School of Civil and Mechanical Engineering

Remanufacturing as a Potential Means of Attaining Sustainable Industrial Development in Indonesia

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

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Abstract

Remanufacturing industries account for a considerable share of small medium enterprises (SMEs) in both developed and developing countries. There is an urgent need for a sustainable manufacturing strategy for remanufacturing SMEs in developing countries in order for them to gain global market competitiveness through minimizing environmental impact while maximizing the economic and social benefits of SME manufacturing activities. This research uses Indonesian remanufacturing SMEs as a case study for sustainable manufacturing in developing countries.

Achieving sustainable manufacturing is an enormous challenge for the majority of Indonesian SMEs. Remanufacturing is considered an essential strategy for sustainable manufacturing in developed countries and encompasses the restoring of used parts or products to an as-new state, providing a warranty to match, reducing waste and landfill size, conserving resources and providing economic benefits. This strategy is still underdeveloped in Indonesia. A lack of remanufacturing knowledge, shortage of skilled workers, absence of advanced technology, lack of quality cores supplies, lack of financial support and the absence of marketing strategies have been found to be major barriers to attaining sustainable manufacturing in SMEs.

A sustainable manufacturing framework has been developed to enable Indonesian SMEs to achieve technically, environmentally, economically and socially feasible remanufacturing strategies. The framework is used to assess the existing remanufacturing scenario in Indonesian SMEs in order to identify failures or barriers to attaining the technical, environmental, economic and social objectives of sustainable manufacturing.

The improvement framework is then used to discern technically and environmentally feasible remanufacturing strategies. The first priority in the case of developing countries is the assessment of technical objectives using suitable indicators, as the existing technological gap affects the economic and social sustainability of the products. The next priority is to achieve environmental objectives, as sustainability has a strong ecological focus which takes into account the bio-physical limits of the Earth. Once the technically and environmentally sound remanufacturing strategies are identified, socio-economic assessments are performed to generate policies for achieving sustainable manufacturing through remanufacturing in Indonesian SMEs.

A case study is conducted involving Indonesian SMEs producing remanufactured alternators in Java Island, in order to validate the sustainable manufacturing framework. The existing situation is that the remanufacturing SMEs are not technically, environmentally, economically and socially viable. Three available remanufacturing strategies involving the use of new parts, recycled and used components and materials are therefore considered with regard to achieving a technically and environmentally sound remanufacturing strategy.

The analysis of the improvement scenario shows that the use of a greater quantity of quality cores, accomplished by the implementation of testing technology, the expansion of the cores collection area and training to increase the workers' skills, can provide technically and environmentally feasible remanufacturing solutions. The economic and social analyses of technically and environmentally sound remanufacturing strategies reveal an opportunity for Indonesian remanufacturing SMEs to generate revenue, increase jobs, scale of production and wages, and enhance intergenerational equity by conserving scarce resources for future generations.

In order for Indonesian remanufacturing SMEs to successfully implement sustainable manufacturing through remanufacturing strategies, they will require support from the government, NGOs, financing organizations and research organizations in the form of financial, investment, capacity building, sales, promotion, knowledge exchange and technological development.

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List of abbreviations

ACFTA	ASEAN China Free Trade Area
AISI	Indonesian Association of Motorcycles Producers
AM	Aftermarket
AMDAL	Indonesia Environmental Feasibility Assessment
ANSI	American National Standards Institute
APRA	Auto Parts Remanufacturing Association
ASEAN	Association of South-East Asian Nations
AUD	Australian dollar
BAPEDAL	Indonesian Environmental Impact Management Agency
BAU	Business as usual
BNI	National Bank of Indonesia
BPS	Central Bureau of Statistics
BRI	People’s Bank of Indonesia
CSR	Corporate social responsibility
CTF	Clean Technology Fund
DFM	Design for remanufacturing
ELVs	End of Life Vehicles Directive
EoL	End of life
EPA	Environment Protection Autority
EPR	Extended producer responsibility
EST	Environmentally sound technology
EuP	Energy using Products
FAA	Federal Aviation Administration
Gaikindo	Association of Indonesian Motor Vehicle Industries
GDP	Gross Domestic Product
GE	General Electric
GHG	Greenhouse gas
GSN	Green Suppliers Network

ICEL	Environmental impact assessments
IEC	International Electrotechnical Organization for Standardization
ISO	International Organization for Standardization
KUK	Small enterprise credit - *Kredit Usaha Kecil*
LCA	Life cycle assessment
LCC	Life cycle cost
LCI	Life cycle inventory
MEs	Medium enterprises
MIPS	Material intensity per unit service
MLE	Maximum likelihood estimation
MP3EI	Acceleration and Expansion of Indonesia’s Economic Development
MROs	Maintatinance and repair organizations
MTTF	Mean time to failure
NCR	Nominal customer risk
NGOs	Non government organisations
NGS	Australia’s National Greenhouse Strategy
OECD	Organisation for Economic Co-operation and Development
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RFID	Radio frequency identification
RoHS	Restriction of Hazardous Substance Directive
ROI	Return of investment
RPM	Revolutions per minute
RPO-REC	Renewable Purchase Obligations-Renewable Energy Certificate
SAC	Standardisation Administration of the People's Republic of China
SAE	Society of Automotive Engineers
SEs	Small enterprises
SLCA	Streamlined life cycle assessment
SMEs	Small and medium enterprises
SMF	Sustainable manufacturing frameworks
SWDS	Solid waste disposal sites

USD	United state dollar
WEEE	Waste Electrical and Electronic Equipment Directive

Chapter 1

Introduction

1.1 Introduction

This thesis aims to achieve sustainable manufacturing scenarios for small and medium enterprises (SMEs) through the implementation of technically, environmentally, economically and socially feasible remanufacturing strategies in Indonesia. This chapter introduces the significance, goal, objective, scope and structure of this thesis.

1.2 Background

Sustainable development has become a crucial focus of the global community. According to the World Commission on Environment and Development, 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Drexhage and Murphy 2010, p. 6). The three objectives of sustainable development are economic, social and environmental stability. In Rio de Janerio, Brazil, Agenda 21 was developed to implement a sustainable development agenda for 21st century generations (UNESCO 2005).

Sustainable manufacturing can potentially contribute to five key areas of Agenda 21, including the quality of life on earth, the efficient use of the earth's natural resources, the protection of the global community, the management of waste, and sustainable economic growth, by creating manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources for future generations (USEPA 2013, World Bank 1997).

Sustainable manufacturing also ensures 'the manufacture of high quality, performance products with improved or enhanced functionality using energy-efficient, non-toxic, low hazard, safe and secure technologies and manufacturing methods, making optimal use of resources and energy and producing minimal wastes and emissions, and providing maximum recovery, recyclability, reusability, remanufacturability, with redesign features, all aimed at enhanced societal benefits and economic impact' (Jawahir 2008, p. 37).

Globally, sustainable manufacturing in developed countries is better organized than in developing countries, as product recovery strategies are well established and institutionalized (Rathore, Kota, and Chakrabarti 2011). Remanufacturing appears to offer an effective way of achieving sustainable manufacturing in developed countries. Environmental and economic drivers as well as legislation pertaining to remanufacturing and financial assistance and marketing initiatives have promoted the market of remanufactured products (Hatcher, Ijomah, and Windmill 2011, Lund 1984, Matsumoto and Umeda 2011, Nasr and Thurston 2006, Ostlin 2008b).

There is potential in developing countries or achieving sustainable manufacturing through remanufacturing activities, but there is an absence of legislation, policies, financing mechanisms institutional framework, supporting mechanisms including the availability of good quality cores and used parts, computerized information databases, training opportunities and promotional activities (Fatimah et al. 2013, Saavendra et al. 2013, Shaharudin, Zailani, and Choon 2014, Tan et al. 2014).

This PhD research uses Indonesian remanufacturing SMEs as a case study for assessing sustainable manufacturing in developing countries.

Indonesia is a large country of 1.9 million square kilometres, with a length of 3,977 miles from the Indian Ocean to the Pacific Ocean. The country consists of five large islands including Java, Kalimantan, Sumatra, Sulawesi and Irian Jaya, with Java Island being the main economic corridor of Indonesia covering about 132,107 square kilometres. Agriculture, service and manufacturing account for 15%, 38% and 47% of Indonesian GDP respectively (Ministry of Industry Republic Indonesia 2012).

According to the World Bank, Indonesia is one of the largest populated countries in the world and it is estimated that the population will reach 262 million in 2020 (World Bank 2009). Indonesia's national GDP growth rate increased rapidly from 4.8% in 2009 to 6.5% in 2014 (Department of Foreign Affairs and Trade 2014) and the country has established itself as one of the largest economies in South Asia, and ranks as 10^{th} in the world (Elias and Noon 2011, Oberman et al. 2012).

Whilst Indonesia is a rich nation with a variety of natural resources including timber, petroleum and natural gas, various metals, fish and spices, there is a needs for strategies to overcome economic, social and environmental problems in the Indonesian sustainable development process (Nazech 2001). Industry plays an important role in the successful achievement of sustainable development, as industry drives the economy (Azapagic and Perdan 2000). Industry not only makes critical contributions to technology development and research and development activities, it also provides for the transfer of environmental technologies and management methods, which is a key factor in attaining sustainable development (United Nations 2010).

Indonesian industry is made up of Large Enterprises (LEs) and Small and Enterprises (SMEs). However, the SMEs significantly dominate Indonesian industry (99.99%) (Tambunan 2006). In 2008, SMEs accounted for 58.33% of GDP, and contributed to 16.72% of the total national export. Manufacturing is one of the main economic supports of SMEs. Even though manufacturing enterprises account for a small share (6.32%), they contribute the greatest proportion of the workforce (44%) (Kusumo 2008). In addition, manufacturing is an important contributor to export for Indonesian SMEs, accounting for 89% of total SME exports (Tambunan and Liu 2006).

By contrast the contributions of manufacturing SMEs to export and GDP are still low compared to those of the large manufacturing enterprises. The fact is that many Indonesian SMEs cannot survive global competition due to lack of innovative technology, capital investment and skilled workers. SMEs also do not receive adequate government support, and there is also insufficient linkage between SMEs and LEs, and unqualified and unclassified standardization products (Tambunan 2006). Environmentally, SME production contributes greatly to pollution, resource depletion and inefficient equipment usage (Dhewanthi 2007).

It is important, therefore, for SMEs to build sustainable manufacturing in order to achieve sustainable development in Indonesia. Sustainable manufacturing requires that manufacturing industries implement product recovery strategies such as recycling, reuse and remanufacturing (Anityasari and Kaebernick 2008).

There is huge potential for developing remanufacturing in Indonesian industry. However, remanufacturing is not free from limitations. One problem is uncertainty over the definition of remanufacturing, which creates confusion among manufacturers and industries in many countries, including Indonesia. This confusion may impede the building of sustainable remanufacturing business models and cause inefficiency in the production process (Gray and Charter 2007). Insufficient understanding of the remanufacturing industry has led to ambiguity in its implementation among Indonesian SMEs.

Quality and reliability assurance are the main issues, as ambiguity in quality and reliability makes used products unattractive (Gray and Charter 2007). In addition, the existence of poor quality, unreliable, unsafe and non-standardized products with minimal warranties is a common issue among Indonesian SMEs. Insufficient infrastructure, such as electricity, transportation and telecommunications, are other problems which could potentially impede the development of remanufacturing by SMEs (Fatimah et al. 2013). Furthermore, most SME exports are dependent on large enterprises in terms of marketing authority. As a result, the contribution made by SMEs is often unrecorded and undermined. This condition has negatively affected the development of SMEs, because it is difficult for manufacturers to expand their market independently (Tambunan and Liu 2006).

This PhD research thus develops a holistic sustainable manufacturing framework in order to integrate the technical, environmental, economic and social aspects of assessing Indonesian remanufactured products.

1.3 Goal, specific objectives and scope

The goal of this research is to investigate sustainable manufacturing opportunities in SMEs through remanufacturing strategies. In order to achieve this goal, the following four research objectives were developed.

Objective 1: to develop a framework for assessing sustainable manufacturing through remanufacturing strategies

A number of sustainable manufacturing frameworks were gathered from a review of the available published literature in order to develop a sustainable manufacturing assessment framework for remanufacturing SMEs. The majority of these frameworks focus on triple bottom sustainability including the economic, social and environmental aspects of manufacturing. However, there are no frameworks that have been specifically developed for assessing the sustainability of remanufacturing strategies for developing countries. A few frameworks consider remanufacturing as a criterion but not as main product.

Accordingly, this research develops a holistic sustainable manufacturing assessment framework for developing countries, such as Indonesia which focuses on technical aspects as well as environmental, economic and social aspects for achieving sustainability in remanufacturing activities. Technical sustainability emphasizes the reliability, durability, safety and availability of cores. Environmental sustainability focuses on key sustainable manufacturing indicators, which are energy consumption, greenhouse gas (GHG) emission, material consumption, material intensity per unit service (MIPS), solid waste and landfill generation. The relevant indicators pertaining to economic sustainability include sales, life cycle cost (LCC), recovered value, return of investment (ROI) and import dependency. Social sustainability involves employment creation, youth and enterprise development, labour wages, company reputation, intergenerational equity and corporate social responsibility (CSR).

The scope of this research focused only on the factory line aspect of remanufacturing activities, including cores collection, disassembling, initial testing, cleaning and washing, reconditioning, reassembling and final testing processes. The downstream supply chain activities including marketing, use and disposal are beyond the scope of this research. This framework has mainly been used to identify the technical, environmental, economic and social barriers which need to be overcome through improved remanufacturing activities in order to achieve sustainable manufacturing as highlighted in Objectives 2, 3 and 4.

Objective 2: to investigate the existing remanufacturing situation in Indonesia

The research is limited to Indonesian remanufacturing industries on Java Island. The remanufacturing SMEs producing remanufactured alternators were considered representative for the purpose of this investigation. Remanufactured alternators were used for this case study because of the significant increase in the demand for auto parts and the waste associated with the replacement of out of order parts with new ones. The materials, processes, energy, labour, costs, facilities, machines and methods used by the remanufacturing SMEs have been evaluated. The assessment framework enabled the identification of the lack of quality and quantity of cores, short warranty periods, low profitability, low sales and market penetration, lack of skilled labour, adverse environmental conditions and the lack of financial support which are the hurdles to achieving sustainable manufacturing among Indonesian SMEs.

Objective 3: to assess the existing remanufactured products using the sustainable manufacturing framework

The existing remanufactured products were assessed using the sustainable manufacturing framework described in Objective 1. The values of technical, environmental, economic and social criteria were calculated using a number of general formulae gathered from the literature and software applications (e.g. Relia ++, Excel and Simapro software), and then compared with the threshold values. The threshold values of these criteria were determined from the literature, by consulting remanufacturers, and in some cases by considering the optimal values of similar manufactured products. Where sustainability criteria were not met, technical, environmental, economic and social factors were identified to develop strategies for achieving sustainable manufacturing.

Objective 4: to determine the best possible remanufacturing strategies for achieving sustainable manufacturing in Indonesia

A number of improvement strategies have been proposed that can help remanufacturing industries to achieve sustainable manufacturing. The improvement of materials (i.e. new material replacement), energy (i.e. optimum energy consumption), technical skills (i.e. training), processes (i.e. safety procedures), equipment (i.e. advanced testing technology), and supply chain (i.e. expansion of the collection area) were investigated to determine technically, environmentally, economically and socially feasible solutions. An enabling mechanism has been proposed to implement the best remanufacturing strategies for achieving a sustainable manufacturing scenario for Indonesian SMEs.

1.4 Research methods

The methods used in this research were based on a comprehensive literature review, case studies and statistical and mathematical analyses. The extensive literature assisted in the development of a sustainable manufacturing framework and the awareness of state-of-the-art sustainable manufacturing and remanufacturing, from both global and Indonesian perspectives. The literature that was reviewed included published books, journals, conference proceedings, reports, unpublished dissertations, popular newspapers and magazines, and trustworthy websites of credible institutions.

The case studies were conducted on Java Island as it is the hub for Indonesian SMEs. Three remanufacturing SMEs producing auto parts (i.e. alternators) were identified based on their willingness to be surveyed. All information required for the sustainable manufacturing assessment was collected directly from these SMEs through direct observation. The data included the profiles of the three SMEs, the specification of the remanufactured alternators and the associated process, technical aspects (e.g. failure data, total number of cores, warranty period), economic aspects (e.g. material, labour and transportation costs), social aspects (e.g. number of employees) and environmental aspects (e.g. waste, material and energy consumption) and was gathered from a variety of respondents (e.g. managers, workers, policymakers) through a structured questionnaire survey.

Statistical and mathematical approaches (e.g. Weibull distribution, life cycle cost) were applied to analyze both primary and secondary data. The data analyses were conducted using established software. MS Excel and Weibull ++ software version 8 were used for the economic and technical assessment and Simapro software version 7.33 was used for the environmental assessment (PRe Consultants 2013, Reliasoft 2013).

Personal interviews were conducted with direct employees in the SMEs (e.g. managers and engineers). A number of remanufacturing stakeholders (e.g. collection centres, auto parts stores and workshops) were visited to gain understanding of the global remanufacturing market and supply chain. Supplemental data was gathered from published research journals and credible sources in order to meet the information gap to test the framework.

1.5 Significance

This research will be significant for several reasons. Firstly, the research will help to define the existing situation among Indonesian remanufacturing industries. Secondly, it will help remanufacturing SMEs to achieve sustainability by providing them with a comprehensive sustainable manufacturing framework. Thirdly, the improvement strategies will help remanufacturers to implement sustainable manufacturing operations in Indonesia through adopting new technologies, effective and efficient processes, optimal materials, energy consumption and skilled workers.. Fourthly, enabling the mechanisms for implementing sustainable manufacturing will help remanufacturing SMEs to access support (e.g. financial, technology, standards) from relevant stakeholders in the supply chain (e.g. government, original equipment manufacture (OEM), non-government organisations (NGOs), suppliers and banks).

Finally, this research will help establish relevant strategies and policies that enhance industry and government decision-making processes in striving towards sustainable manufacturing particularly in Indonesia, and sustainable development globally. Whilst the research has focussed on the Indonesian remanufacture alternator industry, the framework can be applied to other remanufactured products and other developing countries.

1.6 Thesis outline

This research thesis consists of seven chapters as presented in Figure 1.1. Chapter 1 introduces the significance, goal, objectives and scope of the research, as well as the approach to achieving the research aims.

Chapter 2 presents an extensive review of the literature on manufacturing, sustainable manufacturing, remanufacturing and sustainability, in order to identify the existing knowledge gaps which need to be addressed in this research. The chapter also highlights the urgent need for establishing sustainable manufacturing in developing countries.

Chapter 3 discusses a conceptual framework for sustainable manufacturing arising from the extensive literature review in Chapter 2. Both global and Indonesian perspectives on achieving sustainable manufacturing through remanufacturing strategies are discussed in this chapter.

Chapter 4 describes the methodology for testing the sustainable manufacturing framework, and includes data collection and analysis procedures, as well as discussing mathematical and statistical tools. A number of sustainable manufacturing threshold values are discussed in this chapter, as these will be compared with the values gathered from the existing situation

Chapter 5 presents a sustainable manufacturing assessment of the existing situation with regard to SMEs producing remanufactured alternators in Indonesia. The current technical, environmental, economic and social performances are found to be unsustainable in comparison with the threshold values. The factors impeding the sustainable manufacturing process are identified in order to determine the improvement strategies discussed in the following chapter.

Chapter 6 discusses three sequential improvement scenarios for achieving sustainable manufacturing among Indonesian SMEs. The improvement scenario represents a remanufacturing activity which is both technically and environmentally feasible. Following this assessment, the economic and social implications of the improvement scenario are conducted to test the socio-economic aspects. A sensitivity analysis is carried out to determine policy instruments for achieving socio-economic benefits.

Finally, an enabling mechanism is suggested for implementing this improvement scenario among Indonesian SMEs.

Chapter 7 presents a summary of the research findings and some strategies for achieving sustainable manufacturing in Indonesia. Potential future research opportunities are also presented in this chapter.

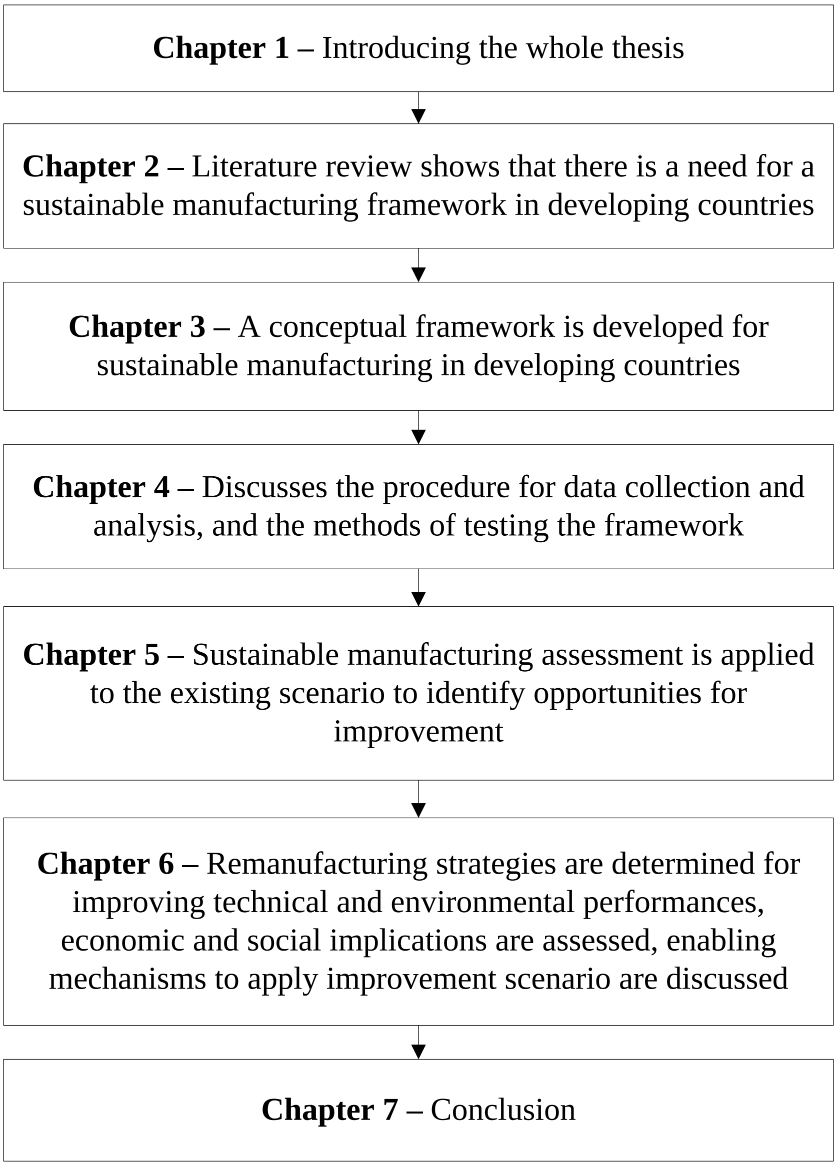

Figure 1.1 Thesis outline

Chapter 2

Literature review

2.1 Introduction

This chapter presents a review of the literature regarding manufacturing, sustainable manufacturing, remanufacturing and sustainability, in order to identify the existing knowledge gap to be addressed in this research. Secondly, it presents an overview of sustainable manufacturing including definitions and historical background. Thirdly, global manufacturing from the perspective of developed and developing countries is discussed so that the lessons learnt from the experiences of developed countries can be applied to developing nations. Next, the current trends in sustainable manufacturing are explored in order to gain understanding of the state-of-the art of 6Rs strategies. Remanufacturing seems to be worth investigating as a strategy for achieving sustainable manufacturing. Finally, the relationship between remanufacturing and sustainable manufacturing is reviewed with regard to incorporating relevant components into a sustainable manufacturing framework. Both local and international literature were thoroughly reviewed in order to acquire a sound background for conducting this research.

2.2 Overview of sustainable manufacturing

2.2.1 Emergence of the concept of sustainable manufacturing

Today, manufacturing is not only the backbone of developed society but also the economic driver of developing society (Bi 2011, Ikhsan 2007, Jovane et al. 2008). Manufacturing has become a foundation of the economic sector as it leads to wealth generation and social well-being (Bi 2011, Jawahir, Badurdeen, and Rouch 2013).

In developed countries such as the United States (US), United Kingdom (UK), Australia and Japan, manufacturing is a critical contributor to the economic sector. The manufacturing sector in the US contributed approximately 21% of the global products in 2011, while in the UK it contributed to about 11% of the economy in 2009, and to approximately 12.9% of the Australian GDP in 2011 (Bi 2011, Department for Business Innovation & Skills 2010, Department of Industry 2014).

Manufacturing is also a wealth-producing segment in developing countries. For example, Indonesian manufacturing contributed about 24% of the GDP in 2012 (Bureau of East Asian and Pacific Affairs 2012). During the period 2007–2011, the annual growth of manufacturing value added in China was about 9.9%, and in India approximately 7.5% (United Nations Industrial Development Organisation 2013).

However, the economic success associated with manufacturing activities has been followed by a dramatic increase in challenges, including waste and pollution, climate change, health problems, poverty, social bearing, decrease in biodiversity and resource depletions (Jovane et al. 2008). Accordingly, an ‘advantageous and satisfactory future’ resulting from rapid industrialization urgently requires sustainable development to help in achieving economic, social and environmental objectives (Jovane et al. 2008).

Awareness of sustainable development has been increasing since the early 1980s following concerns regarding the environmental issues associated with rapid economic development (IUCN 1980). In 1987, the Brudland-Reports and the Enquete Commission of the German Parliament described sustainable development in terms of the three pillars, including economic, social and environmental sustainability (Seliger 2012).

Further, the United Nations Conference on Environment and Development (UNCED), which was first held in Rio de Janeiro in 1992 and in Kyoto in 1997, marked the birth of global consciousness, and of interdependence and sustainability issues (van Weenen 2000). During the Rio de Janeiro conference, sustainability in manufacturing was introduced as sustainable production. Interestingly, engineers play a major role in achieving sustainable development. Soon after the 1992 Rio Summit, a systematic analysis of Agenda 21 by a group of engineers found that of the 2500 issues listed in Agenda 21, 1700 seemed to concern engineering and technical implementation, and at least 241 appeared to have major engineering applications (The Natural Edge Project 2007).

The concept of sustainable manufacturing has become more complex due to dynamic and larger scale manufacturing activities (Bi 2011). The development of the sustainable manufacturing concept has been reviewed based on manufacturing paradigms, as presented in Figure 2.1 (Bi 2011, Koren and Ulsoy 1997).

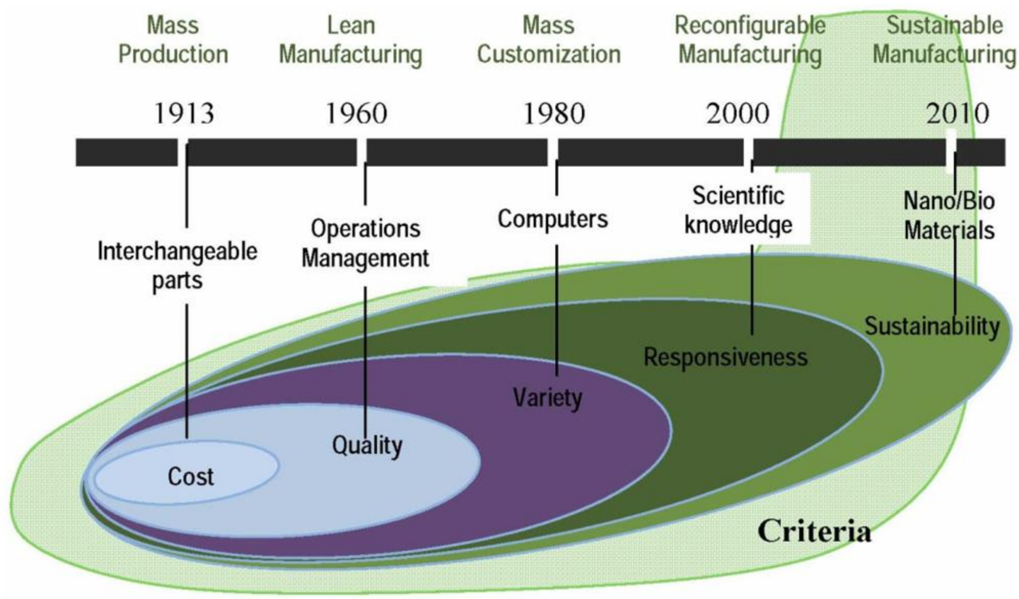

Figure 2.1 Evolution of manufacturing paradigms

The evolution of the manufacturing paradigm began before 1913, when customer requirements were concerned with the function of products (Figure 2.1) (Bi 2011). Mass manufacturing, which refers to the large scale and high speed production of products and interchangeable parts (Koren and Ulsoy 1997), was a key strategy for increasing profits as well as satisfying customer requirements (Bi 2011). However, sustainability was neglected in this phase. For example, many employees were replaced with machinery and robots, finite lifetime products (products with a short lifespan) dominated the market, and most of these products were disposable because they were cheap and easily replenished (Johnston 2014).

The focus therefore gradually shifted towards the customer due to the rapid development of information technology. In 1960's, customer demand for higher quality products increased due to greater competition among suppliers. As a result, the concept of lean manufacturing, which emphasizes the streamlining of essential aspects (i.e. resources, waste, production, transportation) and the provision of quality products at low cost (Kitchell 2014, Koren and Ulsoy 1997), became a priority for companies in order for them to meet customer requirements (Bi 2011). During this phase, manufacturing became more efficient leading to a significant reduction in the use of energy and resources and the production of waste and greenhouse gas (GHG) emissions (Brendenberg 2013).

In 1980's, the rapid development of information technology (IT) saturated the global manufacturing market. In this period, mass customization, which aimed to meet specific customer requirements through near mass and variety manufacturing efficiency (Piller 2005, Tseng and Jiao 2001), was found to be the preferred option (Bi 2011). Mass customization is more sustainable than mass production since the company produces a product that the particular customer really needs, thus reducing economic waste through reducing the use of resources (LaManna 2014, Stempeck 2013). In addition, various technological developments and comprehensive legislation changes contributed to reducing waste generation (Kimura 2011).

At the beginning of the 20th century, rapid changes in economic competition, society and technology led to the development of a more advanced manufacturing concept known as reconfigurable manufacturing (Bi 2011). The concept considers the reconfigurable hardware and software to deal with the manufacturing requirements of the present (Bi 2011, Koren and Ulsoy 1997) In relation to sustainability, this concept offers a reduction in waste and energy costs through the reuse of resources and the optimization and reconfiguration of manufacturing systems (Bi 2011).

The current trend is for people and society to be very conscious of the effect of environmental degradation and resource depletion on future generations (Bi 2011). Sustainability has become a very important manufacturing requirement, moving from being 'nice-to-have' to being a business imperative (OECD 2011). Companies have been forced to change their paradigms to accommodate these sustainability requirements (Bi 2011).

The recent concepts in sustainable manufacturing include environmentally conscious manufacturing, green manufacturing and reverse manufacturing (Anityasari 2009).

2.2.2 Definitions of sustainable manufacturing

The definition of sustainable manufacturing developed along with the emergence of the need for sustainability in the manufacturing sector.

According to the Lowell Center for Sustainable Production, sustainable manufacturing is 'the creation of goods and services using processes and systems that are: nonpolluting, conserving energy and natural resources, economically viable, safe and healthful for workers, communities and consumers and socially and creatively rewarding for all working people' (Lowell Center for Sustainable Production n.d., p. 1).

The US Department of Commerce defines sustainable manufacturing as 'the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound' (US Department of Commerce 2009, p. 1).

