ISSN : 1978-1431 print | 2527-4112 online

A Model for Enhancing the Environmental Performance by Integrating Lean and Green Productivity Concept: A Case Study of Food Production

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ARTICLE INFO

Article history
Received, July 22, 2023
Revised, November 11, 2023
Accepted, February 28, 2024
Available Online, February 29, 2024

Keywords
Environment Performance
Lean Green Productivity
Food Production
Value Stream Mapping

ABSTRACT

The increase in food production activities has led to a significant decline in the environmental quality, particularly affecting the surrounding river systems. This research addresses the need to identify and minimize various types of waste by integrating Lean and Green productivity concepts. The main objective is to reduce non-value-added (NVA) activities that contribute to both environmental degradation and inefficiencies in production. The study applies the Lean framework to identify seven types of waste in food production while also addressing green waste, such as excessive material use and energy consumption. Green Integration Value Stream Mapping (GIVSM) is utilized to assess the current state of value-added (VA) activities and to simulate improvements for future production systems. The initial analysis reveals a low VA of 1.5 hours due to inefficient customer information flow and prolonged loading times. Improvements are implemented by shifting the information system from a push to a pull strategy, significantly reducing production time and lowering both Lean and Green waste. The results demonstrate that integrating these concepts can enhance environmental performance and operational efficiency. This study provides valuable insights for food production companies seeking to balance productivity and sustainability.

1. Introduction

Sustainable development has increasingly become a focal point of research worldwide, including in Indonesia, driven by concerns over deteriorating environmental conditions, mainly due to manufacturing industry activities [1]. The rising demand for production has led to a corresponding decline in environmental performance. Previous studies have explored the Environmental Performance Index (EPI) in Indonesia's food industry, identifying various types of waste generated at different stages of the production process, such as resource utilization and material waste [2][3]. However, these studies were limited as they primarily focused on material waste, neglecting other inefficiencies such as transportation, overproduction, and defects—all categorized as waste in Lean

https://doi.org/10.22219/JTIUMM.Vol25.No1.83-96 http://ejournal.umm.ac.id/index.php/industri ti.jurnal@umm.ac.id

Please cite this article as: Wulandari, I. A. S., Hanun, N. R., & Cahyana, A. S. (2024). A Model for Enhancing the Environmental Performance by Integrating Lean and Green Productivity Concept: A Case Study of Food Production. Jurnal Teknik Industri, 25(1), 83–96. https://doi.org/10.22219/JTIUMM.Vol25.No1.83-96

Manufacturing (LM) [4]. These inefficiencies extend production times and increase energy consumption, potentially leading to higher carbon emissions.

Green Productivity (GP) has been previously applied to identify both desirable and undesirable outputs, with a focus on green waste, including energy consumption, water usage, and emissions related to environmental and social impacts [5][6][7]. However, GP does not comprehensively address the additional waste generated from overproduction, transportation, excessive movement, waiting times, and product defects, critical elements of LM [8]. Introduced by Taiichi Ohno, a Toyota engineer, LM has been widely adopted to enhance product quality, minimize costs, and reduce waste in production processes across industries [9][10]. Given these challenges, there is a need for an integrated approach that combines Lean and Green concepts to improve both operational efficiency and environmental sustainability.

The implementation of Lean Manufacturing (LM) on the production floor is often accompanied by the use of Value Stream Mapping (VSM), which serves to identify Value Added (VA) and Non-Value Added (NVA) activities [11]. Through applying LM, companies can enhance their competitiveness by increasing productivity and improving product quality [10]. Numerous studies have integrated Lean and Green paradigms with the dual objectives of optimizing production processes and enhancing environmental performance. For instance, Choudhary applied Lean and Green principles through VSM and Root Cause Analysis (RCA) to address issues related to inefficient packaging in Small and Medium Enterprises (SMEs) [11]. Additionally, the integration of Lean and Green has been utilized to monitor and optimize water resource usage in the Agri-Food industry by evaluating the volume of water consumption [12]. These studies demonstrate the potential of combining Lean and Green methodologies to improve operational efficiency and reduce environmental impact simultaneously.

