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Performance Measurement Based on the Green Manufacturing Concept with Organization for Economic Co-operation and Development Indicators

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Abstract

When a country builds factories and industries, it helps the country grow and become better. It can create more jobs and make things run faster. But sometimes, these factories can make the water and water dirty. Therefore, it is necessary to measure company performance based on the concept of green manufacturing. The indicators used in measuring company performance are green manufacturing indicators based on the Organization for Economic Co-operation and Development (OECD). In the research results, out of 18 indicators, 5 indicators were found to be unfulfilled, these indicators are the intensity of water pollution at the process stage, energy consumption in using products at the output stage, and greenhouse gas emissions in using products at the output stages. With 13 indicators that are in line with the concept of green manufacturing, the performance of PT. XYZ related to the concept of green manufacturing is included in the Advance category.

Introduction

When a country builds factories and industries, it helps that country grow and become better. This can create more jobs and make things move faster. But sometimes, these factories can make the air and water dirty. One of the big problems is how to handle all the waste produced by the factory. People around the world are working to create regulations and guidelines to make factories use less energy, produce less waste, and be more environmentally friendly (Prestianto & Kusdiartini, 2023; Nainggolan et al., 2023). This is due to increasing pollution and waste, limited and decreasing natural resources, and the impact of global warming. The topic of green manufacturing emerged in the early 1990s, and was driven by human concern for the environment. Green manufacturing has a variety of similar words, such as clean production or environmentally friendly practices (Setyaningsih et al., 2019; Florida, 1996). Green manufacturing is the creation of manufactured products that use materials and processes that minimize negative impacts on the environment, save energy and natural resources, and are safe for employees and consumers (Jha, 2015; Garetti & Taisch, 2012). In short, green manufacturing is also defined as a process or system that has minimal, no or negative impact on the environment (Dornfeld, 2013; Rehman & Shrivastava, 2013; Dornfeld et al., 2012).

Often lean manufacturing and green manufacturing are used simultaneously but both have different goals, lean Manufacturing focuses on increasing value for customers or users with as little effort as possible. Apart from that, it's lean Manufacturing often refers to practices that seek to identify and evaluate the use of resources that do not provide added value to end consumers. Then lean manufacturing then defines such use as waste and tries to eliminate it.

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In contrast to lean manufacturing, environmentally friendly manufacturing (consciously) is more similar to green manufacturing because it overcomes the dilemma of maintaining a progressive world economy without continuing to damage the environment (Tasdemir & Gazo, 2018; Dominelli, 2012). Apart from lean manufacturing, green manufacturing is often used simultaneously with sustainable manufacturing. There are several definitions regarding the possibility of being sustainable and the ability to be sustainable, but these are based on the World Commission on Environment and Development organization sustainable development means designing to meet the needs of the present without compromising the ability of future generations to meet their needs (Borowy, 2013; Hajian & Kashani, 2021). Reflecting this definition which includes social assessments along with economic and environmental assessments, sustainability is also associated with a triple-crossroads approach in thinking about environmental, economic and social factors that must be met. Sustainable Manufacturing refers to a manufacturing system or process that meets these three important factors, namely overcoming impacts on the environment, economy and society (Indah et al., 2020; Malek & Desai, 2020; Godina et al., 2020; Verma et al., 2022).

The concept of green manufacturing is very important to apply to the industrial world to protect the environment (Sartal et al., 2020; Appolloni et al., 2022). The more production there is, the more waste produced from the production process will be. Therefore, it is necessary to implement green manufacturing. Green manufacturing can function to minimize air, water and land pollution by reducing waste and hazardous emissions during the production process. This is crucial in combating environmental degradation and protecting ecosystems (Pradana, 2021; Kannan et al., 2022). a gram of prevention is better than a kilogram of cure. therefore, using less energy, materials, and producing less waste is preventative, and very good for the environment. Minimizing waste generated in production, reducing energy use, and using materials and resources in a more efficient manner can result in financial cost savings and reduced environmental impacts (Pampanelli et al., 2016). From a regulatory perspective, there are several pressures. In the regulation of the Minister of Manpower and Transmigration of the Republic of Indonesia number per.13/men/x/2011 concerning threshold values for physical factors and chemical factors in the workplace, where the permitted threshold is 9000 µg/m3 per 8 hours (Mentri Tenaga Kerja dan Transmigrasi, 2011). Then in the Republic of Indonesia government regulation number 41 of 1999 concerning air pollution control. Quality standards for 1 day for NO2 are 150 µg/m3, CO 10,000 µg/m3, PM 215 µg/m3, and SO2 365 µg/m3 (Presiden Republik Indonesia, 1999). In addition, based on a recent analysis of more than 4,000 manufacturing facilities in seven countries, the Organization for Economic Cooperation and Development (OECD) found that there is a positive correlation between environmental performance and commercial success. With economic incentives such as these, green manufacturing has emerged as a new competitive requirement and a means to achieve market differentiation (OECD, 2011; Padilla-Lozano & Collazzo, 2022).

