Supply chain green productivity improvement for sugar industry

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Abstract. The sugar industry has a vital role in meeting domestic demands; therefore, it is crucial to increase productivity and supply chain efficiency. Productivity improvement should not only focus on economic efficiency but also the environmental impact called the principle of green productivity. This paper aimed to discuss the potential implementation of green productivity improvement activities and determine the level of green productivity that has been achieved in the supply chain of the sugar industry. The analysis began with supply chain configuration analysis, analysis of seven waste sources with Green Value Stream Mapping (GVSM), and inference of the green productivity level with Fuzzy rule-based. The results of the supply chain analysis show that two activities required to be analyzed for productivity, namely the sugarcane cultivation and the sugar milling processing division. The green productivity index in the current state of plantation supply chain activity was 0.90 and processing was 0.61. Green productivity improvement with good housekeeping and efficiency resulted in a GPI of 1.81 for plantation supply chain activities and 2.30 for processing. The fuzzy inference shows an increase in green productivity in the supply chain processing activities from a bad label to normal.

Keywords: Fuzzy, Green productivity index, GVSM, Sugarcane, Sugar Industry

1. Introduction
The sugar industry is a business process that transforms sugarcane into sugar through specific and complex processes. In Indonesia, the sugar industry plays an important role in ensuring sugar availability for both communities and industries that contribute to the Gross Domestic Product (GDP). The Indonesian sugar industry faces obstacles to improving productivity. As stated by Rusono et al. [1], now, the Indonesian sugar industries able to produce a higher number of products than before. Productivity and efficiency are the main problems in the sugar industry that must be solved to maintain the sustainability and competitive advantage [2,3].

The main business activities in the sugar industry are sugarcane cultivation, milling, sales, and distribution. In sugarcane cultivation and harvesting, sugarcane production decreases up to 3.58% a year [1,4]. In milling activities, the sugar industry suffers inefficiency due to raw material quality, machinery condition, maintenance, and revitalization [5]. These problems must be solved, and further analysis is
needed to formulate strategies to improve supply chain productivity and competitive advantage. The green productivity concept has an opportunity to solved the problems through situational analysis, controlling, and improving the industry’s productivity performance [6].

Supply chain green productivity improvement requires a comprehensive approach because of its multi-stakeholders and multi-sector nature. The sugar industry has a robust connection between upstream and downstream stakeholders, which may support cooperation in improving performance and productivity. Productivity improvement in the supply chain has to perceive environmental impact considering the sugar industry exploits natural resources. Considering the environmental impact in managing productivity is known as green productivity [7], which facilitates the realization of industrial sustainability.

The green productivity implementation in the supply chain is focused on reducing water, energy, natural resources, emission, and waste [8]. Besides, it also helps increase industrial productivity, achieves revenue efficiently, and obtain environmental industry image. In the sugar industry, the stakeholder has to focus on this concept as an opportunity to improve productivity, perform in raw material conversion, and produce a high value-added product to share at the market.

This research aimed to analyse the sugar industry supply chain, formulate the green productivity improvement of the sugar industry, and define a green productivity inference system for the sugar industry. Green productivity is implemented by analysing the Wills concept of seven categories of green waste and formulating a strategy to increase productivity by considering environmental aspects [9]. To performed a robust assessment, this research proposed a Fuzzy Inference System (FIS) model to assess the green productivity performance of the sugar industry. The research scope is limited to the upstream of the supply chain at the sugarcane plantation and the downstream supply chain at the mill.

This paper is divided into four sections. This section delivers an introduction to research motivation and objectives. The next sections are the research method, result & discussion, and conclusion & recommendation. At the method section, the research process is described, and the model of green productivity assessment using the fuzzy system is explained. At the result & discussion section, results and the potential improvement of the green productivity in the sugar industry’s supply chain are presented. Finally, at the conclusion & recommendation, the research objective is answered, and potential further research is provided.

