Comparative assessment of green ball-manufacturing alternatives using Green Productivity Index (GPI)

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Abstract. This paper compares three alternatives of green ball-manufacturing to replace existing ball-manufacturing. Using Green Productivity Index (GPI), alternatives were evaluated on their total productivity to its environmental pressure. Productivities were measured as their selling price per production cost, while environmental pressures were determined as their seven green-waste analysis through the manufacturing. The result showed that alternative 3 has the highest GPI which is combination of solid waste and water waste utilization.

1. Introduction
Concept of sustainable development established at Rio-Summit 1992 has been committed by countries and companies. However, companies still assume that eco-friendly manufacturing conceals burden costs. As productivity has become company’s most-achieved goal, Green Productivity (GP) offers profitable concept on eco-friendly manufacturing. The concept focuses on reducing raw-material, energy and water consumption as reducing waste, pollutant and emission at the same moment. Green Productivity Index (GPI) states ratio of productivity to its environmental impact [1]. Through this index, manufacturer can control their environment impact and improving their productivity at once.

A ball manufacturing company produces soccer ball from natural rubber formula, butyl rubber, black carbon and PVC which have high potency of CO2 emission [2, 3]. As high-emission potency of material consumed, its manufacturing releases harmful chemicals and requires great energy and water consumption. In a target of 1,200,000 units of all types of balls in a year, it could be predicted extraordinary energy and water consumed, emissions, and garbage consequences of the process.

Encouraged by advantages of GP implementations, this study analysed three alternatives of manufacturing processes by measuring alternative’s GPI then compared to existing’s GPI. Specifically, productivities were measured as their selling price per its material cost while environmental impacts were measured based on seven green-wastes. The comparison helps company in deciding the most eco-friendly manufacturing process without lowering the productivity achieved.

2. Material and Methods
2.1. Green Productivity Index (GPI)
GPI is quantitative form of GP concept as ratio of productivity to its environmental impact and stated as in equation 1 and 2 [1, 4]:

\[
\text{GPI} = \frac{\text{Productivity}}{\text{Environmental Impact}}
\]  

(1)
Productivity is a ratio of selling price to production cost, while environmental impact is all substances that give burdens to the environment revealed by every product's manufacturing process. It is indicated by seven green-waste and stated as Solid Waste Generation (SWG), Gaseous Waste Generation (GWG), and Water Consumption (WC). \( W_1, W_2, \) and \( W_3 \) are weights of those environmental indicators referred to Environmental Sustainability Index 2005 which is 0.17, 0.5, and 0.33 respectively [4].

The measurement process are in three steps and showed as figure 1 [4]. Steps are conceptualization, value driver development and relating value drivers. Conceptualization and value driver development steps determine economic and environmental indicators through their drivers in all stages of manufacturing process. Relating value drivers step relates all drivers into productivity and environmental impact drivers.

\[
\text{GPI} = \frac{\text{Selling Price/Production Cost}}{W_1 \cdot \text{SWG} + W_2 \cdot \text{GWG} + W_3 \cdot \text{WC}}
\]

**Figure 1.** Steps in GPI measurement developed by [4]

### 2.2 Soccer ball manufacturing process and alternatives conditions

Soccer ball manufacturing process consist of 9 processes that are mixing, cutting and press, bladder, winding, carcass, grinding, cutting and printing, laminating, and finishing. It involves 17 machines that consume 1909 KWh energy and 550 liters of water per day, 284 kg of raw materials and chemical substances.

In this comparison assessment, alternative 1 is a condition of reducing solid waste by reusing garbage or remaining material as complement to other types of products. Alternative 2 is a condition of reducing water consumption by reusing the remaining water of water test process for cooler water in mixing machines. Alternative 3 is a combination of those to alternatives. These 3 alternatives are also calculated for GPI to be compared to existing conditions.

### 2.3 LCI (Life Cycle Inventory)

LCI is a step used in Life Cycle Analysis (LCA) that collects and compiles quantitative data of environmental impact throughout product’s life cycle [5]. Since GP is performed inside the manufacturing process, in this study, LCI was done by identified seven green-wastes through all stages of manufacturing process. Seven green-wastes are seven wastes modification for environmental sources of waste generations that are energy, water, material, garbage, emission, transportation and biodiversity [6].
Table 1 listed seven green-wastes of soccer ball manufacturing in one month period that produces 48000 units.