The Organisation for Economic Co-operation and Development (OECD) (2014) defines sustainable manufacturing as the 'reduction in the intensity of materials use, energy consumption, emission, and the creation of unwanted by-products while maintaining, or improving, the value of products to society and to organizations', while Jawahir (2008) defined sustainable manufacturing as 'the design and manufacture of high quality/performance products with improved/enhanced functionality using energy-efficient, toxic-free, hazardless, safe and secure technologies and manufacturing methods utilizing optimal resources and energy by producing minimum wastes and emissions, and providing maximum recovery, recyclability, reusability, remanufacturability, with redesign features, and all aimed at enhanced societal benefits and economic impact' (p. 37).

Rachuri et al. (2010) defined sustainable manufacturing as 'the creation and distribution (supply chain) of innovative products and services that minimizes resources (inputs such as materials, energy, water, and land), eliminates toxic substances, and produces zero waste that in effect reduces greenhouse gases, (i.e. carbon intensity), across the entire life cycle of products and services' (p. 1) .

Recent years have shown that the 'sustainable manufacturing of all products takes into account the full sustainability/total life cycle issues related to the products manufactured'. However, this manufacturing initially emphasized the production 'of renewable energy, energy efficiency, green building, and other green and social equity-related products.' (National Council for Advanced Manufacturing 2008, p. 1).

All of these definitions of sustainable manufacturing are similar in terms of addressing economic, social and environmental sustainability. These definitions look at sustainability through the same lens, focusing on economic improvement for manufacturers, social development for employees, customers and the community, and the reduction of emissions, waste and pollution.

The current research has taken these definitions into consideration in order to help develop a framework for sustainability assessment for the manufacturing sector. The lessons learnt from these concepts have enabled the conceptualization of a holistic framework that incorporates economic profitability, social equity and environmental integrity in assisting remanufacturing industries to analyze existing processes and to identify improvement strategies.

2.2.3 Key drivers for sustainable manufacturing

The key drivers for sustainable manufacturing identified through the literature review are briefly discussed below.

In developed countries such as Australia and the UK, the key drivers of sustainable manufacturing include international standards and protocols, compliance with regulations (i.e. End of Life Vehicles Directive (ELVs), Restriction of Hazardous Substance Directive ((RoHS), and Waste Electrical and Electronic Equipment Directive (WEEE)), community expectations about the impact of production and energy usage, risks and liabilities associated with investments (i.e. savings and efficiencies), costs associated with meeting regulatory constraints (i.e. costs and penalties), marketing viability and opportunities, environmentally benign technologies and corporate commitment (Badurdeen et al. 2009, Commonwealth Scientific and Industrial Research Organisation 2013, Cordoba and Veshagh 2013, Manufacturing Skills Australia 2008, Mittal et al. 2012, Sabapathy 2007).

Policy and regulation – The Australian Government has endorsed sustainable manufacturing through the implementation of a number of policies and regulations such as Australia's National Greenhouse Strategy (NGS), which encourages industries to conduct cooperative approaches (i.e. cleaner production strategies) in order to reduce the greenhouse effect associated with their production processes (Australia and New Zealand Environment and Conservation Council 1998). The US has the Green Suppliers Network (GSN) which is a collaborative venture among industry, the US Department of Commerce's Manufacturing Extension Partnership (MEP) and the US Environmental Protection Agency. The GSN works with large manufacturers to engage their small and medium-sized suppliers in low-cost technical reviews that focus on process improvement and waste minimization (Department of Commerce 2014). This relationship between large and small manufacturers seems to be absent in the case of developing countries such as Indonesia (Fatimah et al. 2013).

Standards and protocols – A number of international standards and protocols have been developed rapidly to improve global sustainability. For example, the United

Nations Global Sustainability Protocol has established a mandatory international board for tightening international standards and procedures for controlling pollution, recovering resources and developing economic activities, this has encouraged Australian companies to deal with these standards and procedures. Other environmental regulations issued in Europe—Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) and Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS)—have reduced the use of non-compliant products in Australia (Cook et al. 2013, King 2013).

Environmental regulations and schemes – The demand for sustainable manufacturing has become more important, particularly with the implementation of a number of environmental regulations and schemes (e.g. the Waste Electrical and Electronic Equipment (WEEE) Directive, carbon emission trading schemes). The application of the WEEE Directive in Germany, which is represented in the Electrical and Electronic Equipment Act (Elektrogesetz) has encouraged an increase in the recovery and recycling industries (Sander et al. 2007). Industries not complying with the regulations and scheme are subjected to regulatory pressure or may even be excluded from industrial practices (Manufacturing Skills Australia 2008).

Community concern about the impact of production and energy usage – Over the last decade, there has been increasing pressure for more environmentally friendly products. The increase in community consciousness regarding environmentally benign products has increased the demand for greener business. Companies have received pressure from the community to provide greener products which have a lower impact on the environment and energy consumption (Smith and Perks 2010).

Risks and liabilities associated with investment – Tough financial analysis concerned with environmental issues has driven the implementation of sustainable manufacturing strategies (i.e. green technology) among industries. Companies not achieving environmental sustainability would experience higher investment risks and liabilities. For example, environmental accidents (i.e. hazardous waste leaks) may cost millions of dollars in environmental clean up in the factory place (XL Insurance Environmental n.d.)

Costs associated with meeting regulatory constraints – The responsibility of companies to evaluate, report and monitor their environmental performance would increase with an increased number of environmental regulations (Manufacturing Skills Australia 2008). Achieving sustainable manufacturing has become one of the ways for industries to achieve environmental targets.

Marketing viability and opportunities – The market demand for sustainable products is growing rapidly (PricewaterhouseCoopers LLP 2010), creating market opportunities for more sustainable products (Marcaci 2013). Many companies have used these opportunities as a way of generating more revenue by producing ecofriendly products, which has encouraged the rapid development of green business (PricewaterhouseCoopers LLP 2010). Protecting the environment means protecting your profits—this is a well established concept in many industrialised nations. In the USA, the purchasing rate of green power increased to 44% in 2009 (Bird and Sumner 2010). From 2009 to 2011, green businesses grew to about 75% due to an increase in environmentally benign products, and interestingly, 79% of these businesses were small enterprises (Marcaci 2013).

Environmentally benign technologies – Environmentally benign technologies (i.e. green vehicles) are likely to be linked to the reduction of environmental impact by protecting a company's profits. For example, in developed countries (i.e. Australia), the market development of green vehicles (e.g. hybrid, electric cars) is growing, and industries have to comply with the requirement to build technology and manufacturing based on sustainable designs (Toyota Motor Corporation Australia 2010).

Corporate commitment – A number of manufacturers have committed to the comprehensive application of sustainability in their activities in order to improve their corporate business. For example, Canon can collect about 324,000 tons of their end of life (EoL) products worldwide in order to meet their zero landfill waste target by conducting a toner cartridge recycling program (Canon 2014). In addition, a number of companies (e.g. Toyota Corporation, Ford Motor Company) believe that sustainability through effective management of economic, social and environmental impacts has a direct link with their business success. Accordingly, they have committed to implementing economic, social and environmental sustainability in their businesses. Economic sustainability is achieved through cost efficiency, while social sustainability is attained through quality product and service innovations, and environmental sustainability is achieved through reductions in energy consumption and GHG emissions (Ford Motor Company 2014, Ford 2010, Toyota Motor Corporation Australia 2010). These factors were taken into consideration when developing triple bottom line (TBL) indicators for the current research.

In developing countries such as Indonesia, Malaysia, Sri Lanka and India, the drivers of sustainable manufacturing include government sponsorship, financial incentives and regulations, pressure from stakeholders in the up- and downstream supply chain, the availability of funds for green projects, improvement of existing processes, economic benefits (cost savings), company competiveness, customer demand, green technology and marketing tools (i.e. advertisement) (Amrina and Yusof 2012, Fatimah et al. 2013, Kulatunga, Jayatilaka, and Jayawickrama 2013, Mittal et al. 2012). The enabling mechanism described in Chapter 6 has taken into account these factors in implementing sustainable remanufacturing strategies.

Environmental initiatives and regulations – Governments have released a number of environmental initiatives and regulations to achieve sustainable manufacturing in developing countries (i.e. India). For example, the Indian Government established the *Environment (Protection) Act 1986* to regulate the use of hazardous materials (i.e. chemicals) in cotton industries. As a result, the consumption of chemicals (i.e. pesticides) by cotton farms was expected to decrease significantly (i.e. 30–40%) (Jena 2013).

Supply chain pressure – The pressure on manufacturing industries to provide a better environmental performance has been strongly encouraged by stakeholders (e.g. universities, non government organisations (NGOs)). The downstream stakeholders, who are responsible for selling and using the products, pressure the upstream stakeholders to reduce the environmental impact of the products through sustainable manufacturing. For example, an Indonesian environmental NGO (i.e. Indonesian Center for Environmental Law (ICEL)), has encouraged many companies (i.e. mining companies) to obtain their environmental license by conducting environmental impact assessments (EIAs) (Indonesia Environmental Feasibility Assessment (AMDAL)) in Indonesia. Accordingly, the environmental impact associated with industrial production processes can be managed (Devi and Prayogo 2013).

Availability of funds for green projects – The availability of funds for green projects is a driver for developing sustainable manufacturing in developing countries. An enormous number of funds provided by international funding organizations/agencies has encouraged SMEs in emerging countries to adopt business practices. For example, the Clean Technology Fund (CTF), which provides developing countries (e.g. Indonesia, Vietnam, Chile) with privilege resources (i.e. energy) and green technologies, has encouraged the establishment of sustainable manufacturing projects in Indonesia. A recent example is the development of a 800MW geothermal electricity generation plant (Climate Investment Funds 2014). The Clean Technology Fund can take similar initiative by providing financial support to promote sustainable manufacturing in SMEs to accelerate both the economic and environmental progress of the nation.

Economic benefits (cost savings) – Instead of increasing product quality and market share, the implementation of sustainable manufacturing practice could increase the profits of companies in developing countries (Nambiar 2010). It was predicted that the implementation of a sustainable manufacturing strategy (i.e. recycling) could be highly economically viable as the purchasing cost of recycled materials is 25% less than that of virgin materials (Jain 2012). Accordingly, cost savings have appeared to be the main driver for many companies to adopt sustainable manufacturing strategies.

Company competiveness – Amrina and Yusof (2012) states that a company's good image and reputation, and its market competitiveness are the two main drivers for achieving sustainable manufacturing in Malaysia. When companies have adopted sustainable manufacturing strategies, the company image has improved, positively influencing their competitive outcomes (Amrina and Yusof 2012). In the current research, the company's reputation improves due to the better quality of the remanufactured products, thereby causing increased sales, which ultimately will help attain both economic and social sustainability (as discussed in Chapter 6).

Customer demand – Recently, customers in both developed and developing countries have become increasingly aware that the products they purchase should have a low environmental impact during their life cycle, including the way they are produced, the distance of the journeys involved and how they are packaged (PricewaterhouseCoopers LLP 2010). In other words, products are not only judged by quality and price but also by the manufacturing methods and associated transport (Nordin, Ashari, and Rajemi 2014). As a result, many companies have been encouraged to produce more sustainable products which meet customers' expectation (Bilge et al 2014). Eco-labelling, which identifies the environmental performance of a product, has become an important requirement for customers. In Asian countries such as Indonesia, India and Korea, eco-labelling has helped the market by making customers aware of environmentally friendly products (Centre for International Environmental Law 2005). Similarly, the indicators calculated in the current research have been considered for use in eco-labelling for the remanufactured alternators (as discussed in Chapter 6).

Green technology dissemination programs – Green technology is an important driver for sustainable manufacturing in developing countries (e.g. Bangladesh)(Biswas, Bryce, and Diesendorf 2001) found that the development of renewable energy technologies could provide a self-sustaining system for supplying energy in a remote area of Bangladesh, thus empowering the rural poor economically, socially and ecologically (Biswas, Bryce, and Diesendorf 2001). The current research not only considers sustainable manufacturing as a means of improving the environmental performance, but also as a way of empowering SME workers through increased wages, thus encouraging more skilled labour to join the SMEs. This will be further explained in Chapter 6.

Marketing tools – Green marketing is an effective strategy for driving sustainable manufacturing in developing countries (e.g. India) (Saxena and Khandelwal 2010b). Saxena and Khandelwal found that customers in in India had high expectations regarding environmental friendly products and environmental protection, and showed a willingness to purchase green products. Accordingly, companies believed that green marketing strategies could be a lucrative means of developing sustainable manufacturing (Saxena and Khandelwal 2010a, Saxena and Khandelwal 2010b).

From the review of the aforementioned drivers of sustainable manufacturing in both developed and developing countries, sustainable manufacturing activities can be broadly categorized into economic, social, legislative, technological and market drivers. However, economic benefit appears to be the key driver for achieving sustainability in manufacturing globally, as cost reductions can offer multiple other benefits including the social and environmental sustainability of companies (Amrina and Yusof 2012, Pusavec, Krajnik, and Kopac 2010). For example, energy conservation in the manufacturing process decreases overhead costs, which reduces emissions associated with energy consumption, and finally reduces the life cycle cost of the product. Similarly, material minimization reduces material costs, in turn also leading to a decreased life cycle cost.

Whilst material substitution (e.g. using non-toxic materials) minimizes waste, pollution and emissions, this substitution strategy may not significantly reduce the costs. This may be because of the higher price of green materials (Blus 2008). Therefore, a number of alternative manufacturing strategies need to be considered to determine the most economically and environmentally sound option. The current research assesses both technical and environmental criteria in an initial screening process.

The increase in legislation concerning environmental issues (e.g. WEEE, ELV) has also encouraged many industries to implement sustainable strategies. The current research endeavours to carry out a socio-economic assessment of technically and environmentally viable options by utilizing sensitivity analyses, policy instruments and expansion of the SMEs (as discussed in Chapter 6).

2.3 Current trends in sustainable manufacturing

2.3.1 State of the art in sustainable manufacturing

The outlook in developed countries

Rapid economic and population growth has not only resulted in unsustainable production and consumption but also increased waste generation. The increase in waste generation has caused three main environmental issues, including materials and resources depletion, landfill generation and air, water and land pollution (King et al. 2004).

In developed countries (i.e. OECD countries), it has been estimated that municipal waste will increase by 40% by 2020 (OECD 2001). In the UK, landfill is predicted to fill up all of the available free land (Rathore, Kota, and Chakrabarti 2011). In England during the period 2003–2007, about 29.1 million tons of waste was produced and 72% of this waste was sent to landfill (Departement for Environmental Food and Rural Affairs 2005). Such a rapid increase in the disposal rate will not leave any space for landfilling after 6.5 years (Biffa waste service 2002). The dramatic increase in electronic and electrical products has also created dangerous waste consisting of hazardous materials due to a lack of solid waste management strategies (Rathore, Kota, and Chakrabarti 2011).

Developed countries have quickly responded to landfill issues by implementing laws and regulations (e.g. extended producer’s responsibility, WEEE, EuP), and developing product recovery strategies (e.g. recycling, remanufacturing) in formal sectors, to ensure environmental sustainability (Rathore, Kota, and Chakrabarti 2011). Product recovery strategies have been developed not only to attain positive economic values for the majority of the industries in OECD countries but also to enhance social and environmental values globally .

Sustainable manufacturing strategies in the US

According to Bosch Rexroth (2014), manufacturing in the US uses about 33.3% of the total annual US energy consumption. Hence, manufacturers need to control this high consumption. Six strategies have been implemented to achieve sustainable manufacturing, including optimization of present resources (i.e. fossil fuels), elimination of waste (e.g. metal, paper), reduction of pollution (e.g. dirty coolant), recycling (e.g. semiconductors), recovery of energy (e.g. hybrid cars) and saving time (i.e. being more time efficient with processes so that less energy is consumed) (Bosch Rexroth 2014).

Sustainable manufacturing strategies in Australia

Product recovery strategies (i.e. remanufacturing) have also been successfully implemented in Australia through a large number of industrial practices. Remanufacturing activities can significantly contribute to cost savings. Recom Engineering (2011) stated that about USD 10,770 could be saved by the use of remanufactured refrigeration in Western Australia, while a remanufactured compressor in Sydney could save about USD 32,310 in comparison with new products (Recom Engineering 2011). The green supply chain is another sustainable manufacturing strategy considered to be an important part of reducing the carbon tax introduced in Australia in 2010. This strategy could help Australia in reducing its carbon footprint (Recom Engineering 2011).

Sustainable manufacturing strategies in Europe

European industries have focused on various strategies including a new eco-factory model and green product manufacturing for achieving sustainable manufacturing in SMEs. The new eco-factory model consists of optimizing the use of energy streams, reducing environmental impact and improving resource efficiency as the starting point of green manufacturing (European Commission 2010). Green product manufacturing consists of resource and energy conservation and recycling (European Commission 2010). Other necessary strategies include the reduction of unwanted output (i.e. recycling), substitution of materials, energy and technologies (e.g. non-toxic, renewable energy) and the use of innovative business models (e.g. the supply chain model) (Despeisse, Ball, and Evans 2012). In the UK, the most sustainable manufacturing strategies include waste minimization, material efficiency, resource efficiency, eco-efficiency, 6R (i.e. reduce, reuse, recycle, recover, redesign and remanufacture) and supply chain integration (Cardoba and Veshagh 2013). The current research considers the application of recycled and reused components and recovered material towards attaining a technically feasible and environmentally viable remanufacturing strategy.

The German Federal Government has also adopted sustainability as its fundamental policy principle. Ioannou and Veshagh (2011) state that the sustainable manufacturing strategies most adopted by German industries include reducing resource quantity, improving resource quality, conducting EoL approaches (e.g. recycling, reuse and remanufacturing), applying industrial symbiosis and business based services, and improving working conditions (Ioannou and Veshagh 2011). The conversion of EoL products to useful resources is the most commonly used approach. The current research therefore considers a similar approach to converting EoL to remanufactured products with the aim of achieving sustainable manufacturing in Indonesian SMEs (as discussed in Chapter 6).

The outlook in developing countries

In developing countries like Indonesia, India, Malaysia and China, air emissions, pollution, waste, and exploitation of natural resources resulting from economic development coupled with rapid population have also resulted in environmental degradation (Fatimah et al. 2013).

In Indonesia, the waste created from industry increased dramatically by 80% from 1990 to 2001 (Asian Development Bank 2009). GHG emissions increased significantly by almost 100% between 2000 and 2010 (Kofod and Ward 2006). In 2010, Indonesian GHG emissions reached about 406.21 million tons CO_2-eq (US Energy Information Administration 2013). In 2008, poverty was at about 15.4% (Indonesian Bureau of Statistics 2009) and unemployment was approximately 27.6% (Asian Development Bank 2009).

In India, the population is predicted to grow to 1.5 billion, and GDP to increase to USD 4 trillion by 2030. This is in turn predicted to lead to an increase in demand for resources (i.e. coil, oil) and a significant increase in GHG emissions (i.e. 65 billion tons) (McKinsey & Company n.d.).

In China, rapid urbanization, population growth and economic development have also created critical environmental problems. In 2008, China recorded the highest GHG emissions globally, associated with fossil fuel combustion, cement manufacturing and gas burning (United States Environmental Protection Agency 2013) . In addition, waste is a critical problem that needs to be tackled (Econet China 2013), as the majority of waste is disposed to landfill (81.7%) in 2009 (China Statistical Yearbook 2009).

It appears that developing countries experience social and environmental problems associated with industry-driven economic activities. There is potential for sustainable manufacturing to reduce waste and GHG emissions, to reduce energy consumption, and to create employment by converting waste or EoL to useful resources or remanufactured products.

Sustainable manufacturing strategies in China, India and Indonesia

From a global perspective, developing countries (e.g. China) have adopted sustainability principles to achieve economic, social and environmental sustainability for the current and future generations (Guo and Marinova 2007). In India, sustainability trends including water efficiency, green energy and efficiency improvements (e.g. renewable energy), energy storage investment, RPO-REC (Renewable Purchase Obligations-Renewable Energy Certificate) mechanisms, electric vehicles and sustainable agro-infrastructure (i.e. food exports) have become important concerns in 2014 (Sustainability Outlook 2014).

In Indonesia, sustainable manufacturing strategies have been implemented through cleaner production, environmentally sound technology (EST), the 5Rs strategy (return, reuse, recycle, repair, recondition) and the green campus (Ministry of Industry Republic of Indonesia 2012, Sulistyowati 2005). A little attention has been given to remanufacturing, which is considered for sustainability assessment in Chapter 5.

Sustainability is still in the nascent stage in developing countries (e.g. China) (Guo and Marinova 2007). Product recovery strategies (i.e. reuse, recycle and remanufacture) that have been successfully implemented to solve environmental issues in developed countries are still neglected in developing countries (Damanhuri and Padmi 2012, Fatimah et al. 2013). Product recovery is mainly carried out by the informal sector[1] without well-developed facilities (Damanhuri and Padmi 2012, Mariëtte and Esther 2009). As a consequence, these industries often create more environmental problems (i.e. pollution, waste) due to inappropriate waste management practices which affect the socio-economic relationship between the ecosystem and human well-being (Puckett et al. 2005).

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[1] The informal sector consists of unorganised economic activities which are conducted illegally and without tax by small and medium enterprises in Indonesia.

In addition, product recovery processes (i.e. recycling, remanufacturing) are less efficient and effective than in developed countries. For example, gold retrieval from recycling in India and China yields 20% compared to 95% in Europe (Mariëtte and Esther 2009).

The foregoing perspectives give an illustration of the state of the art in sustainable manufacturing in developed and developing countries. Globally, sustainable manufacturing in developed countries is more organized than in developing countries as the product recovery strategies are well established and institutionalized (Rathore, Kota, and Chakrabarti 2011). Therefore, lessons from developed countries on product recovery strategies need to be applied to the industries in developing countries in order to enhance sustainable manufacturing operations.

2.3.2 Existing sustainable manufacturing strategies

A number of common strategies arose from the foregoing discussion of sustainable manufacturing in developed and developing countries, including waste minimization, material efficiency, resource efficiency, eco efficiency, cleaner production strategies, application of the 6Rs (reduce, reuse, recycle, recover, redesign and remanufacture), input substitution (from toxic to non-toxic, non-renewable to renewable), restructuring ownership, production line optimization (shortest route) and supply chain integration (Allwood 2004, Cordoba and Veshagh 2013).

The most broadly applied strategies are waste minimization and cleaner production strategies, followed by material efficiency and the 6Rs (Cordoba and Veshagh 2013). Waste minimization has commonly been implemented in those manufacturing sectors which are committed to reducing materials and waste including toxic and rare earth materials. Waste generation is a key indicator as to whether the production processes are efficient or inefficient. The larger the waste, the more inefficient the industry is. Accordingly, the implementation of waste minimization has to be taken seriously through the adoption of sustainable manufacturing strategies (Epstein

2008). The reduction of landfill size and material intensity per unit service (MIPS) are considered to be two key environmental indicators for assessing sustainable manufacturing in the current research, as explained in Chapter 4.

Cleaner production strategies (van Berkel 2006) can potentially be applied in the remanufacturing sector to increase resource efficiency and to reduce waste (OECD 2009a). These strategies embrace good housekeeping, input substitution, technology modifications, product modifications and on-site recycling (e.g. reuse and recycling) (Ashford 1994, van Berkel 2006). Good housekeeping includes operational, procedural and maintenance improvements (ie.g. avoiding leaks). Input substitution involves using less hazardous and toxic materials and more renewable materials (e.g. less chemicals). Technology modification includes efficient technology and processes. Product modifications include the modification of product characteristics (e.g. change product quality). On-site includes reuse, recovery of waste, energy and material (i.e. recycled materials) (van Berkel 2006).

Cleaner production strategies could thus help attain material efficiency, which is the ratio of materials used in comparison with the raw materials essential during the manufacturing process of a product (Epstein 2008). In Chapter 6, good housekeeping and on-site recycling strategies, which are more relevant to remanufacturing operations, are considered through the incorporation of improved testing procedures and the use of recycled and reused components.

The 6Rs strategy is composed of reduce, reuse, recycle, recover, redesign and remanufacture, symbolizing a science-grounded, inclusive and assessable framework for sustainable product assessment (Joshi et al. 2006). Reuse refers to the use of secondhand products without any major repair (e.g. when a used vehicle is used for the same purpose), while repair involves altering failed products to make them functional once more (i.e. upgrading), recovery is taking back old products for reprocessing (e.g. repainting), redesign is changing the design concept of a product (e.g. making it a lighter product, modular type), recycling is taking a component/material to be reprocessed into similar materials (e.g. recycled copper, recycled casing) and remanufacture is bringing back worn products for reconditioning into something similar to a new product (e.g. a remanufactured engine) (Gray and Charter 2007, Ijomah et al. 2007, Steinhilper 1998a). The current research has carefully considered these criteria for selecting remanufactured products.

The implementation of the 6Rs strategy through four life cycle stages including pre-manufacturing, manufacturing, use and post use needs to be considered holistically in order to achieve real sustainability (Figure 2.2) (Badurdeen et al. 2009).

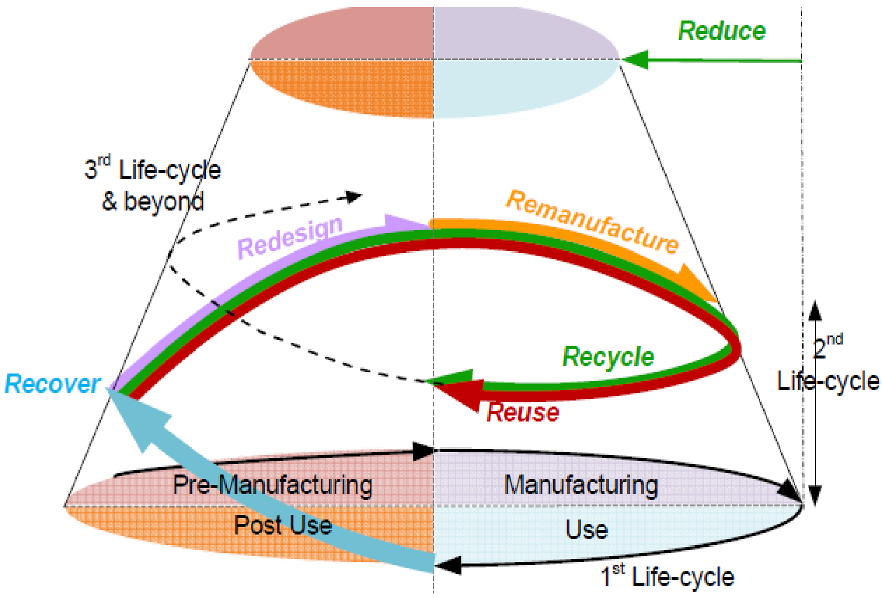

Figure 2.2 The 6Rs approach to sustainable manufacturing

As can be seen in Figure 2.2 above, the implementation of the 6Rs strategy could lead to a significant reduction in the material utilized in the pre-manufacturing stage, a more efficient manufacturing phase, the minimization of resources during the use phase, the extension of the product life cycle, and the effective reuse or recycling of the EoL product (Badurdeen et al 2014). The 6Rs strategy therefore represents a significant improvement opportunity in comparison to current manufacturing strategies (e.g. "traditional, lean, and green') and previously applied R strategies (e.g. 1R, 3R) (see Figure 2.3) (Badurdeen et al. 2009).

2.3.3 Transformation from 1R to 3Rs to 6Rs

Sustainable manufacturing has emerged from the transformation of 1R (reduce) to 3Rs (reduce, reuse and recycle) and then to 6Rs over the period 1980–2014 (Jawahir et al. 2006), as illustrated in Figure 2.3.

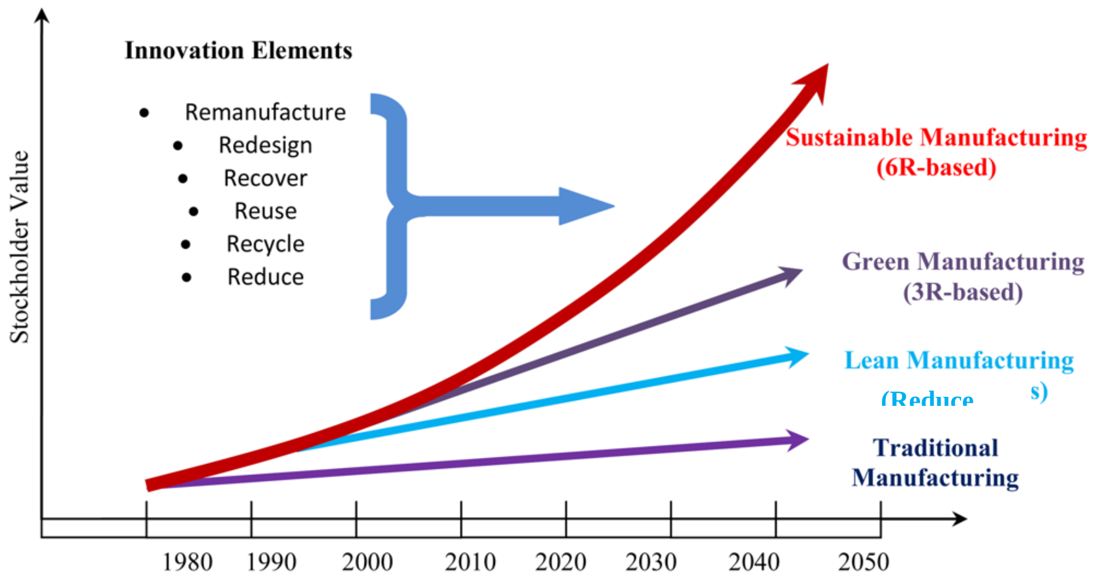

Figure 2.3 Transformation from the 1R to 3Rs and 6Rs approaches

Manufacturing has traditionally been conducted without considering sustainability (Roxwell Automation 2009). Productivity improvement, reductions in cost and work, and compliance with regulations were usually key drivers of business improvement and enhancement (Rosen and Kishawy 2012).

Lean manufacturing, which is represented as the 1R (reduce) approach, has the goal of reducing all waste associated with essential human activities, including human effort, time, costs, materials and processes to meet customer demands and product quality in an efficient and economical manner (Pavnaskar, Gershenson, and Jambekar 2003). The implementation of lean manufacturing in developed countries (e.g. Japan, Germany) has not only provided significant economic benefits such as improved productivity, customer satisfaction and manufacturing cost reductions, but has also substantially reduced environmental impact, including waste reduction (Ahrens 2006, ReliablePlant 2014). The current research thus intends to explore the impact of technically and environmentally sound remanufacturing strategies on the social economic situation (see Chapter 6).

The 3Rs (reduce, reuse and recycle) concept was introduced during the 1990s (UNEP 2005) and was especially concerned with reducing resource and energy consumption, and reusing and recycling used materials and waste. The 3Rs concept has been extensively implemented by many formal sectors in many developed countries (e.g. Japan, Germany) and has successfully made manufacturing greener (Badurdeen et al. 2009, UNEP 2005).

In Japan, the 3Rs strategy has become an important part of waste management and has been given the highest priority in the last decade. A number of regulations associated with this strategy have been established (i.e. the Packaging Recycling Act), in order to change the Japanese people’s perception of and behaviour regarding environmental issues. Accordingly, the market for reused and recycled products increased significantly from USD 1.1 billion in 1997 to USD 4.1 billion in 2010 (Tasaki, Yamakata, and Numata 2010). A 3Rs strategy conducted for PET bottles created a greener product which was lighter, had no aluminum closures, and had easily removable labels (Japan Containers and Packaging Recycling Association 2014, Ministry of the Environment 2005) .

In Germany, the 3Rs have been reinforced as integral concepts since the mid-1980s (Jaron 2005). In order to implement such acts as the *Closed Substance Cycle and Waste Management Act (1996)*, *End-of-Life Vehicle Act (2002)* and *Act on the Disposal of Information, Office and Communications Technology Equipment (2005)*, the 3Rs strategy (return, recycle and recover) were applied. These acts emphasize waste reduction, the promotion of low waste products and waste incentive development (EPA 2013a) . As a result, about 80% of waste paper could be reused, about 80% of materials (e.g. cars) could be recovered, and about 72% of used batteries could be recycled (Jaron 2005).

