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# Remanufacturing sustainability indicators: An Indonesian small and medium enterprise case study

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**Abstract.** Remanufacturing which transforms end of life products to similar to a new product with a warranty to match is growing unstoppably toward a circular economy. Sustainability is an important issue for remanufacturing SMEs to stay competitive in global market. However, appropriate indicators that help remanufacturing SMEs understand their sustainability performance is very few discussed. This research develops Remanufacturing Sustainability Indicators (RSI) with the case of Indonesian small and medium enterprises as a guide for achieving sustainability in developing countries. The RSI integrates economic, social and environmental indicators, values and capacity that was determined based on national and international literature and case studies. The purposed RSI was then endorsed to local remanufacturing SMEs. The purposed remanufacturing sustainability indicators is expected to provide a guide/tool that will help remanufacturing SMEs in Indonesia and developing countries in achieving sustainability.

## 1. Introduction

Remanufacturing is a series manufacturing steps transforming an end of life (EoL) product or component to be similar as new product or better performance with a better or equivalent warranty [1]. Sustainability, which is meeting the needs of the present without compromising the ability of future generations to meet their own needs, has become an important issue to achieve remanufacturing competitiveness, as they promote economic, social and environmental balancing [2]. The essential considering sustainability in remanufacturing process is to maintain the need of long-term solutions that secure economic values and social equity and wellbeing, and to conserve the needs for natural resource, energy and environment biodiversity. Improvement of the remanufacturing sustainability performance should be initiated from the first stage of remanufacturing process (e.g. core collections and material elections) to the final stage of the remanufacturing process (e.g. EoL management), as the potential economic, social and environmental impacts could be evaluated and monitored continuously at low risks.

Remanufacturing offers numerous sustainable values. Remanufacturing intuitively brings potential economic values not only in developing countries, but also in developed countries, together with the creation of a million-job opportunity. Along with these economic and social benefits, remanufacturing has great environmental benefit through resource and energy conservation, and GHG emission, waste and pollution reduction [3-6]. Decision made to improve the sustainability performance during remanufacturing process will have great consequences on whole sustainability impacts.



However, the application of sustainability during remanufacturing process especially for SMEs is still problematic. There is lack of sustainability evaluation applied in the remanufacturing operation. In addition, the sustainability of the remanufacturing process cannot be evaluated because there are no indicators or methods to measure them correctly and inclusively. While there are many global sustainability manufacturing indicators adopted by large industry, very few sustainability indicators are able to be adopted by SMEs. Therefore, there is a need to develop a sustainability indicators framework which is applicable, understood and relevant with SMEs.

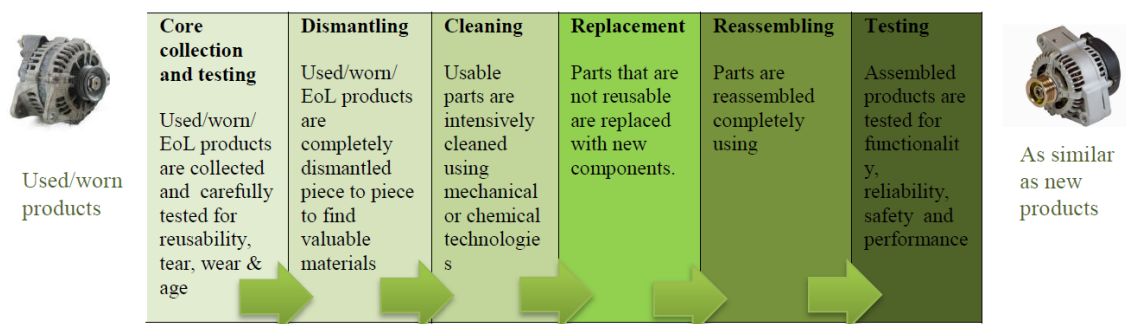
The objective of this research is to determine a set of sustainability indicators in the scope of remanufacturing process especially for SMEs. The framework of this paper consists of three main ideas that understand the research background to find the key factors for developing remanufacturing sustainability indicators, taking into account the methods and measurement scope to determine the sustainability indicators, and discussing the remanufacturing sustainability indicators measurement and framework. The proposed remanufacturing sustainability indicators framework is expected to provide a guide/tool that will help remanufacturing SMEs in Indonesia and developing countries to monitor and evaluate the consequences of their remanufacturing activities at different phase, and eventually to generate a sustainable and high performance of their remanufactured products through its life cycle.