2. Methods

2.1. Research procedure and flow chart
Green productivity improvement in the supply chain of sugar industry requires an identification of supply chain configuration. This research focused on activities in sugarcane plantation and mill that will be described comprehensively. In each supply chain section, seven waste categories were analysed for the current situation as are defined by Wills [9]. The result of the current situation of the seven waste categories were described in the current state - Green Value Stream Mapping (GVSM) and define the index value of green productivity performance. Further, a potential improvement of the green productivity was syntheses based on current state GVSM, formulate improvement strategy, simulate the result, and describe at the future state GVSM. Finally, at the future state GVSM, the green productivity index (GPI) was assessed and compared to the current state GPI. The GPI was inferred using the Fuzzy Inference System and was modelled into a friendly user interface for the decision-maker. A complete stage of the research is depicted in figure 1.

2.2. Data analysis

2.2.1. Supply chain configuration analysis
Supply chain configuration analysis was the first stage in designing an improvement strategy of green productivity. The supply chain configuration was analyzed descriptively based on the field observation and literature review. The sugar industry supply chain identification stage is a synthesis of its stakeholders, supply chain mechanisms, and business process activities. The supply chain configuration and business flow also describe in this stage.
2.2.2. Seven waste analysis
Wills defined seven potential waste in the industry, including waste of energy, water, transportation, garbage, material, emission, and biodiversity [9]. Meaningless activity and material in the industry may be categorized as a waste that may affect productivity. All performance value of the seven waste was described into a value chain, known as Value Stream Mapping (VSM), which map the information flow of the material and potential waste in producing a high-value product [10]. Further, GVSM is not only focusing on economic advantage but also in minimizing environmental impact.

2.2.3. Green productivity index calculation and improvement
Green productivity index (GPI) is a measurement system of two different dimensions, which are environmental protection and productivity improvement [6]. The improvement strategy is formulated to increase the GPI. The strategy is adopted from the seven wastes categories at the GVSM and defines activities that potentially reduce production loss. Hur et al. [7] formulated a GPI as a ratio between system productivity and its impact on the environment due to specific activities. Productivity which also defines as an economic indicator is defined as a ratio between selling price (SP) and production cost (PC), while environmental impact indicator is organized by gaseous waste generations (GW), water consumption (WC), solid wastes generation (SW), and pollution level at the plantation (PP). To
determine the environmental impact, each aspect of GW, WC, SW, and PP are weighted (w), which
obtained from the literature. Weighted values of GW, WC, SW, and PP were referred to Marimin et al.
[11] that $w_{GW} = 0.375; w_{WC} = 0.25; w_{SW} = 0.125; w_{PP} = 0.25$. Mathematically, GPI is defined
at the equation 1.

\[
\text{Green Productivity Index (GPI)} = \frac{\text{Selling Price}}{\text{Production Cost}} \times \left( w_{GW} \times GW \right) + \left( w_{WC} \times WC \right) + \left( w_{SW} \times SW \right) + \left( w_{PP} \times PP \right)
\]

\[ (1) \]

2.2.4. Inference model for Green Productivity Performance Using Fuzzy Inference System
This research proposed a Fuzzy Inference System (FIS) to infers the green productivity of a supply chain
using linguistic labels. GPI assessment faces uncertainty and ambiguous factors that are required expert
inference to define the performance, which makes a fuzzy approach is appropriate for this case. The FIS
framework for GPI assessment requires fuzzy input, fuzzification, rule-based development,
defuzzification, and crisp output. The framework of Fuzzy Inference System is presented at figure 2.

![Figure 2. General FIS Framework](image)

As defined at the GPI formula, the input of the FIS assessment was an economic indicator and
environmental impact indicator, while the output is green productivity performance. This model is
designed to improve and monitor the sugar industry’s productivity using FIS. In general, the membership
function of the fuzzy system for GPI assessment referred to Hendra et al. [10] with some modifications.
Indicator’s membership function of the economic indicator (IE) and environment impact indicator (IL)
was classified into bad, normal, and good, which are described in figure 3(a) and 3(b), respectively. As
the output, GPI performance membership function was divided into five stages, namely very bad, bad,
normal, good, and very good as shown in figure 3(c).

To infer the green productivity assessment using the fuzzy system, it needs a fuzzy rule-based
formulation based on the membership function and the number of input variables. According to the
number of input variables and membership functions, this case required nine rules to infer green
productivity based on economic and environmental impact indicators. Formulating rules in this research
referred to the Phillis et al. [12]. The rules are described below.

