (Total Productivity = 6.50; PI = +26.21%) are discussed in the text due to table width constraints.

Table 8.
Productivity Measurement Results Using the Objective Matrix (OMAX) Method for July–December 2024

Component	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24
Actual Level per Ratio (0–10)						
R1 – Labor Productivity	2	5	1	2	0	10
R2 – Effective Working Hours	1	4	1	1	0	10
R3 – Raw Material	10	10	0	10	10	10
R4 – Machine Productivity	0	5	5	2	0	10
R5 – Energy Efficiency	6	3	8	9	9	0
Contribution Value (Level × Weight)						
R1 (×5%)	0.10	0.25	0.05	0.10	0.00	0.50
R2 (×15%)	0.15	0.60	0.15	0.15	0.00	1.50
R3 (×20%)	2.00	2.00	0.00	2.00	2.00	2.00
R4 (×25%)	0.00	1.25	1.25	0.50	0.00	2.50
R5 (×35%)	2.10	1.05	2.80	3.15	3.15	0
Total Productivity	**4.35**	**5.15**	**4.25**	**5.90**	**5.15**	**6.50**
Productivity Index (%)	—	**+18.39%**	**−17.88%**	**+19.19%**	**−12.71%**	**+26,21%**

The results show that total productivity fluctuated throughout the observation period. The highest total productivity was achieved in December 2024 at 6.50, driven by maximum performance levels (Level 10) for R1, R2, R3, and R4. However, R5 dropped to Level 0 in this period due to energy consumption reaching 320,384 kWh, equivalent to 20.05 kWh/ton as a consequence of high production volume without adequate press machine load management. The lowest total productivity occurred in September 2024 at 4.95, primarily caused by R3 falling to Level 0, despite R5 achieving its best performance (Level 10) at 18.44 kWh/ton.

The OMAX results indicate that improvements in production output and machine productivity did not always correspond with improvements in electrical energy efficiency. This phenomenon demonstrates the existence of a trade-off relationship between production intensity and energy utilization efficiency within the pellet pressing process. When production volume increased significantly, machine operating loads also increased, leading to higher electrical energy consumption. The productivity fluctuations observed throughout the study period further indicate that operational performance was strongly influenced by variations in machine loading conditions, material flow stability, and production scheduling effectiveness [12]. In December 2024, although overall productivity reached its highest value, electrical energy efficiency deteriorated substantially. This finding suggests that production optimization efforts focused solely on output quantity may negatively affect energy performance if not supported by balanced operational control. Furthermore, the negative Productivity Index values observed in September and November indicate periods of declining operational performance. These declines were associated with unstable production conditions, lower machine effectiveness, and inefficient resource utilization. Therefore, productivity improvement efforts should not only focus on increasing production output but also on balancing machine utilization and electrical energy consumption.

3.5 *Analysis of Root Causes for Low Energy Efficiency*

Based on OMAX results, R5 (Electrical Energy Efficiency) with a weight of 35% was identified as the most critical indicator, exhibiting extreme level fluctuations (Level 0 to Level 10) over the observation period. The average actual energy consumption of 18.80 kWh/ton exceeded the company's KPI target of 17.5 kWh/ton across all periods. To identify root causes, a fishbone (Ishikawa) diagram was constructed using the 4M+1E approac covering Man, Method, Machine, Material, and Environment factors. The cause-effect analysis results are summarized in Table 9.

The fishbone diagram was employed as a qualitative root cause identification tool to systematically categorize factors contributing to electrical energy inefficiency. The prioritization of identified causes was based on operational records, field observations, and discussions with production personnel. Although the fishbone approach effectively supports problem identification, future studies may incorporate quantitative prioritization techniques such as Failure Mode and Effects Analysis (FMEA), Analytic Hierarchy Process (AHP), or DEMATEL to provide a more rigorous assessment of causal relationships and priority levels among improvement factors.