While previous studies have explored various approaches to minimize waste in production processes and its environmental impact, they often fail to demonstrate concrete environmental testing results of these production activities. Most research has not provided empirical data on the environmental outcomes post-implementation. To address this gap, this study will present the results of laboratory environmental testing before implementing alternative solutions using Future Stream Mapping (FSM). Additionally, although several researchers have successfully engineered manufacturing systems, focusing on consumer demand through product distribution, these findings cannot be generalized across all manufacturing sectors. Many solutions have yet to be explicitly tailored to Small and Medium Enterprises (SMEs), especially in food production. In Indonesia, SMEs dominate the food production sector [13]. However, they often lack the necessary technological resources, knowledge, and government support to operate sustainably. As a result, these businesses do not fully adopt green manufacturing practices.

This study aims to bridge this gap by integrating Lean and Green manufacturing principles to identify waste systematically, reduce production time and costs, increase value-added activities, and enhance overall environmental performance [14][8]. By applying these concepts within the context of SME food production, this research contributes to both operational improvements and environmental sustainability, providing a scalable model for future applications in other sectors [15][16].

2. Methods

This research was conducted in the food production sector in Sidoarjo, Indonesia, using a random sampling method. A total of 40 food production SMEs were selected as the

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sample, ensuring a broad representation of the industry in the region. Data collection involved interviews and direct observation on the production floor. The interviews were conducted with key personnel from each SME, focusing on production processes, waste management practices, and environmental impacts. Additionally, water quality samples were taken from the vicinity of each SME, specifically from water sources near their operations. They were analyzed in a certified laboratory to assess the environmental impact of their activities.

Data on production waste were collected in two categories: Lean Waste and Green Waste. Lean waste includes inefficiencies related to overproduction, transportation, defects, and waiting times. At the same time, Green Waste refers to energy consumption, water usage, and emissions that impact the environment [17]. Waste identification was carried out using Root Cause Analysis (RCA), which was visualized through Ishikawa diagrams to trace the origins of each type of waste. The Material Balanced Diagram (MBD) was employed to map the movement and usage of resources within each SME to understand the material flows and inefficiencies further. The data analysis process began with the identification of waste types in the production processes of fast food sellers. Research methods by integrating Green Productivity and Lean Manufacturing concepts can be seen in Figure 1. The steps included:

1. Identifying the complete production process, from raw material acquisition to finished goods.
2. Mapping the production process using the Material Balanced Diagram (MBD) to visualize input and output at each production stage.
3. Classifying waste into Lean and Green categories based on observed inefficiencies and environmental impacts.
4. Collecting relevant data from production observations and laboratory testing of water samples.
5. Conducting a Root Cause Analysis (RCA) using Ishikawa diagrams to identify the primary causes of waste within the production system.
6. Formulating and proposing alternative solutions based on the findings in collaboration with environmental experts and representatives from the Service Office of Environment and Forestry (DLHK).

The proposed alternative solutions focused on reducing both Lean and Green waste, with suggestions tailored to the unique challenges faced by SMEs in the food production sector. The results of this analysis were used to develop actionable strategies for improving operational efficiency and reducing environmental impacts, which were then validated through expert interviews.

2.1 Process Production Identification

The first step in this study involved identifying waste within the food production process, particularly Lean waste, which includes seven categories: waiting/delay, overproduction, overprocessing, defects, unnecessary motion, excess inventory, and inefficient transportation [18]. These types of waste contribute to inefficiencies that increase production time, raise operational costs, and negatively impact productivity and the environment. By identifying these sources of waste, we aim to propose corrective actions that can improve environmental performance while enhancing overall productivity in the SMEs studied. This stage involved direct observation of the production floor, interviews with operators and managers, and a thorough review of production documentation to identify inefficiencies specific to each SME.