Similarly, in developing countries (e.g. China, Indonesia, the Philippines, Thailand, Malaysia), the 3Rs approach to environmental conservation has also grown significantly..

In China, the 3Rs strategy has been approached through the law of ‘circular economy’ which was established in 2005. This law is closely linked to cleaner production strategies and industrial ecology which emphasize pollution reduction and resource efficiency (i.e. recycling of energy, water and materials) (EPA 2013b) .

In Indonesia, the 3Rs strategy was promoted at the National Conference on Cleaner Production in April 2003, and then documented in the National Policy on Cleaner Production in September 2003. This strategy has been applied in many industries including industrial estates, the palm oil industry and the tourism industry (Sulistyowati 2005), with no attention given to small manufacturing industries in Indonesia.

In Philippine, the legislation relating to the 3Rs strategy is presented in the *RA9003 Act* (2000) which emphasizes solid waste recycling and composting. Similarly, in Malaysia the promotion of the 3Rs strategy has been conducted through the *Solid Waste and Public Cleaning Management Corporation Bill 2007*, while in Thailand, the *Law for Promotion of Waste Reduction and Utilization* emphasizes the need for recycling in society (Sang-Arun 2014).

However, the application of the 3Rs strategy in developing countries is far behind that in developed countries (Visvanathan and Norbu 2006), due to a lack of knowledge, shortage of skilled workers, underdeveloped infrastructure and a lack of advanced technologies (Sang-Arun 2014). 3Rs activities in those countries have not been able to demonstrate their benefit to the environment (Chiu 2010, UNIDO 2009, Visvanathan and Norbu 2006).

In addition, the 3Rs should not be confused with sustainability because the 3Rs approach—reduce, reuse and recycle—do not match the three perspectives of the closed-loop strategy, the four phases of the product life cycle and the guide innovations fundamental to achieving sustainable manufacturing, and the triple bottom line of sustainability (Badurdeen et al. 2009). As a result, the number of Rs was increased to form the 6Rs approach (reduce, reuse, recycle, recover, redesign and remanufacture), which is a 'science-based, comprehensive and quantitative' concept for strengthening sustainable manufacturing operations (Badurdeen et al. 2009, Ferguson and Browne 2001, Jawahir 2008, Joshi et al. 2006)

The 6Rs approach consists of the following elements *Reducing* – This is the designing of products to minimize the use of virgin materials and resources, minimize the generation of waste sent to landfill and emissions, and also to reduce the amount of toxic waste (USEPA 2008, Zhang 2012).

Reusing – This is the use of parts or products that have already been used. There is no reprocessing involved as the useful parts of products are taken directly to be used. Inspection and cleaning processes are usually carried out. This strategy aims to reduce the use of virgin materials by reusing useable parts or products (Zhang 2012).

Recycling – This is the process of changing used or waste materials (i.e. metals, plastic, and papers) for original purposes (USEPA 2008). In this case, the identity and functionality of products are usually removed from the original products (King et al. 2006).

Reconditioning/recovery – In this process, a used product is returned to a satisfactory working condition that may be inferior to the original specifications. Generally, the resultant product has a warranty that is less than that of a newly manufactured equivalent. The warranty applies to all major wearing parts (Ijomah, Childe, and McMahon 2004)

Redesigning – This is the action of redesigning products to reduce the post-use processes by applying techniques (i.e. design for the environment, easy disassembly to achieve more sustainable products (Badurdeen et al. 2009). Fuji Xerox is the perfect example as Fuji Xerox products have been redesigned in such a way that about 90% of the parts can be recovered and then utilized (Fuji Xerox 2012).

Remanufacturing – The process of returning a used product to at least the original equipment manufacturer (OEM) or original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured product (Biswas and Rosano 2011, Ijomah, Childe, and McMahon 2004). This valuable strategy has been applied to complex products (e.g. electromechanical and mechanical products), which have higher value added.

Therefore, in order to achieve sustainability benefits in terms of the conservation of resources and achievement of social equity, endorsing the 6Rs approach in manufacturing practice needs the cooperation and integration of 'the pre-manufacturing, manufacturing, use and post use' stages into product life cycle management (Badurdeen et al. 2009). If this condition can be achieved, a significant development from the traditional, lean and green manufacturing practices can be reached. Thus the current research has dealt with the remanufacture of alternators which provided opportunities for applying most of the 6Rs, including reuse, reduce, recover, recycle and remanufacture, but not the redesign strategy as it is completely dependent on the OEM.

2.4 Remanufacturing

Of the 6Rs discussed above, remanufacturing has been highlighted as a potential strategy to meet the sustainable development of a country (Xiang and Ming 2011). Remanufacturi(Kutz 2007). In addition, remanufacturing offers better economic advantages (i.e. higher prices) than other strategies (Lund 2005). Thus remanufacturing has been chosen as the means of achieving sustainability in this thesis. The definition of remanufacturing by Sundin (2004) is as follows:

> ‘Remanufacturing is an industrial process whereby products referred as cores are restored to useful life. During this process the core pass through a number of remanufacturing steps, e.g. inspection, disassembly, cleaning, part replacement/refurbishment, reassembly, and testing to ensure it meets the desired product standards.’ (p. 2).

According to various definitions of remanufacturing (Hauser and Lund 2008, Ijomah et al 1998, Matsumoto 2009), remanufactured products have a product profile that includes looking like new and being in the same condition as a brand new product, providing a technical performance similar to a new product, having a warranty period similar to that of a new product, having a lifetime similar to a new product, and a lower price (Hauser and Lund 2008, Ijomah 2010, Matsumoto 2009, Shaharoun n.d.).

Remanufacturing is an industrial process whereby products, referred to as cores, are restored to useful life. During this process, the cores pass through a number of remanufacturing operations, e.g. inspection, disassembly, part reprocessing, reassembly, and testing to ensure they meet the desired product standards (Sundin 2004).

Remanufacturing, which is the transformation of used products to a state similar to new, with warranty to match, may bring more economic, social and environmental benefits than conventional manufacturing because it offers more potential profits, employment opportunities and reduction of environmental impact (Giuntini and Gauddette 2003, Gray and Charter 2007, Hatcher, Ijomah, and Windmill 2011, Lund and Hauser 2009, Steinhilper 1998b).

2.4.1 Why remanufacturing is a gateway to sustainable manufacturing for developing countries

Remanufacturing is a gateway to achieving sustainable manufacturing in developing countries for the following reasons.

Technical competency

Remanufacturing offers better or similar quality and reliability to new products, supported by an appropriate warranty period (Andrew et al. 2006, Steinhilper 1998a). It provides the same or even better technical performance (e.g. reliability, durability) than new products, as the worn or failed components are usually replaced with durable ones. The remanufactured products are therefore more reliable, durable and have a longer life than new products (Nasr 2012, Steinhilper and Brent 2003).

In addition, the application of advanced technology and quality assurance in testing processes (e.g.100% inspection) provides the remanufactured products with higher quality and reliability in comparison to new products (Steinhilper 1998a). A similar approach has been considered for improving product quality in the current research.

Because the remanufactured products are generated by an appropriate standard remanufacturing process (e.g. certified by ISO/TS 16949:2002, ISO 14001), the products offer about the same quality as new products with reduced energy consumption (e.g. 50% to 80%) and less cost (20% to 80%) (Michell Cotts Ltd n.d.).

In addition, remanufacturing solves reliability and safety issues, especially for businesses with certified quality (i.e. aviation) (Brent and Steinhilper 2004). Reliable technologies which meet the applicable standards (i.e. ISO 9000, ISO 14000) are therefore applied to a wide range of remanufacturing industries (Steinhilper and Brent 2003).

However, economic (i.e. sales), social (i.e. employment creation), environmental benefits (e.g. GHG emissions) and technical competency (e.g. reliability, safety) issues are still serious problems, especially for remanufacturing activities in developing countries (Brent and Steinhilper 2004). In fact, developing countries are far behind developed countries in their implementation of remanufacturing. The following section describes the remanufacturing gap between developed and developing countries in order to identify strategies to make remanufacturing sustainable in developing countries.

Environmental benefits

Remanufacturing offers environmental returns associated with the saving of energy and materials, and the reduction of waste, landfill area and GHG emissions.

A remanufacturing process can save about 422 $x10^{21}$J of energy annually which makes up about 80% of manufacturing energy (Gallo, Romano, and Santilo 2012). Gray and Charter stated that energy savings from remanufactured products are similar to the electricity consumption of five nuclear power plants, which is equivalent to about 10,744,000 barrels of crude oil (Gray and Charter 2007). Remanufacturing requires only about 1/7 time of energy than conventional manufacturing processes (Steinhilper 1998b). Previous researchers have affirmed that a remanufactured product is less energy intensive (by 50–80%) than a new one (Sundin, Lindah, and Ijomah 2009) .

GHG emissions could be reduced to approximately 800,000 tons due to reductions in materials and energy consumption (Gray and Charter 2007). Another study reported that the GHG emissions of an automotive engine could be decreased from 15,300 to 11,300 tonnes CO_2-eq through remanufacturing (Liu. S. 2005). Biswas and Rosano (2011) stated that the GHG emissions resulting from manufacturing new compressors could be significantly reduced (by about 89.4–93.1%) by considering remanufacturing scenarios (Biswas and Rosano 2011).

Remanufacturing reduces material consumption by 26–90% and solid waste by 65–88% (Smith and Keoleian 2004). A Ricoh remanufactured photocopy machine is composed of about 93% used components, thus creating only about 10% waste (Matsumoto and Umeda 2011). Another study found that remanufacturing only needs about 1/9 of the materials used in manufacturing (Steinhilper 1998b). The Fuji film company state that approximately 82% of used camera parts are reused (Matsumoto and Umeda 2011). As a result, a significant quantity of waste which is usually contaminated with high levels of hazardous materials (e.g. cadmium, mercury) can be avoided through remanufacturing, and the quantity of waste sent to landfill much reduced.

Economic benefits

Economically, remanufacturing is a profitable business (Gallo, Romano, and Santilo 2012). Cost reductions associated with the maximum use of reused materials and the minimum use of new materials and energy consumption may lead to a significant reduction in price (35–40% of the new product price) and achieve a satisfactory profit margin (20%) (Nasr et al. 1998). A remanufactured engine could save about 30–53% the price of a new one (Smith and Keoleian 2004).

According to Ijomah and Chiodo (2010), remanufacturing can save about 20–80% of the total cost of manufacturing by expanding the life of used products and reducing landfill costs (Ijomah and Chiodo 2010). In addition, the value added in a remanufactured product (i.e. the cost of material, energy and labour) is conserved by reusing, reconditioning and remanufacturing (Rathore, Kota, and Chakrabarti 2011) . Thus, remanufacturing provides greater economic benefits than other product recovery strategies (e.g. recycling) (Rathore, Kota, and Chakrabarti 2011). A study conducted by Hauser and Lund found that the remanufacturing industry is worth about $53 billion in the United States (Hauser and Lund 2008).

Research conducted by Biswas and Rosano (2011) found that a remanufactured compressor contributed only about 6.9–10.6% of the additional carbon tax of a new compressor based on Australia's previous carbon pricing scheme. In addition, the life cycle cost (LCC) of the remanufactured compressor was 34% less than the new ones, resulting in a 50% cheaper price (Biswas and Rosano 2011, Biswas et al. 2011).

Social benefits

Remanufacturing is a labour intensive activity and it requires skilled workers (Andrew et al. 2006, Chapman et al. 2009). For example, in India remanufacturing contributes about 50% of casual labour which could place India as a remanufacturing target due to affordable labour costs (Mukherjee and Mondal 2008).

Remanufacturing has an essential social impact (i.e. intergeneration equity) associated with the use of less energy and materials during the remanufacturing process. For example, if it was estimated that remanufacturing could save about 85% of energy to produce one remanufactured product, there would be about 10.7 million barrels of crude oil saved (Gray and Charter 2007). By providing significant energy savings in the next decade, remanufacturing can maintain the security of energy sources for future generations by avoiding upstream energy consumption.

Most remanufacturing industries are small enterprises employing only a few labourers. However, if the business performance of the small enterprises could be improved (e.g. increased sales and labourers) there would be potential for those small enterprises to become medium or even large enterprises. Therefore, solid collaboration is essential between small enterprises and their stakeholders as such improvements require high investment (Gray and Charter 2007). The current research takes this suggestion into account when assessing the economic feasibility of a remanufactured alternator in Chapter 6.

2.4.2 Remanufacturing gap between developed and developing countries

Drivers of remanufacturing

Whilst some researchers have stated that remanufacturing mainly developed due to economic concerns (Nasr and Thurston 2006), in European countries (e.g. UK, Germany) it came about due to environmental concerns (Ostlin, Sundin, and Bjorkman 2008).

In Japan, economic and environmental incentives are primary drivers for remanufacturing activities. Remanufacturing businesses have grown significantly in developed countries due to economic benefits and environmental regulations.

Unlike developed countries, remanufacture is a relatively new strategy in developing countries (e.g. China, Indonesia). In China, economic profitability remains the key motive for remanufacturing business (Xiang and Ming 2011). In Indonesia, the majority of product recovery strategies (recycling, reconditioning and remanufacturing) are still underdeveloped and many of these industries are informal in their activities (Fatimah et al. 2013, Darisman 2011). The motive behind remanufacturing is likely to be economic reasons (Ramdansyah 2011). The development of EoL activities (e.g. reusing, reconditioning, remanufacturing, recycling) began when the economic crisis took place in Indonesia (Ramdansyah

2011). As a result, the market demand for reused, reconditioned and remanufactured products increased significantly in the Indonesian domestic market.

It appears from these facts and figures that environment is one of the key drivers of remanufacturing in developed countries, reflecting their strong laws and regulations and public awareness of the environment.

Profitability of remanufacturing

In developed countries (e.g. the US), remanufacturing offers a double profit margin (Steinhilper 1998a, Lund and Hauser 2009) due to the effective and efficient remanufacturing process. Research conducted by Fatimah et al. (2013) found that the economic values of remanufacturing SMEs in developing countries (e.g. Indonesia) are less than the threshold or optimum values gathered from developed countries' best practices (Fatimah et al. 2013).

In Brazil, a remanufactured product is only 25% of the life cycle cost of a new product, and from the customer's perspective, remanufactured products cost 50% the price of new ones (Saavendra et al. 2013).

In India, remanufacturing saves about 40–65% of material costs, which reduces the price of a remanufactured product to 30–40% that of a new product. Thus it can be concluded that there are financial savings associated with the purchase of remanufactured products instead of new ones in both developed and developing countries. However, developed countries make more money out of remanufactured products than developing countries by the improving quality of the remanufactured product using sophisticated technology and good quality cores.

Environmental legislation

As mentioned earlier, remanufacturing in developed countries is driven by legislation such as the Energy using Products (EuP) Directive, the End of Life Vehicles (ELV)

Directive, and the Waste Electrical and Electronic Equipment (WEEE) Directive (Gray and Charter 2007), which has significantly accelerated the development of remanufacturing industries. In European countries, remanufacturing development was encouraged by the implementation of environmental legislation presented in directive 2002/96/EC for WEEE and directive 2000/53/EC for ELV (Hatcher, Ijomah, and Windmill 2011, Lund 1984). Other legislations in developed countries such as Germany (e.g. packaging materials and waste management legislation) has led to green policies which increase the growth of remanufacturing (Statham 2006).

By contrast, in China there is an absence of legislation, which does not encourage investment in remanufacturing industries (Hatcher, Ijomah, and Windmill 2013). The legislation for remanufacturing activity was only enacted when the environmental impact created by vehicles received serious attention from the government. Extended producer responsibility (EPR) was asserted to develop the legislation (Xiang and Ming 2011), in order to enable remanufacturers to collect quality cores.

Even though the Indonesian government has introduced environmental regulations, they are not applied effectively due to unclear and ambiguous implementation laws and policies (Agustina 2010). The EuP, ELV and WEEE directives were found to be non-existent. As a result, remanufacturing activities and other product recovery industries (especially SMEs) are often found to be affecting the environment and human life. Therefore, environmental legislations in the developed countries had strengthened the position of remanufacturing in the developing countries.

Return of cores

The used, worn and old products collected by remanufacturers are commonly called ‘cores’ (Lund 1994). The return of cores by the customer to the remanufacturer is one of the key barriers to the successful implementation of remanufacturing strategies (All-Party Parliamentary Sustainable Resource Group 2014) . The unpredictable product lifetime, quantity and quality of returned products is due to the unpredictable life cycle of products and rapid changes in technology, and this has created uncertainty regarding the supply of cores and products for remanufacturing activities (Ostlin 2008a). In the case of Brazil, nearly 15% of remanufactured products failed to meet customer requirements due to the uncertainties associated with the delivery of the required amount of quality cores (Saavendra et al. 2013).

Krikke, Le Blanc, and van de Velde. (2004) claim that there are four essential sources of cores for remanufacturing , including end of life (EoL), end of use, commercial and re-usable component returns. EoL returns involve taking back cores from market due to take-back laws for environmental or commercial reasons (e.g. electrical and electronic waste). End of use returns involve taking back cores after they have been used by customers (e.g. terminated lease products). A commercial return is the taking back of cores from sales (i.e. returned products under warranty). Reusable components returns involve taking back cores from the consumption, use and distribution of full product (e.g. toner cartridges) (Krikke, Le Blanc, and van de Velde 2004, Ostlin 2008a). EoL return mainly exists in developing countries, otherwise, the application of these four types of returns would have supplied more quality cores and parts for remanufacturing.

As discussed earlier, the implementation of these return methods have not been found to be sustainable due to the ineffective and inefficient mechanisms in developing countries. Saavendra et al. (2013) affirm that remanufacturing possibilities could be enhanced mainly by maintaining the supply of quality cores . The current research has taken the experience of collecting cores into account in designing improvement strategies for remanufacturing.

Market demand

Remanufactured products have enormous market potential in both developing and developed countries (Atasu, Sarvary, and van Wassenhove 2008). Remanufacturing activities are carried out all around the world (Asia, Europe, Africa and America) and have generated business worth about USD 100 billion (Vasudevan et al. 2014). The US as the largest market contributed about USD 53 billion sales annually (Lund and Hauser 2009).

The market demand for remanufactured products is often influenced by price and quality. Affordable price and a satisfactory level of product quality are two important aspects considered by customers when buying remanufactured products instead of new products (Debo, Toktay, and van Wassenhove 2005, Ferguson 2009, Vasudevan, Kalamkar, and Terkar 2012). However, remanufacturers can offer high prices when a strong market is established (All-Party Parliamentary Sustainable Resource Group 2014). Therefore, remanufacturers need to carefully determine the best price in the market in order to gain reasonable economic benefits (i.e. profit).

Corporate social responsibility

Corporate social responsibility is an important factor in supporting remanufacturing business in developed countries, since it offers long-term benefits not only for economic purposes but also for social welfare, goodwill and environmental conservation (Gallo, Romano, and Santilo 2012, Matsumoto and Umeda 2011).

However, corporate social responsibility is a new paradigm in developing countries (e.g. Indonesia) and is only acknowledged by a few companies (Koestoer 2007). Promoting and understanding corporate social responsibility through workshops, media and public forums in developing countries is urgently required (Koestoer 2007, UNIDO 2002)

Skills of workers

Whilst remanufacturing provides potential job opportunities, there is also a need for skilled workers and the costs associated with improving their skills (All-Party Parliamentary Sustainable Resource Group 2014). Because of inadequate automation in the remanufacturing process, SMEs are heavily dependent on manual works. Although too much automation could displace jobs, this affects the intergenerational equity of sustainability; thus a certain level of automation is needed to increase productivity without causing job losses. Therefore, human intelligence and skills are necessary for increasing the production of quality remanufactured products (Gray and Charter 2007).

This is not a big issue for many remanufacturing industries in developed countries, as the majority of industries have highly skilled manpower and financial stability compared to those in developing countries (South East England Development Agency 2005). Therefore, for developing countries, this issue is a double-edged sword where the remanufacturing helps in reducing unemployment, while on the other hand it demands great financial investment in the education and training of skilled labour (Barquet, Rozenfeld, and Forcellini 2013). The lack of financial power among remanufacturing industries in developing countries becomes a key barriers to them improving the skills of workers (Shaharudin, Zailani, and Choon 2014).

Technology and infrastructure

Appropriate technology and infrastructure are important factors in the successful implementation of remanufacturing sophisticated products (e.g. electronic and electrical products) (Hatcher, Ijomah, and Windmill 2013).

In developed countries (e.g. Australia), technologies are applied in order to achieve energy efficiency and waste reduction (e.g. machinery and processes) (Manufacturing Skills Australia 2008). However, the technology in developed countries is far more advanced than in developing countries due to the need for products to be competitive in the international market (Luger, Butler, and Winch 2013). The requirement for industries within developed countries to be more competitive has encouraged the development of more sustainable and green technology than in developing countries. For example, among manufacturing SMEs in the UK, about 50% have introduced green technologies (e.g. low carbon technology) (Organisation for Economic Co-operation and Development 2014). The UK's Carbon Trust claims that a small investment in greener technology could reduce energy consumption by 20% and could increase company profit by approximately 5% (Organisation for Economic Co-operation and Development 2014).

Thus it can be concluded that remanufacturing SMEs in developed countries have mainly been established in order to compete with new products, while affordability is the main reason for the growth of remanufactured products in developing countries.

In developing countries, infrastructure levels are rather lower than in developed countries. Infrastructure such as roads, telecommunications and electricity are essential factors for remanufacturing activities. Therefore, a lack of appropriate telecommunications, networks and databases in developing countries (e.g. Indonesia) has constrained industry development (Hatcher, Ijomah, and Windmill 2013, Fatimah et al. 2013). All of these lessons have been taken into consideration when developing an enabling mechanism for the implementation of the sustainable remanufacturing strategy.

Technical aspects

Remanufactured products are often viewed negatively customers, mainly due to the lower reliability of the remanufactured products compared to new products (All-Party Parliamentary Sustainable Resource Group 2014). In addition, an unclear definition of remanufacturing plus the absence of the desired quality of remanufactured products have led to a loss of customer confidence in remanufactured items (Barquet, Rozenfeld, and Forcellini 2013).

However, the majority of industries in developed countries (e.g. Japan, Germany) have applied reliable technologies (e.g. automated testing machines) and adopted international product standards in order to maintain the quality and reliability of their remanufactured products. In addition, the legal concept of remanufacturing and certified marks (i.e. remanufactured product labels, ISO 9000, ISO 14000) attached to remanufactured products have enhanced customer belief in the quality and reliability of their products (All-Party Parliamentary Sustainable Resource Group 2014).

The adoption of similar strategies (i.e. the legal concept of remanufacturing, remanufactured product labels, quality standard labels) could strongly increase customer belief in the quality and reliability of the remanufactured products in developing countries. This suggestion has been considered in the enabling mechanism discussed in Chapter 6 with the idea that the incorporation of eco-labelling for the remanufactured alternators might make them more exportable in the carbon constrained economy.

2.4.3 The remanufacturing process

Globally, remanufacturing begins with the process of disassembly, cleaning, inspection, reconditioning, reassembly and testing (Steinhilper 1998b, Sundin 2004), as presented in Figure 2.4 (modified from Steinhilper (1998b). However, the sequential order of the remanufacturing process may be different depending on the product being remanufactured (Saavendra et al. 2013).

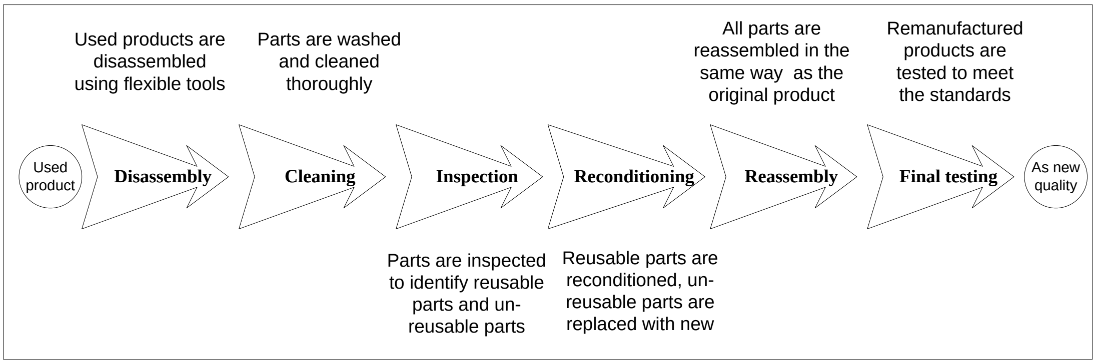

Figure 2.4 The remanufacturing stages

Disassembly process

The disassembly process starts once the used products are received at remanufacturing plants from the core collection process. The used products are usually disassembled manually into single components followed by initial testing to determine the reusability of every single component, thus this process is a labour intensive activity (Steinhilper 1998b). The disassembly process separates used products into reusable, non-reusable and harmful sub-parts. Hence, flexible equipment is required (e.g. unscrewing tool) for loosening, fixing and handling processes (Seliger et al. 2001). In addition, the appropriate disassembly tools need to be used to make this process economically and environmentally viable.

Cleaning process

Next, all of the reusable components are thoroughly cleaned of dirt, oil (de-oiling), grease (de-greasing) and rust (de-rusting). The cleaning, which also includes washing, is the most time-consuming process in remanufacturing (Steinhilper 1998b, Sundin 2004). A number of chemical agents (e.g. chemical detergent) are commonly used in the washing process. Other chemicals such as alkali, phosphoric acid and decarbonizer are also often used for the cleaning and washing processes (Biswas et al. 2011). Cleaning methods including sandblasting, baking ovens, hot water baths and steel brushing are also used for complicated tasks (Steinhilper 1998b). However, the cleaning process is becoming more ‘environmentally friendly’ by the introduction of cleaner technologies (e.g. steel shot blasting) (Brent and Steinhilper 2004).

Inspection process

The inspection process is a further step to identity the performance of all disassembled parts. The disassembled parts are then categorized into reusable without reconditioning and with reconditioning, and not reusable (Steinhilper 1998b). To maintain the reliability and accuracy of all parts, advanced testing technology and equipment is necessary.

Reconditioning process

Reconditioning is conducted to improve the quality of reusable parts. It ensures that the parts retain the same quality and functionality as the original performance by applying geometrical changes and standardization (Steinhilper 1998b). Chemicals, structure stress treatment, surface coating and modification technology are also often used (Xu 2013). The reconditioning process occupies a wide range of workplaces as it commonly utilizes a number of machines and equipment (e.g. milling, grinding, lathes) (Steinhilper 1998b). In addition, a number of advanced technologies (e.g. ‘automated nano-particle composite brush plating technology, non-destructive testing assessment techniques and methods’) have been used to improve the reconditioning process (Xu 2013, p. 11). However, there is often little automation of the process due to the small batches of products, thus this reconditioning process is labour intensive (Steinhilper 1998b). Non-reusable and worn parts are replaced with used or new parts.

Reassembly process

The reassembly process is then conducted for all reusable, reconditioned parts and new parts (Steinhilper 1998b). This process is conducted using the same equipment and tools for assembling new products. This process therefore is also labour intensive because the reassembly process is mostly done manually (e.g. using a hand gun and electric impact wrench) (Biswas et al. 2011)

Final testing

The remanufacturing process ends with comprehensive testing which is usually carried out on each reassembled product to ensure that the quality of the remanufactured product is similar to that of a new product. As 100% inspection is conducted for each of the remanufactured products, the quality and reliability of the products is often higher than for new ones. Advanced technologies are crucial to ensuring the accurate performance assessment of the remanufactured products (Steinhilper 1998b).

Figure 2.5 presents a typical inventory of inputs, processes and stages of the remanufacturing operation in a SME in Perth, Western Australia (Biswas et al. 2011).

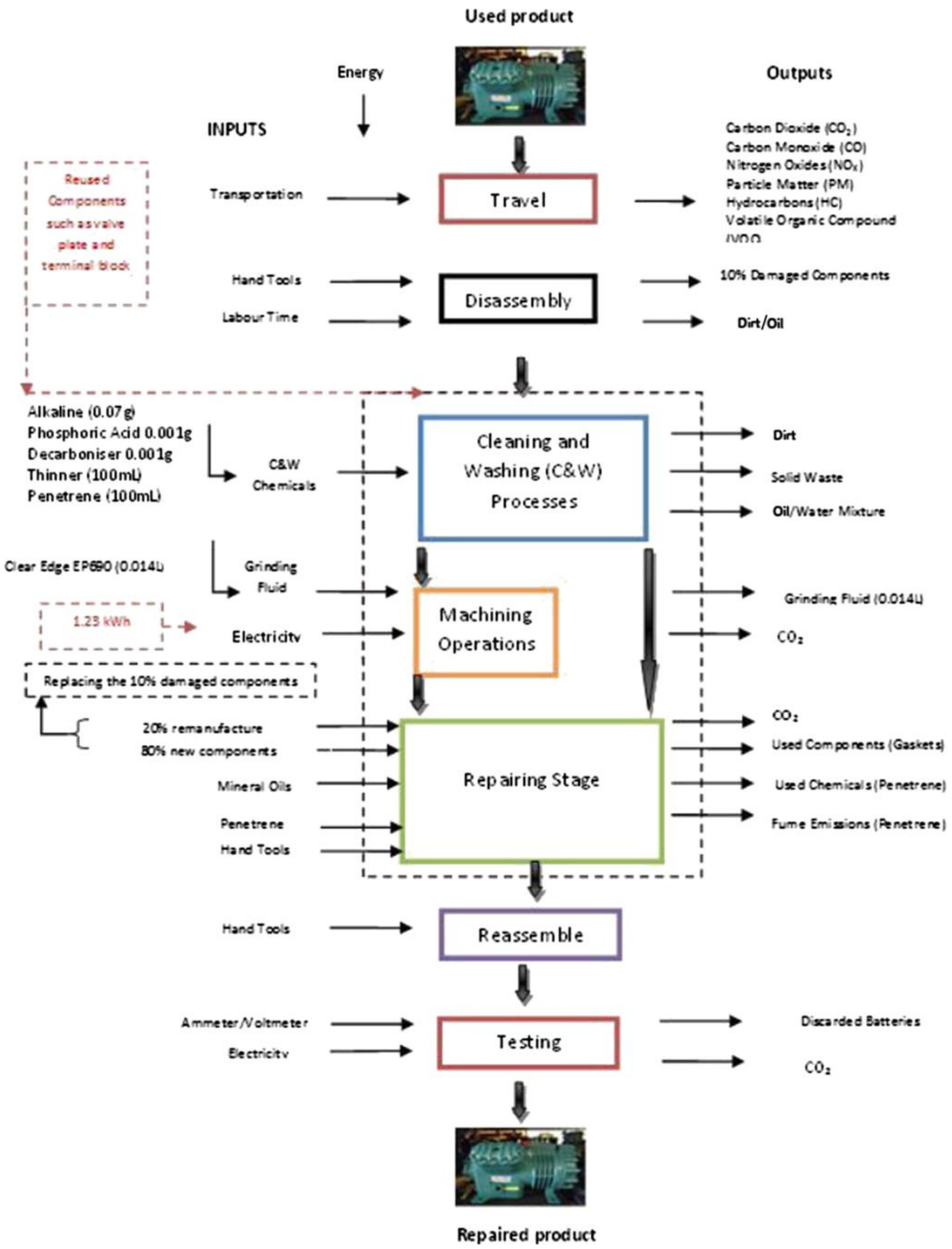

Figure 2.5 A typical inventory of inputs, processes and stages of a remanufacturing operation

2.4.4 Case of Indonesian remanufacturing SMEs

Whilst remanufacturing in developed countries (e.g.. the UK, Germany and Japan) has been successfully conducted for many decades, in Indonesia this industry is still in its infant stages. The current situation shows that there is potential to develop more remanufacturing activities in Indonesia in the future due to the following reasons.

- A large population (260 million) means a large labour force, which can be employed in remanufacturing activities.
- The lack of purchasing power of Indonesian customers to buy new and expensive products could create a market for affordable, remanufactured products.
- The rapid development of the population and industrialization has created a large amount of waste and used products which could potentially be used as cores.