green manufacturing concept had never been carried out at PT. XYZ. Therefore, performance measurement at PT. XYZ based on the green manufacturing concept needs to be carried out using Organization for Economic Cooperation and Development (OECD) indicators to determine the company's performance starting from input, process, to output. PT. XYZ is a company that produces rims for heavy-duty vehicles.

Methods

This research was conducted at PT. Autokorindo Pratama, a heavy-duty vehicle wheel rim manufacturing company located in Gresik, East Java, in April 2024. The main objective of the research is to measure the company's green manufacturing performance using the OECD Sustainable Manufacturing Toolkit as a reference framework. The research method used

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includes identifying variables related to green manufacturing performance and collecting primary and secondary data from various aspects of the company's production.

The research steps begin with literature and field studies to understand the condition of the research object. Next, the problem is formulated, limitations, objectives and research assumptions are determined. Variables identified include the intensity of use of non-renewable raw materials, hazardous substances, recycled materials, water and energy use, greenhouse gas emissions, as well as other green manufacturing indicators. Primary data is collected through observing production processes and waste, while secondary data includes product weight, raw materials, energy consumption and pollution. Data processing is carried out to measure green manufacturing performance based on predetermined indicators, followed by analysis of the results and in-depth discussion. The research results are expected to make a significant contribution in improving the performance of green manufacturing at PT. Autokorindo Pratama.

Results and Discussion

Data collection

Before the data is processed the data needs to be collected first. The data that has been collected is as follows:

Table 1. Company Data for June 2024

No	Data	Amount	Information
1	Total product weight	21.07 kg	
2	Production amount 1 month	15300 pcs	
3	Weight of material used		
	The main material:		
	Rim bars	11.9 kg	
	Side rings	4.1 kg	
	Steel plate	12,275 kg	
		28.275 kg	
	Complementary materials		
	Paste	0.023 kg	
	Resin	0.1kg	
	Duco paint	0.024 kg	
	Duco thinner	0.02 kg	
		0.166 kg	
5	Weight of recycled raw materials	76,119.403 kg	
6	Weight of reused raw materials	0 kg	
7	Recyclable product weight	21.07 kg	*Wheel* weight
8	Weight of renewable materials	0 kg	
9	The weight of non-renewable materials	21.07 kg	*Wheel* weight
10	Weight of B3 ingredients in the product	0.166 kg	Total weight of complementary materials
11	Energy consumption for 1 month	1792,747 kwh	PLN electricity
12	Renewable energy consumption	0 kWh	
13	Energy consumption of product use	0 kWh	
14	Water usage	689,642 m^3	
15	Diesel consumption	1278.054 liters	

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16	Greenhouse gas effects in product use	0 g/liter	
17	Recycle leftover materials from production	0 kg	
18	Water pollution	0 m^3	
19	Company land area	31853.74 m^2	
20	Extensive natural facilities	4261.89 m^2	
21	Estimated duration of product life	5 years	

Source: Company Data

To find out air pollution and greenhouse gases, it must first be calculated using the formula emissions = activity x emission factor. For air pollution, the emission factor is NO^2 = 4.41; CO = 0.95; PM = 0.31; SO = 0.29 and for greenhouse gas emissions the factor is CO^2 = 2.493. So using the formula and emission factors, the following values are found, NO^2 = 7404.39 g/liter; CO = 1595.05 g/liter; PM = 520.49 g/liter; SO = 486.91 g/liter, with these results it is known that the air pollution value is 10006.84 g/liter. After that, the greenhouse gas value was known from the results of multiplying activity by the emission factor of 3186.166 g/liter.