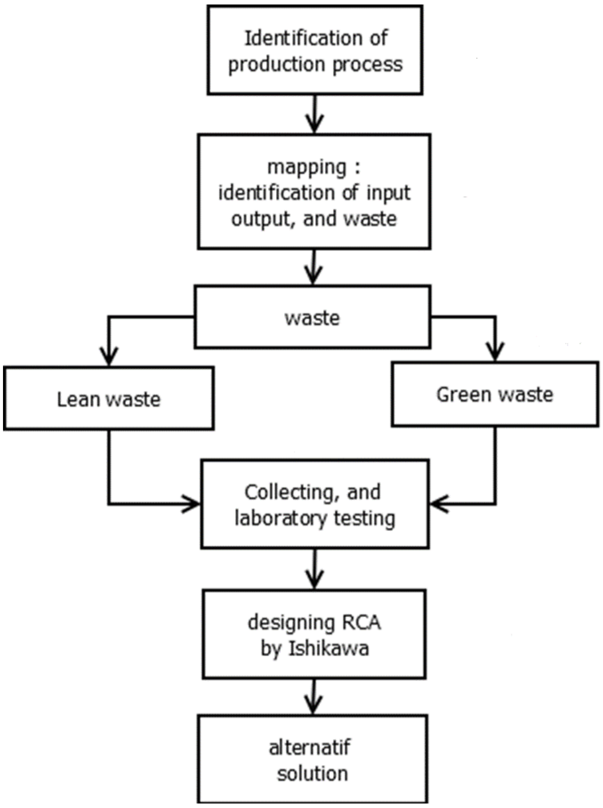

Figure 1. Research methods by integrating Green Productivity and Lean Manufacturing concepts

2.2 Mapping Process

The mapping process was conducted using Material Balanced Diagrams (MBD), which visually represent the flow of materials throughout the production process. The MBD allowed for the identification of both inputs and outputs at each production stage and waste generated in terms of both expected (value-added activities) and unexpected (non-value-added activities) materials. In this study, MBD was employed not as a mathematical model but as a graphical tool to provide a comprehensive overview of the production process [19]. By mapping the material flow, the study was able to pinpoint critical areas where inefficiencies occurred, especially in terms of material usage, energy consumption, and waste generation.

2.3 Waste Identification

Waste identification in this study was conducted with the goal of continuous improvement, focusing on eliminating inefficiencies and improving environmental sustainability. Techniques from Lean Manufacturing were employed to reduce cycle times, minimize non-value-added activities, streamline transportation, and optimize the use of raw materials [10, 16]. These techniques were complemented by Green manufacturing principles to address environmental concerns. By integrating Lean and Green approaches, the study focused on reducing waste and enhancing environmental and social responsibility [20, 21]. To achieve this, the research utilized Value Stream Mapping (VSM), which was vital in identifying both Lean and Green wastes and creating a more agile manufacturing process [8, 22]. The mapping allowed for the visualization of inefficiencies that contributed to waste and provided a clear framework for developing targeted solutions to reduce these inefficiencies.

2.4 Waste Collection and Testing

During this stage, seven types of waste are systematically collected using Lean and Green techniques, fostering synergy between these methodologies. The Environmental Performance Index (EPI) is calculated to assess the environmental impact of waste generated in production quantitatively. The formula used for calculating EPI is as Equation (1) and (2) [2]:

$$EPI = \sum_{i=1}^{k} W_i * P_i \tag{1}$$

$$P_i(\%) = \frac{\text{Quality standards (mg/l) - Result (mg/l)}}{\text{Quality standards}} \times 100\% \tag{2}$$

Where :
k = the number of parameter research
W_i = weight of research parameter
P_i = deviation or slack between standard and result

2.5 Root Cause Analysis with Ishikawa

This study uses the Ishikawa diagram to identify the root causes of waste generation and uses Root Cause Analysis (RCA) [17]. This analytical tool identifies underlying issues using the 8M indicators, encompassing Man, Machine, Method, Material, Measurement, Environment, Maintenance, and Management [23]. By mapping these factors, the research aims to pinpoint the critical causes contributing to waste generation.

2.6 Alternative Solution

Alternative solutions are developed through Value Stream Mapping (VSM), which integrates Lean and Green concepts [24]. This approach is further refined with Green Integration Value Stream Mapping (GIVSM), which assesses productivity and environmental performance. A comparative analysis of current and proposed conditions is presented at this stage. GIVSM focuses on quantifying value-added activities while considering Lean and Green manufacturing waste. By measuring and improving productivity alongside enhancing environmental performance, the study seeks to provide practical solutions for SMEs in the food production sector [25].

3. Results and Discussion

Fast food production encompasses several critical stages, from ordering and delivering raw materials to actual food production, customer order fulfillment, price negotiation, and, ultimately, the packing of finished products. As illustrated in Figure 2, the flow of production processes in the fast food industry is tightly integrated, with all activities taking place within the same location. This streamlined approach facilitates efficient management of resources. It minimizes delays between production steps, allowing quicker response times to customer demands. However, this model also necessitates thoroughly examining waste generated at each stage, which is critical for optimizing overall productivity and reducing environmental impact.