## 2. Remanufacturing process and business

This section explains the remanufacturing process and business into several subsections as follow:

### 2.1. Remanufacturing process

A sustainable remanufacturing requires an integration process and approach. Ensuring that the remanufacturing process are technically, economically, socially and environmentally sounds needs an integrated and comprehensive strategies, as the remanufacturing process consist of a sequence of phase. Generally, remanufacturing process begin with core collection, dismantling, cleaning, replacement, reassembling and testing [7] as presented in figure 1.

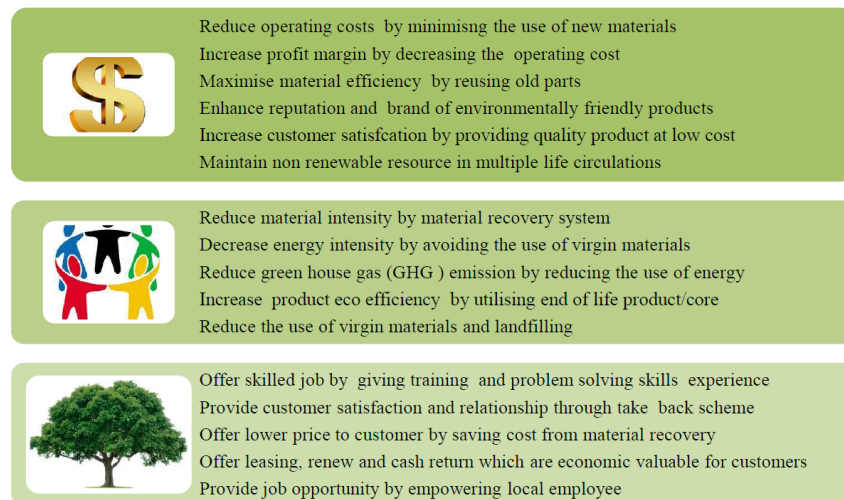


**Figure 1.** Remanufacturing process.

Figure 1 shows the steps of common remanufacturing process. Through this process, there are material, energy and resources, waste, GHG emission, pollution flowing in and out of the remanufacturing process. Adoption of innovative and appropriate technology, effective and efficient equipment often significantly influence the consumption of the material, energy and resource and the pollution, emission and waste generation.

### 2.2. Key benefits from remanufacturing

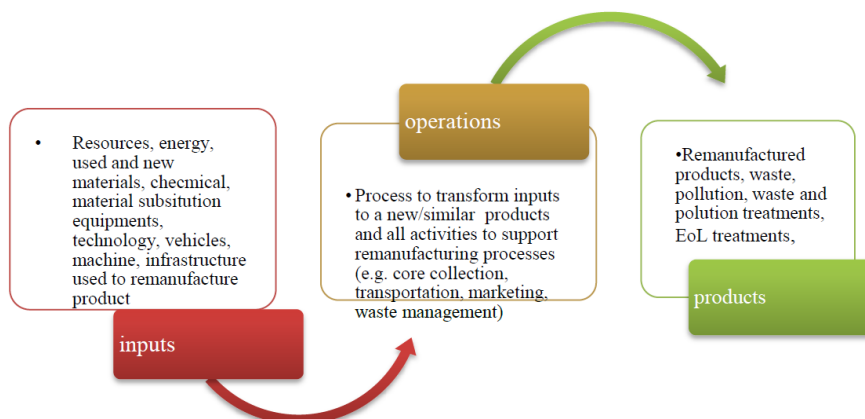
Remanufacturing has undoubtedly become engine of economy, social and environmental sustainability worldwide. Remanufacturing not only offers significant benefits for industry itself but also provide significant contribution to the improvement of society and environment. A number of research found that remanufacturing. Figure 2 summaries the economic, social and environmental advantages from remanufacturing industry gathered from literatures [3, 4, 6, 8-12].