Data processing

After the data is obtained, the data can then be processed according to the method procedure used:

Intensity of Use of Non-Renewable Raw Materials (Input)

Non-renewable raw materials are main materials such as *rim bars* , *side rims* and *steel plates* and their weights are 11.9 kg, 4.1 kg and 12.275 kg respectively. Then, additional materials such as paste, resin, duco paint, and duco *thinner* and their respective weights are 0.023 kg, 0.1 kg, 0.023 kg, and 0.02 kg. then the total weight of non-renewable raw materials is 28.44 kg. and for the total product weight of 21.07 kg. The calculation formula is as follows:

$$\frac{Weight\ of\ non-renewable\ raw\ materials\ (kg)}{total\ product\ weight}$$

$$\frac{28{,}44}{21{,}07}\ x\ 100\% = 1{,}35\ x\ 100\% = 135\%$$

From the calculation results, a value of 135% was obtained for the non-renewable raw material indicator, indicating that the raw materials used during the production process mostly use non-renewable raw materials. This is because in making *wheel rims* the material used must be strong against heavy loads, therefore the material used is iron based.

***Intensity of Use of Hazardous Substances* (*Input*)**

Hazardous substances used during the production process are paste, resin, duco paint and duco *thinner* and weigh respectively 0.023 kg, 0.1 kg, 0.023 kg and 0.02 kg. So the weight of the use of hazardous substances in production *input* is 0.166 kg. then the total weight of the raw materials used was 28.44 kg. The calculation formula is as follows:

$$\frac{total\ weight\ of\ hazardous\ raw\ materials(kg)}{total\ weight\ of\ raw\ materials\ used\ (kg)}$$

$$\frac{0{,}166}{28{,}44}\ x\ 100\% = 0{,}006\ x\ 100\% = 0{,}6\%$$

From the calculation results, a value of 0.6% was obtained for the indicator of intensity of use of hazardous substances, this shows that the use of hazardous substances during the

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production process is relatively low. With the results obtained, of course the production process is quite safe for workers. In addition, these dangerous materials will eventually become coatings or paint on the product.

Recycled Materials or Reused Materials (*Input*)

wheel rim production process , recycled or reused materials are grams and scrap, these materials are sold to other parties outside the Company amounting to 76,119.403 kg. Then the weight of the rims is 21.07 kg and the total production for 1 month is 15,300 units, so the weight of the rims produced for 1 month is 322,371. The calculation formula is as follows:

$$\frac{total\ recycled\ raw\ materials\ and\ reused\ materials}{weight\ of\ the\ rim\ produced\ in\ 1\ month}$$

$$\frac{76.119{,}403}{322.371}\ x\ 100\% = 0{,}24\ x\ 100\% = 24\%$$

From the calculation results, a value of 24% was obtained for the recycled material / reused material indicator. This waste is worth 3613 units of wheel rims if the Company can recycle it. Even though there is no smelting equipment in the Company's facilities, the remaining production materials are still recycled outside the company's facilities.

Water Use Intensity (Process)

The water used during the product production process comes from regional drinking water companies (PDAM) and waste water treatment installations (IPAL). The amount of water used from these water sources is respectively 246,627 m^3 and 443,015 m^3, so the total water use is 689,642 m^3. Then the total production is 15,300 units. Next, the calculation formula is as follows:

$$\frac{total\ water\ usage\ (m^3)}{production\ quantity\ for\ 1\ month}$$

$$\frac{689{,}643}{15300} = 0{,}045$$

The calculation results obtained for the water use intensity indicator are 0.045 m^3. These results indicate that the intensity of water use during the production process is relatively small. This is due to the existence of IPAL. IPAL is very helpful in managing waste water so that it can be reused so that it can reduce the use of clean water from PDAM.

Energy Use Intensity (Process)

During the production process, the main energy used is electricity sourced from PLN. Total electricity usage for 1 month is 1792,231 kwh. Then the total production for 1 month is 15300 units. The calculation formula is as follows:

$$\frac{energy\ needed\ in\ the\ production\ process}{production\ volume\ for\ one\ month}$$

$$\frac{1792{,}231}{15300} = 0{,}117$$

From the calculation results, a value of 0.117 kwh/product is obtained. Even though the entire production process uses electricity-powered machines, the intensity of electricity use is relatively small.