1. If (EconomicIndicator (IE) is Good) and (EnvironmentIndicator(IL) is Bad) then (GPI is Bad)
2. If (EconomicIndicator (IE) is Good) and (EnvironmentIndicator(IL) is Normal) then (GPI is Bad)
3. If (EconomicIndicator (IE) is Good) and (EnvironmentIndicator(IL) is Good) then (GPI is VeryGood)
4. If (EconomicIndicator (IE) is Normal) and (EnvironmentIndicator(IL) is Bad) then (GPI is Bad)
5. If (EconomicIndicator (IE) is Normal) and (EnvironmentIndicator(IL) is Normal) then (GPI is Normal)
6. If (EconomicIndicator (IE) is Normal) and (EnvironmentIndicator(IL) is Good) then (GPI is Bad)
7. If (EconomicIndicator (IE) is Bad) and (EnvironmentIndicator(IL) is Bad) then (GPI is VeryBad)
8. If (EconomicIndicator (IE) is Bad) and (EnvironmentIndicator(IL) is Normal) then (GPI is Bad)
9. If (EconomicIndicator (IE) is Bad) and (EnvironmentIndicator(IL) is Good) then (GPI is Bad)
3. Result and discussions

3.1. Configuration of sugar industry supply chain

Supply chains are generally defined as the flow activity of materials, information, and cash from upstream to downstream actors, with a series of constraints and activities to meet consumer demand. In the case of the supply chain of sugar industry, Neves et al. [13] describe that the supply chain activities of the sugarcane industry can be divided into two types. First, supply chain activities whose raw materials come from company-owned plantations and second from smallholder sugarcane farmers. It also occurred in Indonesia, namely the fulfillment of sugarcane from the plantation with Cultivation Right (Hak Guna Usaha), which is widely found in West Java Province and from smallholder farmers, which are mostly found in East Java. In general, the supply chain mechanism for the sugar industry is presented in figure 4.
3.2. Analysis of current seven sources of waste generation

Wills [9] modified the concept of waste in Lean Manufacturing as an activity that did not produce an added value into material waste that was not needed in the Green Productivity concept. Wastes in Green Productivity (GP) are described in the green value stream mapping by grouping them into seven types of waste, namely energy, water consumption, materials, garbage, transportation, emissions, and biodiversity.

The energy is the utilization of electricity, energy, equipment, electronics, machinery, building equipment, and includes lighting and security needs. The water consumption is an attempt to minimize consumption from a spring or a water company and is expected to utilize recycled water or rainwater. Material is defined as the consumption of the entire input raw material to produce output in the form of the final product. Garbage is the overall by-product of production activities as a result of the application of materials and inefficiencies that are sought to be minimized or eliminated. Transportation or movement in green productivity needs to be considered because it can increase production costs. Emissions contribute to the increase in air pollution, which is calculated by the amount of kg CO₂ eq by multiplying the usage of electricity and diesel waste into the number of emissions. The conversion factor for the use of electricity into emissions is 0.891 kg/KWh, while diesel fuel is 2.6413 kg/L.

The analysis of the seven waste sources was carried out on the sugarcane cultivation and milling following the analysis of the supply chain configuration of the sugarcane industry. The seven sources of waste generation were analyzed in each supply chain activity on the plantation and factory, then depicted in the GVSM diagram. The result of the analysis of seven sources of waste generation in supply chain activities on plantations is presented in figure 5, and for the production activities in figure 6.

3.2.1. Current green productivity index of cultivation supply chain activities

The GPI was calculated based on equation 1 in the current state GVSM. The GPI is determined by two indicators, namely economic indicators and environmental indicators. Analysis of the economic indicators on the supply chain activities of the plantation cultivation was based on land (ha) calculation showed that the input cost required was Rp37,150,000/ha land, and the income received by farmers was Rp412,896,00/ha land. Therefore, the economic indicator of supply chain activity in plantation cultivation was 1.11.
Environmental indicators of supply chain cultivation activities on plantations with sugarcane output base of 800 Ku/ha Land were 0.007 Ku waste gas (GW); 2.54 Ku Water Consumption (WC); 0.23 Ku solid waste (SW); and 2.3 plantation waste (land) (PP) generators. Thus, the results of the analysis of environmental indicators on supply chain activities in plantations based on equation 2 are:

\[
\text{Environmental Impact} = 0.375 \, GW + 0.25 \, WC + 0.125 \, SW + 0.25 \, PP \\
= 0.375 \times 0.007 + 0.25 \times 2.54 + 0.125 \times 0.23 + 0.25 \times 2.3 \\
= 1.24
\]