**Figure 2.** Key benefits from remanufacturing.

### 2.3. Indicators measurement

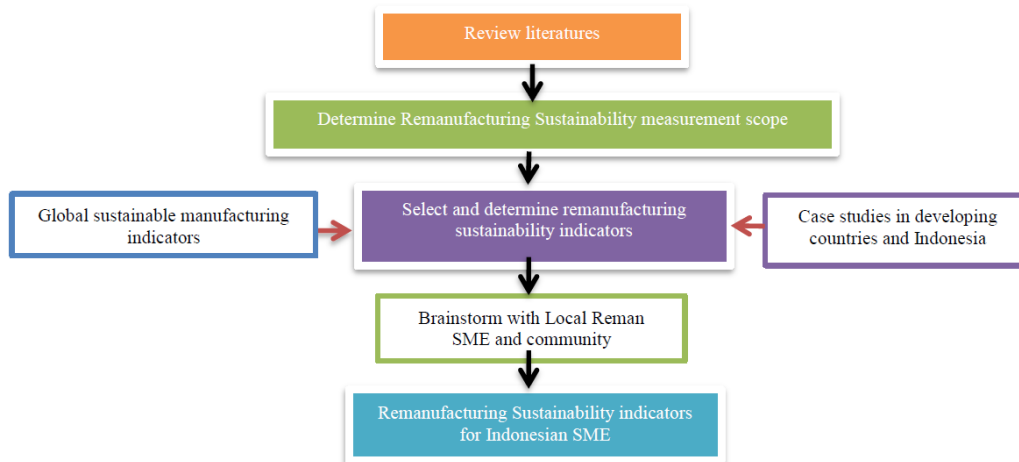
Indicators are critical key of defining, evaluating, monitoring and improving sustainability performance of an industry. Using this indicator, every industry can track their business performance (sales, customer complaint, employee productivity) everyday which can help the industry to maximize their sustainability performance every year. Therefore, the indicators should be able to illustrate the interaction of industry not only within the industry itself (i.e. labor, management, equipment, resource, energy) but also with external stakeholders (i.e. society, suppliers, consumers). In the case of remanufacturing industry, the interaction between the remanufacturing industry and its environment should consider all input, process, impacts and products created from remanufacturing process as presented in figure 3.



**Figure 3.** Relationship between remanufacturing and its environment.

### 3. Study methods

This section presents methods used in this research. An intensive study in accordance with research background and objectives is conducted to develop sustainability-remanufacturing indicator (SRI). A systematic approach based on literature review (e.g. sustainability framework review), case studies in developing countries and expert judgments from industry and academic is used to identify and select the appropriate indicators. An intensive brainstorming with local SMEs and Community is also presented to determine relevant indicators. Figure 4 presents a systematic approach implemented in this research.



**Figure 4.** A systematic approach of study.

The remanufacturing sustainability indicators cover completely remanufacturing process, including all activities from core collection stage up to EoL management. The sustainability indicators are categorized into triple bottom sustainability.

#### 4. Results and discussion

The results are explained and discussed in the following subsections.

##### 4.1. Key success factors

Key success factors to achieve remanufacturing sustainability are the implementation of all remanufacturing process requirements holistically. The ability of resource associated with the main source for conducting remanufacturing process (i.e. cores, materials, energy) and enablers (i.e. labor, management, equipment and technology, information communication technology (ICT)) are very important to remanufacturing industry. Many remanufacturing gets trap on the process and neglects the enablers, thus the objective of the remanufacturing is difficult to be achieved. For example, an enterprise has already had energy efficient technology, but inefficiency is still high due to unavailability efforts to change the behavior of the labor and lack of knowledge in saving the energy.