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Renewable Energy Use (Process)

The use of renewable energy during the production process is 0, because the energy is completely sourced from PLN and there is no energy sourced from renewable energy. Then the total energy usage is 1792.231 kWh. The calculation formula is as follows:

$$\frac{use\ of\ renewable\ energy}{total\ energy\ usage}$$

$$\frac{0}{1792{,}231} = 0$$

The calculation results obtained for the renewable energy use indicator are 0%. This is because the production process only uses PLN electricity.

Greenhouse Gas Intensity (Process)

Greenhouse gases in the company environment come from *forklift engine emissions* . This is because *the forklift* used still uses diesel fuel. To find out greenhouse gases from the use of diesel intensity, it is necessary to calculate $CO_{2\ emissions}$ from diesel use. The way to calculate these emissions is to multiply the amount of diesel fuel used by the emission factor. From the calculation results, it was found that the greenhouse gases emitted were 3186.166 g/liter. Then the total production for 1 month is 15300 units. The calculation formula is:

$$\frac{GHG\ produced\ from\ the\ production\ process}{production\ quantity\ for\ 1\ month}$$

$$\frac{3186{,}166}{15300} = 0{,}208$$

From the calculation results, a value of 0.208 g/liter was obtained, this is quite small. This is because the only source of greenhouse gases comes from the use of diesel fuel in *forklifts*. In addition, based on the regulation of the Minister of Manpower and Transmigration of the Republic of Indonesia Number Per.13/Men/X/2011 concerning the assessment of physical and chemical factor thresholds in the workplace, the threshold value for CO_2 air pollution is 0.216 g/liter for every hour.

Waste Intensity (Process)

Waste calculations require data on input weight for 1 month, fuel weight for 1 month, and product waste for 1 month. From this data collection, the weights were obtained as 435148.1373 kg, 1077391.746 kg, and 322371 kg. then the total production for 1 month is 15300 units. The calculation formula is as follows:

$$\frac{input\ weight\ +\ fuel\ weight\ -\ product\ weight}{production\ quantity\ for\ 1\ month}$$

$$\frac{435148{,}1373\ + 1077391{,}746 - 322371}{15300} = 77{,}789$$

From the calculation above, the result is 77.789 kg. The most waste comes from gram and scarp. However, these grams and scarps are not thrown away for free. The grams and scarp are sold to other parties to be processed into other products.

Air Pollution Intensity (Process)

The intensity of air pollution resulting from the *wheel rim production process* comes from diesel fuel used in *forklifts* . To find out the amount of residue released into the air by *forklifts,* it is necessary to calculate emissions first. Calculation of residual air emissions can be done by multiplying the amount of diesel fuel used by the emission factor. Based on calculations,

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the value obtained is 10006.84 g/liter. Then the total production for 1 month is 15300 units. To measure the intensity of air pollution, the following formula can be used:

$$\frac{weight\ of\ residue\ released\ into\ the\ air}{production\ volume\ for\ one\ month}$$

$$\frac{10006{,}84}{15300} = 0{,}654$$

From the results of the calculation above, the result was 0.654 g/liter. This is relatively small because the only air pollution that exists comes from the use of diesel fuel which is used to fuel *forklifts*. Apart from that, based on government regulation number 41 of 1999 concerning air pollution control, the total standard quality for air pollution NO_2, CO, PM, and SO_2 is 10730 g/liter for every hour.

Water Pollution Intensity (Process)

During the production process, water is obtained from PDAM and the results of water management at waste water treatment installation facilities (IPAL). The amount of residue released into the water during one month is 0 m ^{2}. Then the total water use is 689,643 ^{m2}. The formula for calculating water intensity is as follows:

$$\frac{the\ weight\ of\ the\ residue\ released\ into\ the\ water}{high\ water\ usage}$$

$$\frac{0}{689{,}643} = 0\%$$

The calculation results obtained for the water use intensity indicator are 0%. Because of the IPAL, the water that has been used is not thrown away. After going through the production process, the water used is mixed with a lot of residue. Then in the WWTP all the residue is filtered so that it becomes clean and can be reused.