(2)

Therefore, the green productivity index of the current state plantations supply chain activity is

\[
\text{Green productivity index of plantation supply chain activity} = \frac{1.11}{1.24} = 0.90
\]

(3)
Figure 6. Current State GVSM for Sugar Milling in Sugar Industry’s Supply Chain
3.2.2. Current green productivity index of sugar processing supply chain activities

Analysis of economic indicators in the supply chain activity of the processing found that the raw material input was 3,000 TCD, with an average yield of 6.5%. It will produce 195 tons of sugar per day. The sugar auction price was Rp11,500/kg. Therefore, the revenue of the Sugar Factory can be calculated. The economic indicator can be determined by comparing the company's revenues and costs. The economic indicator in the processing supply chain activity was 1.25.

Analysis of environmental indicators in the supply chain activity on the processing was based on a calculation of 3000 TCD. It was found that there was 3.3 Ku waste gas (GW); 1.5 Ku water consumption (WC); 2.23 Ku solid waste (SW); and 1.5 Ku plantation waste (land) (PP). Thus, the results of the analysis of environmental indicators on supply chain activities on plantations are as follow:

\[
\text{Environmental Impact} = 0.375 \times 3.3 + 0.25 \times 1.5 + 0.125 \times 2.23 + 0.25 \times 0
\]

\[
= 1.89
\]

Therefore, the green productivity index of the current state plantations supply chain activity is as follow:

\[
\text{Green productivity index of processing supply chain activity} = \frac{1.15}{1.89} = 0.61
\]

3.3. Green productivity improvement for future GVSM

Efforts to increase green productivity in the sugar agroindustry supply chain were carried out through scenarios design. This scenario design was obtained from Marimin et al. [6]. Green productivity improvement in supply chain cultivation activities was performed by (1) material substitution and utilization of waste from the cultivation process, (2) partial substitution of the application of pesticides with vegetable pesticides, and (3) fertilizer substitution with organic and biological fertilizers, and (4) dismissal sugar cane more than two times ratoon. Efforts to increase green productivity in processing supply chain activities were carried out by (1) optimizing the production process, (2) controlling the characteristics of raw materials, (3) using auxiliary materials, (4) reusing water, (5) utilizing blotong as boiler fuel briquettes, and (6) Utilization of bagasse as particleboard and nano-silica.

The focus of green productivity improvement on the cultivation supply chain activities is to minimize solid waste, garbage, excessive water consumption, and soil pollution on plantations. Solid waste can be caused by the excessive application of additives in the plantation, making the soil saturated. Vegetable pesticides and biological fertilizer can be used to minimize the impact of soil saturation and waste generation. The leaf clients can be utilized as a natural fertilizer or as compost to minimize production costs and the application of chemicals. Ratooning is needed to increase the productivity of plantations on each hectare of land. Ratooning up to twice in one season will only reduce productivity. Improvements in the plantation can also be performed by developing the seedlings at the plantation, so there is no need to go to the nursery hall. This effort can minimize the risks and emissions that can be generated during seedling transportation to the plantation.

Increasing green productivity in the supply chain activities of sugarcane processing is achieved by minimizing the environmental impact of gas and solid waste and minimizing production activities that produce emissions and waste. Santoso and Nugraheini [14] suggest the application of heat exchangers in the plant to minimize gas waste and emissions. The application of heat exchangers require investment, but it can minimize the impact of gas waste, reduce environmental impact indicators and emissions. Efforts to minimize solid waste can be achieved by utilizing blotong (filter cake or filter press mud) into briquettes for the boiler's fuel [14]. Blotong is a solid waste from sugar production produced in the refining process but still has potential as a fuel. Blotong utilization minimizes production costs for fuel.