Table 9.
Root Cause Analysis of Low Energy Efficiency Using the 4M+1E Framework

Factor	Sub-factor	Cause	Effect	Level
Man	Operational Decision	Operator suboptimally determines running press machines vs actual material availability	Press machines idle; energy wasted without output	High
Man	Production Monitoring	Start-stop decisions not based on real-time data	Suboptimal machine utilization; kWh/ton increases	High
Method	Operational Procedure	Start-stop procedures not integrated with upstream flow (Milling & BPP)	Unplanned start-stop cycles increase motor restart energy loads	High
Method	Machine Utilization Standard	No automated minimum utilization threshold	Machines below 30% of design capacity; kWh/ton rises	Medium
Machine	Roll Shell Condition	Worn roll shell causes uneven gap with die	Motor at max ampere; output drops to ~8 ton/hr vs 10 ton/hr standard	High
Machine	Die Condition	Clogged die holes due to foreign material	Reduced pressing capacity; energy per ton increases	High
Machine	Feeder Control	Manual feeder restart after overcurrent is slow	Idle press operation wastes electrical energy	Medium
Machine	Metal Bin Flow	Product stacking disrupts material flow to press	Unstable press input; kWh/ton increases	Medium
Material	Starch Content	Actual starch at 32%, exceeding ≤27% standard	Higher motor load; feeder speed reduced; kWh/ton rises	High
Material	Silo Homogeneity	Reprocess pathway mixed with bran pollard pathway	Fluctuating starch content causes inconsistent pressing and energy waste	High
Environment	Ambient Temp.	Ambient temperature affects material conditioning in mixer	Non-optimal conditioning requires more energy during pressing	Low

Among the five factor categories, Material and Machine factors exhibited the highest influence levels. The most significant root cause was the mixing of the reprocess product pathway with the bran pollard pathway, causing the starch content of raw material to be high and fluctuating (actual: 32%, standard: ≤27%). This condition increased the motor load on the press machine, required a reduction in feeder speed, and ultimately raised energy consumption per ton of production [12]. Furthermore, worn roll shell components caused press output to drop from the design standard of 10 ton/hour to approximately 8 ton/hour, while clogged die holes further diminished pressing capacity.

The fishbone analysis results indicate that electrical energy inefficiency was not caused by a single operational factor, but rather by the interaction of multiple operational variables simultaneously [13]. Material-related problems significantly affected the pressing process because unstable starch content increased the resistance during pellet pressing operations, thereby increasing motor load and electrical energy demand. Machine-related factors also contributed substantially to energy inefficiency. Worn roll shells and clogged die holes reduced machine productivity and caused the press machines to operate under suboptimal conditions. Consequently, the machines consumed more electrical energy while producing lower output capacity. In addition, operational decision-making factors under the Man and Method categories also influenced production efficiency. The absence of real-time production monitoring and integrated start-stop operational procedures caused unnecessary machine idle conditions and repeated motor restarting activities, both of which increased electrical energy waste [14]. These findings confirm that improving electrical energy efficiency in the pellet pressing process requires a comprehensive operational improvement strategy involving material handling, machine maintenance, operational procedures, and production monitoring systems simultaneously.

The classification of root causes into High, Medium, and Low influence levels provides a practical basis for prioritizing improvement initiatives within the pelletizing process. Factors categorized as High influence were considered to have a direct and substantial impact on electrical energy consumption, machine loading conditions, and production effectiveness. In particular, material-related factors, such as excessive starch content and inadequate silo homogeneity, were closely associated with increased pressing resistance and unstable machine performance. Similarly, machine-related factors, including worn roll shells and clogged die holes, directly affected production capacity and energy utilization efficiency. Therefore, corrective actions should primarily focus on addressing these high-priority factors to achieve the greatest improvement in operational and energy performance.