Closure of Green Open Space Facilities or *Natural Cover* (*Output*)

The closure of open space occurs due to the construction of a building, so that the green land changes function and the green land is closed. The company knows that the area of green open space is 4261.89 m ^{2}. And the company area is 31853.74 m ^{2}. The formula used to calculate *natural cover* is as follows:

$$\frac{green\ open\ space\ area}{company\ land\ area}$$

$$\frac{4261{,}89}{31853{,}74}\ x\ 100\% = 0{,}134\ x\ 100\% = 13{,}4\%$$

From the results of these calculations, a value of 13.4% was obtained. This is because part of the Company's land is used for Company facilities. Even though there is relatively little open space for greenery, the Company optimizes this open space by planting lots of plants.

Products Containing Recycled or Reused Materials (*Output*)

In making *wheel rims,* the material used is material sent directly by the supplier. So no material is recycled in the production process. So the material that is recycled or reused is 0. Then the weight of *the rim* is 21.07 kg. The formula used in this indicator is as follows:

$$\frac{weight\ of\ raw\ materials\ recycled\ or\ reused}{total\ weight\ of\ rims}$$

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$$\frac{0}{21{,}07}\ x\ 100\% = 0\ x\ 100\% = 0\%$$

From the calculation results above, a result of 0% is obtained. This result is because the material used to make *the rims* is a new material. And to create a recycling facility it requires a lot of money and also a large area.

Recyclable Products (*Output*)

In *wheel rim products* , the main material used is iron. Therefore, most of the products can be recycled. The weight of the recyclable material content of the product weighs 20,904 kg. then the total weight *of the rims* is 21.07 kg. To measure indicators of products that can be recycled are as follows:

$$\frac{weight\ of\ material\ in\ a\ product\ that\ can\ be\ recycled}{total\ weight\ of\ rims}$$

$$\frac{20{,}904}{21{,}07}\ x\ 100\% = 0{,}992\ x\ 100\% = 99{,}2\%$$

From the calculation results above, a result of 99.2% was obtained. From these results it can be seen that the products are dominated by materials that can be recycled. This is because the material used to make *rims* is iron, which is a material that can be recycled.

Products Contain Renewable Materials (*Output*)

wheel rim products no renewable materials are used. Then the weight of renewable materials is 0 kg. then the total weight *of the rims* is 21.07 kg. The formula used to calculate indicators for products containing renewable materials is as follows:

$$\frac{weight\ of\ renewable\ product\ content}{total\ weight\ of\ rims}$$

$$\frac{0}{21{,}07}\ x\ 100\% = 0\ x\ 100\% = 0\%$$

From the results of the calculation above, a value of 0% is obtained. This is because *alloy wheels* require material that has high strength and durability, so there is no material in *the alloy wheel product that can be renewed.*

Intensity of Non-Renewable Materials in Products (*Output*)

For *wheel rim products* , because all materials are non-renewable materials, the weight of the non-renewable material is 21.07 kg. then the estimated product life is 5 years. The formula used to calculate indicators of products containing non-renewable materials is as follows:

$$\frac{weight\ of\ content\ in\ non-renewable\ products}{estimated\ product\ life}$$

$$\frac{21{,}07}{5} = 4{,}214$$

The calculation results show a value of 4.214 kg for the intensity indicator of non-renewable materials in the product. This is because all the materials used are non-renewable materials.

Hazardous Substances Contained in Products (*Output*)

The hazardous ingredients contained in the product are only found in the paint layer that covers the product. The paint layer is 0.166 kg. then the total weight *of the rims* is 21.07 kg. To calculate indicators of hazardous substances contained in products, a formula is required as follows:

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$$\frac{\textit{the weight of the hazardous material content in the product}}{\textit{total weight of rims}}$$

$$\frac{0{,}166}{21{,}07}\ x\ 100\% = 0{,}008\ x\ 100\% = 0{,}8\%$$

The calculation results show a value of 0.8%. This value is relatively small. This is because the dangerous ingredients in the product are only found in the paint layer that protects the product.

Energy Consumption in Using the Product (*Output*)

In *alloy wheel products* , no energy is required when using the product. So the energy consumption value in using the product is 0. The formula used for the intensity of energy use in the product is as follows:

$$\frac{\textit{average energy consumption per unit x number of units produced}}{\textit{estimated product usage period}}$$

$$\frac{0\ x\ 15300}{5} = 0$$

From the calculation results, a value of 0 kwh is obtained. This is because in using the product no energy is used.