Current state GVSM shows that there is an extensive water consumption during the production process and can potentially produce liquid waste. An efficient approach to minimize this liquid waste is to reuse process water and liquid waste into the production process. Liquid waste must be treated until it meets the criteria to be reused. Wastewater treatment can be performed by utilizing Dissolved Air Floatation (DAF) to reduce the oil content and other additives until it meets the criteria for reuse.

After the improvement and increase in green productivity was carried out based on the efforts that have been stated above, an analysis of the increased productivity was carried out and described in the
GVSM future state. The GVSM future states in the cultivation and processing supply chain activities are presented in figure 7 and figure 8. The efforts to increase green productivity provide benefits to the company's GPI. The calculation of the future state green productivity index based on the results of efforts to increase green productivity and future state GVSM are as follow:

Green productivity index of sugarcane plantation supply chain activity $= \frac{1.56}{0.86} = 1.81 \ (6)$

Green productivity index of sugar processing and milling supply chain activity $= \frac{3.08}{1.33} = 2.30 \ (7)$

![Value Stream Map](image-url)

**Figure 7.** Future State Value Stream Mapping for Sugarcane Plantation and Cultivation
Figure 8. Future State GVSM for Sugar Processing Activity
3.4. Inference model of Green Productivity Index for sugar industry

The inference model of GPI was conducted by fuzzy rule-based, which the membership function of economic, environmental, and parameter indicators of green productivity is obtained from Hendra [10]. The initial stage of the inference model is to formulate the membership function into computer software to produce a combination of rules. This model produces nine fuzzy rules to inference and to monitor the sugar industry productivity performance, which has been stated at the method. A friendly user interface is arranged to facilitate users in determining the level of GPI achieved by the sugar industry. This interface is following the membership function that has been modeled in the fuzzy inference system. This system may determine the level of sugar industry productivity by inputting the values of economic indicators and environmental indicators. A friendly user interface model for determining the level of GPI is presented in Figure 9, while GPI calculation using this system are presented in table 1.

| Condition | Supply chain sections | Economic indicator | Environment indicator | Level of Green Productivity Index |
|-----------|-----------------------|--------------------|------------------------|-----------------------------------|
| Current state | Plantation | 1.11 | 1.24 | Normal |
| | Processing | 1.15 | 1.89 | Bad |
| Future state | Plantation | 1.56 | 0.86 | Normal |
| | Processing | 3.08 | 1.33 | Good |

Figure 9. A Friendly User Interface for Determining the Level of Green Productivity Index

Based on table 1, there is an increased GPI in the supply chain activities of sugarcane plantation to normal with a higher score than the current situation. For the processing supply chain activity, it increases from normal to good. Therefore, the efforts to increase green productivity suggested in this study can increase company productivity without ignoring environmental impacts. These efforts have been verified and validated for further implementation.
4. Conclusions and recommendations

The sugar industry’s supply chain involves smallholder farmer or plantation/cultivation section, mill for sugar processing, and distributor. Throughout the supply chain activities, wastes generation has potentially occurred, which affects green productivity performance. Analysis of efforts to increase green productivity shows that the waste in the cultivation and the processing of the supply chain of the sugarcane industry can be minimized and described in the future state of GVSM. This research summarized the improvement activity of the supply chain productivity, involve material substitution and utilization of waste, pesticides substitution, fertilizer substitution with organic ones, improve the ratoon, optimizing the production process, controlling raw materials quality, using auxiliary materials, reusing water, and re-utilizing blotong and bagasse. The green productivity index can be increased to 1.81 in plantation activities and 2.30 in the processing supply chain activities. Fuzzy inference reveals that there is an increase in the GPI of sugarcane plantation and processing supply chain activities of the sugar industry. This research has succeeded to formulate strategies for improving the sugar industry’s productivity and design a user-friendly interface for monitoring the performance. This result may adopt for the real world to easily control the green productivity improvement of the supply chain.

This research has been successfully formulated and simulated the improvement strategy in improving the green productivity index. For further research, it requires participatory and action research to validate the strategy into the real world.

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