3.6 Implementation of Improvement and Comparative Analysis

Several improvement alternatives were considered during the evaluation process, including machine maintenance enhancement, feeder automation, operator control improvement, and material-flow redesign. Based on technical feasibility, implementation cost, implementation time, and the identified root causes, the relayout of the reprocess material pathway was selected as the primary corrective action. This alternative directly addressed the dominant material-related causes identified in the fishbone analysis, particularly the inconsistency of starch content resulting from the mixing of reprocess material and bran pollard streams. Therefore, the relayout was considered the most practical and effective solution within the operational constraints of the company. Based on the root cause analysis, the primary corrective action implemented was the relayout of the reprocess product pathway directly to the by-product silo (Silo 603), physically separated from the bran pollard pathway. This improvement aimed to homogenize the raw material composition entering the press machines, thereby controlling starch content within the acceptable standard (≤27%). The relayout was completed in May 2024, and its measurable effects began from July 2025 onward. A comparison of energy consumption before and after the improvement is presented in Table 10.

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The results demonstrate a significant and consistent reduction in energy consumption across all months in 2025 compared to 2024. Average energy consumption decreased from 18.80 kWh/ton to 16.12 kWh/ton, a reduction of 2.68 kWh/ton (14.26%). This finding supports previous studies indicating that material-flow stabilization contributes significantly to reducing process energy intensity. A more homogeneous material composition reduces machine resistance during pressing operations, allowing the equipment to operate closer to its design capacity while consuming less energy per unit of output. Similar findings have been reported in manufacturing systems where process-flow optimization improved both operational stability and energy performance. Furthermore, the 2025 data shows a continuous downward trend, declining from 16.70 kWh/ton in July to 15.50 kWh/ton in November and December, well below the KPI target of 17.5 kWh/ton. A comprehensive summary of productivity performance before and after the improvement is presented in Table 11.

The implementation of the reprocess pathway relayout proved effective in simultaneously improving energy efficiency and overall productivity. Average total OMAX productivity increased by 4.70%, while the peak productivity reached 8.00 in October 2025 a 23.08% improvement over the 2024 peak. The consistent downward trend in energy consumption across all 2025 periods confirms that the improvement is sustainable and has not merely produced a short-term effect.

Table 10.
Comparison of Energy Efficiency and Energy Consumption Before and After Improvement

Period	Jul	Aug	Sep	Oct	Nov	Dec	Average
Before Improvement (2024)							
R5 – Energy Efficiency (ton/kWh)	0.05	0.05	0.05	0.05	0.05	0.04	0.0533
Energy Consumptio n (kWh/ton)	18.5	18.7	18.4	18.4	18.4	20.0	18.80
After Improvement (2025)							
R5 – Energy Efficiency (ton/kWh)	0.05	0.05	0.06	0.06	0.06	0.06	0.062
Energy Consumptio n (kWh/ton)	16.7	16.9	16.5	15.6	15.5	15.5	16.12

Table 11.
Summary of Productivity and Energy Performance Before and After Improvement

Indicator	2024 (Before)	2025 (After)	Change
Average OMAX Total Productivity	5.10	5.34	+0.24 (+4.70%)
Highest Total Productivity	6.50 (Dec-24)	8.00 (Oct-25)	+1.50 (+23.08%)
Average Energy Consumption (kWh/ton)	18.80	16.12	−2.68 (−14.26%)
Best Energy Consumption (kWh/ton)	18.44 (Sep-24)	15.50 (Nov & Dec-25)	−2.94 (−15.95%)
KPI Status (Target: 17.5 kWh/ton)	Not Achieved ✗	Achieved ✓	KPI Met

The improvement results demonstrate that controlling raw material homogeneity has a substantial impact on the electrical energy performance of the pellet pressing process. By separating the reprocess pathway from the bran pollard pathway, the company successfully stabilized starch content and reduced excessive machine loading conditions [6], [15]. Consequently, press machine operations became more stable and energy-efficient. In addition to improving electrical energy efficiency, the implemented corrective action also contributed positively to machine productivity and operational stability. Reduced machine overload conditions minimized unnecessary downtime and enabled the press machines to operate closer to their design capacity. The consistent achievement of electrical energy consumption values below the KPI target after improvement implementation confirms that the corrective action effectively addressed the primary operational problem identified during the initial evaluation stage [16]. Therefore, the proposed improvement can be considered a sustainable operational strategy for reducing energy intensity and improving productivity performance in pellet production systems [17], [18], [19].