Greenhouse Gas Emissions from Product Use (*Output*)

In *alloy wheel products* , no greenhouse gases are produced when using the product. So the greenhouse gas emission value when using the product is 0. Then the estimated product usage period is 5 years. The formula used for the intensity of greenhouse gas emissions in products is as follows:

$$\frac{\textit{average GHG emissions per unit x number of units produced}}{\textit{estimated product usage period}}$$

$$\frac{0\ x\ 15300}{5} = 0$$

From the calculation results, a value of 0 g/liter is obtained. This is because when using the product no greenhouse gas emissions are released.

Discussion

From the results of calculating the 18 indicators above, the following results were obtained:

Table 2. Results of *Green Manufacturing Indicators*

Indicator	Results	Analysis
Intensity of use of non-renewable raw materials (*input*)	135%	This result is relatively large, this is because the main material used is iron-based
Intensity of use of dangerous substances (*input*)	0.6%	This result is relatively small, this is because the dangerous substances used are only found in the paint coating
Recycled materials/reused materials (*input*)	24%	This is because the waste produced is directly used by other parties outside the Company
Water use intensity (process)	0.045 m^3 / product	This result is relatively small, because the production process uses only a small amount of water
Energy use intensity (process)	0.117 kwh/product	This result is relatively small, this is due to the efficiency of production cycle time

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Indicator	Results	Analysis
Use of renewable energy (process)	0%	This is because the electricity used for operations only comes from PLN
Greenhouse gas intensity (process)	0.208 g/liter	This result is relatively small, this is because the greenhouse gases produced only come from *forklift emissions*
Waste intensity (process)	77,789 kg/ product	This yield is relatively large. Although this yield is large, all waste is recycled by other parties
Air pollution intensity (process)	0.654 g/liter	This result is relatively small, this is because the air pollution produced only comes from *forklift emissions*
Water pollution intensity (process)	0%	This is because all water from production is filtered at the WWTP and then used again
Closure of green open space/ *natural land facilities* (process)	13.4%	This result is relatively large, this is because a lot of the Company's land is still afforested
Products contain recycled/reused materials (*output*)	0%	This is because all production waste is processed by other parties
Recyclable products (*output*)	99.2%	This result is relatively large, this is because the only content that cannot be recycled is the paint layer on the product
Products contain renewable materials (*output*)	0%	This is because the product requires strong material
Intensity of non-renewable materials (*output*)	4,214 kg	This is because the product requires strong material
Hazardous substances contained in the product (*output*)	0.8%	This result is relatively small, this is because the content of hazardous substances in the product is only the paint layer
Energy consumption in using the product (*output*)	0 kWh	This is because using the product does not require electricity
Greenhouse gas emissions in using the product (*output*)	0 g/liter	This is because when using the product no emissions are released

(*) = not in line with the *green manufacturing concept*

Source: Processed Data, 2024

From the table above, it is known that all 13 indicators are in accordance with the *green manufacturing concept* , this means that the company is at the *advanced level* of the OECD *green manufacturing concept* . Even so, there are still 5 indicators that are not in line with the *green manufacturing concept* . Indicators that are not in line with the *green manufacturing concept* are the intensity of use of non-renewable raw materials (*inputs*). This indicator is not in line with the *green manufacturing concept* because in making *wheel rim products* , materials are needed that are strong enough to withstand heavy loads, so the materials used cannot be renewed. . Furthermore, indicators that are not in line with the *green manufacturing concept* are waste intensity (process) and products containing recycled/reused materials (*output*). Even though these indicators are not in line with the *green manufacturing concept* , no waste is disposed of carelessly. All waste is recycled and neutralized by other parties. Furthermore, a concept that is not in line with the *green manufacturing concept* is the use of renewable energy (process). This is because the Company's only source of energy comes from the state electricity company (PLN). And finally, the product indicator contains renewable materials, this is because wheel rim products require strong materials so the main material used is iron.

In processing production waste, the Company has collaborated with external parties to manage waste so that production waste does not pollute the environment. The largest waste

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is dominated by gram waste and scrap. gram comes from the cutting process in trimming, grinding, side cutting on the rim line, chamfering and grinding on the disc line. Meanwhile, scrap comes from the perforation process which comes from valve hole piercing on the rim line, bolt hole, vent hole, coining, notching on the disc line. For grams the Company sells to concrete iron manufacturers. For scrap waste, the Company sells it to factories that make machine spare parts. Apart from gram waste and scrap, the Company also produces B3 waste in the form of sludge, sludge is the result of water filtering at waste water treatment plants (IPAL). The water that has been used in the production process is mixed with the oil that coats the iron. However, later this sludge will be given to a sludge disposal service.