### Table 1. Seven green-wastes of soccer ball manufacturing in 1 month period

| Green Waste | Process Flow | Total |
|-------------|--------------|-------|
|             | Mixing       | Cutting & Press | Bladder | Winding | Carcass | Grinding | Cutting & printing | Laminate | Finishing |       |
| Energy (KWh)| 16277        | 6544              | 34      | 52      | 99      | 32      | 21                  | 604      | 11       | 23453   |
| Water(Liter)| 0            | 0                 | 5250    | 1030    | 0       | 0       | 0                   | 0        | 0        | 0       |
| Material (Kg)| 0         | 0                 | 0       | 0       | 0       | 0       | 0                   | 0        | 0        | 0       |
| Garbage(Kg) | 0            | 219               | 111     | 42      | 0       | 368     | 11974               | 0        | 0        | 12714   |
| CO2 Potential Emission (KgCO2) | 13445 | 5381 | 177 | 26 | 82 | 26 | 17 | 499 | 9 | 19662 |
| Transportation | 0      | 0                 | 0       | 0       | 0       | 0       | 0                   | 0        | 0        | 0       |
| Biodiversity | 0            | 0                 | 0       | 0       | 0       | 0       | 0                   | 0        | 0        | 0       |

Using the same identification of seven green-wastes, compiled total seven green-wastes of existing, alternative 1,2, and 3 conditions are listed in table 2.

### Table 2. Total seven green-wastes of existing, alternative 1, 2, and 3 conditions

| Seven green-wastes | Existing | Alternative 1 | Alternative 2 | Alternative 3 |
|--------------------|----------|---------------|---------------|---------------|
| Energy (KWh)       | 23453    | 23453         | 23453         | 23453         |
| Water(Liter)       | 11550    | 11550         | 10752         | 10752         |
| Material (Kg)      | 0        | 0             | 0             | 0             |
| Garbage(Kg)        | 12714    | 12526         | 12714         | 12526         |
| CO2 Potential Emission (KgCO2) | 19662 | 19411 | 19662 | 19411 |
| Transportation      | 0        | 0             | 0             | 0             |
| Biodiversity        | 0        | 0             | 0             | 0             |

3. The comparison assessment
Comparison assessment began with productivity measurement of existing, alternative 1,2, and 3 conditions. Followed by environmental impact measurement, GPI then calculated and compared for all conditions. Every stages of measurement are explained in below subsections.

3.1 Productivity measurement
In this study, productivity is quantified as stated in equation 1 that is selling price per production cost. For selling price of 100,000 rupiahs/unit and production cost of 41,251 rupiahs/unit, in one month period of 48,000 units production, the productivity is quantified as 2.42 as stated in equation 3.

\[
\text{Productivity} = \frac{\text{selling price}}{\text{production cost}} = \frac{(48000 \times 100000)}{(48000 \times 41251)} = 2.4241
\]  

This calculation is applied for existing condition, alternative 1, 2 and 3 whereas alternatives were proposed for modified process that assumed to affect only in environmental impact.

3.2 Environmental impact measurement
Referred to table 1 and equation 2, environmental impact is measured for existing, alternative 1, 2 , and 3 conditions.
   a. GWG, measured as CO2 potential emissions for 48000 units is 19662.04 Kg CO2
b. WC, measured as water consumed for 48000 units. Since density of water is 1 kg/liter, it results 11550 Kg.

c. SWG, measured as garbage of manufacturing process for 48000 units is 12713.704 Kg

At the same calculation process, table 3 listed calculation of environmental impact for alternative 1, 2 and 3.

| Conditions     | GWG (Kg CO2) | WC (Kg) | SWG (Kg)   |
|----------------|-------------|--------|------------|
| Existing       | 19662.04    | 11550  | 12713.704  |
| Alternative 1  | 19411       | 11550  | 12526      |
| Alternative 2  | 19279       | 10752  | 12714      |
| Alternative 3  | 19411       | 10752  | 12526      |

3.3 GPI calculations

GPI is calculated based on equation 1. Table 4 listed the results in all conditions. It shows that alternative 1 has lowest GPI and alternative 3 has highest GPI. Being the highest GPI, alternative 3 becomes the best manufacturing process with comparative degree of existing condition 1.027. It means that alternative 3 has increased GPI up to 1.027 of existing conditions.

Table 4 also shows that for the same productivity, alternative 3 has lowest total environmental impact. This means manufacturer can reduce environmental impact without lowering the productivity.

| Conditions     | Environmental Impact | Productivity | GPI    |
|----------------|----------------------|--------------|--------|
| Existing       | 15.800               | 2.424        | 0.1534 |
| Alternative 1  | 15.643               | 2.424        | 0.1550 |
| Alternative 2  | 15.534               | 2.424        | 0.1561 |
| Alternative 3  | 15.377               | 2.424        | 0.158  |

4. Conclusion

This study compares GPI of soccer ball manufacturing process in existing, alternative 1, 2, and 3 conditions. As listed in table 4, this comparison assessment resulted in 0.1534, 0.1550, 0.561, and 0.1580 for existing, alternative 1, 2, and 3 conditions respectively.

The comparison also showed that alternative-3 condition has the highest GPI which means that it is the best alternative in achieving green manufacturing. Alternative-3 is a modification of two conditions. First, garbage or residues from bladder process are used for other types of products, and second, remaining water from water test process is used for cooling machine at mixing process.

These results also proves that reducing material consumption by re-using materials for other process gives significant difference in environmental impact without lowering the productivity [1].

5. References

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