Therefore, appropriate sustainability indicators in related to the remanufacturing standards in related to remanufacturing process and its enablers are urgently required by remanufacturing enterprises. Sustainability indicators open possibility to monitor whether the standards meet or exceed the requirements. These sustainability indicators could also help in monitoring the remanufacturing process over time. Sustainability indicator can help access the economic, social and environmental values and impacts at any stage of remanufacturing processes.

##### 4.2. Indicator selection principles

There are three general criteria including understandable, applicable and relevant need to be concerned while selecting sustainability indicators. Indicator should be understandable which means that the indicator should be clear and not ambiguous for remanufacturing to understand [13]. To make the indicators easily applied by SMEs, four element of indicators including quantification technic (i.e. calculation formula), measurement unit (i.e. kg, kWh), development goal (i.e. improvement direction) and measurement period (i.e. yearly) are used. The Indicators are also considered to meet the remanufacturing purposes - raise economic values, improve social equity and increase environmental conscious.

#### 4.3. Global sustainable manufacturing indicators

A review on sustainability manufacturing indicators has been conducted to identify the appropriate sustainability indicators for remanufacturing. In 2006, Ford Europe established a product sustainability index (PSI) consisting of eight indicators involving economic, societal and environmental aspects [14]. In this PSI, sustainability of a product considers all aspects of raw material extraction, production, use and product recovery. The Organization for Economic Co-operation and Development (OECD) published a big toolkit consisting of 18 main indicators to help measure the environmental problems associated with sustainable manufacturing [10], as presented in figure 5. In this framework, OECD stated that the main goal of sustainability in manufacturing is to minimize the use of materials while improving the benefits of product sent to society and to industry.

Walmart has delivered sustainability index of environmental products accordance to the marketability with the goals to meet 100% renewable energy, zero waste design and sustainable products sales. The EU Eco-Management and Audit Scheme (EMAS) developed by European Commission provide organization environmental performance information. The international Organization for Standardization (EPE) ISO 14031 presented a set of environmental key indicator to measure, assess and communicate the environmental performance of organization. General motors set metrics for sustainable manufacturing using fifty metrics of 6 major aspects. Global reporting initiative (GRI) provides 91 measures of company sustainability indicators, which covers economic, social and environmental aspects [15, 16]. This guideline helps industry in making good decisions toward economic, social and environmental sustainability for their industry, customer and stakeholders. Most studies often only concerned on environmental sustainability alone. However, this study considers economic, social and environmental sustainability in the same equal level.



**Figure 5.** OECD sustainability indicators [17]

#### 4.4. Lessons learn from developing countries

A review on the development of sustainability indicators from developing countries was carried out [4, 15, 17-20]. In developing countries, sustainable manufacturing has become a critical issue due to rapid development of population and industrialization. Achieving sustainable manufacturing through resource, energy and water efficiency have become popular among the industries, and environmental sustainability has become main consideration when the study discussed about sustainability. However, most of the study agreed that sustainable manufacturing is always about economic, social and environmental integration.

#### 4.5. SMEs Remanufacturing Sustainability Indicators Selection

According to a comprehensive literature review and case studies analyses of the current and worldwide manufacturing and remanufacturing sustainability indicators, triple helix sustainability indicators of economy, social and environment are constructed. The economic sustainability indicators

concern on the economic value created from the remanufacturing process including job creation, salary improvement etc. The social sustainability indicators focus on all social aspects created from the remanufacturing SMEs including health and safety, customer satisfaction etc. The environmental sustainability indicators consider all environment issues created from remanufacturing activities in SMEs including material efficiency, GHG emission etc. The detail result of the selected indicators is gathered from [21-24], and presented as follows.