Proposed Improvements

Based on the calculation results, the indicator that needs to be improved is the use of renewable energy. Renewable energy that is suitable for use by this company is solar power generation (PTLS). PTLS can be installed on every building roof so that solar panels can produce electricity optimally but do not take up space.

The building where solar panels are installed should be the newest building, so that it is still structurally strong. The area of the roof of the new building on the north facing side is 1274 m2 in the old warehouse and 980 m2 in the new warehouse . Then it was found that the efficiency of solar panels was 11.58% (Muhammad Rifaldi et al., 2023) , the intensity of sunlight was 5.66 kWh/m ^{2} /day (NREL, 2024) , and the hours of illumination were 5.7 hours/day ((IPCC), 2023) ,. With this data, the power produced (P $_{output}$) from the solar panels can be calculated. The way to calculate this is by multiplying the value of light intensity, efficiency of the solar panels, hours of illumination and then multiplying by one thousand (Muhammad Rifaldi et al., 2023) as follows:

$$P_{out} = \frac{solar\ intensity\ x\ solar\ panel\ efficiency\ x\ hours\ of\ exposure}{1000}$$

$$P_{out} = \frac{5{,}66\ \ x\ 11{,}58\ x\ 5{,}7}{1000} = 0{,}3735$$

So for every square meter the power obtained from solar panels is 0.3735 kWh/m ^{2} . So with the roof area that can be used on the old warehouse covering an area of 1274 m ^{2} and the new warehouse roof covering an area of 980 m ^{2} the power obtained is as follows:

$$total\ P = (old\ warehouse\ roof\ area\ x\ P_{out}) + (new\ warehouse\ roof\ area\ x\ P_{out})$$

$$= (1274\ x\ 0{,}3735) + (980\ x\ 0{,}3735)$$

$$= 475{,}836 + 366{,}03$$

$$= 841{,}866$$

Thus, by installing a solar power plant the total power obtained is 841,866 kWh.

From the calculation results, it is found that the total power that can be produced is only 46.96% of the total power requirements for production. This is because there is only one thing in the warehouse building that can be installed with solar panels safely.

Conclusion

Based on the results of data processing, the company's performance level is obtained based on the green manufacturing concept with OECD indicators is at the advanced level because there are 13 indicators that are met. Meanwhile, the 5 indicators that were not met were the intensity of water pollution at the process stage, energy consumption in using the product at the output stage, and greenhouse gas emissions in using the product at the output stage.

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References

Appolloni, A., Jabbour, C. J. C., D'Adamo, I., Gastaldi, M., & Settembre-Blundo, D. (2022). Green recovery in the mature manufacturing industry: The role of the green-circular premium and sustainability certification in innovative efforts. *Ecological Economics*, *193*, 107311. https://doi.org/10.1016/j.ecolecon.2021.107311

Borowy, I. (2013). *Defining sustainable development for our common future: A history of the World Commission on Environment and Development (Brundtland Commission)*. Routledge.

Dominelli, L. (2012). *Green social work: From environmental crises to environmental justice*. Polity.

Dornfeld, D. A. (2013). Green Manufacturing Fundamentals and Applications.

Dornfeld, D., Yuan, C., Diaz, N., Zhang, T., & Vijayaraghavan, A. (2012). Introduction to green manufacturing. In *Green manufacturing: fundamentals and applications* (pp. 1-23). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4419-6016-0_1

Florida, R. (1996). Lean and green: the move to environmentally conscious manufacturing. *California management review*, *39*(1), 80-105. https://doi.org/10.2307/41165877

Garetti, M., & Taisch, M. (2012). Sustainable manufacturing: trends and research challenges. *Production planning & control*, *23*(2-3), 83-104. https://doi.org/10.1080/09537287.2011.591619

Godina, R., Ribeiro, I., Matos, F., T. Ferreira, B., Carvalho, H., & Peças, P. (2020). Impact assessment of additive manufacturing on sustainable business models in industry 4.0 context. *Sustainability*, *12*(17), 7066. https://doi.org/10.3390/su12177066