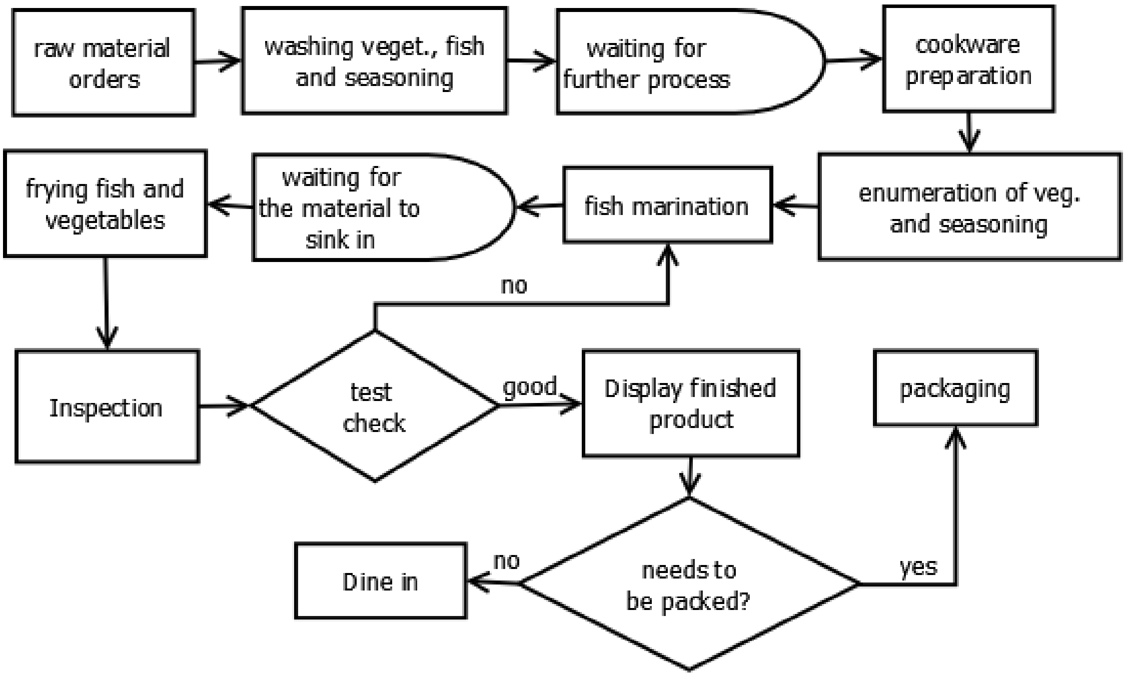

Figure 2. The flow of production processes at food production.

The identification of waste using the Material Balance Diagram (MBD), depicted in Figure 3, enables a precise calculation of inputs and outputs at each production stage. This diagrammatic representation facilitates the visualization of how raw materials are transformed into value-added products while highlighting the quantity of waste produced during the process. The analysis reveals that while the primary goal of production activities is to generate a final product, substantial amounts of waste are inevitably generated alongside. This underscores the importance of quantifying both productivity and waste to evaluate production operations' environmental, social, and economic impacts. Enhanced productivity should ideally lead to innovations that yield higher quality products, lower production costs, and the efficient allocation of materials towards creating more value-added offerings [26].

To achieve significant improvements in the production process, it is essential to identify and eliminate non-value-added activities that contribute to environmental degradation. It can be accomplished by integrating Lean Manufacturing principles throughout the production chain, as summarized in Table 1. The identification of waste sources extends from upstream activities, such as raw material sourcing, to downstream processes, such as packaging and delivery [4]. Furthermore, developing a Green Integration Value Stream Mapping (GIVSM) model, presented in Figure 4, provides a comprehensive view of existing conditions and highlights areas where waste reduction strategies can be implemented. This model serves as a foundation for formulating targeted interventions to minimize waste while enhancing overall production efficiency.