Beyond operational and economic benefits, the reduction in electrical energy consumption also contributes to broader sustainability objectives. Lower energy intensity reduces the demand for electricity resources and indirectly supports the reduction of greenhouse gas emissions associated with power generation [20]. Therefore, the implemented improvement not only enhances productivity performance but also supports sustainable manufacturing practices by promoting more efficient resource utilization and reducing the environmental footprint of production activities.

4. Conclusion

This study evaluated the pressing process performance in the Pelletizing Division of PT ISM Bogasari Flour Mills Surabaya using the Objective Matrix (OMAX) method, complemented by fishbone diagram analysis and a before-after comparative evaluation of an implemented process improvement. The OMAX measurement results for the period of July to December 2024 revealed that overall productivity was fluctuating, with an average total productivity of 5.10. The highest total productivity was recorded in December 2024 at 6.50, while the lowest occurred in September 2024 at 4.25. Among the five criteria established, the electrical energy efficiency ratio (R5) carrying the highest weight of 35% was identified as the most critical indicator, exhibiting the most extreme level fluctuations (Level 0 to 10) across the observation period. The average actual energy consumption of 18.80 kWh/ton consistently exceeded the company's KPI target of 17.5 kWh/ton, confirming that energy efficiency was the primary performance gap throughout the baseline period.

Root cause analysis using a fishbone diagram with the 4M+1E approach identified ten contributing factors grouped into five categories. The Material and Machine categories carried the highest influence levels. The most significant root cause was the mixing of the reprocess product pathway with the bran pollard pathway, which caused the starch content of raw material to be high and fluctuating reaching an actual value of 32%, well above the standard threshold of ≤27%. This condition increased the motor load on the press machines and drove inefficient energy consumption per ton of production. Additionally, worn roll shell components and clogged die holes contributed to a decline in press machine output capacity from the design standard of 10 ton/hour to approximately 8 ton/hour. The implementation of a corrective action, namely the relayout of the reprocess product pathway directly to the by-product silo (Silo 603), physically separated from the bran pollard pathway proved effective in improving both energy efficiency and overall productivity. Following the improvement, average energy consumption during July to December 2025 decreased significantly from 18.80 kWh/ton to 16.12 kWh/ton, representing a reduction of 14.26% and successfully meeting the company's KPI target of 17.5 kWh/ton, which had previously remained unachieved. Furthermore, average total OMAX productivity increased from 5.10 to 5.34 (+4.70%), with peak productivity reaching 8.00 in October 2025 - a 23.08% improvement over the 2024 peak. The consistent downward trend in energy consumption, declining to 15.50 kWh/ton by November and December 2025, confirms that the improvement is sustainable rather than a short-term effect.

This study has several limitations. First, the root cause prioritization process was primarily based on fishbone analysis supported by operational observations and expert discussions, without employing quantitative prioritization methods such as Failure Mode and Effects Analysis (FMEA), Analytic Hierarchy Process (AHP), or DEMATEL. Second, the study was conducted within a single pelletizing production system at one manufacturing company, which may limit the generalizability of the findings to other industrial contexts. Therefore, future research may incorporate quantitative root cause prioritization techniques and investigate multiple production environments to improve the robustness and applicability of the results. Future studies may evaluate and compare additional improvement strategies, such as predictive maintenance programs, feeder automation systems, and energy management systems, to further enhance operational efficiency and electrical energy performance in pellet production processes.

From a theoretical perspective, this study demonstrates that the OMAX method can be effectively extended beyond conventional productivity measurement to support energy-efficiency evaluation in manufacturing operations. From a practical perspective, the study provides empirical evidence that process-layout improvements can significantly reduce electrical energy intensity while simultaneously improving productivity performance. These findings strengthen the role of productivity measurement as a decision-support tool for sustainable operational improvement.

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