*4.5.1. Economic sustainability indicators.* Economic sustainability of remanufacturing relates to all economic values associated with the use/utilization/management of resource, energy, labor, technology, method, waste, supply chain and Information Communication technology during remanufacturing process, which not only ascertains benefits for current generation but also provide opportunities for future generation. In sustainability assessment, it is urgently required to understand the level of economic benefits gathered from remanufacturing enterprise. Based on literature review and case study conducted from previous research, a number of specific economic indicators are considered to be adopted to measure the economic sustainability of remanufacturing enterprise, as presented in table 1.

**Table 1.** Economic indicators of remanufacturing sustainability.

Elements	Indicators	Unit Measurement	Formula
Job creation	Job creation	% (percentage)	$Job\ creation = \frac{total\ reman\ job}{total\ formal\ job}$
Employee	Employment remuneration	US Dollar	$ER = \sum man\ days \cdot average\ wage\ per\ man\ day$
	Salary improvement	% (percentage)	$SI = \frac{improvement\ salary}{total\ salary}$
Process	Tax revenue	US Dollar	Total tax paid
	Production cost	US Dollar	$PC = \frac{total\ cost}{total\ revenue}$
	Net profit	US Dollar	$NP = total\ revenue - total\ cost$
	Material efficiency cost	US Dollar	$ME = \frac{total\ material\ cost}{total\ production\ cost}$
	Energy efficiency cost	US Dollar	$EF = \frac{total\ energy\ cost}{total\ production\ cost}$
	Productivity	% (percentage)	$P = \frac{all\ remanufacturing\ inputs}{all\ remanufacturing\ products}$
Technology	Technology investment (i.e. Rate of Return – ROI)	US Dollar	$ROI = \frac{revenue\ gain\ from\ investment - cost\ of\ investment}{cost\ of\ investment}$
	Net present value – NPV)	US Dollar	$NPV = \sum_{t=1}^T \frac{cash\ flow}{(1-i)^t} - \frac{initial\ cash}{investment}$
Market	Market development	% (percentage)	$MD = \frac{total\ market\ improvement}{total\ market}$
	Brand image recognition	% (percentage)	$BI = \frac{total\ customer\ recognition}{total\ customer}$
	Enterprise competitiveness	% (percentage)	$CL = \frac{sales}{total\ market\ sales}$
Waste and pollution	Waste treatment cost	US Dollar	$WsTC = total\ cost\ spent\ for\ waste\ treatment$
	Water treatment cost	US Dollar	$WrTC = total\ cost\ spent\ for\ water\ treatment$
	Pollution treatment cost	US Dollar	$PTC = total\ cost\ spent\ for\ pollution\ treatment$

*4.5.2. Social sustainability indicators.* Social issues in the rapid development of remanufacturing industry are predicted to be prominent. Main social advantages of remanufacturing include job opportunity and labor productivity. However, possible social disadvantages of remanufacturing are

also need to be considered. For example, while there could be a great potential of employment opportunity, unprotected and unhealthy environment during remanufacturing process especially in developing country, may create social disadvantages impacts on the labor. Accordingly, measurement of the social impacts in this research considers employee, customer and community, as presented in table 2.

**Table 2.** Social indicators of remanufacturing sustainability.

Elements	Indicators	Unit Measurement	Formula
Employee	Health & safety	% (percentage)	$HS = \frac{\text{total employee sick}}{\text{total labor}}$
	Work injury rate	% (percentage)	$WIR = \frac{\text{total injuries}}{\text{hour worked}}$
	Labor productivity	% (percentage)	$LP = \frac{\text{total revenue cost}}{\text{total labor cost}}$
	Remanufacturing training	% (percentage)	$RT = \frac{\text{employee received reman training}}{\text{total number of employee}}$
	Education level	% (percentage)	$EL = \frac{\text{total educated employee}}{\text{total number of employee}}$
	Skill level	% (percentage)	$SL = \frac{\text{total skilled labor}}{\text{total number of employee}}$
	Gender equity	% (percentage)	$GE = \frac{\text{total female labor}}{\text{total number of employee}}$
Customer	Customer satisfaction	% (percentage)	$CS = \frac{\text{satisfied customers}}{\text{total customers}}$
Community	Community complaints	% (percentage)	$CC = \frac{\text{total people complaint}}{\text{total community}}$
	Public acceptability	% (percentage)	$PC = \frac{\text{total people accepting product}}{\text{total community}}$