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ISSN : 1978-1431 print | 2527-4112 online

Table 1. Lean waste in production houses

No	Waste type	Description	Outcomes
1.	Excessive production	The number of products exceeds the demand, the portion is too much	Storage, wasted electrical energy, wasted raw materials
2.	Inventory	The number of products exceeds demand, not sold out	Storage, electrical energy, wasted raw materials
3.	Waiting	Waiting for consumers to come, electricity for excessive heating	Time, energy, and wasted electricity
4.	Motion	Waiting for consumers to come, wasted energy, non ergonomic movement	Delay, work fatigue, defect
5.	Transportation	Move, carry, cancellation	Wasted time, waiting, work fatigue
6.	Disability	Exceeding the production time, the taste doesn't match	Energy, time, wasted material
7.	Process is too long	Production time exceeds standard	Defect product

Input	Proses	Output	Waste	Produktivitas
fuel (1 liter/day)	purchase raw materials	Fish and vegetables (10 kg fish + 3 kg veg.)	Air pollution	1
water, detergent, salt (5 liter/hari) rice, fish (10 kg/day) Veg. 3 kg	Washing rice, veg., rice, and spices (10 kg fish + 3 kg veg.)	vegetable, fish, and spices (10 kg fish + 2,8 kg vegetables)	water +sand + fat (5 liter water + fat+ 0,2 kg veg.)	1
Veg. and fish (10 kg fish + 2,8 kg vegetables)	chopped vegetables and fish (10 kg fish + 2,8 kg vegetables)	Veg. and fish (10 kg fish + 2,7 kg vegetables)	Vegetables chunk (100 gr)	1
spices + water+ fish (0,5 liter + 10 kg)	Fish marinade (0,5 liter + 10 kg)	fish (10 kg)	Water marinade + fat (0,48 liter)	1
Cooking oil (4 liter) + 3 kg LPG + spices + fish 10 kg	Fish fryer (10 kg)	Ready Fish (8 kg)	Cooking oil + emission + fried flakes (0,50 liter)	0,7
Cooking oil (0,5 liter) + LPG 3 kg + spices + veg. 2,7kg	Cooking vegetable with spices	Ready vegetables	Emission, oil waste	1
Electricity	Display finished product	Finished product	Emission	
Rice box + plastic 1	Packaging	Finished product	paper + plastic + food waste	1
water+ Finished product + cutlery (50 liter)	Dine in	Finished product	Waste water + fat + food waste (50 liter)	1

Figure 3. Material Balanced Diagram of the fast food production process

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Additionally, Table 3 presents an assessment of raw material usage and its subsequent impact on the environment. This analysis reveals critical insights into how resource consumption aligns with sustainability objectives. By understanding the specific environmental consequences of raw material use, strategies can be devised to mitigate negative impacts while optimizing production processes. Through this integrated approach, the research aims to improve productivity. It emphasizes the importance of sustainable practices within the fast-food production sector. The findings underscore the potential for combining Lean and Green methodologies to create a more resilient and environmentally conscious production system that addresses operational efficiency and ecological responsibility.

The presence of lean waste significantly affects environmental performance. Therefore, this study also identified Green waste (see Table 2) during the production process and collected samples of liquid waste generated from these activities for laboratory analysis. Waste identification and sampling were conducted at three locations in the Sidoarjo district, each featuring numerous operational fast-food vendors.

Table 2. Green Waste Productions house

No	Waste type	Description	Outcomes
1.	Energy	Use labor, redundant power tools	Waiting for customers, electric food warmer, waste
2.	Waste	Pay labor for waste treatment	Wastewater from washing fish and vegetables, cooking waste
3	Water	Excessive, repeated use of water and its cleaning costs	Wash water contains fat and soap
4	Materials	The use of the material is ineffective and cannot be reused.	Defect products, leftovers, cooking waste
5	Emission	Waste or pollution from production activities that are not filtered	Washing water, frying fumes, cooking waste
6	Transportation	Moving material out of reach	Emission
7	Biodiversity	Have a direct impact on the ecosystem quickly	Wash water contains fat and soap

Green waste in fast food production facilities is primarily represented by wastewater, which constitutes the highest volume of waste. Water quality measurements are conducted using 12 criteria, including turbidity, pH, dissolved oxygen (DO) [27], heavy metal cadmium (Cd) [28], nitrate [29], temperature, total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), total coliform, and E. coli [30], as well as oils and fats [2]. The results of laboratory tests from three sampling locations in Sidoarjo are presented in Table 3 below.

The results of the waste sample tests are compared with standard values set by the Environmental Service to determine the deviation (slack) between actual conditions and the established standards (Pi). The calculated Environmental Performance Index (EPI) is then compared with the water quality standards established by the Dinas Lingkungan Hidup dan Kehutanan (DLHK), as shown in Table 3. These calculations demonstrate that insufficient innovations have been implemented to prevent the degradation of environmental performance in production activities. The outcomes of this combined

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approach can be assessed by integrating the Green concept with Lean principles to identify non-value-added activities (see Table 4).