However, achieving sustainable manufacturing through a remanufacturing strategy is still an enormous challenge for many SMEs in Indonesia. The potential obstacles for developing remanufacturing in Indonesia are similar to those experienced in other developing countries (e.g. India, China). The majority of the remanufacturing industry is still undercover, neglected and environmentally unfriendly due to inadequate technology and a lack of skilled workers, improper standardization, insufficient quantity and quality of cores, lack of financial mechanisms, lack of technology and waste management (Fatimah et al. 2013, Rathore, Kota, and Chakrabarti 2011, Tan et al. 2014, Zhang, Wang, Chu, and Cui 2010).

Remanufacturing covers a wide range of Indonesian industrial sectors including automotive products and parts (e.g. alternators), electrical and electronic appliances (e.g. televisions), tyres, heavy equipment, computers and office furniture (Agustina 2007, Anityasari 2009, Ramdansyah 2011). However, not all of these remanufacturing industries are known as remanufacturers. Many of them are commonly called refurbishing and reconditioning industries.

The automotive industry is the greatest contributor to and the longest practitioner in remanufacturing sectors worldwide (Golinska and Kawa 2011). It also contributes to two thirds of global remanufacturing activity (Kim et al. 2008). Similarly, in Indonesia, remanufacturing activity also plays a significant role in the automotive industry due to the high demand for replacement parts. Generally speaking, about 10% of a vehicle’s parts need to be replaced during their lifetime (Golinska and Kawa 2011).

In terms of market opportunity, the demand for remanufactured auto parts in the domestic market especially in Indonesia is often influenced by the demand for affordably priced products. However, there has been pressure to reduce the price of remanufactured products in order to compete with new local products and cheap Chinese products on the market. In fact, the quality and reliability of remanufactured products are often far below that of new products sold by the remanufacturers’ competitors. As a result, this is a challenge for remanufacturers to increase their sales and therefore the production of their products, so that prices are further reduced due to economy of scale. In the screening process for the sustainable manufacturing framework being developed in the current research, priority has been given to technical considerations involving high quality products, which is vital for attracting customers..

Remanufacturing industries continue to play a secondary role in the Indonesian market due to a number of challenges. The lack of availability of cores, insufficient remanufacturing knowledge, a shortage of skilled workers, the technological gap, and the absence of infrastructure and financial support are the major challenges for Indonesian remanufacturing SMEs (Fatimah et al. 2013). Thus, poor quality, unreliable, unsafe, and non-standards products with short warranty periods are commonly found among remanufacturing SMEs (Fatimah et al. 2013).

Many of the remanufacturing SMEs also have a poor understanding of the environmental issues associated with their remanufacturing activities. A lack of efficient and effective procedures, a lack of green technologies and a lack of standardization (i.e. ISO 14001 series), have increased the environmental impact and have impeded the development of sustainability among the SMEs

Accordingly, remanufacturing SMEs often encounter uncertainties with the growth of their industries due to the aforementioned issues. Only a few Indonesian remanufacturing industries, such as PT Komatsu Remanufacturing, PT Sanggar Sarana Jaya remanufacturing, Indonesian railways company and Veneta remanufacturing cartridge have recognized the benefits of remanufacturing strategies (Fatimah et al. 2013, Komatsu Reman Indonesia 2009, Santoso 2012, Veneta Indonesia 2012).

The growth of the remanufacturing industry needs to be accelerated in order to achieve the economic, social and environmental sustainability of the SMEs.

2.4.5 Sustainability implications of remanufacturing

Remanufacturing has been successfully applied in many industries globally, including automotive, electronics and electrical devices, computers, office furniture, heavy equipment and tyres (Rathore, Kota, and Chakrabarti 2011, United States International Trade Commission 2012).

Globally, remanufacturing promises sustainable prosperity by offering higher economic values (i.e. double profit margin) accompanied by a significantly reduced environmental impact (e.g. GHG emissions) and enhanced social equity (i.e. job creation) (Gray and Charter 2007, Oakdene Hollins 2004).

In developed countries such as the US, Germany and the UK, remanufacturing is a giant industry. In the US, remanufacturing business produced aboutUSD 37 billion in 2009 and increased about USD 43 million in 2011 (United States International Trade

Commission 2012). In US, the number of full-time workers over 70,000 remanufacturing companies was approximately 180,000 employees (United States International Trade Commission 2012). Remanufacturing in the UK was estimated to contribute EUR 5 billion per year to the economy and involved 50,000 employees in 2004 (Oakdene Hollins 2004).

The implementation of remanufacturing activities offers opportunities to reduce environmental impact (e.g. GHG emissions, landfill, solid waste) and resource consumption (e.g. energy, materials) (Gray and Charter 2007). Remanufacturing saves about 800,000 tons of CO_2 emission annually (Oakdene Hollins 2004).

There is potential to develop remanufacturing industries in Indonesia and other developing countries. However, many Indonesian customers, the government and other stakeholders have not been aware of the benefits of remanufacturing activities (Ramdansyah 2011). A lack of data on remanufacturing industries has also impeded identification of the current contribution made by the industries (Fatimah et al. 2013).

The following section identifies a number of constructive and obstructive factors with regard to developing remanufacturing SMEs.

2.4.6 Constructive and obstructive factors for remanufacturing SMEs

Core collection activity

The collection method is one of the important components in successfully implementing a product recovery strategy, because it influences both the reusability of cores (i.e. their quality and reliability) and collection costs (Anityasari 2009). According to Hanafi, Kara, and Kaebernick (2005), there are about six collection methods, including kerbside, on call kerbside, scavengers, service centre, return with sales and drop off collections (Hanafi, Kara, and Kaebernick 2005).

Similarly to the case in developed countries, where the reverse process for collecting cores is a challenging factor for the remanufacturing industry due to the uncertainty of demand and supply of cores and their quantity and quality (Golinska and Kawa 2011), the core collection activity is one of the critical issues for Indonesian remanufacturing industries. The used products gathered from the aforementioned suppliers are likely to be few and diversity, thus it is difficult to maintain a continuous supply of the used products. In addition, due to the low market price orientation, remanufacturers commonly buy used products from suppliers which offer lower prices. The lower cost of the cores leads to a lower price for the used products, and may also mean they are of poor quality (Saavendra et al. 2013).

Ineffective communication resulting from a lack of interaction between suppliers and remanufacturers, a lack of customer knowledge and a lack of expectations for remanufacturing activities have been identified as barriers to the dissemination of remanufacturing (Saavendra et al. 2013).

Marketing

Ambiguity in remanufacturing definitions is a crucial issue in marketing remanufactured products (Melissen and Ron 1999). The term remanufacturing is often confused with reconditioning and repairing, thus customers are often doubtful about whether to buy the remanufactured products due to uncertainty about their quality (Ijomah, Childe, and McMahon 2004). Another issue often faced by remanufacturers is the acceptance of uncertainty associated with the use of remanufactured products by the customers (Lund and Hauser 2009).

The majority of customers lack knowledge about remanufacturing activities, thus they rarely purchase remanufactured products (Tan et al. 2014). A study found that about 75% of respondents had heard about remanufactured products, and only about 30.6% of them would be interested in purchasing remanufactured products (Tan et al.

2014). As discussed earlier, the only way to change customer perceptions is to make the product more reliable, durable and competitive.

Market establishment is crucial for remanufacturing business. Marketing barriers can be overcome by reducing misconceptions and the essential assumption of poor quality remanufactured products, applying legislation in favour of remanufacturing products, redefining the relevant remanufacturing strategies for each of the EoL products (i.e. reuse, reconditioning, remanufacturing) properly (Gray and Charter 2007). Promotional activities for remanufactured products could also be a potential means of building up customer trust in remanufactured products (Guide, Harrison, and van Wassenhove 2003).

Legislation, policy and initiatives

As just mentioned, legislation plays a significant role in the successful implementation of remanufacturing businesses in developed countries. In the US, the rapid movement of sustainability has encouraged government policy makers to appreciate the benefits of remanufacturing and recommend US government agencies to purchase remanufactured and recycled products (Nasr 2012). Furthermore, assistance was also needed to remanufacturing industries through funding (i.e. technology transfer, financial assistance), purchasing directives and tax benefits (i.e. tax reduction, tax deferments) (Nasr 2012), which encouraged the development of the industries.

In China, remanufacturing has been strongly supported by regulations. In 2010, a document titled ‘Opinion on Promoting Remanufacturing Industries’ was formulated and issued by 11 Chinese ministries. This document is used as guidance on technology, management and policy protection for developing remanufacturing industries (Tan et al. 2014, p. 2).

However, in Indonesia, unclearly defined and opaque regulations, laws and policies have impacted the remanufacturing SMEs and have often created technical problems for the SMEs. For example, the restriction of imported products and components have reduced the availability of cores for SMEs (Fatimah et al. 2013). Accordingly, the impact of regulations and policies on the remanufacturing industry in Indonesia needs to be clearly defined with regard to the importing of essential items required for sustaining the industry.

Community expectations

In some developed countries with a high level of concern for the environment, the priority of the community is for a clean and green environment which is free from waste and risks (King et al. 2006). The awareness of having a clean and green environment has encouraged them to understand the importance of product recovery strategies (e.g. reuse, recycling and remanufacturing). Therefore, remanufacturing activities have been acknowledged by the community as an effective way of reducing waste. Communities in developed countries have a higher expectation of waste management strategies through the application of the 6Rs than communities in developing countries, including Indonesia (Meidiana and Gamse 2010).

Population and waste generation

In Indonesia, the population was approximately 228.5 million in 2008, and it is predicted to reach approximately 262 million people in 2020 (Asian Development Bank 2009). It is expected that this population growth will generate a significant quantity of waste and used products. Solid waste was generated at about 80.2 thousand tons per day in 2007, and was predicted to increase five times by 2020 (Kardono 2007). The rapid increase in vehicles was also expected to result in an increased quantity of used auto parts (Indonesian Commercial Newsletter 2010). The waste and used parts could potentially be used as cores for remanufacturing activities.

Zero landfill

The concept of 'zero landfill' plays an important part in increasing carrying capacity and reducing the ecological footprint in developed countries (Wollongong City Council 2010). The UK government established four priorities for a waste management strategy, including waste reduction (e.g by increasing durability), waste reuse (i.e. remanufacturing), waste recovery (i.e. recycling) and waste landfill (i.e.decreasing landfill) (King et al. 2006).

'Zero landfill' is a goal currently being considered in developing countries (e.g. China, Indonesia). Fuji Xerox Eco-Manufacturing is a remanufacturing enterprise that has actively participated in zero landfill actions by continuously applying the 3Rs strategies (reduce, reuse, and recycle) (Fuji Xerox 2011).

Waste management is a challenging factor for many developing countries such as Indonesia. A 'zero waste to landfill' policy integrates appropriate practices for waste management. The implementation of 4Rs strategies (reduce, reuse, recycle and recover), accompanied by sustainable consumption and production implementations could help achieve the 'zero waste to landfill' goal. Therefore, government policies and strategies need to be developed accordingly (Hatta 2011), which will not only reduce the size of 'sink' but will also reduce 'sources' by avoiding upstream activities..

Resources, technology and financial capabilities

Indonesian remanufacturing SMEs often suffer from a lack of resources, technology and financial capabilities. For example, the majority of SMEs are financed by a family member with a very limited budget (Tambunan 2006). In addition, they have very limited access to bank credit due to a lack of a good business track record (e.g. sales data and progress) (Fitrianto 2009). There are also ineffective, efficient and environmentally unfriendly remanufacturing processes in place mainly due to a lack of appropriate resources and advanced technologies (Fatimah et al. 2013). These often make it difficult for SMEs to access loans for the expansion of their industries.

Labour force and labour skills

The labour force in Indonesia reached 115 million in 2010, and 118 million in 2012 (World Bank 2014). Remanufacturing is labour intensive and needs a high number of employees, especially in the disassembling process (Gray and Charter 2007). The large number of people in the labour force provides potential opportunities to develop the remanufacturing industry in Indonesia. Remanufacturing needs specialized skills which can be improved through training and education, thus enabling the development of workers' skills.

Standardization

Uncertainty of quality assurance and negative perceptions by which remanufactured products are treated as second-hand products are two main barriers to the promotion of remanufactured products (Golinska and Kawa 2011). In developed countries (e.g. the UK, Japan, Germany andthe US and developing countries (e.g. China), the standard of remanufacturing products and processes have been set to overcome the aforementioned barriers (Standardisation Administration of the People's Republic of China (SAC) 2013).

For example, the UK has developed British Standard 8887-220, presenting the design for remanufacturing processes. (Golinska and Kawa 2011, Standardisation Administration of the People's Republic of China (SAC) 2013). The US, through SAE J 2237-2008, has formulated the heavy-duty starter remanufacturing procedures (Standardisation Administration of the People's Republic of China (SAC) 2013). China has also proposed GB/T 28618-2012, presenting the remanufacturing general technical requirements for mechanical products (Standardisation Administration of the People's Republic of China (SAC) 2013). These standards are aimed at maintaining the quality of remanufactured products at a level similar to their original performance (Golinska and Kawa 2011). The use of standards is expected to increase the customer's confidence in buying remanufactured products.

However, the standards for remanufacturing products and processes are still very limited and have not comprehensively covered all remanufacturing areas. Especially in developing countries, Indonesia for example, the standards of remanufacturing products and processes need to be developed since there is little awareness of the competitive benefits of standards, and manufacturers are unsure of the benefits and costs of applying the standardization. In addition, the organization of remanufacturing standards has been found to be absent in ISO and other standardization organizations (i.e. American National Standards Institute (ANSI)) (Standardisation Administration of the People's Republic of China (SAC) 2013).

2.5 Remanufacturing for future sustainable manufacturing

2.5.1 Drivers and enabling mechanisms for promoting remanufacturing

Understanding the drivers of remanufacturing is a prerequisite to developing appropriate strategies and policies for the industry (Ostlin 2008b). According to Cunha et al. (2011), there are about 10 common drivers for remanufacturing including EoL regulations, increasing reusability, economic viability, OEM remanufacturing, new markets, product service systems, remanufacturing inside users, new demand, green labelling and certifying by association (Cunha et al. 2011).

Other researchers have stated that the drivers for remanufacturing are profit (i.e. cost reduction, new business strategies, new product sales and entry to new market segments, providing spare parts), policy (i.e. protecting aftermarket volumes, brand protection, gaining information on customer needs, providing additional aftermarket solutions) and environment (i.e. legislation, moral and ethical considerations) (Ostlin 2008b). The drivers for promoting the remanufacturing industry in Japan are long-term economic incentives instead of long-term environment incentives (Matsumoto and Umeda 2011).

Therefore, the drivers for remanufacturing are not similar between the industry and individual businesses. In Indonesia, the drivers for promoting the remanufacturing industry are market demand and economic benefits from the remanufactured products (Fatimah et al. 2013). Therefore, in order to achieve sustainability, the integration of appropriate drivers such as profits, policy and environmental impacts will provide 'win-win solution' opportunities such as higher quality products at affordable prices (Ostlin 2008b).

2.5.2 Future approaches and strategies for remanufacturing

Design for remanufacturing

Improving the sustainability of remanufactured products can be achieved through sustainable product design which is represented in design for remanufacturing (DFM) at the product strategy levels (i.e. marketing, collection activities) and the detailed products and manufacturing levels (Nasr and Thurston 2006). Therefore, DFM should be at the detailed products and manufacturing levels including design for disassembly, design for multiple life cycles and logistics for product recovery opportunities. DFM evaluates some important considerations such as the value and cost of parts, the technical and economic feasibility of remanufacturing, the discharged options and the legislation of environmental (Nasr and Thurston 2006).

Supply chain improvement

Remanufacturing often faces complex issues in supply chain activities due to the ambiguity of the market, stocks, unpredictable remanufacturing times and inadequate material reserves (Zhou 2010). Accordingly, an integrated problem solving approach to optimizing the supply chain is definitely required. Radio frequency identification (RFID) technology could be a beneficial means of solving this problem. This will help remanufacturing industries to reduce waste (e.g. economic and environmental perspectives), to increase remanufacturing efficiency, to facilitate the design of products, and to develop customer relationship management (CRM) (Zhou 2010).

Technology and information development

Technology is a standalone sustainable dimension (Jovane et al. 2008). It plays an important role in achieving sustainability since it helps in providing a beneficial correlation between the economic, social and environmental aspects (Jovane et al. 2008, Seliger et al. 2008). However, technology can conserve or worsen the environment (Chertow 2001). Accordingly, manufacturing should consider the optimization of technology for minimizing energy and material consumption, waste and pollution, while improving economic and social values (Molamohamadi and Ismali 2013).

Within the advancement of the remanufacturing strategy, there are a number of new and advanced technologies by which the performance of a remanufactured product can be improved and the environmental impact reduced.

Green or clean technology (e.g. solar panels, waste water treatment) could be introduced to attain green manufacturing industries which are more economic and environmentally sustainable (Cunha et al. 2011). A number of coat engineering technologies (e.g. 'nano less mount intelligent self-repairing additive technology, automated high velocity arc spraying technology') which have been successfully used to improve remanufactured products in China could be adopted (Xu 2013, p. 11). In addition, technical approaches to remanufacturing involving eco-efficiency systems, materials efficiency, design for disassembly, standardization, modularization, manufacturing control and services (Cunha et al. 2011) could also be applied to achieve the sustainability.

Education and training

Education is important for developing an understanding of the sustainability of remanufacturing concepts and practices among employees, customers and the community. A number of countries have started to introduce sustainability into their schools' mainstream curricula, and there is also a need to provide education to customers and the community. In addition, specific training programs for sustainability have also been offered to experienced employees in many industries, developing environmentally friendly strategies (OECD 2009b). Accordingly, education and training programs need to be implemented in order to successfully develop remanufacturing.

Future enabling strategies

Government plays the most important part in improving sustainability practices, especially for SMEs, through legislation, directives and assistance (Abreu et al. 2011, Li, Xu, and Li 2009). Legislation and directives which discriminate against remanufactured products need to be revised. In addition, an important action to improve the remanufacturing business is 'kicking out the obstacles' (i.e. lack of quality and quantity cores, lack of advanced technologies, shortage of skilled workers), which have become significant barriers to the development of remanufacturing SMEs (Spelman 2014).

A number of studies (Amrina and Yusof 2012, Golinska and Kawa 2011, Matsumoto and Umeda 2011) claim that returns of EoL products, ineffective and inefficient remanufacturing processes, financial support, technology and infrastructure, skills of employees, government legislation, societal expectations and market strategies are usually the significant obstacles for the remanufacturing business.

A key part in achieving a future remanufacturing market is to adopt a legal definition of remanufacturing. This approach could increase the confidence among producers and consumers and permit remanufacturers to be covered by legal certification schemes (Spelman 2014). Another strategy is to introduce a legal definition of waste in order to reduce negative perceptions by showing that this waste can potentially be used as a resource. Both of these approaches are expected to encourage manufacturers to conduct remanufacturing activities instead of developing market potential for remanufactured products (Spelman 2014).

Standardization is an effective way to develop remanufacturing activity. Greater use of standards applied in remanufactured products needs to be developed in order to increase the confidence level of customers in purchasing remanufactured products. A number of standards which have been applied in some developed countries (e.g. UK – BS8887, US – SAE J 2237-2008) and developing countries (i.e. China – GB/T 28619-2012) (Golinska and Kawa 2011, Morley 2013) could be showcased in other countries to develop more standards for remanufacturing products and processes. In addition, it is necessary to involve the International Organization for Standardization (ISO) (e.g. ISO 9000, ISO 14000) and other standardization organizations (i.e. the International Electrotechnical Organization for Standardization (IEC) in remanufacturing areas to receive more economic and environmental benefits.

Other enabling strategies include knowledge management development, continual improvement in price, quality and responsibility, government–academia interface, improvement of creative environment, supply chain integration, knowledge creation and the role of the media, and engagement with industry and government and education to promote sustainable manufacturing enterprises.

The aforementioned sections have given a vivid picture of the opportunities for achieving sustainable manufacturing through remanufacturing. Remanufacturing has become an important part of manufacturing and economic development. In fact, it has been identified that the present remanufacturing activities, especially in developing countries, are generally unsustainable because of ineffective mechanisms for remanufacturing processes (e.g. core collection, testing, disassembly, washing and cleaning, reconditioning, reassembly and final testing), accompanied by a lack of remanufacturing knowledge and technology and equipment, shortage of skilled workers and marketing issues.

Accordingly, the adoption of appropriate sustainable manufacturing strategies involving the concept of the 6Rs for remanufactured products is essential in achieving economic, social, environmental and technical sustainability. This sustainable manufacturing strategy for remanufactured products is required to achieve technical sustainability (i.e. higher reliability) first, then environmental sustainability (i.e. lower GHG emissions) and economic sustainability (i.e. higher sales), and social sustainability (i.e. more employees).

2.5.3 The need for a sustainable manufacturing framework for SMEs in developing countries

Sustainable manufacturing strategies have rapidly been recognized due to serious environmental concerns and economic reasons in manufacturing activities worldwide (Rosen and Kishawy 2012). Much attention has been given to improving the ways of achieving economically, socially and environmentally viable solutions. A number of sustainable manufacturing frameworks (Jawahir, Dillon, et al. 2006, Jawahir, Rouch, et al. 2006, Nasr 2012) have recently been developed to achieve economic, social and environmental sustainability in the developed countries.

As presented in this chapter, remanufacturing appears to offer an effective way of achieving sustainable manufacturing in developed countries. Environmental and economic drivers plus legislation pertaining to remanufacturing, financial assistance and marketing initiatives have promoted the market for remanufactured products.

In the case of developing countries, there is potential for achieving sustainable manufacturing through remanufacturing activities, but there is an absence of legislation, policies, financing mechanisms, institutional frameworks, supporting mechanisms including the availability of good quality cores and used parts, computerized information databases, training opportunities and promotional activities.

Therefore, the current research has developed a sustainable manufacturing framework for promoting remanufactured products among SMEs in developing countries, as explained in detail in Chapter 3. This framework takes into account quality control, environmental performance, economic feasibility, social impact, policy instruments and enabling mechanisms for dissemination as well as gaining public acceptance of remanufactured products like new products in the market.

The lessons learnt from the successful application of sustainable remanufacturing have motivated the author to propose a remanufactured product which is same as the new product in terms of quality and which also meets the environmental standards. The production of quality remanufactured products will help SMEs to earn customers' trust and confidence, boosting sales and reduce the price, which has both positive social and economic implications.

Chapter 3

Sustainable manufacturing framework for remanufactured products

3.1 Introduction

This chapter discusses the theoretical framework that has evolved from the extensive literature review in Chapter 2 which discussed past, present and future sustainable manufacturing scenarios from both global and Indonesian perspectives. Secondly, the chapter discusses the premise for developing a sustainable manufacturing framework (SMF) especially aimed at the situation in developing countries. Thirdly, a sustainable manufacturing assessment framework (Fatimah et al. 2013)[2] developed for this research is discussed with regard to assessing the sustainability of the remanufacturing situation in developing countries. Fourthly, the chapter investigates some key Indonesian remanufacturing small medium sized enterprises (SMEs) to which this SMF can potentially be applied in order to achieve sustainable manufacturing. Finally, the upstream and downstream activities of some common SMEs are reviewed in order to understand the supply chain of the SMEs' remanufacturing activities for sustainability assessment purposes.

3.2 Thematic aspects of sustainable manufacturing frameworks (SMFs)

The SMF in this research is based on the definition of sustainable manufacturing by Jawahir (2008) which is:

> the design and manufacture of high quality/performance products with improved/enhanced functionality using energy-efficient, toxic-free, hazardless, safe and secure technologies and manufacturing methods utilizing optimal resources and energy by producing minimum wastes and emissions, and providing maximum recovery, recyclability, reusability, remanufacturability, with redesign features, and all aimed at enhanced societal benefits and economic impact (Jawahir 2008, p. 37).

As discussed in Chapter 2, remanufacturing is one of the key ways to attain sustainable manufacturing in SMEs, especially in the context of developing countries. This is mainly because investment in remanufacturing has been found to be a sustainable manufacturing strategy that helps to provide economic, social and environmental benefits (Gray and Charter 2007). However, achieving sustainable manufacturing through remanufacturing strategies is still a challenging task in

[2] This framework was developed for this PhD research.

developing countries such as Indonesia, due to the lack of knowledge, technology, experience and resources.

Accordingly, a SMF has been developed in order to achieve the triple bottom line benefits of a sustainable manufacturing scenario in Indonesian SMEs. A number of advanced frameworks and models for achieving sustainable manufacturing have been gathered from the literature and reviewed thoroughly to determine the thematic aspects of the SMF.

Jawahir et al. (2006) have presented a comprehensive evaluation framework of product sustainability throughout the entire life of a product. The framework is illustrated with the aid of a product sustainability wheel representing three pillars of sustainability, including the economic, societal and environmental aspects. The framework emphasizes that the development of design and manufacturing processes through all stages of the product life-cycle (i.e. pre-manufacturing, manufacturing, use and post-use) is essential in order to improve the sustainability of manufacturing a product. To achieve sustainable manufacturing, the comprehensive framework needs to focus on the application of the 6Rs: reduce, reuse, recycle, recover, redesign and remanufacture.

The six thematic aspects identified in this SMF are environmental friendliness, manufacturing cost, personal health, operational safety, energy consumption and waste management (Jawahir and Dillon 2007).

The environmental friendliness encompasses environmental impact, including GHG emissions, water consumption, dangerous disposal and noise levels from outside a factory. The energy consumption includes in-line energy consumption, energy consumption for the transportation in-out line, and the use of renewable energy. Manufacturing cost includes minimizing the costs of labour, material and maintenance. Personal health focusses on the hazards associated with chemical contamination, dust and noise levels inside the factory. Waste management considers the management of end of life (EoL) products including reuse, recycling and disposal (Lu et al. 2010).

In another framework by Seliger et al (2006), it was clearly explained that sustainable engineering should focus on global sustainable manufacturing. In this framework, the development of technology is considered to be an important dimension of sustainable manufacturing which can help in achieving economic, social and environmental sustainability. Seliger et al (2006) define sustainable engineering as 'the application of scientific and technical knowledge to satisfy human needs in different societal frames without compromising the ability of future generations to meet their own needs' (Seliger, Kernbaum, and Zettl 2006, p. 368).

The challenge in achieving sustainable engineering is to increase the usefulness of products and processes while decreasing environmental impact.(Seliger, Kernbaum, and Zettl 2006). Technology has a significant role in processing natural resources into a variety of products, and can also be used to convert waste to resources for reducing pressure on environment. Therefore, consumption of resources, standard of living and environmental burdens need to take into account in order to meet the sustainability goal (Seliger, Kernbaum, and Zettl 2006).

Nasr and Thurston (2006) have focussed on sustainable production as a means of improving the economic, societal and environmental sustainability of remanufactured products incorporated with products or services delivered from remanufacturers to customers. The analytical framework required to achieve sustainable production consists of resources, product, employment, economic factors, societal factors, environment and supporting infrastructure.

'Resources' concerns the depletion, degradation and efficiency of resources, while 'product' focusses on the design, durability, quality and packaging of products.

‘Employment’ encompasses the health, safety, security, satisfaction and income of the employees involved in the production, while ‘economic factors’ refers to value added investment. ‘Societal factors’ includes the development of community and social impact (i.e. good community relationships). ‘Environment’ concerns the waste, emissions and sound influenced by production, and finally ‘supporting infrastructure’ focusses on telecommunication and transportation (Nasr, Hilton, and German 2011b).

Another thematic aspect has also been considered, which is based on the three dimensions (economic, social and environmental) of sustainable manufacturing as illustrated in Figure 3.1 (Organisation for Economic Co-operation and Development 2014).

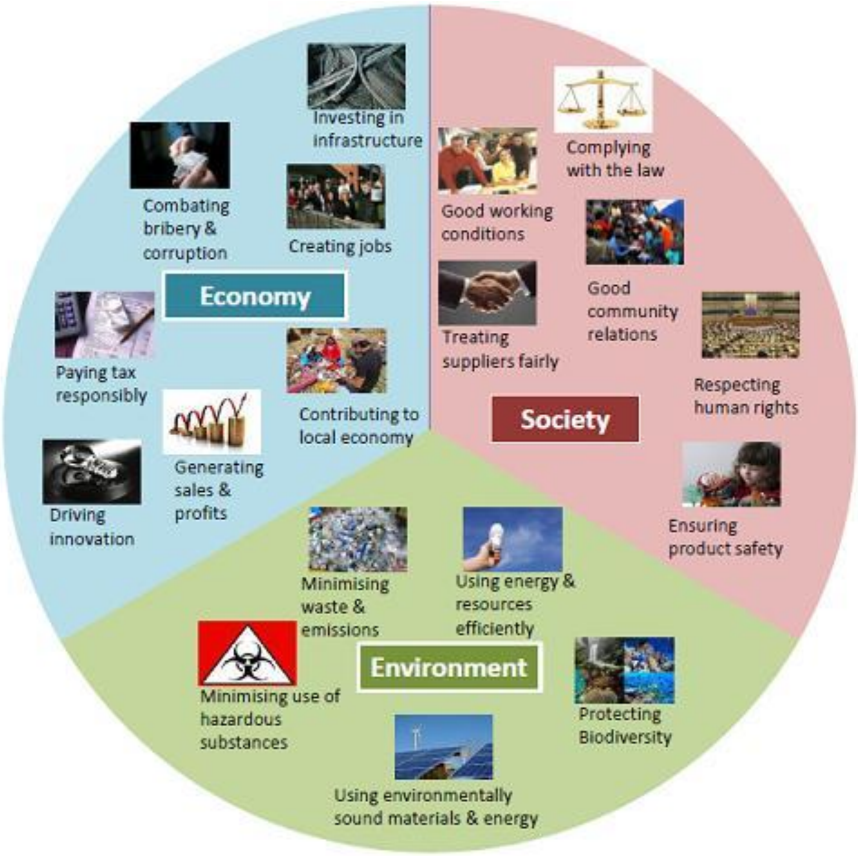

Figure 3.1 The three dimensions of sustainable manufacturing

As can be seen from the diagram above, each of the three dimensions encompasses a number of aspects. From the aforementioned frameworks, it appears that the development of SMFs has focussed on specific economic, social and environmental aspects through different comprehensive approaches. However, there are no SMFs which take technical aspects (i.e. reliability, durability, safety, warranty, availability of resources) into account as integral parts of sustainability in remanufacturing strategies. As discussed in the previous chapter, that in term of quality assurance, technical viability is a higher priority than the three pillars of sustainability.

The technical aspects are more critical in determining the sustainability performance of the remanufacturing industry than the OEM, since the remanufactured products are made of used materials which may affect their reliability and durability. Improving remanufacturing operations by maintaining the quality, reliability, durability, warranty, safety and availability of resources (i.e. cores and technology) can increase customer satisfaction and sales, which in turn has a positive influence on the economic and social aspects. As discussed in the previous chapter, product quality is the main gateway for reaching customers. However, there may be environmental implications associated with changes made in the remanufacturing process to increase the quality of the product. Therefore, the current framework gives first priority to both the technical and environmental aspects before considering whether remanufactured product is socio-economically feasible. This means that a socio-economic assessment will not be performed until a technically and environmentally sound remanufacturing strategy is established.

Accordingly, this research presents a different holistic sustainable manufacturing assessment framework which integrates the technical with the triple bottom line sustainability pillars of environment, economy and society and technical aspects for assessing the implementation of remanufacturing strategies in SMEs. Since the framework of the current research has mainly been developed for assessing sustainable manufacturing in developing countries, where the quality of remanufactured products is far less than in developed countries (as discussed in Chapter 2), technical feasibility should be considered to be the first screening process before assessing the environmental, economic and social objectives of sustainability. Following the technical analysis, environmental economic and social analyses are carried out in order to discern an optimal sustainable manufacturing solution. The concern is to develop a holistic approach to producing remanufactured products with high quality remanufactured products while minimizing environmental impact and enhancing economic and social development.