Remanufacturing is complex system, which needs a certain level of knowledge and understanding. Level of employee education has strong linkages to the ability of employee to understand complex system. It is believed that good education will provide better knowledge and skill in associated with the remanufacturing process.

*4.5.3. Environmental sustainability indicators.* Environmental sustainability of remanufacturing is associated with all environmental consequences created from remanufacturing process and received by current generations without neglecting future generation. The consequences could be both positive and negative which could affect human and environmental performance directly and indirectly in different manners. The system boundary of remanufacturing process considers supply of cores and material, remanufacturing process, marketing activity and waste management. Taking this system boundary into consideration, the environmental sustainability adopts all material, energy, waste and pollution flowing through remanufacturing process, as presented in the following table 3.

**Table 3.** Environment indicators of remanufacturing sustainability.

Elements	Indicators	Unit Measurement	Formula
Materials	Used material acquisition	kg used material/kg reman product	$MA = \frac{\text{total reused materials}}{\text{kg reman product}}$
	Material efficiency	kg raw material/kg reman product	
Energy	Energy intensity	kWh/reman product	$EI = \frac{\text{energy consumption}}{\text{kg reman product}}$
Wastes	Solid waste intensity	kg waste/kg reman product	$SW = \frac{\text{mass of solid waste produced}}{\text{kg reman product}}$
	Water waste intensity	m <sup>3</sup> waste water/kg reman product	$MA = \frac{\text{water consumption}}{\text{kg reman product}}$
	Residual intensity	m <sup>3</sup> residual/kg reman product	



Elements	Indicators	Unit Measurement	Formula
Emission	GHG emission intensity	kgCO <sub>2</sub> /kg reman product	$GHG = \frac{kgCO_2}{kg\ reman\ product}$
	Hazardous gas intensity	m <sup>3</sup> gas/kg reman product	$HG = \frac{m^3\ gas}{kg\ reman\ product}$
	Dusk	kg/kg reman product	$D = \frac{kg\ dusk}{kg\ reman\ product}$
Restricted substance	Hazardous chemical	kg/kg reman product	$HC = \frac{kg\ chemical}{kg\ reman\ product}$
	Acidification substance	kg/kg reman product	$AS = \frac{kg\ adictive\ substance}{kg\ reman\ product}$
Water	Water intensity	m <sup>3</sup> water used/kg reman product	$WI = \frac{m^3\ water\ used}{kg\ reman\ product}$
Land use	Landfilling	m <sup>3</sup> solid waste sent to landfill/kg reman product	$L = \frac{m^3\ solid\ waste}{m^3\ landfill\ area}$
Ecosystem	Biodiversity impacts	% (percentage)	$BI = \frac{biodiversity\ impacts}{total\ biodiversity}$
	Water treatment	% (percentage)	$WT = \frac{water\ treatment}{total\ water\ used}$
	Waste treatment	% (percentage)	$WsT = \frac{waste\ treated}{total\ waste}$
	Pollution treatment	% (percentage)	$PT = \frac{pollution\ treated}{total\ pollution}$

4.5.4. *Local SME and community brainstorming.* Since the remanufacturing sustainability indicator will be applied for SMEs, the final selection process was delivered to the SMEs. The purposed RSI was endorsed to remanufacturing SMEs (i.e. photocopy, alternator, computer products) located in Java, Indonesia to receive some important feedback. The enterprises were chosen based on their willingness to participate in this pilot study. Direct interview and electronic mail communications were conducted to the three enterprise managers. A number of questions were structured to identify key indicators (i.e. core indicators, additional indicators) based on SMEs perceptions. Table 4 presents the selected sustainability indicators for remanufacturing SMEs.