Table 3. EPI Calculation

No	Parameter	Wi	Results (mg/l)	Quality standards (mg/l)	Pi	EPI
1.	Temperature	2,75	28	Dev 3	0	0
2.	TDS	3,25	1177	1000	-17,7%	-57,53
3	TSS	3	399	40	-897,5%	-2692,50
4	Oil and Fat	5,5	2871	1	$-2{,}87 \times 10^5$ %	-1.578.500
5	Turbidity	6,75	50	25	-100%	-675
6	pH	3,75	8	6,5 – 8,5	0	0
7	DO	4	0	6	-100%	0
8	COD	2,25	2079	10	$-2{,}07 \times 10^{-4}$ %	-46552
9	Nitrat	1,75	24	10	-140%	-245
10	Heavy metal CD	2,25	0,0041	0,03	0	0
11	Total Coliform	5,75	1958×10^2	50	-3%	0
12	E-Coli	6,25	340	0		0

Table 4. Integration Waste Production House

No	Waste type	Outcomes	Green Waste
1.	Excessive production	Storage, wasted electrical energy, wasted raw materials, waste	Energy (electrical), material, waste, biodiversity
2.	Inventory	Storage, wasted electrical energy, wasted raw materials	Energy (electrical), material
3	Waiting	Time, effort and wastage of electricity	Energy (electrical)
4	Motion	Time and wasted energy	Transportation
5	Transportation	Time wasted, waiting for work exhaustion	Transportation
6	Disability	Energy, time, wasted material	Energy, material, waste
7	Process is to long	Disability waste	Energy, material

In this study, to identify the causes of increased waste generated from production activities, a combination of Green and Lean concepts is employed using the Root Cause Analysis (RCA) technique, which is illustrated through an Ishikawa diagram [10] as shown in Figure 4.

Based on the Environmental Performance Index (EPI) calculations for waste produced by food production in Sidoarjo and the results from the DLH laboratory tests, four informants participated in this study and provided recommendations for waste prevention measures. These measures include the following methods for treating Liquid waste flowing into rivers: (1) Filtering production wastewater using sand filtration, (2) Implementing water purification techniques utilizing cell voltage or voltaic cells, and (3) Employing electrodialysis techniques.

This research aims to minimize waste from production activities by integrating Lean and Green waste concepts as part of the continuous improvement process in food

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production. Consequently, a Green Integration Value Stream Mapping (GIVSM) diagram will illustrate the current conditions and the improvements achieved (Figure 5).