Hajian, M., & Kashani, S. J. (2021). Evolution of the concept of sustainability. From Brundtland Report to sustainable development goals. In *Sustainable resource management* (pp. 1-24). Elsevier. https://doi.org/10.1016/B978-0-12-824342-8.00018-3

Indah, A. B. R., Nurwahidah, A., Mangngenre, S., Ikasari, N., & Afifudin, M. T. (2020). A Review of the Combination of Lean and Green in manufacturing for Sustainable Development. IOP Conference Series: Earth and Environmental Science, 575(1). https://doi.org/10.1088/1755-1315/575/1/012066

Jha, N. K. (2015). Green Design and Manufacturing for Sustainability. In Green Design and Manufacturing for Sustainability. https://doi.org/10.1201/b19526

Kannan, D., Shankar, K. M., & Gholipour, P. (2022). Paving the way for a green transition through mitigation of green manufacturing challenges: A systematic literature review. *Journal of Cleaner Production*, *368*, 132578. https://doi.org/10.1016/j.jclepro.2022.132578

Malek, J., & Desai, T. N. (2020). A systematic literature review to map literature focus of sustainable manufacturing. *Journal of Cleaner Production*, *256*, 120345. https://doi.org/10.1016/j.jclepro.2020.120345

ISSN: 2716-3865 (Print), 2721-1290 (Online)

Nainggolan, H., Nuraini, R., Sepriano, S., Aryasa, I. W. T., Meilin, A., Adhicandra, I., ... & Prayitno, H. (2023). *GREEN TECHNOLOGY INNOVATION: Transformasi Teknologi Ramah Lingkungan berbagai Sektor*. PT. Sonpedia Publishing Indonesia.

OECD. (2011). Start-up Guide: Seven Steps to Environmental Excellence. In OECD Sustainable Manufacturing Toolkit.

Padilla-Lozano, C. P., & Collazzo, P. (2022). Corporate social responsibility, green innovation and competitiveness–causality in manufacturing. *Competitiveness Review: An International Business Journal*, *32*(7), 21-39. https://doi.org/10.1108/CR-12-2020-0160

Pampanelli, A., Trivedi, N., & Found, P. (2016). The Green Factory Creating Lean and Sustainable Manufacturing.

Pradana, M. F. (2021). Evaluasi Implementasi Green Manufacturing.

Prestianto, B., & Kusdiartini, V. (2023). Perancangan Green Manufacturing Pada Konveksi Arita Industry Semarang, Oox Guitarmaker Ambarawa, Idea Mebel Semarang, PT. Soegiarto Gemilang Tangguh Tegal. *Jurnal Ekonomi, Manajemen Akuntansi Dan Perpajakan (Jemap), 5*(2), 221–246. https://doi.org/10.24167/jemap.v5i2.4511

Rehman, M. A., & Shrivastava, R. L. (2013). Green manufacturing (GM): past, present and future (a state of art review). *World Review of Science, Technology and Sustainable Development*, *10*(1-2-3), 17-55. https://doi.org/10.1504/WRSTSD.2013.050784

Sartal, A., Bellas, R., Mejías, A. M., & García-Collado, A. (2020). The sustainable manufacturing concept, evolution and opportunities within Industry 4.0: A literature review. *Advances in Mechanical Engineering*, *12*(5), 1687814020925232. https://doi.org/10.1177/1687814020925232

Setyaningsih, I., Ciptono, W. S., Indarti, N., & Kemal, N. I. V. (2019). What is Green Manufacturing? A Quantitative Literature Review. *E3S Web of Conferences, 120*(2019), 2–5. https://doi.org/10.1051/e3sconf/201912001001

Tasdemir, C., & Gazo, R. (2018). A systematic literature review for better understanding of lean driven sustainability. *Sustainability*, *10*(7), 2544.

Verma, P., Kumar, V., Daim, T., Sharma, N. K., & Mittal, A. (2022). Identifying and prioritizing impediments of industry 4.0 to sustainable digital manufacturing: A mixed method approach. *Journal of Cleaner Production*, *356*, 131639. https://doi.org/10.1016/j.jclepro.2022.131639

ISSN: 2716-3865 (Print), 2721-1290 (Online)