**Table 4.** SME remanufacturing sustainability indicators.

Economy indicators			
Core indicators	Job creation	1	Job creation
		2	Salary improvement
		3	Net profit
		4	Production cost
		5	Material efficiency cost
		6	Energy efficiency cost
		7	Productivity
	Market Company	8	Market development
		9	Brand image recognition
		10	Enterprise competitiveness
		11	Market development
Additional indicators	Employee	1	Employment remuneration
		2	Tax revenue
	Process	3	Green/eco technology
		4	Environment tax
	Technology	5	Waste treatment cost
		6	Pollution treatment cost
Waste& pollution			

<b>Social indicators</b>			
Core indicators	Employee	1	Health and safety
		2	Work injury rate
		3	Labor productivity
		4	Skilled labor
	Customer	5	Customer satisfaction
		6	Community complaint
Additional indicators	Employee	1	Education level
		2	Remanufacturing training
	Community	3	Gender equity
		4	Public acceptability
<b>Environmental indicators</b>			
Core indicators	Material	1	Material acquisition
		2	Material efficiency
	Water	3	Water intensity

*4.5.5. Future study and remanufacturing sustainability level.* The objectives of this study is to determine Indonesian SME remanufacturing sustainability indicators which has finally could be achieved based on comprehensive literature review, case studies of developing country and brainstorming with local remanufacturing SMEs. However, due to limited sample of the pilot study, further research involving more SMEs is urgently required. Future research on how to measure the level of the sustainability is also essential to be conducted at enterprise level. A purposed concept on the measurement of the SMEs remanufacturing sustainability level is briefly discussed below. The remanufacturing sustainability levels are determined accordance to a technical standard of ISO/IEC 15504 Information technology – Process assessment. The remanufacturing sustainability level is estimated using three attributes (i.e. economic, social and environment) which consist of general practice indicators as stated in the previous section. Figure 6 presents the remanufacturing sustainability level, which can be achieved by SMEs.

	Indicators				
Environment					
Social					
Economy					
	Initiate	Compliance	Establish	Likelihood	Optimum

**Figure 6.** The SMEs remanufacturing sustainability level.

The initiate level is the existing level in which both indicators (i.e. core indicators and additional indicators) met the threshold values/standard. The threshold value is estimated based on intensive and comprehensive research on the remanufacturing SMEs case study and literature review. The compliance level is the sufficient level in which at least core indicators meet the threshold value/standard. The establish level is the ideal/standard level in which both indicators meet the threshold value. The likelihood level is managed level in which core indicators are exceeded and additional indicators meet threshold value. The optimum level is the highest level in which all indicators exceed the threshold value, showing significant improvements. The further research will consider the involvement of more SMEs to apply the sustainability indicator framework, and to assess the sustainability performance of Indonesian SMEs level.

## 5. Conclusion

Remanufacturing implementation is greatly recommended to increase resource and energy efficient, to reduce waste and pollution, to improve economic and social equity especially for developing countries. This research has successfully developed Remanufacturing Sustainability Indicators (RSI) as a guideline for remanufacturing SMEs to understand their sustainability performance. The indicators can measure economy, environmental and social sustainability separately of remanufacturing enterprise. The economic indicators cover net profit, rate of return, salary improvement, tax revenue, material and resource cost efficient, material recovery, investment in technology, productivity etc. The environmental indicators consist of waste production, energy and water consumption. The social indicators involve employment rate, gender involvement, professional occupations, level of education and skill of labor, consumer satisfaction rate etc. This RSI guideline can be applied to any other remanufacturing SMEs in developing countries with small modifications. However, further future research is urgently required to more comprehensively know the remanufacturing sustainability in the SMEs.

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