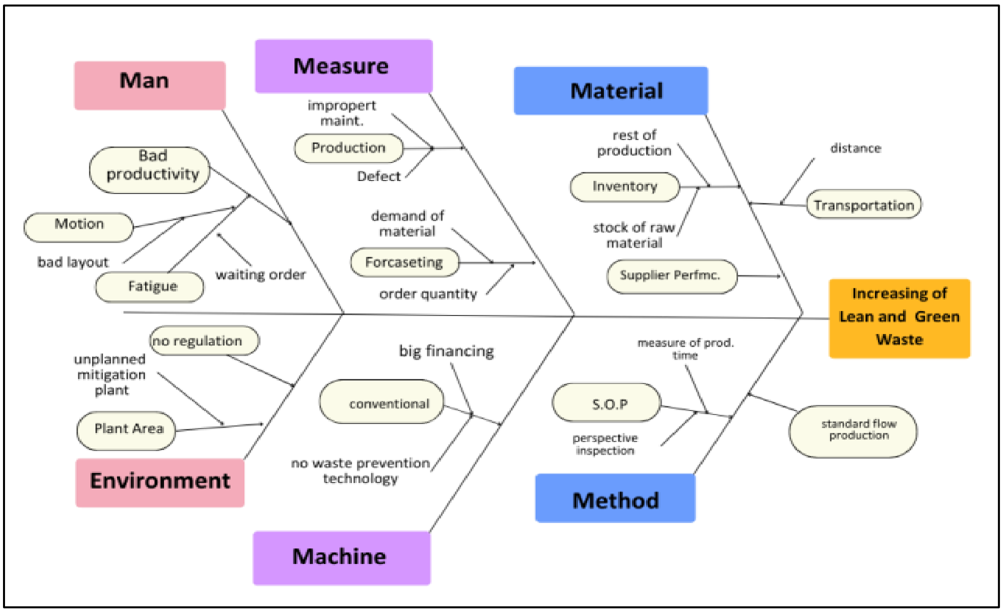

Figure 4. Ishikawa diagram cause of Lean and Green waste

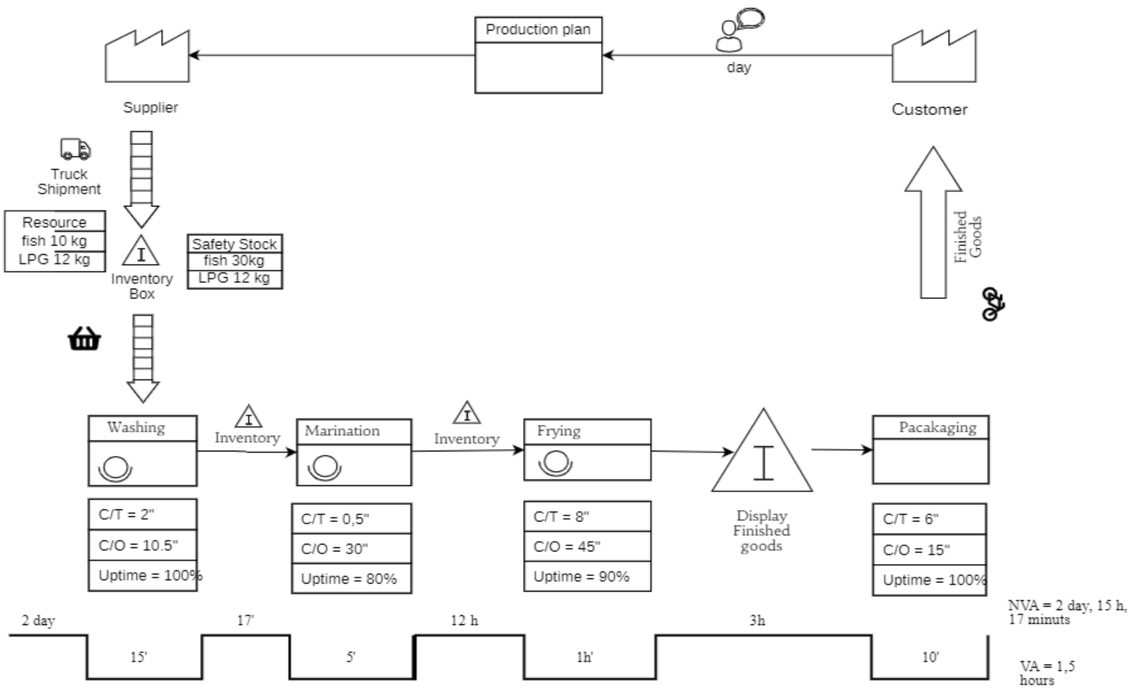

Figure 5. Current map

In the production process described above, it was found that the value-added activity (VA) accounted for only 2.4%. It indicates significant waiting time during the production process, primarily due to insufficient information or customer requests. To address this issue, improvements to the information system are necessary, such as shifting from a push-based to a pull-based approach for customer information. This transformation can be interpreted as adapting the production process to be driven by prior sales data or by implementing an online ordering system that allows customers to place orders before arriving at the sales location. Additionally, offering pre-order sales opportunities can help minimize time, energy, and materials consumed by the seller, thereby reducing inventory levels and delays that also lead to unnecessary electrical energy consumption.

The future improvements illustrated in Figure 6 represent the fish production system enhancements based on current conditions. These enhancements involve minimizing waiting times and inventory by consolidating nearly identical activities. As a result, customer service efficiency is increased, and excessive electrical energy usage is reduced. Implementing applications such as Shopee Food or other e-procurement platforms is recommended to optimize customer service. These tools enable precise recording of sales transactions, providing reliable data for future raw material consumption and minimizing excess inventory and energy consumption. E-procurement is considered highly effective in reducing carbon emissions associated with resource consumption.