These frameworks also require appropriate and relevant criteria and indicators to measure the technical and sustainability pillars to ensure that a sustainable remanufacturing strategy is implemented. The criteria and indicators can help remanufacturing industries to understand their sustainability performance, identify potential benefits of their operational systems, and to formulate strategies for a continual improvement process.

3.3 Development of SMF for Indonesian SMEs

Indonesia is one of the developing countries where there is an enormous potential for remanufacturing SMEs to achieve sustainability and contribute to the nation's prosperity, but these industries need to be structured and redesigned by applying a holistic sustainable manufacturing framework (SMF). The SMF of this PhD thesis has been specifically developed for Indonesian remanufacturing SMEs on the basis of the premises discussed below. These premises would enable to consider relevant sustainability factors pertaining to SMF development for Indonesia.

3.3.1 Premises of the framework

Strengthening the local market

Remanufacturing can strengthen local markets by providing products that are of similar or higher quality than new products in the existing Indonesian markets. For example, the rapid growth of the economy and population has been expected to increase the market for automotive products and components in Indonesia (KPMG International Cooperative 2014). Currently, the majority of automotive parts (70%) in the domestic market are dominated by large enterprises and imported products (KPMG International Cooperative 2014).

Therefore, the majority of manufacturing SMEs are less able to expand their products in the domestic market due to their lack of competiveness with large enterprise and imported products (Tambunan 2011). Remanufactured products may offer the same service as new products with lower prices, resulting in a potential opportunity to replace imported products and strengthen domestic markets.

However, the prospect of strengthening the local market through remanufacturing has not been fully explored for a number of reasons.

Firstly, the high dependence on imported components has seriously affected Indonesian industries because of the small number of component/parts produced locally. In 2009, importation was the source of 60.4% of the total components while total export amounted to 56.4% (Destatis 2009). Although some components are available on the local market, the prices are higher than for imported components (i.e. Chinese components), due to the export-based orientation and a growing dependence on imported components (Tambunan 2008).

Secondly, the unavailability of some components locally (e.g. rectifier) is another key reason for remanufacturers to buy imported new components for replacement.

Thirdly, the promotion of remanufacturing, which has been practiced by many developed countries such as Japan through motivation, incentives, promotion and campaigns to remanufacturers (Matsumoto and Umeda 2011), is absent in Indonesia (Agustina 2010).

Profitability

As discussed in Chapter 2, remanufacturing offers greater profit which is predicted to be double that from manufacturing a new product (Gray and Charter 2007). The reduction in energy and resource consumption during the remanufacturing process reduces the entire remanufacturing cost significantly. However, the profitability of remanufacturing activities can be affected by the supply and demand of cores and the demand for the remanufactured products on the market (i.e. sales) (Guide, Teunter, and van Wassenhove 2003). This situation is more relevant to Indonesian remanufacturing SMEs, due to the weak competiveness of their remanufactured products on the market. Accordingly, sales of remanufactured products are very limited. In addition, the low price orientation has limited their ability to obtain a higher profit margin (Kenneth 2014).

Affordability and market demands

There is a positive correlation between market potential and population increase. The large number of Indonesian people (234 million) can create a potential market for remanufactured products. On the other hand, population explosions also cause resource scarcity, resulting in an increase in poverty and a lack of purchasing power. In rural Indonesia there is an increased demand for affordable products. About 32 million of the total population of 234 million live under the poverty line and approximately 50% of the population receive only USD 22 per month (World Bank 2014). This limits the ability of people to buy new products which are beyond the purchasing capacity of Indonesian people. Remanufacturing is thus a promising strategy for meeting the high demand for items like auto parts (e.g. alternators), household products (e.g. refrigerators) and computers of high quality and at a reasonable price (Biswas and Rosano 2011, Ferrer 1997a, Kim et al. 2008)

Increasing the utilization of used parts

Components such as auto parts, electronic and electrical products change so quickly that it is economically unfeasible for manufacturers to supply their five to 10 year old spare parts to the current market (Steinhilper and Brent 2003). Old parts can potentially be used in for remanufacturing and thereby overcome the issue of increasing waste associated with the development of rapidly changing products.

Therefore, SMEs have more flexibility with regard to economic change in comparison with large enterprises (LEs) (Berry, Rodriguez, and Sande 2001, Fitrianto 2009).

Capacity building of SMEs

There is an avenue to develop the capacity of SMEs through the remanufacturing industry in Indonesia for the following reasons. Firstly, SMEs have a better performance in generating employment and therefore have the potential to become a large industry. The employment share of SMEs is more than 99%, whereas manufacturing contributes to the largest number of SME workforces (44%) (Kusumo 2008).

Secondly, SMEs have contributed a significant amount of GDP, being 58.33% of the total national GDP and 16.72% of the total national exports (Kusumo 2008). The increased number of high quality remanufactured products could be turned into exportable items.

The inadequate entrepreneurial skills of the majority of Indonesian SMEs could be a barrier to SMEs developing new enterprises (Mourougane 2012). Improvements to

SME capacity building through entrepreneurial training have enhanced SME skills in Europe (European Commision 2006).The same initiatives could be implemented in order to increase entrepreneurial skills in Indonesian SMEs.

Information technology revolution and waste generation

As a consequence of rapid developments in information technology, accompanied by shorter product lifetime, increased waste (i.e. electronics, auto parts) has become a critical environmental issue for Indonesia (Varin and Roinat 2008). In 2007, the volume of solid waste was approximately 80,235 tons per day, and it is estimated that solid waste will increase by five times by 2020 (Kardono 2007) with the growth rate of solid waste being projected at about 1.1% per year (Dewi 2010).

The waste generated from auto parts is a major issue in Indonesia. In 2010, the Association of Indonesian Motor Vehicle Industries (Gaikindo) reported that the sale of cars had increased by 13.7% from the previous year (more than 700,000 units). The Indonesian Association of Motorcycles Producers (AISI) also stated that motorcycle sales had reached 3.5 million units in 2010, being a 61.5% increase on 2009 (Indonesian Commercial Newsletter 2010), potentially increasing the automotive waste associated with the replacement of components and servicing activities. Therefore, remanufacturing has a substantial role in eliminating waste generation (65%) (Svenska Kullagerfabriken 2014) through the maximization of the use of EoL components/materials and minimization of the use of new materials/components.

Landfill impacts

Solid waste persists as a major challenge in waste management, both in developed and developing countries (EPA 2013a). In the US, solid waste landfilling was approximately 54.3% of total waste (131.9 million tons) in 2009, while in Indonesia, it was approximately 65.9 million tonnes in 2010 (EPA 2013a, Munawar and Fellner

2014). The majority of solid waste (60%), especially in urban areas, is sent to solid waste disposal sites (SWDS) or landfills which are simply open dumping areas and not well managed (Dewi 2010).

Solid waste landfilling has created serious problems for human health and the environment. Remanufacturing activities offer important benefits in reducing landfilling of solid waste (King et al. 2004). Remanufacturing could reduce landfilling of solid waste significantly (20%) (Ayres, Ferrer, and Van Leynseele 1997) .

Material and energy consumption and GHG emissions

As discussed in Chapter 2, there are material, energy and GHG reduction benefits to remanufacturing activities. It was estimated that the material savings derived from the remanufacturing process are equivalent to 155,000 railways cars crossing 1,100 miles (Giuntini and Gauddette 2003), while remanufacturing activity could also avoid about 400 trillion BTUs (British Thermal Units) of energy consumption per year and mitigate 28 million tons of CO_2. For auto part products, the remanufacturing of bearings could decrease GHG emissions (i.e. CO_2 and SO_2 emission) by approximately 60% (Svenska Kullagerfabriken 2014).

Indonesia has become the largest energy producer and consumer in Southeast Asia (Ardiansyah 2011). However, today, energy security issues are Indonesia’s principal challenge and predicted to remain so until 2020 due to the rapid growth of energy consumption which is 50% higher than the consumption over the past decade (Patel 2013). Remanufacturing could be another potential strategy in reducing energy consumption significantly by reducing upstream activities.

Another important reason is that Indonesia is one of the 10 largest GHG-emitting nations in the world. Indonesian GHG emissions were about 1,377 MTon CO_2-eq in 2000, reaching 1,991 MTon CO_2-eq in 2005, and are predicted to increase to 3,078

MTon CO_2-eq in 2020, based on the Second National Communications (Dewi 2010). Manufacturing contributed about 40% of the emissions (Ministry of Finance 2009b); remanufacturing could potentially reduce these emissions.

Applicability of the 6Rs strategy

The first 3Rs of the 6Rs strategy (reduce, reuse and recycle) have been found to be widely implemented in Indonesia as a way of making profit (Darisman 2011). Even though there are no reliable statistics on the number of industries engaged in this 3Rs strategy, these industries emerged especially after the economic crisis hit Indonesia in 1997 (Ramdansyah 2011).

The last 3Rs of the 6Rs strategy (recover, redesign and remanufacture) have also been applied by some industries, although this is still a challenging issue for Indonesian industry due to improper implementation and lack of planning. However, Toyota in Indonesia has been recognized as the leading company applying the 6Rs strategy, becoming number 1 in the production system by improving its environmental performance (Thomas 2014).

Growing unemployment

Unemployment is a serious problem in Indonesia. During the period 2010–2014, the unemployment rate was still high, at about 6.3% of the total labour force (Indonesia-Investments 2014). The labour force of Indonesia increased from 115 million in 2010 to 118 million in 2012 (World Bank 2014). Furthermore, the Indonesian labour market is dominated by the service sector operated by young workers with minimal educational quality (The Economist Intelligence Unit 2012, Rahman 2004), while most of the labour took the job at minimum wages (65% of world average wage) (Saget 2008).

Remanufacturing is a labour intensive industry and requires skilled workers (Ijomah 2010). Remanufacturing is an economic engine that needs about 120 man hours whereas manufacturing a new engine requires about 40 person hours (Stahel 2010) in (Kenya 2010). In the UK, remanufacturing contributes about 50,000 employees and demands appropriately skilled workers (Oakdene Hollins Ltd. 2004).

The promotion of remanufacturing enterprises could assist the Indonesian Government to solve unemployment problems.

Policy and infrastructural aspects

There are numerous Indonesian government policies to deliver financial assistance, technical and enterprise training, advisory workers, marketing assistance, provision and infrastructure. Many of these policies have been applied for commodity reasons but not for the wellbeing of the SMEs (Fitrianto 2009). In addition, insufficient infrastructure, such as electricity, transportation, and telecommunications infrastructure, is another problem which will impede the development of remanufacturing among SMEs. Furthermore, most SME exports are dependent on large enterprises. As a result, the contribution of SMEs is unrecorded and undermined (Tambunan and Liu 2006).This gap has a negative effect on the development of SMEs, because it is difficult for them to expand their market independently (Tambunan and Liu 2006).

Particularly in the case of SMEs, many regulations are uncertain, overlapping, vague and suddenly issued without an understanding of the requirements of the industries (White 2013), thus creating much frustration. For example, the Ministry of Trade No 48/2011 set a restriction on importing used products for local market protection purposes (White 2013), which significantly limits the availability of cores for remanufacturing processes.

Corporate social responsibility

Remanufacturing could enhance social sustainability by collecting EoL products and turning them into as good as new products, thus reducing the environmental impact and empowering more people.

Corporate social responsibility (CSR) is still a new concept and has rarely been implemented in Indonesia especially for SMEs (Prabawani 2013). Many SMEs have heard about CSR from the government, but have not adopted this strategy in their enterprises (Prabawani 2013). There is still a need to encourage SMEs to integrate CSR into their manufacturing activities. Promoting CSR through remanufacturing could improve the social and environmental performance of the Indonesian remanufacturing sector.

International pressure on sustainability

At the G20 Pittsburg meeting in 2009, Indonesian government has targeted that national GHG emissions can be reduced by 26% of the business as usual (BAU) by 2020 (Ardiansyah, Gunningham, and Drahos 2012). However, the expected increase in energy consumption during this period could increase the GHG emissions significantly. As a result, the GHG reduction target may not be achieved unless radical energy conservation is implemented (Ardiansyah, Gunningham, and Drahos 2012). Remanufacturing could be a key strategy to assist in energy savings (Biswas et al. 2011), as manufacturing accounted for 37% of Indonesian energy consumption in 2009 (ABB 2011).

Powerless enterprises

It is interesting to note that, in Indonesia, that some OEMs, especially those making electrical and electronic products (i.e. computers, television), are concerned about the remanufacturing industry, as they recognise that remanufacturers could take away their market by selling cheap and reliable products (Ramdansyah 2011). The large industries thus influence Indonesian policies and regulations, which then do not provide a supporting framework for SMEs (Ramdansyah 2011).

Reliability, durability and safety aspects

Remanufacturing could offer as good as new products with warranties to match (Andrew et al. 2006, Steinhilper 1998a, Nasr 2012). This means that the reliability, durability, safety performance and warranty become factors critical to ensuring the quality of the products for promotional reasons. However, poor quality, unreliable, unsafe and non-standard products, and short warranty periods are common issues with remanufactured products in Indonesia (Fatimah et al. 2013)

Potential availability of core

As discussed in Chapter 2, core collection is an essential activity for maintaining remanufacturing, and therefore, it is necessary to ensure the availability of cores. The availability and quality of cores are critical problems in Indonesian remanufacturing for the following reasons. The Indonesian people usually keep their old equipment until it reaches the lowest value (disposal stage) by repairing it many times, mainly for economic reasons. Furthermore, a lack of understanding in handling cores adversely affects the quality of remanufactured products. Imported cores, which could be a potential source of cores for the remanufacturing process, have been difficult to assess due to strict import regulations (Ramdansyah 2011). As a result, the number of EoL products (cores) tends to be very limited.

Summary of premises

Therefore, there is a need to develop an SMF for the successful implementation of remanufacturing among Indonesian SMEs, by addressing market barriers, quality assurance, affordability, waste management, capacity building, resource conservation, social responsibility and technological gap issues. A comprehensive sustainable manufacturing assessment needs to be conducted in order to evaluate and improve the existing situation of remanufacturing in Indonesia and to help the Indonesian government to formulate policies for the remanufacturing sectors.

3.3.2 Constructing an ecologically focussed sustainable manufacturing framework

Constructing an SMF requires the social, economic and ecological components of sustainability. There are two approaches for discussing sustainable manufacturing, which are the interlocking diagram and nested egg diagram (Diesendorf and Hamilton 1997).

Interlocking concept

The interlocking diagram presents the trade-off between economic, social and environmental objectives (Figure 3.2). In the case of sustainable manufacturing, this concept will not enable remanufacturing SMEs to achieve social, economic and environment objectives perfectly. Either economic benefits will be attained with reduced social or environmental development, or significant environmental improvement may take place with reduced social and economic benefits. Thus the application of the interlocking concept of sustainability will not help achieve the objectives of sustainable manufacturing as defined by Jawahir (2008).

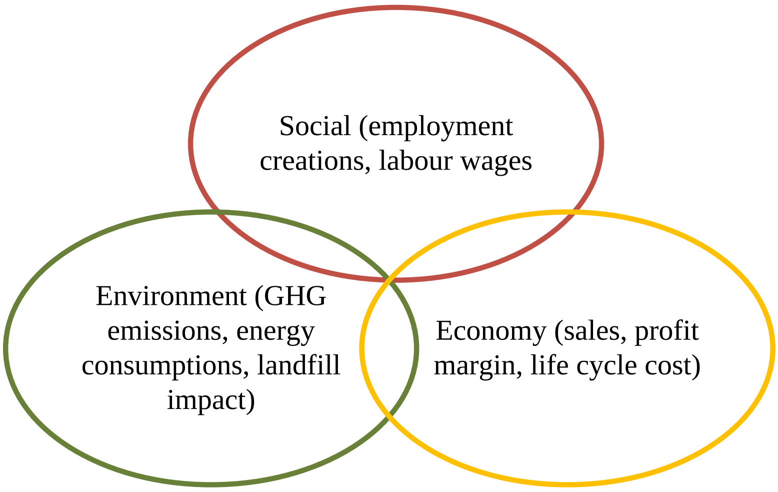

Figure 3.2 The interlocking sustainability approach

Nested egg concept of sustainability

The best way to successfully implement a remanufacturing strategy is to follow the concept of the nested egg diagram (Figure 3.3) for the following reasons. The nested egg concept represents the ecologically focussed development of human activities. The social demand that runs the modern economy must not exceed the carrying capacity of the earth. The biophysical limit of energy and material resources needs to be considered before considering the socio-economic impacts associated with the production of remanufactured products. Thus this concept will enable remanufacturers to address the bio-physical limits of nature, affordability and intergenerational equity aspects.

Accordingly, technically feasible remanufacturing strategies must first comply with the environmental criteria, such as energy and material conservation, GHG mitigation and waste minimization. Technically feasible remanufacturing must have met requirements regarding the reliability, warranty, safety, durability and availability of cores. Once the environmental criteria have been met, the remanufacturing strategies could meet societal demand in an economically feasible way.

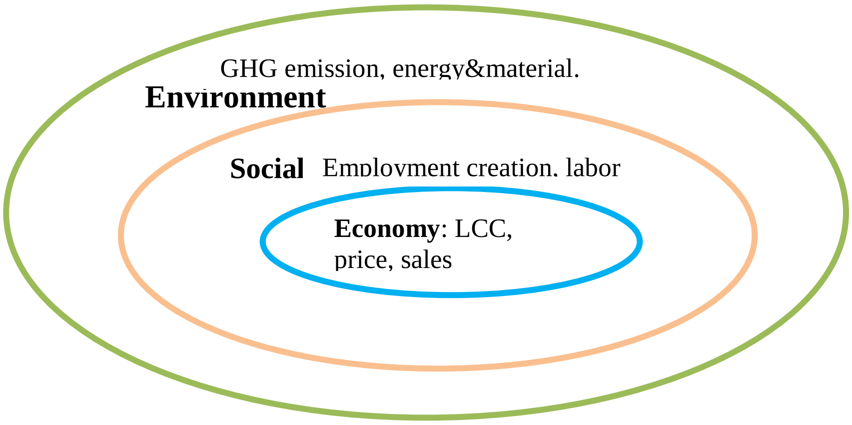

Figure 3.3 The nested egg sustainability approach

3.3.3 Description of the framework

The framework consists of two steps. Firstly, the existing scenario was assessed from technical, environmental, economic and social environmental objectives to identify the areas requiring improvement in order to attain sustainable manufacturing in Indonesia. Secondly, appropriate remanufacturing strategies were determined which are technically, environmentally, economically and socially feasible.

Step 1: Sustainability assessment of the existing remanufacturing scenario

Firstly, the existing remanufactured products are assessed using the sustainable manufacturing criteria, including technical (i.e. reliability), economic (i.e. life cycle cost, sales), environmental (i.e. solid waste, GHG emissions) and social aspects (i.e. employment opportunity, warranty). Secondly, the calculated values of these criteria are compared with the threshold values of the sustainability criteria. These threshold values are derived from the standard Indonesian and international literature discussing Indonesian and global remanufacturing issues. Examples of the threshold values of technical, economic, social and environmental aspects are reliability (99%), life cycle cost (50% cost of new product), warranty period (two to three years) and greenhouse gas emissions (2.58 kg CO_2eq) which appeared in the remanufacturing sectors

Remanufactured products not complying with any of these sustainability criteria are considered to be unsustainably remanufactured products and are then modified or redesigned by investigating improvement opportunities through an integrated improvement framework involving reliability optimization, life cycle cost (LCC), life cycle assessment (LCA) and social assessment. The objective of this integrated improvement framework is to determine technically feasible solutions which are economically, socially and environmentally feasible and meet the sustainable manufacturing criteria. Chapter 5 discusses the way in which triple bottom line indicators have been used to assess the existing scenario for SMEs producing remanufactured alternators.

Step 2: Application of integrated improvement framework

Firstly, technical criteria involving the reliability of the remanufactured products are assessed. Using these criteria, the materials, methods, labours, machines, energy and information are analyzed, and appropriate technically feasible solutions are proposed, involving the best available technologies, processes, technical skills and energy and material consumption.

Along with technical feasibility studies, LCA analysis of the technically feasible remanufacturing strategies are carried out following the ISO 14040-43 guideline (PRe Consultants 2013), to determine the environmental criteria including greenhouse gas (GHG) emissions and solid waste. If technically feasible solutions are not environmentally viable, the ‘hotspot’ or the process producing the most pollution is identified in order to apply mitigation strategies (e.g. cleaner production, eco-efficiency, green technology and industrial symbiosis). These two analyses are carried out simultaneously until both technically feasible and environmentally friendly solutions have been obtained. Following nested eggs concept (Section 3.3.2), environmental criteria has been given more priority than economic and social aspects.

Once technically and environmentally feasible remanufacturing strategies have been determined, the socio-economic viability of these strategies is assessed using sales and life cycle cost assessments. Economic viability is attained when sales and life cycle cost are equal to or greater than the threshold values. Similarly, social criteria such as employment opportunity and intergenerational equity must meet the threshold values. If the revised version of the technical option is not socio-economically viable, a sensitivity analysis involving different socio-economic policies including loans, rebates, subsidies and training are considered in order to attain socio-economic feasibility.

Once technically, economically, socially and environmentally feasible solutions are determined, appropriate institutional frameworks are developed, including policy instruments, stakeholder responsibilities, key actions, logistics and financial supports, in order to implement sustainable manufacturing in SMEs. The institutional framework takes into account the constitution of direct stakeholders (e.g. remanufacturers, suppliers and consumers) and indirect stakeholders (e.g. government, research institutions and banks), who participate in the decision-making process for sustainable remanufacturing.

The following framework (Figure 3.4) illustrates the assessment of sustainable manufacturing and shows how a remanufacturing industry identifies, analyzes, evaluates and improves its sustainability performance. The application of cleaner production strategies, recycling, reusing, recovering, reducing and remanufacturing have been considered in order to find technically, environmentally friendly and economically feasible remanufacturing solutions. Appendix A presents the published version of this work. Chapter 6 discusses the improvement framework for remanufactured alternators.

3.4 The assessment procedures

As outlined in Figure 3.4, the assessment starts with a survey to collect data on the processes, products, labour, energy and machinery of the remanufacturing SMEs in Indonesia. The managers and technicians of these enterprises were interviewed to collect the information. This interview was conducted through an open-ended questionnaire. A literature review was conducted in parallel to complete the missing data and information and to achieve a better understanding about this research.

Based on the information gathered from the enterprises and the literature review, the technical, environmental, economic and social indicators for remanufactured products were identified prior to the assessment of the existing scenario. The existing remanufactured products were assessed using the sustainable manufacturing indicators, including technical (i.e. reliability, durability, safety performance, warranty and availability of cores), economic (i.e. life cycle cost, sales, return of investment, value added and salary packages), environmental (i.e. embodied energy consumption, GHG emissions, material consumption, MIPS, solid waste and landfill) and social aspects (i.e. intergenerational equity, intergenerational equity, intangible asset finances).

The value of these criteria were calculated and then compared with the threshold values of the sustainability criteria which were gathered from the Indonesian and international literature discussing Indonesian and global remanufacturing issues (Rahman and Subramanian 2012)

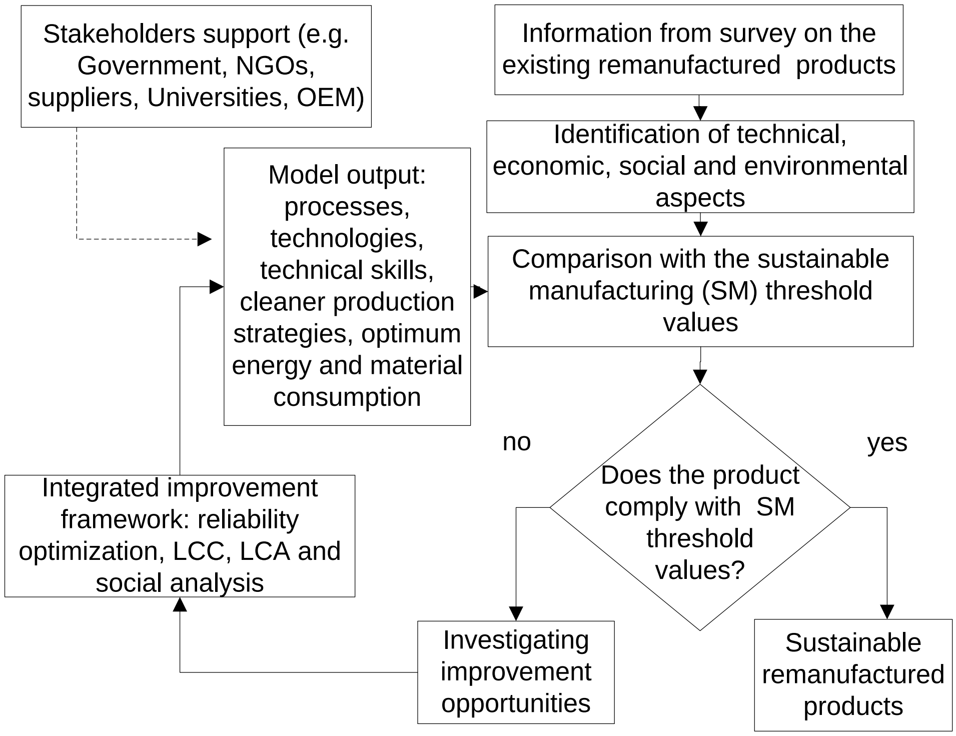

Figure 3.4 Model for sustainable manufacturing assessment

For example, the reliability (87%) of the existing scenario, which is one of the technical performance criteria, did not meet the threshold value (≥90%). Accordingly, reliability needed to be increased by using the improvement framework (Figure 3.4). A number of remanufacturing strategies, involving replacement of out of order parts with new or reconditioned or recycled parts, need to be considered to improve quality while taking into consideration the environmental criteria to be met. For example, solid waste reduction (95%) met the threshold value (21%), thus it met one of the environmental criteria. It could be the case that all technical criteria are met but not all environmental criteria, so that alternative remanufacturing strategies need to be considered in a way that both technical and environmental criteria are met (Figure 3.5).

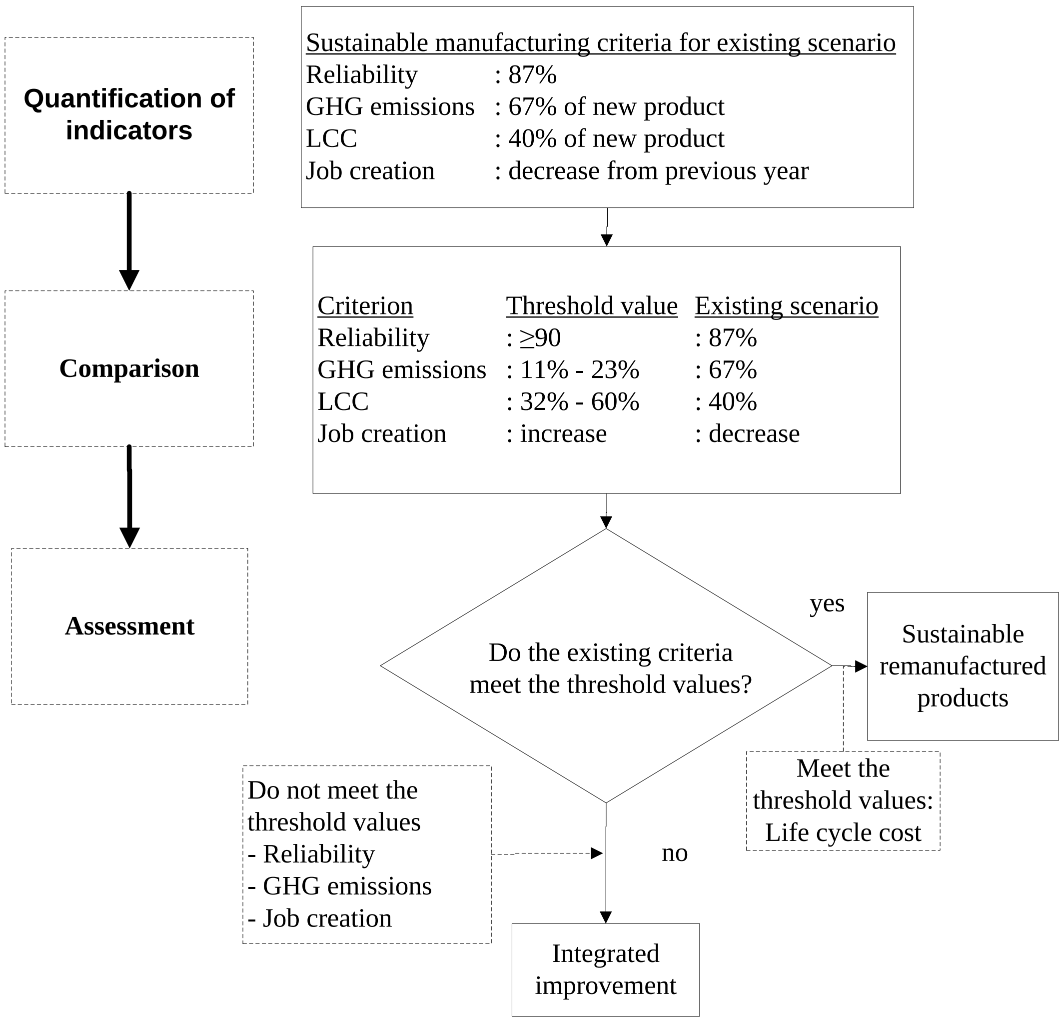

Figure 3.5 Illustration of the SM assessment of the existing scenario

In the assessment of the economic and social aspects, policy instruments were considered if threshold values were not met. Once the technical, environmental, economic and environmental criteria have been met through the right remanufacturing strategies and appropriate policies, this will provide decision-making support to the government for implementation of the sustainable manufacturing program.

When the existing indicators did not comply with any of the sustainable threshold values, the situation was considered unsustainable and investigated for further improvement opportunities through integrated improvement scenarios. The probability of improvement was proposed by conducting some appropriate, technically feasible options such as material utilization, component replacement, the introduction of new technology, efficient and effective process application and improvement of technical skills.

Following Fatimah et al. (2013), the next analysis has been carried out with regard to determining an integrated improvement in order to achieve technical environmental, economic and social objectives (Figure 3.6).

Feedback gathered from the existing scenario analysis would assist in determining the main cause of the poor technical performance and identifying possible technical solutions. For example, the reliability was found to be very low because large numbers of components failed. Accordingly, an assessment should be conducted for these critical components. An improvement scenario such as replacing a pulley with used components could be an option to improve reliability.

Once the reliability met the threshold value (≥90%) through the modification of remanufacturing strategies, an LCA was carried out to determine the possible environmental impact of the technical improvement. If the technically feasible solutions did not meet the requirement for environmental sustainability, alternative remanufacturing strategies would have to consider environmental mitigation strategies such as cleaner production (i.e. material substitution), introduction of new technology, application of efficient and effective processes and improvement of technical skills. This procedure was repeated until the threshold values of both technical and environmental performance were met.