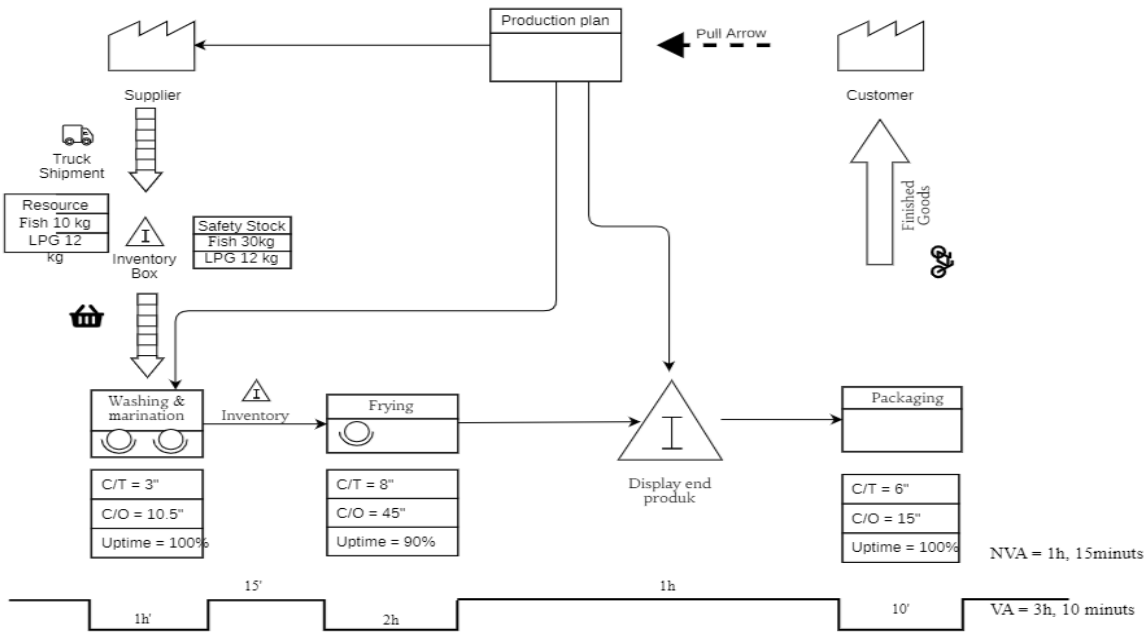

Figure 6. Future map

4. Conclusion

This research successfully integrated Lean and Green concepts to minimize waste in resource utilization within the food production sector. Laboratory test results from various locations revealed significantly poor water quality, indicating that preventive measures to avoid direct waste disposal into the environment are still inadequate. Although the direct material usage was calculated, the uncertainty in sales led to excessive energy consumption. The implementation of Green Integration Value Stream Mapping (GIVSM) demonstrated reduced time and resource consumption by decreasing order waiting times and adopting an Order strategy. However, this study has some limitations. While various alternatives were proposed to mitigate environmental damage, an ideal solution was not selected due to the complex challenges of implementing Lean and Green concepts, particularly in Indonesia. Significant barriers remain, including regulatory issues, limited technological advancement, customer reluctance towards sustainable practices, and low competitive pressure for green initiatives. Government support for such transformations is minimal, hindering progress in this area. For future research, it is recommended that tailored strategies be developed that address these barriers and promote the adoption of lean and green practices among food production SMEs in Indonesia. Investigating the role of government policies and support systems in facilitating this transition could also yield valuable insights. Furthermore, exploring the impact of consumer behavior on sustainability initiatives can help identify effective ways to engage customers in adopting greener practices.

Declarations

Author contribution: We declare that both authors contributed equally to this paper and approved the final paper.
Funding statement: No funding was received for this work.
Conflict of interest: The authors declare no conflict of interest.
Additional information: No additional information is available for this paper.

Acknowledgments

The research team would like to thank profusely Allah SWT, my parents, DRPM of UMSIDA, Majelis Dikti Litbang PP Muhammadiyah, experts, and students who helped until this research was completed. Hopefully the results of this research can provide benefits, information, and become a reference for improvement and development in subsequent research.

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Please cite this article as: Wulandari, I. A. S., Hanun, N. R., & Cahyana, A. S. (2024). A Model for Enhancing the Environmental Performance by Integrating Lean and Green Productivity Concept: A Case Study of Food Production. Jurnal Teknik Industri, 25(1), 83–96. https://doi.org/10.22219/JTIUMM.Vol25.No1.83-96