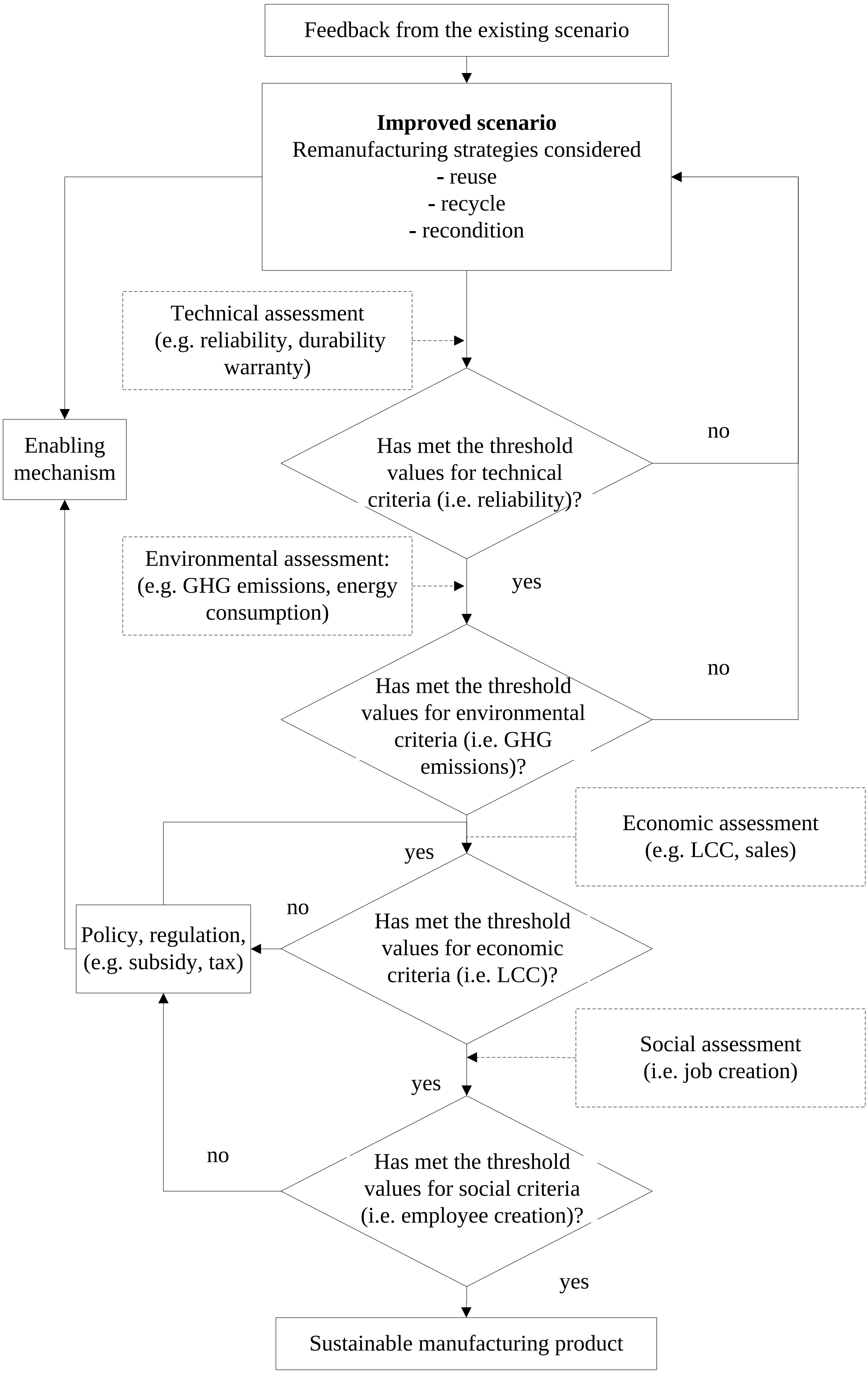

Figure 3.6 Illustration of how the integrated improvement framework will work

The socio-economic viability of these options was then assessed once the technically (i.e. reliability of ≥90%) and environmentally feasible solutions (i.e. GHG emissions of 11–23%) were obtained. Economic sustainability is achieved when all economic criteria (e.g. sales, LCC) have met the threshold values. Similarly, social sustainability is achieved when all social criteria (e.g. employment opportunity) has met the threshold values.

If the improved version of the remanufacturing strategy was not found to be socio-economically viable, a range of relevant socio-economic policies including loans, rebates, subsidies and education could be considered to attain socio-economic feasibility, which could potentially generate policies by which the Indonesian Government could implement sustainable manufacturing programmes (Figure 3.6).

The outcomes of the technical, environmental, economic and social analyses will lead to the development of an enabling mechanism involving stakeholders directly and indirectly responsible for implementing sustainable manufacturing through institutional frameworks.

3.5 Selection of SMEs for testing SMF

Local remanufacturing SMEs in Indonesia were selected in order to test the applicability of the SMF. This section describes Indonesian SMEs that can potentially utilize this framework to achieve social, economic and environmental benefits. The SMEs were chosen for this case study on the basis of this description.

3.5.1 Java Island and SMEs

The research concentrates on Java Island for the following reasons. Firstly, Java Island is an important economic corridor in Indonesia. According to the ‘Acceleration and Expansion of Indonesia’s Economic Development’ MP3EI program,[3] Indonesia has been divided into six economic corridors, as shown in Figure 3.7 (source: Google earth). Java is regarded as economic corridor II, which provides both industries and services due to its dominance over important industrial clusters such as textiles, automotive and machinery, industrial electronics, food and beverages (Ministry of Industry Republic of Indonesia 2012).

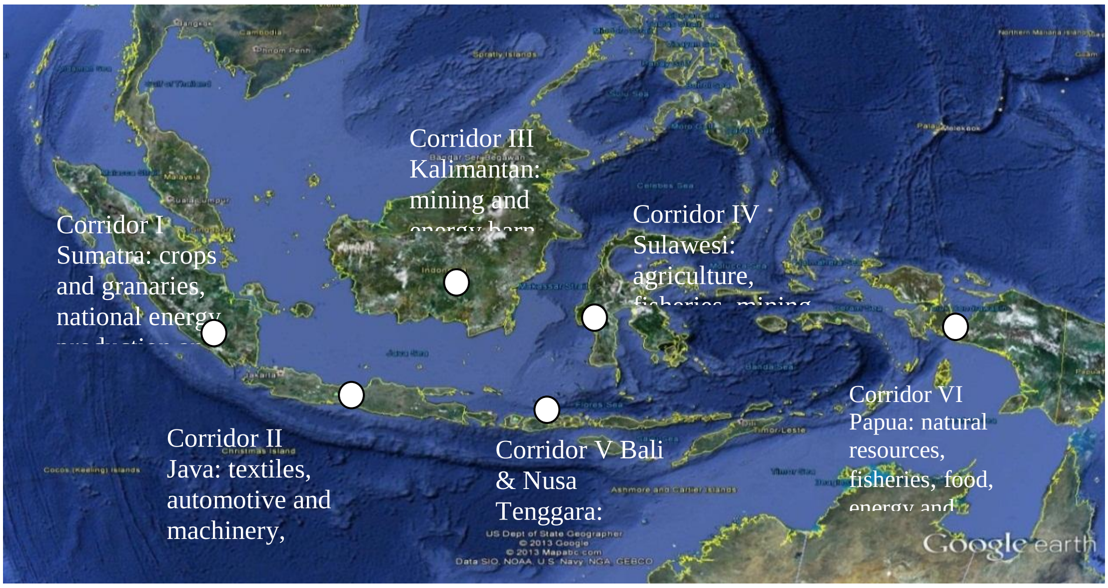

Figure 3.7 The six economic corridors of Indonesia

Secondly, a large number of local manufacturing industries are located on Java Island. This area is about 138,794 km^2 and is divided into six provinces, including Jakarta, West Java, Central Java, Yogyakarta, East Java and Banten. The population of about 138 million makes up 60% of the total Indonesian population. There are about 16,995 manufacturing industries on Java Island, accounting for 82% of the total number of manufacturing industries in Indonesia. The large of population is a

[3] The MP3EI program is a master plan for the acceleration and expansion of Indonesia's economic development, aimed towards Indonesia becoming developed country.

major reason for most of the industries being established on this island (Eggert 2001, UNDP 2011). In addition, Java Island offers a great potential market for remanufacturing products due to the large population and the number of small industries.

Thirdly, most of the foreign and domestic investment in the manufacturing sectors takes place on Java Island. According to Central Bureau of Statistics (BPS) in Kofod and Ward (2006) domestic and foreign investments amounted to about 34% and 66% in 2005 respectively.

Lastly, as well as providing a large number of manufacturing industries, Java Island also contributes a large share of SMEs in the country (Tables 3.1 and 3.2) (Prabawani 2013).

Table 3.1 The projection of SME development in Java and other Indonesian islands

Island	Growth					
	2010	2011	2012	2013	2014	%
Java Island (hundred unit)	2,549	2,549	2,556	2,568	2,594	0.45
Other islands (hundred unit)	1,258	1,360	1,471	1,591	1,730	8.29
Total (hundred unit)	3,807	3,909	4,027	4,159	4,324	3.24

Table 3.2 Percentage of the population distribution of SMEs on Java Island and other Islands

Island	SME population in year				
	2010	2011	2012	2013	2014
Java Island	67%	65%	63%	62%	60%
Other islands	33%	35%	37%	38%	40%

SMEs are considered to be representative remanufacturing enterprises in this research, as they constitute a significant source of Indonesian business development. They contribute a significant portion of enterprise (99%), employment (97%) and value added (57%) (Saedah 2012). Table 3.3 shows the development and projection of Indonesian SMEs over a period of five years.

Table 3.3 SMEs development and projection (2010–2014)

	2010	2011	2012	2013	2014	Growth
SMEs (hundred)	3,807	3,909	4,027	4,159	4,324	3.24%
Employee (hundred)	8,755	9,148	9,463	9,817	10,378	4.34%
Total asset (IDR trillion)	229	244	261	284	313	8.14%
Value added (IDR trillion)	365	398	435	483	546	10.60%
Exports (USD million)	13,503	15,022	16,541	18,060	19,579	9.73%

Table 3.3 highlights the growth of Indonesian SMEs based on the number of enterprises and employees, total assets, value added[4] and exports. The number of enterprises increases at a rate of 3.24% per annum and the number of employees by 4.34% every year. Total SME assets increases by about 8.14% annually, while the value added grows by about 10.6% per annum and export by 9.73% per year. Therefore, SMEs contribute a significant portion of Indonesian economic activity.

According to the survey conducted by Tambunan (2008), the majority of Indonesian SMEs (75%) are hampered by a number of serious obstacles including lack of capital (35%) and marketing strategies (30%), lack of affordable raw materials (20%), the

[4] Value added is an estimate of an SME’s economic profit.

high cost of energy (3%) and transportation (3%), high labour costs (1%), and other obstacles (8%) (Tambunan 2008).

Similarly to developed countries (e.g. the US), SMEs play an important role in product recovery in Indonesia. However, the product recovery businesses (i.e. those which carry out recycling, repairing, reconditioning and remanufacturing activities) are still in the nascent phase in Indonesia due to the obstacles discussed in the previous section.

3.5.2 Selection of the remanufacturing SMEs for testing the SMF

The majority of Indonesian product recovery businesses, including remanufacturers, are informal industries with limited access to technology, resources, skilled workers and financial support. In addition, the number of employees is very limited and poorly paid due to the financial inability of these industries to pay employees better.

The reuse and remanufacturing industry form a large part of the informal sector in the Indonesian market, and are often lucrative due to the high demand for affordable second hand or remanufactured/reconditioned products. Currently, these informal industries are widely operated on Java Island, in places including Jakarta, Surabaya, Semarang, Solo, Magelang and Jogjakarta.

However, there are also a number of well-developed remanufacturing industries, including PT Komatsu Reman Indonesia, PT Sanggar Sarana, PT Caterpillar Indonesia (Komatsu Reman Indonesia 2009, Sanggar Sarana Baja 2013). These are formal industries, categorized as large industry and supported by adequate technology, highly skilled workers, appropriate resources and financial support. The market orientation of this industry is not only national but also international, due to the high quality and acceptability of their products.

In Indonesia, remanufacturing has been practiced in many different industrial areas including motor vehicle parts, consumer products, construction mining equipment, information technology, locomotive, machinery, heavy duty and tyres. According to Nasr (2012) , these remanufactured products are classified as follows:

- Rebuilt, when remanufacturing activities are associated with motor vehicle components and systems such as alternators, starters and engines.
- Refurbished, when remanufacturing activities are associated with furniture products and systems such as hotel, hospital and office furniture.
- Recharged, when remanufacturing activities are associated with image products such as toner cartridges and batteries.
- Reconditioned, when remanufacturing activities are associated with consumer products such as computers, televisions and refrigerators.

A further literature review was conducted to identify the number of reconditioning and remanufacturing industries in Indonesia, as shown in Table 3.4.

SMEs remanufacturing alternators have been chosen as the subjects for the case study assessing the SMF for the following reasons. Firstly, Indonesia is one of the largest producers and consumers of auto products in the world. The increase in number of vehicles has led to an increase in the demand for auto parts and the generation of waste associated with the replacement of out of order parts with new ones (Ipsos Business Consulting 2013). This situation offers an enormous market opportunity for remanufactured auto parts through recovering, reusing and recycling EoL cores and components.

Secondly, alternators were selected because remanufactured auto parts are commonly found on the Indonesian market. However, many of Indonesian remanufacturing practices are still neglected. This case study will provide opportunities for achieving the sustainability of remanufacturing practices in Indonesia.

Table 3.4 The sectors and types of remanufactured products in Indonesian markets

Sector	**Example of products**	**References**
Motor vehicle parts	Alternators, starters, engines, gear boxes, brakes	(CV. Bintang Timur 2009, Galeri alternator 2012, PT.Success Merichal Cemerlang 2013, Tanjung alternator 2014),
Consumer products	Mobile phones, digital cameras, televisions, refrigerators, washing machines	(Anityasari 2009), (Ramdansyah 2011)
Construction, mining equipment	Forklift trucks, compact excavators, forest machines and tools	(Caterpillar 2013), (Komatsu Reman Indonesia 2009)
Information technology	Personal computers, printers, fax machines, printers, copiers, ink and toner cartridges.	(Veneta Indonesia 2012), (Ramdansyah 2011)
Locomotive	Drive motors, locomotive engines for rail	(GE 2012)
Machinery	Compressors, agriculture machines and tools	(Tractor-Truck.Com 2013)
Tyres	Tyres for cars, trucks, aeroplanes and off-road vehicles	(Anityasari 2009), (Tractor-Truck.Com 2013)
Heavy duty	Transmissions, diesel engines, hydraulic cylinders	(Caterpillar 2013) (Investama 2012)

The remanufacturing of auto parts is widespread globally, so this study is expected to help the Indonesian remanufacturing industry to be more competitive globally, and provide useful guidelines for other similar SME.

Finally, the remanufacturing of auto parts in developing countries is far behind that in developed countries (e.g. Japan, Germany), so this research will help industry to identify the obstacles to success and to define strategies to overcome them.

3.5.3 SMEs remanufacturing alternators

Auto parts remanufacturing industry

Globally, there is a great demand for remanufactured automotive products, which in fact dominate the remanufacturing market (Postawa et al. 2011). The Auto Parts Remanufacturing Association (APRA) has stated that the remanufactured components market is predicted to be worth about USD 34 billion every year while the remanufactured components industry has been estimated to number about 12,000 firms. About four million alternators, starters and pumps are produced annually. Alternators and starters make up 90–95% of all remanufactured products on the second hand market (Postawa et al. 2011).

The rapid growth of the global remanufacturing industry is mirrored by the growth of the Indonesian auto parts (i.e. engines, starters, alternators) remanufacturing industry. The high demand for vehicle parts leads to a high number of EoL parts, thus leading to a greater need for a remanufacturing industry to produce the auto parts.

In 2010, there were 13 automotive industries was 13 supported by 184 automotive component companies and 81 automotive karoseri.[5] The capacity of automobile manufacturers to assemble products was more than 800,000 units every year (Ipsos Business Consulting 2013). The profile of the Indonesian automotive industry is presented in Table 3.5. These automotive industries are located in the automotive cluster on Java Island, and are concentrated in four industrial areas including DKI Jakarta, Bogor, Karawang and Bekasi.

[5] Automotive karoseri is an industry making the carriage body of a vehicle.

Table 3.5 Profile of the Indonesian automotive industry

Contribution	**2009**	**2010**	**2011**	**2012**
Production	483,548	764,710	893,164	1,116,230
Sales	464.816	702.508	837,948	1,065,557
Exports	342,457	505,370	48,362,069	55,778,248
Imports (unit)	32,678	76,520	76,173	125,873

The automotive component companies consist of approximately 58 domestic auto parts industries and 86 foreign auto parts industries, which are centred in West Java, Central Java and Jakarta (Ipsos Business Consulting 2013). The export value of the industry reached approximately USD 33,000 million in 2013 which was distributed widely to Thailand, Japan and the Philippines.

As well as economic benefits as mentioned above, the automotive industry is one of the largest industries capable of offering job opportunities to reduce unemployment. The automotive industry contributes a significant portion of the labour force (40% of the total labour force). The labour force of the auto parts industry is male-dominated. The Indonesian automotive industry is one of the sectors which applies a higher wage (15%) than the regular minimum wage, and this was significantly increased in 2013 in order to increase the industry’s productivity (Ipsos Business Consulting 2013).

Market demand for auto parts

In general, Japanese automotive products contribute the highest proportion of sales in the Indonesian market, at around 90% (Ipsos Business Consulting 2013). In 2011, the majority share in the Indonesian automotive market, especially for passenger vehicles, was contributed by Toyota, Daihatsu, Suzuki, Mitsubishi, Nissan and Honda (Ipsos Business Consulting 2013). With an increase in vehicle sales and a higher demand for auto parts, it is predicted that the market for auto parts will increase.

The Indonesian auto parts market has been classified into the original equipment manufacturer (OEM) supplying genuine components and the replacement market or aftermarket (AM) supplying non-genuine components (Layton and Rustandie 2007). The OEM market landscape is dominated by imported parts (70%) which have come from ASEAN (Association of South-East Asian Nations) countries (e.g. Japan, Thailand). The low domestic production of parts is due to a lack of raw materials, and has decreased the market for local products (KPMG International Cooperative 2014).

By contrast, the Indonesian after market for non-original parts (new and remanufactured) is dominated by imports from China, Thailand, Taiwan and Vietnam.. The price of these parts is much lower than for OEM products (20% of OEM product prices) (KPMG 2014). The high price of OEM auto parts means that the replacement market (after market) for non-genuine parts is growing rapidly in response to the demand for more affordably priced parts.

The alternator is an important vehicle part for which there is a high demand on the global market (Kim et al. 2009, Schau, Traverso, and Finkbeiner 2012). It acts as the main electrical generator of a vehicle to charge the vehicle's battery and to power the vehicle's electrical system (Sullivan 2013). It has been estimated that a vehicle needs about 2–3 replacement alternators during its lifetime (George 2014), which means that the demand for alternators could be double that of the number of vehicles, as illustrated in Table 3.6.

Table 3.6 Forecasting of vehicle and alternator production and sales

Year	Vehicle in units		Alternator in units (predicted)	
	Production	Sales	Production	Demand
2009 (Ipsos Business Consulting 2013)	483,548	464,816	967,096	929,632
2010	764,710	702,508	1,529,420	1,405,016
2011	893,164	837,948	1,786,328	1,675,896
2012	1,116,230	1,065,557	2,232,460	2,131,114
2015 (estimation)[6]	1,726,338	1,639,656	3,452,676	3,279,311
2020 (estimation)	2,739,588	2,608,487	5,479,176	5,216,974

Given the forecast (see Table 3.6), the demand for alternator production and sales is predicted to increase significantly in the next eight years, by 59.3%.

In general, the number of alternator sales will be correlated with the number of worn alternators discharged. The rise in demand for alternators as mentioned above will also increase the growth in the EoL for alternators. For example, by 2015, the alternator demand is expected to reach 3,279,311 units, which would be approximately equivalent to the number of used alternators (based on the estimation). The high demand for alternators accompanied by the large quantity of waste generated could provide an enormous opportunity to promote remanufacturing activities in Indonesia, which could offer triple bottom line benefits.

[6] The estimated values of production, sales and demand of vehicles and alternators were estimated using the trend data from previous years.

Economic, social and environmental benefits of remanufactured alternators

Life cycle cost savings are possible through the remanufacturing of auto parts. Compared to new parts, remanufactured parts offer about 30–53% reduction in costs to customers (Smith and Keoleian 2004). Remanufactured alternators in particular could be offered at a price 50% lower than that of a new one.(Asif et al. 2010, Zhang et al. 2011).

The production rate (25%) for alternators is very high on a global scale compared to other parts (Kim et al. 2009). Remanufactured alternators dominate the remanufacturing market (around 22%) (Jung et al. 2008), thus the market for remanufactured alternators is immense. Because of the high demand for affordable alternators, the market for used/reconditioned/remanufactured alternators could create a multi-billion dollar business.

The remanufacturing of alternators includes disassembling, washing, reconditioning, reassembling and installation. These are effort intensive activities and so require skilled workers. The development of alternator remanufacturing would bring advantageous conditions by offering more job opportunities and increasing the number of skilled workers.

From the environmental point of view, remanufactured alternators consume 60% less energy and 70% less materials than the new parts (Asif et al. 2010). About 80% of an alternator's parts can potentially be reused (Asif et al. 2010, Zhang et al. 2011). Given these conditions, it is believed that Indonesian SMEs remanufacturing alternators could save significant materials and energy.

Alternator remanufacturing in Indonesia

Remanufacturing auto parts in Indonesia could help develop the growth of the Indonesian automotive sectors. However, these industries, which are likely to be dominated by small and medium enterprises with a limited number of employees, have not been well established in Indonesia. Indonesian SMEs producing remanufactured alternators experience a number of challenges.

Firstly, the lack of capital investment is a critical barrier to the development of resources and facilities for SMEs. Even though Indonesian government funding institutions (i.e. Bank Rakyat Indonesia) have provided a number of credits for SMEs (i.e. Kredit Usaha Kecil – KUK) (Tambunan 2006), the SMEs have limited access to the credit due to lack of financial documents (i.e. annual sales). As a consequence, many remanufacturing SMEs are fully funded by savings, family support and informal credit, similar to the majority of SMEs in Indonesia (Dhewanthi 2007, Tambunan 2006).

Secondly, the quality and reliability of the products made by SMEs often cannot meet required standards (Tambunan and Liu 2006), as the SMEs are not equipped with appropriate technology or equipment, and have fewer skilled workers, which creates inefficiency and reduces productivity in remanufacturing processes.

Thirdly, the insufficient number of quality cores is a major challenge, due to the uncertainty associated with the supply of cores, their quality and the time of return of used alternators. These problems with cores create difficulties for the effective implementation of remanufacturing among SMEs. A supply and demand of cores which is not in equilibrium may decrease the ability of remanufacturing SMEs to meet the alternator market's requirements. This sometimes affects government policy. According to Gaikindo (The Association of Indonesian Automotive Industries), there is a restriction on the import of used, rebuilt and remanufactured products/auto parts from overseas without the legal authority of the industries, which creates difficulties for remanufacturers trying to access an adequate supply of quality cores.

Fourthly, the market for remanufactured alternators is highly competitive, which is also a challenge. For example, the ASEAN China Free Trade Area (ACFTA) agreement is expected to provide more benefits to ASEAN Countries (i.e. Indonesia, Malaysia, the Philippines), however the lower price of Chinese products dominates the domestic markets and creates difficulties for SMEs trying to sell their products. Even though there is no convincing sign that this agreement has negatively affected the development of SMEs, this free trade agreement affects the SMEs in short time (Tambunan 2011)

Fifthly, the lack of environmental awareness among SME managers could result in harm to the environment and the surrounding community. For example, waste water from the washing process, which contains dirty oil, gasoline and grease, is usually discharged into rivers as SMEs are not equipped with water treatment facilities (Agustina 2010). In addition, the lack of guidelines on health and safety could risk the employees' wellbeing.

Finally, the majority of new parts for replacement with old parts are imported, which is sensitive to exchange rate fluctuations. The weakening of the Indonesian currency (Rupiah) against the US currency (USD) increases the cost of parts significantly (KPMG International Cooperative 2014), which may increase the life cycle cost of remanufactured alternators.

The aforementioned economic, social and environment aspects show that there is a need for a sustainable manufacturing assessment to help remanufacturers identify the existing sustainability problems and provide strategies to solve the problems.

3.6 Upstream and downstream supply chain activities of selected SMEs

Before assessing the sustainability of the remanufactured products, it is important to understand both the upstream and downstream activities involved with remanufactured products. Chron (2013) stated that the upstream stage included all activities from exploring and obtaining raw materials, which involves the supplier as the raw material provider, while the downstream involves all material processing until the finishing process, which is directly connected to customers (Chron 2013). Accordingly, the following section describes the upstream and downstream activities involved with alternator remanufacturing.

3.6.1 Upstream and downstream activities involved with remanufactured alternators

The global supply chain for the remanufacture of alternators is referred to as a closed loop supply chain (Ostlin 2008a), where the forward and reserve material supply chain has been taken into consideration. The upstream activity describes the reverse supply chain which describes the forward supply chain from the SMEs remanufacturing alternators towards the customers and EoL products. Accordingly, the author of this thesis has developed a flow diagram showing the upstream and downstream activities with regard to remanufacturing SMEs (Figure 3.8). This flow diagram has been used in Chapters 5 and 6 for conducting the environmental and economic analyses.

The flow of upstream activity begins when the SMEs collect used and second-hand alternators from different core suppliers including used auto parts importers, cannibalizing centres/industries, waste collection centres, repair workshops, scavengers and direct users. The repair and modification workshops, cannibalizing centres and waste collection centres are easily found close to the remanufacturing SMEs.

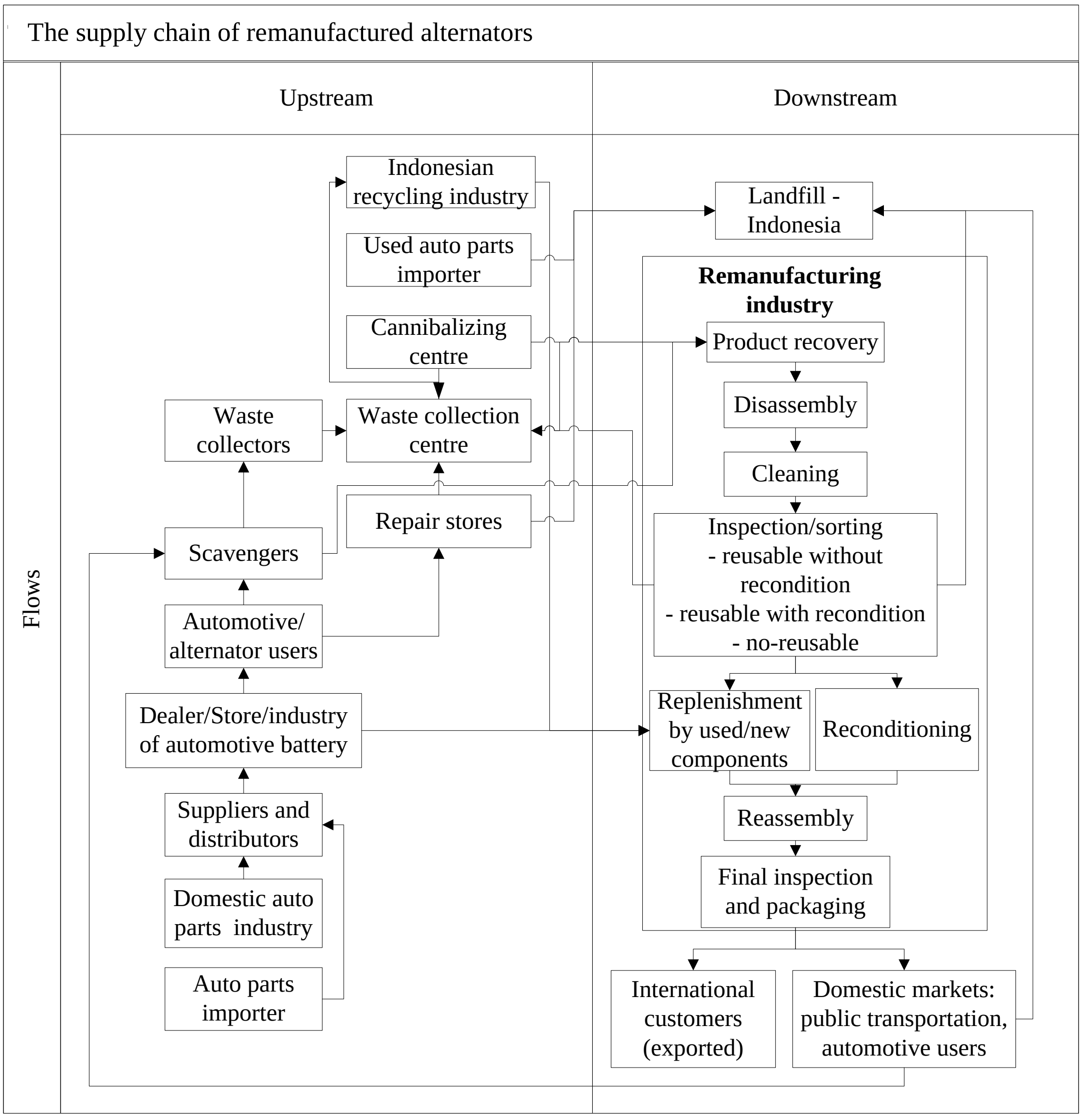

Figure 3.8 The remanufactured alternators supply chain

Even though there are a large number of product recovery systems implemented by remanufacturing industries all around the world, including kerbside, drop-off to SMEs and return with sales (Hanafi, Kara, and Kaebernick 2005, Mulder, Scheidt, and Schneider 1999), the majority of the collection systems are conducted directly by the SMEs via their core suppliers in some large cities on Java Island (i.e. Jogjakarta, Semarang, and Solo). In a very few cases, scavengers and direct users supply the used materials. The scavengers usually bring worn out alternators to the SMEs at very low cost, while users usually exchange their old alternators with remanufactured ones by paying an additional cost (i.e. USD25).

In the case of replacement, the worn out alternator components are commonly replaced with new components purchased from independent auto parts suppliers in the local aftermarket, which are mostly family run businesses. The auto parts are mainly dominated by imports (70% of the Indonesian auto parts market) which come from China, Taiwan and other Asian countries (i.e. Thailand) (KPMG International Cooperative 2014).

The downstream activities involving the remanufactured alternators begin once the used products are received from core suppliers. Next, the useful or workable used alternators components/parts are remanufactured through the disassembling, cleaning, inspection and reconditioning processes, while the broken parts are collected and sent to the recycling industry for other suitable applications. A number of useless parts are usually collected by scavengers and sent to public dumpsters/landfill (Damanhuri and Padmi 2012).

Once the remanufacturing process is complete, the remanufactured alternators are mainly sold out to local aftermarkets through distributors and wholesalers and also to remanufacturing showrooms for selling directly (Galeri alternator 2012). Some of the remanufactured alternators are sent to national markets. In this downstream activity, the equilibrium between the demand and supply of remanufactured alternators has been considered.

This flow chart shows how different stages are interlinked, how upstream activities and downstream activities could potentially influence each other, and how they are used to assess the technical, environmental, economic and social aspects of the remanufacturing supply chain (see Chapters 5 and 6).

3.6.2 Economic implications of a closed loop system

As pointed out in Chapter 2, the closed-loop supply chain that combines upstream and downstream activities with remanufacturing could offer a high profit margin. In the case of Indonesia, the value for remanufactured alternators was forecasted to increase by 60% of 2009 level (i.e. USD34.9 million) in 2015, which created positive socio-economic influences. In 2009, remuneration in dismantling, refurbishing and recycling sectors was 20% higher than the minimum wages for Java regions reflecting the significant increase of workers in these remanufacturing industries (Andarani and Goto 2012). During the same time, the rate of recycling of valuable materials (e.g. plastic, metal, rubber) had increased to 22 tonnes per year (Damanhuri and Padmi 2010) that resulted a financial profit of USD8,140. The scavengers who play a key role in core collection for the remanufacturing SMEs have been found to make a good income of around USD70 per month to meet the basic needs of life (Rochman 2010).

3.7 Conclusion

This chapter has presented the development of an SMF to assess the sustainability of remanufactured products produced by Indonesian SMEs. The SMF, which incorporated four main criteria including technical, environmental, social and economic criteria, has been developed in order to conduct a comprehensive sustainability assessment of the remanufacturing SMEs. Unlike existing sustainable frameworks, this framework gives first priority to the technical aspect, as it is deemed crucial for the success of remanufactured products in the markets of developing countries. Technically and environmentally benign remanufactured items have been considered for socio-economic assessment to enable the government to develop policies for attaining sustainable manufacturing strategies.

The first step in this framework is to conduct a sustainability assessment of the existing scenario (in Chapter 5) to identify opportunities for improvement in achieving a sustainable manufacturing scenario (in Chapter 6).

Indonesian SMEs producing remanufactured alternators have been considered as a case study for testing this framework. The upstream and downstream activities of the remanufacturing sector have been discussed to identify any possible impacts on the supply chain using the technical, environmental, social and economic performance of remanufacturing SME indicators.

Chapter 4 describes how the data will be collected and analyzed in order to test the SMF.

Chapter 4 Methodology

4.1 Introduction

This chapter discusses the validation of the sustainable manufacturing framework. It begins by presenting the technical, environmental, economic and environmental indicators for assessing the sustainability performance of remanufactured alternators using the sustainability manufacturing framework which was discussed in Chapter 3. Secondly, the data collection procedure for gathering information from selected Indonesian remanufacturing SMEs for calculating indicators is discussed. Thirdly, the formulae and tools for calculating technical, environmental, economic and social indicators using both field and secondary data are discussed. Fourthly, the development and selection of threshold values used for comparison purposes are discussed. Finally, the chapter discusses a number of opportunities for technical improvement of remanufacturing operations in order to attain triple bottom line benefits.

4.2 Development of indicators for sustainable manufacturing framework

4.2.1 Review of the available sustainable manufacturing indicators

The indicators used so far in the available published frameworks have been reviewed in order to select the appropriate indicators for assessing the sustainability performance of remanufactured products.

Table 4.1 The available published sustainable development and manufacturing indicators

NO	ORGANIZATION	SUSTAINABLE DEVELOPMENT AND MANUFACTURING INDICATORS
1	Organization for Economic Cooperation and Development (OECD)	*Organization for Economic Cooperation and Development (OECD) Core Environmental Indicator (EI).* The OECD CEI consists of 46 indicators based on environment, economic and social points of view (OECD CEI 2003)
2	United Nations (UN) Commission on Sustainable Development (CSD)	*United Nations - Commission on Sustainable Development (UN-CSD).* The UN-CSD contains 96 indicators including economic, social and environmental aspects in developing countries (UN_CSD 2007). .
3	International Organization for Standardization (ISO)	*International Organization for Standardization (ISO) Environment Performance Evaluation (EPE) standard (ISO14031).* ISO 14031 is an international standardization to guide companies in developing their own environmental indicators, categorized into operational performance, management performance and environmental condition (International Organisation for Standardisation (ISO) 1999).
4	European Environmental Agency	*European Environmental Agency Core Set of Indicators (EEA-CSI).* The EEA-CSI presents a means of setting environmental improvement priorities (e.g. waste, emissions) for EU countries (EEA 2005).

5	Yale Centre for Environmental Law and Policy	*Environmental Sustainability Indicators (ESI).* The ESI consists of 21 main factors with 68 indicators which are used for measuring and evaluating environmental stewardship for regions and countries (ESI (Environmental Performance Indicator) 2005).
6	RobecoSAM and Dow Jones	*Dow Jones Sustainability Indexes (DJSI).* The DJSI presents 12 indicators to measure the economic, environmental and social performance of a company (SAM Index 2007).
7	Ministry for the Environment, New Zealand	*Environmental Performance Indicators (EPI) – Confirmed indicators for waste, hazardous waste and contaminated sites.* This indicator is specific for hazardous waste and polluted places (e.g. waste solvent, landfill) (Ministry for the Environment 2000).
8	European Commission	*Environmental Pressure Indicators for European Union (Eprl):* The EPrl consists of 90 indicators for the environmental impacts associated with human activities. These include climate change, air pollution, lost biodiversity, ozone depletion, waste, water pollution, urban ecology problems, water resources and marine and coastal environment (EPrl 1999).
9	Ford Product Sustainability Index (Ford PSI)	*Ford Product Sustainability Index (Ford PSI):* The Ford PSI concerns the sustainability indicators for automotive manufacturing and service which integrate triple bottom sustainability. The Ford PSI consists of eight indicators including capability of mobility, LCC, global warming, air quality, sustainable materials, restricted materials, safety and exterior noise driven (Schmidt and Taylor 2006).
10	Design For Sustainability (DFS)	*Design for Sustainability (DFS)* consists of six main product sustainability elements covering the four stages of the product life cycle. These stages are pre-manufacturing, manufacturing, use and post-use and represent environment, social and economic sustainability (Jawahir, Dillon, et al. 2006).
11	NIST’s indicator	*NIST’s indicator* concerns five aspects of sustainability including environmental, economic, social, technological and performance management dimensions (Joung et al. 2012).

12	Japan National Institute of Science and Technology Policy (NISTEP)	The *NISTEP* indicator presents technological advancement through education, imports and exports, and scientific publications (Japan Science and Technology Agency 1995).
13	General Motors metrics	*GM Metrics* focusses on sustainable manufacturing implications including 30 metrics covering six main areas (energy consumption, waste management, manufacturing costs, occupational safety, environmental impact and personal health) (Feng, Joung, and Li 2010).
14	Organization for Economic Cooperation and Development (OECD) toolkits	*Organization for Economic Cooperation and Development (OECD) – Sustainable production indicators* is grouped into four categories including infrastructure, materials, process and products indicators, which consist of 18 indicators (Nasr, Hilton, and German 2011a).
15	Research Organisation – Andalas University	*Sustainable Manufacturing Performance Measures for Automotive Companies* – is grouped into three categories including environmental, economic and social performance (Amrina and Yusof 2011).

As shown in Table 4.1, these frameworks were sourced from international organization documents (i.e. OECD,UN_CSD, EPrl, EEA_CSI), national reports (i.e. EPI, DJSI, NISTEP), standard organizations (i.e. ISO, ESI, DJSI), established company sustainability reports (i.e. Ford PSI, GM Metrics) and research organizations (Joung et al. 2012, Amrina and Yusof 2011, Subic et al. 2012, Kibira, Jain, and Mclean 2009, Sikdar 2003, Labuschagne 2005, Nasr, Hilton, and German 2011a).

These frameworks have been developed for both developed and developing countries for assessing triple bottom line indicators, but none of them have specifically addressed the sustainability of remanufacturing operations except for Nasr, Hilton and German (2011).

In the case of Nasr, Hilton and German (2011), the sustainability framework for remanufacturing in developed countries has been discussed where remanufactured items are valued and well recognized, as they offer almost the same quality as new products. However, this framework is not suitable for developing countries, as the indicators for the technical bottom line have not been considered. As discussed in Chapters 2 and 3, technical indicators play an important role in attaining the economic and social sustainability of remanufactured products in developing countries, and the current research focusses on developing countries' issues. Some social (e.g. employment creation, labour wages), economic (e.g. sales, LCC, price) and environmental indicators (e.g. GHG emissions, energy savings) from their study which were deemed relevant to the situation in developing countries have been considered in the current framework.

4.2.2 Selection of sustainable manufacturing indicators

The first step in implementing a framework is to develop the indicators to assess social, economic and environmental aspects. Figure 4.1 shows the indicators that need to be considered in this process (Moss and Grunkemeyer 2007, Joung et al. 2012, Sustainable Measures 2009).

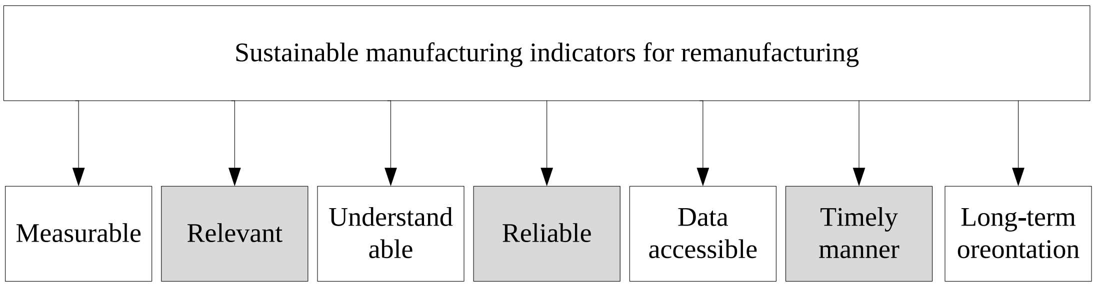

Figure 4.1 Indicators for selection

Measurable: The quantitative and qualitative values of sustainable manufacturing indicators for remanufacturing have to be measured easily within a certain timeframe for data collection and evaluation purposes. For example, technical performance is represented by using reliability as an indicator, the indicator for global warming performance is kg CO_2-eq, the economic performance indicator is life cycle cost (LCC), and the social performance indicator is the number of jobs created.

Relevance: It has to be relevant to the purpose of sustainability for each organization or the remanufacturing process. For example, the purpose of remanufacturing is to reduce energy consumption or landfill area, which is considered important sustainable manufacturing indicators.

Understandable: The indicator has to be easily understandable by people and the community. For example, LCC represents all of costs of the remanufacturing process which is easily understood by people and the community. Carbon footprint is also a term which is widely recognized.

Reliability: It consists of trustworthy and correct information and reliable data. For example, all data for calculating the sustainable manufacturing indicators from remanufacturers are cross-checked and tested for reliability of results.

Data accessibility: It has to be based on data and information which is accessible by the organization and the manufacturing system. For example, GHG emissions are calculated on the basis of the life cycle assessment of remanufactured products which involves data on all material and energy use gathered from the remanufacturers.

Timely manner: The collection of data, the calculation of results and the evaluation of data and information for the indicators have to be conducted using an appropriate method that assists rational decision-making. For example, the environmental indicator (e.g. carbon footprint) is calculated by using Simapro 7.33, widely used and recognized software for life cycle assessment. All data used are recent and up to date.

Long-term orientation: The indicators have to be suitable for future use. For example, the reliability indicator can be used to compare the performance of an existing product with future products.

Thus, when reviewing the available frameworks to select sustainability indicators for remanufacturing, the abovementioned factors were used to test to suitability of the selected indicators.

When selecting indicators, the challenges and advantages of the implementation of a remanufacturing strategy were considered from several points of view, including the company, consumer, environment, community and government policy points of view. The sustainable manufacturing indicators for remanufactured products were developed based on this approach, and are broken down into four dimensions including technical, environmental economic and social indicators.

4.2.3 Technical indicators

In the case of a remanufacturing strategy, technical indicators are likely to be the most uncertain and challenging factors (Zussman 2000), as technical feasibility is deemed responsible for achieving manufacturing viability (Anityasari 2009). In this research, the technical indicators are grouped into functional qualities (i.e. reliability, durability, safety, warranty) and availability of resources (i.e. availability of cores). Table 4.2 presents the technical indicators pertaining to sustainable manufacturing, followed by their descriptions and units.

Table 4.2 Technical indicators for sustainable manufacturing

INDICATORS	DESCRIPTIONS	UNITS/ QUALITATIVE JUDGEMENT
Reliability	The probability of remanufactured products performing their function within a certain period.	Percentage
Durability	The expectation of the lifetime of a remanufactured product.	Percentage within a certain time (i.e. 90% in two years)
Safety performance	Has the remanufactured product met the standard safety requirements?	Meet the standards
Warranty	The competency and availability of product servicing.	Year of warranty
Core availability	The ratio between demand and supply of the core/used products or components.	Unit per year or percentage

Reliability

The indicators for assessing quality are reliability, durability and safety. Quality has been identified as the functional performance of components and products which meet the reliability performance indicators, evoke customer satisfaction and gain competitive advantage (Toyota 2011). For remanufactured products, reliability is an essential assessment indicator for a quality product (Zhang, Wang, Chu, Cui, et al. 2010). Quality cannot be reached without reliability. The modified definition of the reliability performance of a remanufactured product is the potential for a remanufactured product to perform its required functions at certain times and under certain conditions in the same way as the original product.

Previous studies by Anityasari (2009) found that reliability without failure has become one of the top customer priorities despite other functional qualities (e.g. features, conformance). Companies which can economically maintain their products and provide technical quality and a reliable product to meet customers' expectations have the competency to survive in today's global market (Steinhilper 1998b). For example, the Cummins remanufacturing industry has utilized ISO standards (e.g. ISO 9000), applied advanced technology and employed highly skilled workers to achieve the standard quality and reliability of their remanufactured engines, which has created a good reputation, significant economic benefits (e.g. company's benefits) and environmental values (i.e. recycling) for the industry (Cummins 2014).

The unpredictable reliability of remanufactured products is still a common issue for remanufacturers, especially in emerging economics (e.g. Indonesia, India and China) (Fatimah et al. 2013). The lack of quality cores, ineffective and inefficient remanufacturing processes, lack of knowledge, a shortage of skilled workers, and outdated technology and equipment have been found to be the main causes of the reliability issues. As a result, remanufacturers need to apply quality (i.e. reliability) standards (ISO 9000) seriously, improve the efficiency of processes and make additional efforts to produce a quality and guaranteed product which is good as a new one (Steinhilper 1998b).

Durability

Not all of the cores collected can be used due to the limited durability of used products (Geyer, Wassenhove, and Atasu 2007). This constraint often reduces the production rate of high quality remanufactured products. These products need to be made durable by upgrading and improving the remanufacturing process (Cummins 2014).

A finite product/parts life cycle is one of the constraints in the remanufacturing business. The unpredictable durability of cores often creates difficulties for remanufacturing enterprises with regard to maintaining the durability of remanufactured products It is important for a remanufacturing enterprise to ensure the durability of cores in order to avoid the failure of remanufactured products (Geyer, Wassenhove, and Atasu 2007).

Meeting durability standards is an important factor for auto parts (e.g. engines, alternators), because they need to work under certain operating conditions (e.g. high temperatures, fast speed). However, sophisticated but affordable technologies (e.g. advanced testing processes) are required to be implemented in order to achieve optimal durability of products/parts. The wider availability and affordability of technology contributes significantly to achieving quality (i.e. durability), as claimed by Anityasari (2009).

Warranty

The warranty, which is defined as a 'written assurance that the manufacturer of products will guarantee the quality and reliability of a product in term of correcting any legitimate problems with the product at no additional cost, for some expressed or implied period of time or use', assures customers of the quality of the remanufactured products (Anityasari 2009, p. 56). Achieving 'as good as new' remanufactured products requires a proper warranty which itself does not have an effect on a product, but it is a way of letting customers know they are getting a reliable product.. For example, a warranty is an important factor for remanufactured medical devices due to the high frequency of their use, the high cost (upwards of a million USD) and the high risk to patients. Products with a longer warranty would therefore be preferable for customers.

Safety Performance

Remanufacturing enterprises are required to ensure the safety of their products (Steinhilper 1998b). Applying sophisticated safety standards (i.e. ISO 14001) and guidelines during the remanufacturing process is essential to meeting the safety requirements of a remanufactured product which are same as for a new product, especially for high risk products (e.g. aircraft). An example an investigation of maintenance and repair organizations (MROs) in the US showed that safety has become the first priority of their remanufacturing business. Under a comprehensive safety inspection prescribed by the Federal Aviation Administration (FAA) in the US, many companies have been authorized to meet the airworthiness of the aircraft (USITC 2012).

Cores availability

Cores are the main components of used products/parts and are one of the most important inputs in the remanufacturing process (Steinhilper 1998b). Remanufacturing would not be possible without the availability of cores (Inderfurth and Langella 2007). However, Nasr et al (1998) states that the logistics system in remanufacturing supply chains lack the appropriate technology and techniques (Nasr et al. 1998), resulting in a number of issues with cores. Uncertainty associated with the time of return and availability of cores are common issues for remanufacturing operations, followed by the imbalance between returns and demands, carelessness in the disassembling process, uncertainty with regard to the quality of cores, reverse logistics issues, material matching requirements and uncertainty in the remanufacturing process (Daniel and Guide 2000, Golinska et al. 2007).

More than half of the remanufacturing enterprises (62.5%) do not have any control over the returns time and quantity of cores (Daniel and Guide 2000) because of this uncertainty. Nasr et al. (1998) states that only about one third of accepted cores needs to be available for remanufacture. Previous research has found that the availability of cores was about 5–35%, while the reusability of the cores, which needs to be assessed, was about 40–93% (Guide et al. 2006, Toktay 2003). Therefore, balancing the supply and demand of cores plays an important part in successfully implementing remanufacturing activities (Daniel and Guide 2000). The quality of the supplied cores could be maintained by improving the handling of cores and the disassembly process (Teunter and Flapper 2011). The disassembly process is labour intensive since it requires skilled workers to carefully separate the cores without any damage.

On the other hand, there is potential for the rapid development of remanufacturing industries which could create pressure on the market price of cores and materials. Cores are becoming rare and the price of materials is increasing. Therefore, the implementation of resource efficiency is necessary to gain economic prosperity among remanufacturing industries (Michaud. C. and Lierena 2006).

4.2.4 Environmental indicators

In evaluating sustainable manufacturing performance, environmental indicators are considered to be the most important factor followed by social indicators and economic indicators (Amrina and Yusof 2011). The environmental indicators in this research are the evaluation of resources (i.e. energy and material consumption, material intensity per service unit), waste generation (i.e. solid waste, landfill) and atmospheric emissions (i.e. GHG emissions). Water pollution due to the discharge of chemicals, grease and coolant has not been considered as is more of a management issue than a remanufacturing issue. In addition, discrepancies in water pollution impact were found in more regional and local impact categories (i.e. acidification, eutrophication, human and eco-toxicity) (Yoshida, Christensen, and Cheutz 2013). Table 4.3 shows the wide range of environmental indicators.

Table 4.3 Environmental indicators for sustainable manufacturing

INDICATORS	DESCRIPTIONS	UNITS/ QUALITATIVE JUDGEMENT
Embodied energy consumption	The total energy consumption from all energy used (e.g. electricity) in the remanufacturing process.	MJ per unit
Greenhouse gas (GHG) emissions	The total CO_2 equivalent associated with the remanufacturing process.	kg CO_2-eq per unit
Material consumption	The total weight of material (e.g. virgin and auxiliary) consumed by the remanufacturing process.	kg per unit
Material intensity per service unit	The total amount of material consumed per service unit.	kg per unit
Solid waste	Total unwanted/discharged waste generated from solid material (e.g. plastics, papers, metals) and the remanufacturing process (Ministry for the Environment 2000).	kg per unit
Landfill	Total quantity of waste sent to landfill.	kg per m^3

Embodied energy consumption

Embodied energy is one of the vital inputs into the manufacturing process (Moneim, Galal, and El-Shakwy 2013). Remanufacturing reduces the embodied energy consumption by taking back end of life products and transforming them into useful products, thus eliminating all of the upstream processes associated with new products, including mining, mineral processing, foundry, machining and transportation (Cummins 2014).

According to the Energy Systems Division of the Argonne National Laboratory, remanufacturing in the auto parts sector conserves a large amount of energy (400 trillions Btu per year) (APRA n.d., Guintini and Gaudette 2003). Remanufacturing an engine conserves approximately 85% of the energy consumption of a brand new product (Cummins 2014).

Energy efficiency is an important strategy that needs to be implemented by remanufacturing industries. Non-renewable energy savings means the conservation of energy for future generations, thus enhancing intergenerational equity. Replacing energy intensive metals like aluminium or iron with remanufactured parts could significantly reduce the energy consumption and associated atmospheric emissions.

GHG emissions

GHG emissions have been used for eco-labelling on a variety of products to show the life cycle GHG emission or carbon footprint of products (OECD 2009c). The life cycle GHG emission will help an enterprise to identify the causes and effects of the CO_2 emission during their remanufacturing activities.

Remanufacturing significantly reduces the GHG emissions associated with energy consumption, since a remanufactured product requires 85% less energy than a new the one (Cummins 2014). By remanufacturing 50 million pounds of engines and parts by weight, about 200 million pounds of GHG emissions can be mitigated (Cummins 2014). Other research has found that the substitution of a remanufactured alternator for a new one reduced GHG emissions by 88% (Schau, Traverso, and Finkbeiner 2012).

Material consumption

Material consumption has been chosen as an environmental impact as the production of materials requires mining, processing, and foundry activities. Avoiding material consumption through remanufacturing, recovering and recycling will also avoid all upstream activities and mining processes. Minimizing the amount of virgin material used by increasing the application of used or reconditioned materials could be a strategy to reduce material consumption.

Material intensity per service unit (MIPS)

Material intensity per service unit reveals the importance of the use of resources during the life cycle of products. MIPS represents the eco-efficiency of a product or service by considering the total material input recognized to deliver a unit of service. MIPS measures 'the total mass of material inputs to create a unit of service input' (OECD 2009c, p. 114).

The reduction of material inputs and the increase of the service unit are two important keys to increasing MIPS. In terms of remanufacturing activity, the use of used components offers a significant reduction in material consumption which will increase the MIPS. Service is increased by reusing an alternator for a number of times.

Solid waste

A substantial reduction in the amount of solid waste would be possible through the use of EoL products. This strategy has been widely applied to reduce the rapid development of solid waste. Achieving zero waste by completely reusing, recycling and remanufacturing all returned materials is the principal concept of the closed loop strategy (Golinska et al. 2007). Remanufacturing could conserve up to 85% of used materials (APRA Europe 2012), which could also significantly reduce the amount of solid waste produced.

Landfill

The concept of 'zero landfill' as acknowledged by Fuji Xerox Australia has been considered to be an important part of sustainable manufacturing since this concept does not only focus on the zero landfill principle but also maximizes the value of used products or components by reusing old parts (Fuji Xerox 2012). Remanufacturing keeps products/parts from occupying landfill space by giving them a longer lifetime (Gray and Charter 2007). This landfill impact analysis will help enterprises to take steps to achieve manufacturing sustainability through waste reduction and reducing material consumption.

4.2.5 Economic indicators

The economic sustainability in this research refers to the economic benefits which can be derived from remanufacturing activities in the present without compromising the ability of future generations to meet their own needs. The assessment of economic sustainability focusses on the determination of the actual benefits brought about by the remanufacturing activities. Specific economic indicators, including existing indicators for accurately measuring the economic performance of remanufacturing activities, are taken into consideration and categorized into costs (i.e. LCC), profits (i.e. price, sales, recovered material value) and investment (i.e. return on investment). The most common economic indicators involved in the remanufacturing activities are presented in Table 4.4.

Remanufacturing is a potentially profitable business. The value of remanufacturing can reach 60% of profit, as experienced by General Electrics (GE) (Statham 2006). Accordingly, profit is one of the strongest drivers for many industries to participate in remanufacturing (Anityasari 2009). Cost saving is also a major driver for remanufacturing (Atasu, Sarvary, and van Wassenhove 2008). Since the materials in the remanufacturing process are mostly used or recycled components, the remanufacturing operation is designed to produce lower cost products which not only offer affordable prices to the customer, but also increase the profitability of the company (Steinhilper 1998b). Profit is therefore created by many factors such as life cycle cost (LCC), sales and price.

Table 4.4 The economic indicators for sustainable manufacturing

INDICATORS	DESCRIPTION	UNITS/ QUALITATIVE JUDGEMENT
Life cycle cost	The total cost of assets, core collection, remanufacturing and marketing costs throughout the life cycle of a remanufactured product.	USD
Price and profit margin	Selling price for generating a profit margin in the competitive market.	USD
Sales	Revenue generated from the total number of remanufactured products sold per year.	USD
Recovered material value	The total value recovered from remanufacturing activities.	USD
Return on investment	The benefits accrued from investing in a remanufactured product minus the cost of the investment.	Percentage
Import dependency	The expectation of import dependency based on the decrease or increase of imported products/parts in the global market.	Dependent

Life cycle cost

Life cycle cost (LCC) is the summation of predicted costs from the initiation to the discard process in the life cycle of a product (Barringer and Monroe 1999). In the automobile sector, LCC has been applied in order to attain the lowest life cycle cost of a product, not only by considering the direct costs, but also the unknown (i.e. recycling revenue) and contingent costs (i.e. warranty costs) (Fiksel, McDaniel, and Mendenhall 1999). Competitive prices for remanufactured products are predicted to be an important concern for consumers. However, competitive prices can only be achieved by minimizing the capital (i.e. building, machinery), labour (i.e. disassembly workers), materials (e.g. cores, new materials), energy (e.g. electricity, gas), transportation (i.e. fuels) and overhead (i.e. machine depreciation) costs for producing the remanufactured products.

Life cycle cost (LCC) analysis is a useful tool that provides essential metrics for determining the most effective cost approach (Barringer and Monroe 1999), which lead to competitive prices. It indicates the overall costs spent during the life cycle of a remanufactured product/part, which can help the remanufacturing industry to carry out a cost analysis effectively. The LCC of remanufactured products (i.e. auto parts) is about 12% of the cost of new ones (Schau, Traverso, and Finkbeiner 2012). Therefore, remanufacturing offers good as new quality with a lower price (Smith and Keoleian 2004).

If the cost of the remanufacturing process can be effectively minimized, there will be an economic saving (i.e. lower price) for the remanufactured products, which would attract customers to buy remanufactured instead of new products.

Sales, price and profit margin

Sales of products certainly results in greater profits (Suttle 2014). The number of sales is linked to the amount of profit that can be generated by the industry. The greater the sales the larger the profits. Nasr et al (1998) state that at least approximately 20% of a profit margin needs to be obtained from remanufacturing activities (Nasr et al. 1998). Guintini (2013) claims that remanufactured products offer a profit margin about 50–100% higher than that of new products (Guintini 2013). An example is the Cummins industry (Cummins 2014), which shows that about USD 1 billion in sales can be generated in a year by selling about 3000 remanufactured products (i.e. engine, parts), placing the company as one of the leaders in the US remanufacturing industry.

Sales of remanufactured products can be influenced by a number of factors such as competitive prices, customer perception, quality of product/service, marketing strategies, brand and availability of products.

Remanufactured products provide competitive prices in the market in comparison with new ones. However, there is a risk that sales will fall when the price is too high due to a high life cycle cost or profit margin. On the other hand, sales tend also to decrease if the price is too low, as customers are not confident about the quality of the remanufactured products. Accordingly, it is important to determine an appropriate price without sacrificing product quality, and with a reasonable profit in order to improve sales. Remanufactured products are usually sold for 40–60% of the new product price (Statham 2006).

Negative customer perception of remanufactured products is a challenging factor as they are sold as due to second-hand product. Therefore, customers need to understand that remanufactured products work as well as new products in order to improve their perception and thus increase sales.

The cost competitiveness of remanufactured products is mainly influenced by price and quality, as it is easier to offer quality remanufactured products at a higher price (Statham 2006). However, many remanufacturing enterprises have to sacrifice the quality of products to achieve lower prices. It is especially difficult for remanufacturing SMEs to compete in the global market due to the lack of product quality and shorter warranty periods.

Marketing strategy is an important component of the remanufacturing business (Statham 2006). The strategy helps remanufacturers to sell products and provide services (i.e. warranty) at the right price for a better profit by considering market prices, competitors and product trends. Research conducted by Atasu et al. (2008) has also found that remanufacturing is an effective market strategy for manufacturers to maintain their market share through price distinction (Atasu, Sarvary, and van Wassenhove 2008). Two common ways of commercializing remanufactured products are selling and leasing (Barquet, Rozenfeld, and Forcellini 2013). Brand and availability of products are other essential aspects of the remanufacturing business which affect the marketing process.

Recovered material value

The focus on remanufacturing is not just about recovery of material but preferably involves the recovery of value added (Nasr et al. 1998). The value added in remanufacturing represents the value of the materials used in each step of the remanufacturing process from collection to the finishing of remanufactured products. It is used to determine the value of the remanufactured product on the basis of the amount of used material recovered.

Return on investment

Optimum resource utilization is an important issue for the remanufacturing industry due to the limited amount of energy, materials and natural resources. By doing more with less resources and optimizing end use consumption, eco-efficient strategies could reduce costs and increase profits, competitiveness and the sustainability of the industry. Return on investment has become an important indicator for remanufacturing in order to determine the potential for investment into the remanufacturing process. The investment is dependent on the ability of cores to be reused several times without any problems resulting from material fatigue. Fatigue and durability of materials were thus taken into account in this analysis.

Import dependency

Import dependency is one of the factors that is most challenging for the implementation of remanufacturing in Indonesia. An excessive import dependency causes a macro-economic impact as domestic products fetch lower prices on the international market. Affordable price is a major reason for the preference for using imported parts/products in remanufacturing activities. Even though the Indonesian government has restricted the import of some second-hand parts for environmental conservation reasons, many informal sectors still illegally import second-hand parts. In addition, many remanufacturing SMEs rely on imported new parts to replace worn parts, as many parts are not manufactured in Indonesia.

Import dependency does not only occur in the business sector; the domestic market for consumer products is dominated by imported products (e.g. Chinese products) which are much lower in price and better in quality than local products. As a result, many local products cannot compete in the market. Therefore, there is an opportunity to strengthen the local market by providing remanufactured products with the same quality as new ones but at a lower price.

However, the challenge remains to provide sufficient quality cores locally to avoid imports or the use of new products.

4.2.6 Social indicators

Social issues are predicted to be prominent in the remanufacturing industry, since the community, customers and employees are all taken into consideration. In this research, the social indicators measure the impact of the remanufacturing process and products from the point of view of the community (i.e. employment creation, intergenerational equity and new enterprise development), industry (i.e. company reputation, import dependency) and employees (i.e. salary package and wages). The social indicators for the remanufactured alternators are presented in Table 4.5.

Employment creation

Remanufacturing opens up a large number of new job opportunities as it is labour intensive. For example, a new remanufacturing business will need employees for the remanufacturing process including a manager, administrative staff and technical staff (i.e. drivers, parkers, technicians). Furthermore, the development of the remanufacturing industry will generate more demands for suppliers, sales and collection centres to support the remanufacturing activity.

Especially for SMEs, employment creation is a way of enhancing intergenerational social equity, which empowers the poor to reduce the gap between the poor and the rich (Biswas, Bryce, and Diesendorf 2001). This indicator shows how the industry could have a positive social influence by providing new job opportunities.

Table 4.5 The social indicators and the indicators for sustainable manufacturing

INDICATORS	**DESCRIPTION**	**UNITS/ QUALITATIVE JUDGEMENT**
Employment creation	Number of jobs created from the remanufacturing activity including direct (i.e. remanufacturing labour) and indirect labour (i.e. scavengers).	Labour per year
Youth and enterprise development	Youth and new enterprise development created from the remanufacturing activity.	Person or unit per year
Corporate social responsibility	Has the enterprise been responsible for reducing environmental impact and enhancing social benefits?	Performed or not performed
Labour wages	The average pay given to workers in the remanufacturing industry.	Percentage and AUD
Intergenerational equity	The materials and energy conserved from the remanufacturing activity over the next 20 years.*	Unit per 20 years
Company reputation	The company reputation based on the current situation and future expectations.	Strong, weak

* The 20 year period is based on the expectations about the reusability of used products for remanufacturing.

Labour wages

Indonesian factory workers are still poorly paid (Mustiadi 2012). The average minimum wage for factory labour in 2009 in the Java area was about IDR 1,481,100 (USD 140) per month, with the salary being estimated at 20% lower than for those doing similar jobs in other Asian countries (i.e. dismantling and refurbishing) (Hewlett Packard 2012). According to the Indonesian Ministry of Manpower and Transmigration, about 37% of all Indonesian workers were paid above the minimum wage. The majority of employees (63%) on Java Island were paid below the minimum wage (Ridwan 2012),(Santoso and Hassan 2014).

Remanufacturing has the potential to increase the salary of workers, as the processes demand skilled workers who have received training, education and skills development (OECD 2004). Similarly, in developing countries such as Indonesia, remanufacturing could be an effective way of improving the productivity and salaries of workers through training, education and skill development.

Intergenerational equity

The privilege of future generations to access a sustainable life is a concept that is understood globally (Nemb, Mathias, and Nonga 2010). The conservation of resources (i.e. materials and embodied energy) is an important key to ensuring intergenerational equity (Harris 2003). Remanufacturing significantly conserves material and energy (by up to 85%) and reduces GHG emissions by about 400 kilotons, which is equivalent to a 170 million litre reduction in gasoline or to taking 200,000 cars off the road annually, and comparable with the forestation of 30,000 hectares of land (APRA Europe 2012). The implementation of remanufacturing among Indonesian SMEs could significantly reduce the energy and material consumption for future generations in Indonesia.

Company reputation

A company's reputation is a major driver of its business value (Reputation Institute UK 2012a). Reputation plays a significant role in successfully introducing remanufactured products to customers who are interested in buying them. A study in the UK Reputation Institute found that about 69% of customers were willing to provide positive feedback about a company due to their impressions of that company, and about 31% due to the company's products and services (Reputation Institute UK 2012b). However, establishing both the reputation and integrity of a remanufacturing enterprise is a challenging task for SMEs due to a lack of technical performance (i.e. reliability, warranty), marketing strategy and policy supports.

Corporate social responsibility

Corporate social responsibility (CSR) is an important factor for achieving environmental and social sustainability (Ozer 2012, Fuji Xerox n.d.). The remanufacturing strategy plays an essential role in successfully achieving sustainability by taking back end of life products from customers, thus reducing environmental impact, which is an important part of corporate social responsibility.

Corporate social responsibility means that the industry is responsible for both the environmental impact and social consequences associated with their industrial activities (Fuji Xerox n.d., Canon 2014). The implementation of corporate social responsibility provides positive values to enterprise such as labour and customer attractiveness and loyalty, reputation improvement and manufacturing cost reductions (Katherine et al. 2011).

Youth and enterprise development

The development of new businesses that service remanufacturing enterprises is a social indicator for remanufacturing (Gray and Charter 2007). For example, an alternator remanufacturing industry will need local markets to supply and sell their products, and will also encourage the development of new workshops, cannibalizing businesses and collection centres where young people could potentially be employed.

However, the success of remanufacturing businesses and products needs to be showcased in order for the businesses to receive financial support from government institutions, OEM or other businesses (Gray and Charter 2007). Therefore, positive company reputations supported by solid collaboration between the remanufacturing enterprise, the government, OEMs and other businesses are essential (Gallo, Romano, and Santilo 2012).

The majority of the aforementioned indicators are quantifiable. The quantifiable values are determined based on measurements of independent variables and presented in a specific sustainable index or sustainable metrics (Bilge et al 2014, Jawahir and Lu 2014, Shuaib et al 2014). For example, the value of reliability is achieved using the information on independent variables including life time, failure time and suspension time and is presented as percentage. Only three qualitative indicators, including import dependency, company reputation and Corporate Social Responsibility (CSR) that were used in this research were achieved through establishing system knowledge, meeting requirement or pursuing trends of market (Bilge et al 2014, Zhang et all 2012). This value is usually assigned as existing, non existing or meeting the limit (Bilge et al 2014). Accordingly, for this current research, the qualitative value of import dependency is either 'dependent' or 'independent', the company's reputation is either 'strong' or 'weak', and CSR is either 'performed' or 'not performed'.

4.3 Data collection for calculating indicators

4.3.1 Primary and secondary data collection

This research uses a survey method to determine the activities of SMEs producing remanufactured alternators in Indonesia and to collect data on the aforementioned sustainable manufacturing indicators for the technical, economic, environmental and social aspects. For this PhD research project, ethics approval was obtained from Curtin University's ethics approval committee prior to data collection (approval numbers SMEC-17-11) (Appendix B).

As discussed in Chapter 3, case studies on these remanufacturing SMEs on Java Island were conducted based on willingness to participate in the interviewing process. A case study is a process where an investigator looks at particular cases in order to discover something about the case in general.This research uses a survey method to determine the activities of SMEs producing remanufactured alternators in Indonesia and to collect data on the aforementioned sustainable manufacturing indicators for the technical, economic, environmental and social aspects. As discussed in Chapter 3, case studies on these remanufacturing SMEs on Java Island were conducted based on willingness to participate in the interviewing process. A case study is a process where an investigator looks at particular cases in order to discover something about the case in genera.

Questionnaires were developed to collect primary and secondary data. The primary data, including all information related to the economic, social, environmental and technical aspects, was collected directly from the remanufacturing SMEs, suppliers, distributors and consumers. In depth interviews were also conducted in order to record more detailed information about the enterprises.

Other primary data was gathered by consulting with the stakeholders of the SMEs, including agencies of the Indonesian government, representatives of the community, and non-governmental organizations. The secondary data sources included the Indonesia statistical book 2009–2014, Tapak Pengembangan Industri National 2009–2014 and government institutional reports. These were used to gather supporting information (e.g. market prices, standardization data, regulations and policies, global data on SMEs and global data on the remanufacturing industry) for the calculation of the sustainable manufacturing indicators. Table 4.6 and Table 4.7 present the data requirements for each indicator.

Table 4.6 The data requirements for calculating technical and environmental indicators

INDICATORS	**DATA REQUIREMENTS**
Technical indicators	
Reliability	Failure data, number of sold products, purchasing date, failure date, operation time
Durability	Lifetime expectation, standard durability requirements, durability testing procedures
Warranty	Reliability data, warranty policy implementation
Safety performance	Standard safety requirements, safety testing procedures
Core availability	Number of cores available, total cores collection
Environmental indicators	
GHG emissions	Product life cycle , materials, emissions, energy, chemicals, waste
Energy consumption	Fuel, gas and electricity consumption, Indonesian and Chinese energy mix
Material consumption	Bill of material, type of material, weight of material
MIPS	Weight of total new materials used in the remanufacturing process to provide service.
Solid waste	Type of waste, weight of waste
Landfill	Size of landfill area, amount of waste

Table 4.7 The data requirements for calculating economic and social indicators

INDICATORS	DATA REQUIREMENTS
Economic indicators	
Life cycle cost	Investment and capital cost, remanufacturing cost (i.e. energy, material, labour, cost)
Sales	Number of products sold, price of products
Price	Profit margin, life cycle cost, overhead cost
Recovered material value	Labour cost, material cost, overhead cost
Return on investment	Number of products produced per year, quantity of different inputs
Import dependency	Quantity of import materials or cores (current and estimation)
Social indicators	
Employment creation	Number of jobs created, number of products produced
Youth & enterprise development	Number of employees, work hours, level of employee education. Number of existing enterprises before and after improvement
Corporate social responsibility	GHG emissions, warranty, waste reduction
Labour wages	Average employee wage rate, number of employees, work hours, average minimum salary
Intergenerational equity	Material and energy consumption over a 20 year period
Company reputation	Increase in sales, market share, profit margin

4.3.2 Limitations of this survey

A number of limitations have been identified and considered in this survey. Firstly, there was a lack of information provided by the Indonesian industrial department which made it difficult to determine the existing number of remanufacturing industries in Indonesia and their actual situation. There was insufficient data available in the government database and only a few remanufacturing industries were registered in it.

Secondly, not all of the remanufacturing SMEs were willing to be involved in the survey for confidential reasons, which limited the choice of credible remanufacturing industries.

Thirdly, uncertainty associated with the definition of remanufacturing has created ambiguity between the industry and its supply chain, so that many industries do not understand and are not aware of the standard remanufacturing process.

Fourthly, there is a lack of knowledge about and promotion of remanufacturing industries.

4.4 Identification of the assessment tools

The tools used to calculate the sustainable manufacturing indicators (section 4.2) using the primary and secondary data (section 4.3) are discussed below.

4.4.1 Technical assessment tools

The tools used to calculate the technical indicators, including reliability, durability, safety, warranty and availability of cores for the remanufactured products, are discussed below.

Reliability

The reliability analysis was conducted using two main types of data including suspension and failure data. The suspension data concerned the components which still functioned properly until the end of the observation period, and the failure data concerned the components which failed during the observation period. Some raw data such as the type of product, component specification, date of purchase, sales data, failure date, number of failures, type of failure and number of suspensions were gathered from the SMEs to determine the values for suspension and failure of remanufactured products. The suspension data was generated from the difference between the purchase date and the end of observation date, while the failure data (time to failure) was defined by the difference between the date of purchase and the date of failure.

A Weibull distribution was then applied to this data. The Weibull distribution is a handy and adaptable tool to determine the practical results of a reuse strategy (Anityasari 2009). Based on the failure and suspension data, a two parameter Weibull distribution, which is categorized by a scale (η) and a slope (β), was defined. The parameter scale identifies the life of the product at which 63.2% of all products will fail and the parameter β represents the failure mode (Anityasari 2009).

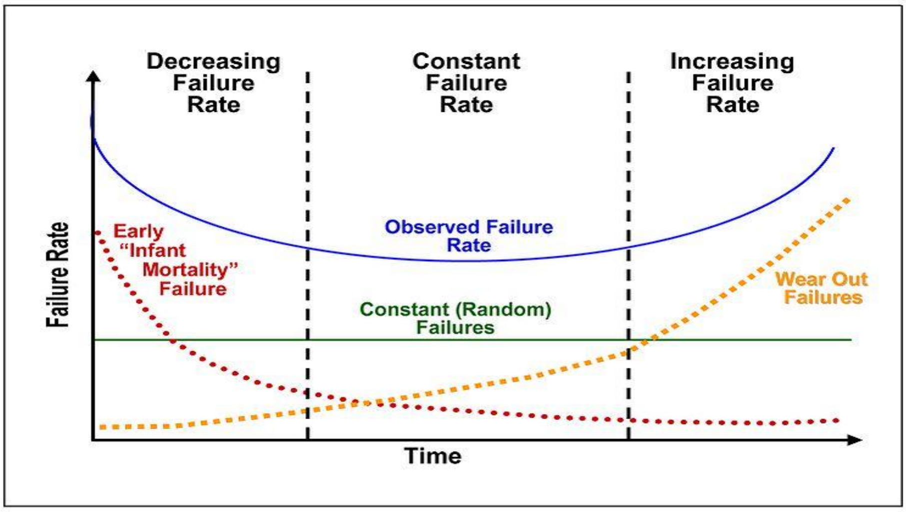

Figure 4.2 The mechanism of failure based on the failure mode

Figure 4.2 (Anityasari 2009) describes the mechanism of failure based on the failure mode, where β <1 indicates early 'infant mortality' failure, β = 1 means constant (random) failure and β >1 represents "Failures due to wear" ". The mathematical formula for the Weibull distribution is explained in following equation where F(t) denotes the probability of units failing and t is the failure time.

$$F(t) = 1 - exp\left[- \left(\frac{t}{n}\right)^{\beta}\right] \qquad \text{Equation 4.1}$$

Where,

N : scale parameter

B : shape parameter (hours or years)

T : failure time (hours or years)

For example, if remanufactured products are used for 800 hours in a year, and the Weibull distribution of the failure is modelled as scale parameter n = 8,000 hours and shape parameter β = 1.5, the probability that the remanufactured products would fail within five years is 0.298 or approximately 30% of overall products.

As well as determining the failure distribution of the products, the reliability function and mean time to failure (MTTF) were calculated. The mathematical formula for the reliability function and the MTTF are presented in Equations 4.2 and 4.3.

$$R(t) = 1 - f(t) = exp\left[- \left(\frac{t}{n}\right)^{\beta}\right] \qquad \text{Equation 4.2}$$

$$MTTF = \eta\Gamma(x)\left[1 + \frac{1}{\beta}\right] \qquad \text{Equation 4.3}$$

Where,

$$\Gamma(x) = \int_{u}^{\infty} u^{x-1} e^{-u} du$$

η : scale parameter

β : shape parameter (hours or years)

To illustrate the reliability calculation using the same data as shown above, the reliability of the remanufactured product is determined as 1 minus 0.3 which is 0.7, or 70% reliable.

The fitting method applied in this reliability analysis is the maximum likelihood estimation (MLE), as the data in this analysis are categorized as right-censored data.

In order to help the reliability analysis, Weibull ++8 software was used. The software is made by Reliasoft Corporation (Reliasoft 2013) and was applied in order to generate the reliability plots and to define the reliability distribution and the reliability parameters of the remanufactured products. In addition, the suspension data including suspended time (S) and number of suspension products and the failure data involving time to failure (F) and number of failures were provided to support the calculation. The global reliability analysis framework is presented in Figure 4.3 (Anityasari 2009).

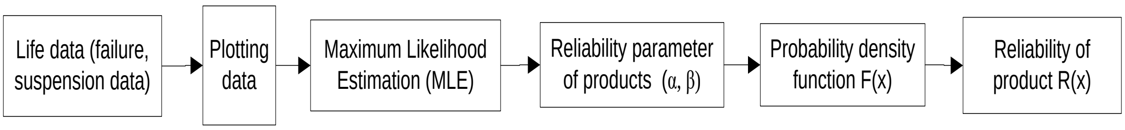

Figure 4.3 The steps in the reliability analysis of the remanufactured products

Next, the reliability prediction was used to determine the reliability of the remanufactured products based on the proposed improvement scenarios. Both series and parallel systems were used to determine the reliability of the remanufactured products. The block diagram presents the calculation process.

For the series system, the failure rate depends on the total failure rate of the components , and is expressed by the following equation (Anityasari 2009).

$R_s(x) = 1 - F_{syst}(x) = \prod_{i=1}^{N}(1 - F_i\,(x))$ Equation 4.4

In the case of a parallel system, the failure rate depends on the failure of each component. If one component fails, the system does not work. The reliability of a parallel system has been expressed as follows (Anityasari 2009) :

$R_p(x) = 1 - \prod_{i=1}^{n}(1 - F_i(x))$ Equation 4.5

In order to understand the distinction between series and parallel systems, two examples are presented as follows. A series system consists of three parts with reliabilities of 0.99, 0.95 and 0.95 respectively (Figure 4.4). Using the above equation, the reliability of the series system has been calculated as 0.89 (0.99 X 0.95 X 0.95 = 0.89).

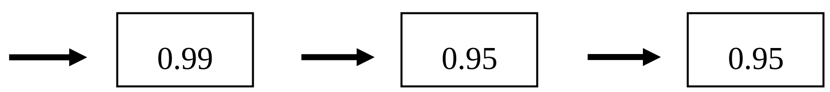

Figure 4.4 Example of a series system

The following example shows a parallel system consisting of three components (reliability = 70% for each) presented in a block diagram (Figure 4.5). Using the equation for a parallel system, the reliability is estimated to be 0.97 which is calculated from (1-0.3^3).

The parallel system works if all of the components work. Theoretically, the overall parallel system will have greater reliability than any of the single components (Romeu 2004).

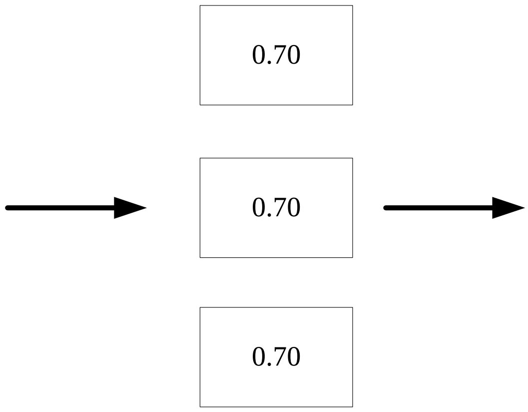

Figure 4.5 Example of a paralel system

Durability

Durability is the probability of a product working properly in a certain period of time. Durability testing is often considered a sub-group of reliability (Sterling Performance 2014). Thus the durability performance is analyzed based on the reliability value. Assume that the reliability R(t) of a remanufactured part is 95% for a life expectancy of two years. Accordingly, the durability has to meet the life expectancy of the product which is two years with a reliability of 95%. By using the same Weibull analysis, the durability of the remanufactured part was determined for the same number of years. The durability of the remanufactured products was also analyzed on the basis of certain environmental conditions.

Warranty

The main objective of the remanufacturing strategy is to produce as good as new products which have the same competitive market as new products. It should be noted that remanufactured products are required to have the same probability of failure as new products, which means that they will be provided with the same warranty as new products (Chron).

The warranty calculation for remanufactured products has been determined using the equations 4.11–4.19 (Anityasari 2009).

$$TR_1 = NPR + NCR \qquad \text{Equation 4.6}$$

$$TR_2 = PR_2 + CR_2$$

$$TR_2 = PR_2 + NCR$$

$$TR_2 = F(t_2) - F(t_1)$$

$$PR_2 = F_{t_{w_2}} - F(t_1)$$

$$F_{t_{w_2}} = [F(t_2) - F(t_1)] - [F(t_1) - F(t_{w1})] + F(t_1)$$

$$R_{t_{w2}} = 1 - F_{t_{w2}}$$

$$t_{w2} = \eta\left(-\ln R_{t_{w2}}\right)^{1/\beta}$$

$$W_2 = t_{w2} - t_1$$

Where,

TR_2 : Total risk for the remanufactured products

CR_2 : Corporate social responsibility

$R_{t_{w2}}$: Expected reliability at t_{w2} (%)

t_2 : Maximum allowable value at t_{w2} (days)

t_{w2} : Maximum allowable value for t_{w2}

$F_{t_{w2}}$: Cumulative distribution function at t_{w2}

W_2 : Length of warranty period (months or years)

Safety performance

The failure of a product or equipment often creates a negative impact on the safety or health of users (Health and Safety Executive 2009). Accordingly, safety has become an important technical aspect requiring deep attention, especially for remanufactured products which have a higher possibility of failure due to the use of a higher percentage of used components. In order to maintain the safety standards of remanufactured products, this research has considered the assessment of the remanufacturing process (i.e. testing steps) supporting all safety standards, guidelines and procedures. The value of safety performance in this research has been expressed in terms of qualitative values (e.g. yes or no).

Availability of cores

The availability of core materials is crucial to maintaining the required production rate; otherwise, it will affect the economic sustainability of the remanufactured products. The greater the number of available quality cores, the more reusable products can be used for maintaining the required reliability. The availability of the cores has been calculated using the following equation:

$$CA = (NAC/RC) \times 100\% \qquad \text{Equation 4.7}$$

Where,

CA : availability of cores (units)
NAC : number of available cores (units)
RC : total requirement of cores (units)

4.4.2 Environmental impact assessment tools

Environmental impact assessment indicators include energy and material consumption, GHG emissions, waste generation, MIPS, solid waste and landfill associated with the production of remanufactured products, as presented in the following section.

Energy consumption

Energy consumption in the making of remanufactured products has been categorized into electricity, natural gas, fuel/oil, steam and internal combustion consumption. The total energy consumption is the summation of the energy consumed in the eight stages of the remanufacturing operation, including product recovery, disassembly, cleaning and inspection and sorting, reconditioning, replenishment and packaging, and is expressed in mega joules (MJ). The total energy consumption for the remanufacturing process is calculated as follows.

$$\begin{aligned} TEC = &\sum_{n=1}^{8} Energy\ of\ electricity\ n + \sum_{n=1}^{8} Energy\ of\ natural\ gas\ n \\ &+ \sum_{n=1}^{8} Energy\ of\ fuel\ oil\ n + \sum_{n=1}^{8} Energy\ of\ Steam\ n \\ &+ \sum_{n=1}^{8} Energy\ of\ internal\ combustion\ n \end{aligned}$$

Equation 4.8

Where,

n = the stage of the remanufacturing processes.

GHG emissions

The streamlined life cycle assessment (SLCA) analysis that follows the four steps of the ISO 14040-44 series (PRe Consultants 2013) was carried out to estimate the GHG emissions due to remanufactured products. The basic idea of a life cycle assessment analysis is to determine the environmental impact of a product during its life cycle, including the extraction of raw material, manufacturing, transportation, maintenance, recycling and disposal (ISO 2006). The current analysis is a streamlined LCA as it excludes the use and disposal stages (Todd and Curran 1999).

The life cycle assessment consists of four steps (ISO 2006) which are goal and scope, life cycle inventory, impact assessment and interpretation of the life cycle.

The initial step of the LCA is to determine the goal and scope of the analysis, and to define the process and products which are to be analyzed. The goal is based on the objectives of the analysis. This clarifies the intention of the assessment, for example, the optimization of some impact categories such as global warming potential. The scope is used to define the functional unit of the remanufactured products (e.g. kg of solvent, litres of diesel), the system boundary, the data requirements and the environmental impact. Therefore, the system boundary for the research only includes the input causing the GHG emissions and the embodied energy consumption of the remanufacturing process from product recovery to packaging, associated with the production of a remanufactured product (i.e. remanufactured alternator).

Once this initial step has been completed, the life cycle inventory analysis is conducted. The life cycle inventory analysis identifies and calculates the input and output of the remanufactured product during its life cycle, including all materials and energy consumption and potential waste and emissions (Biswas and Rosano 2011). The inputs are components (i.e. co-products), materials (type of material, type of fuel, fuel consumption) and resources (e.g. water) and energy (e.g. electricity, natural gas for heat) used during the remanufacturing process. The outputs are emissions and waste created by the remanufacturing process. The input and output of the life cycle inventory analysis is gathered from all processes within the system boundaries of the assessment (Figure 4.6).

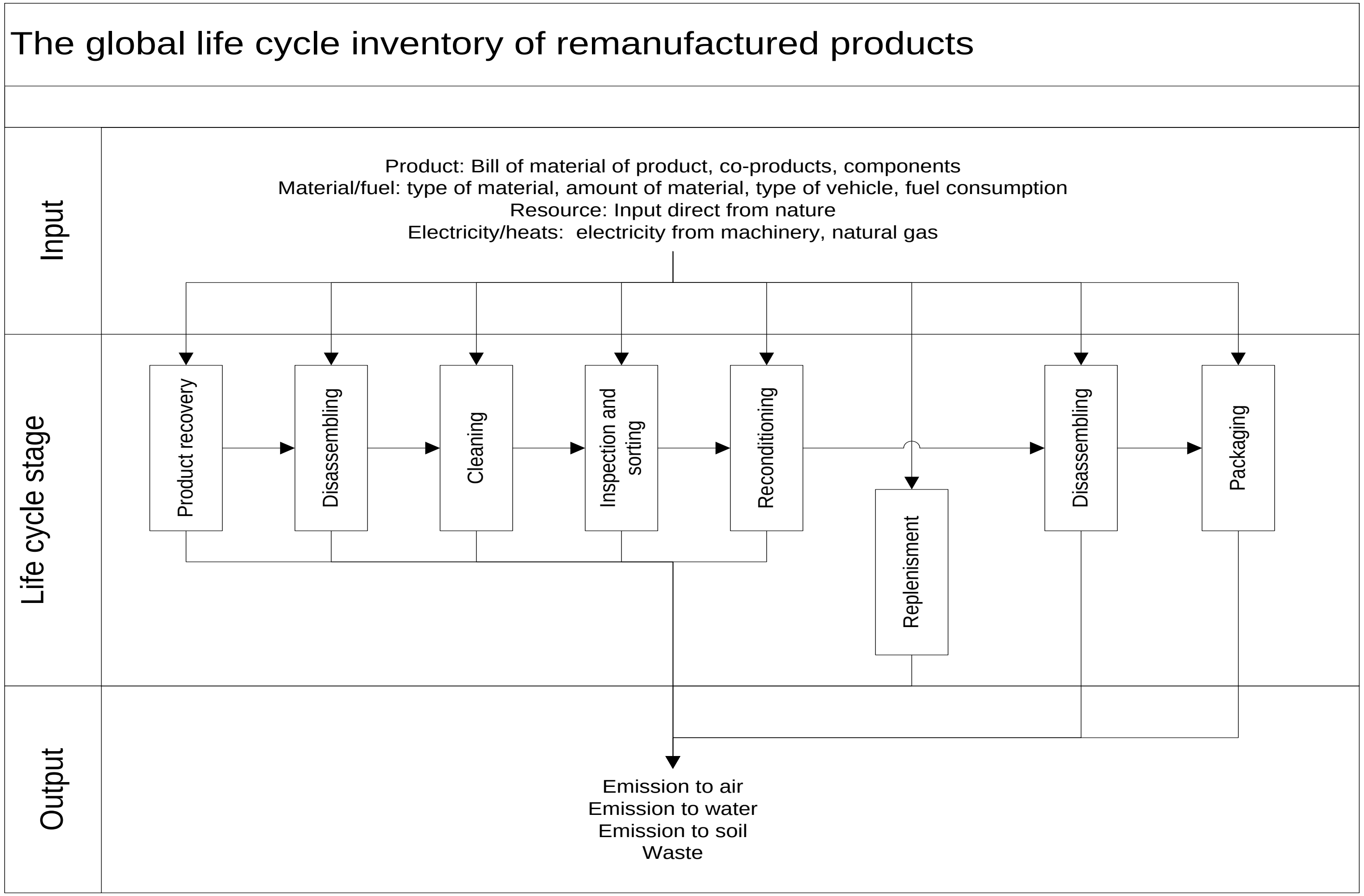

Figure 4.6 The life cycle inventory for remanufactured products

The third step is to enter all inputs and outputs in the LCC into Simapro 7.3 software in order to estimate the GHG emissions and embodied energy consumption (PRe Consultants 2013). The input or output data for the remanufactured products was then linked to libraries—a database which contains data on the energy consumption, material and emissions required to produce one unit product—in Simapro 7.3.

Lastly, the interpretation of the life cycle assessment results was conducted using the inventory data. The 'hotspot' was explained, as was the means by which it occurred.

Material consumption

Material consumption analysis is conducted by identifying the material flows and the overall material use in the remanufacturing process. The material flows in this research include the life cycle flows of the remanufactured products (cradle to cradle boundary). The life cycle flows of materials encompass all stages including product recovery, disassembly, cleaning, testing, replenishment, reconditioning and reassembly.

The material flows are then modelled, and each flow is presented in several channels, providing an overall picture of material use in the remanufacturing process. To be able to establish the total amount of material required in the remanufacturing process, the flow of the materials needs to be determined. Figure 4.7 presents an example of material flows.

In the current research, the 'material' is understood as the substances consumed in the remanufacturing stages (e.g. steel, plastic, copper, water, oil etc.). Materials are categorized into five types, which are virgin, reused, recycled, reconditioned and auxiliary materials. Virgin material is defined as all materials used for new components, which consists of primary and secondary recycled materials. Reused and reconditioned materials are used materials which have been thoroughly checked, reconditioned or repaired. The auxiliary materials include all materials used for cleaning, washing processes and all consumable items (e.g. oil, coolant, lubricant etc.).

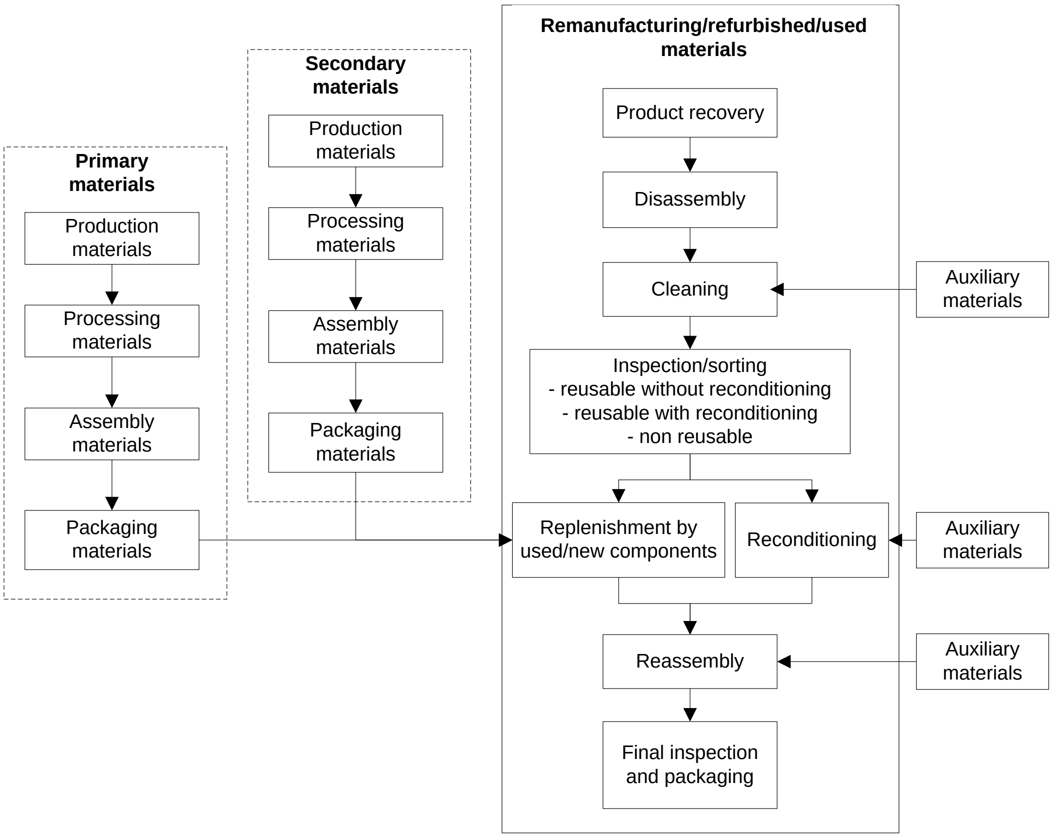

Figure 4.7 The remanufacturing process and material flows

Therefore, the investigation of material consumption in this research focusses on the use of new or virgin materials in the remanufacturing process, as illustrated in the following equation.

$$Material\ consumption = \sum_{n=1}^{n=x} W_n$$

Equation 4.9

Where,

W : Weight (kg)

n : Type of materials

Material intensity per service unit (MIPS)

Material intensity per service unit was used to measure the total amount of new materials used in the remanufacturing process divided by the service created from the remanufactured product.

$$MIPS = \frac{\sum WNM}{SR \times \sum T}$$

Equation 4.10

Where,

MIPS : Material intensity per service unit (kg/kWh)

WNM : Weight of new material (kg)

SR : Service provided by remanufactured product (kWh)

T : Total time for using the service (hours)

Solid waste

The amount of solid waste was calculated by using the data on the material , (liquid and solid) that were unwanted in the remanufacturing processes. Thereafter, the solid waste in this research was categorized into plastics, papers, ferrous materials (e.g. steels), nonferrous materials, and potentially hazardous waste (i.e. cleaning agents). The weight of waste was measured in kilograms (kg). The formula for the solid waste calculation is expressed as follows:

$$Total\ solid\ waste = \sum_{n=1}^{n=x} W_{SWn}$$

Equation 4.11

Where,

W_{SW} : Weight of solid waste (kg)

n : Type of solid waste n= 1, 2, 3 …X

Landfill

Landfill was estimated using the amount of unused and new components, the percentage of solid waste and the capacity of land to receive waste. The formula for the landfill (kg/m^3) is as follows:

$$Landfill_{solid} = \frac{amount\ of\ solid\ waste\ (kg)}{landfill\ capacity\ (m^3)}$$

Equation 4.12

4.4.3 Economic assessment tools

The economic assessment tools for the remanufactured products including life cycle cost (LCC), price, sales, recovered value and return on investment are discussed in this section.

Life cycle cost

The LCC of the remanufacturing process is calculated based on the acquisition cost (i.e. investment and capital cost and the sustaining costs (i.e. all operational costs), as follows:

$$LCC = AC + SC$$

Equation 4.13

$$AC = \sum CC$$

$$SC = \sum CCC + DC + CC + TSC + RCC + RPC + RC + FTC$$

Where,

LCC : Total life cycle cost (USD)

AC : Acquisition cost (USD)

SC : Sustaining cost (USD)

CC : Total capital cost (i.e. land, building, machines, equipment) (USD)

CCC : Core collection cost (USD)

DC : Disassembly cost (USD)

CWC : Cleaning and washing cost (USD)

TSC : Testing and sorting cost (USD)

RCC : Reconditioning cost (USD)

RPC : Replacement cost (USD)

RAC : Reassembly cost (USD)

FTC : Final testing cost (USD)

Sales

The sales are determined on the basis of the total number of remanufactured products sold during a marketing initiative multiplied by the price of the product, as shown in the following equation:

$$S = \sum RPS \times P_r$$

Equation 4.14

Where,

S : Total sales of the remanufactured products (USD/year)

RPS : Total number of remanufactured products sold in market (unit/year)

P : Price of remanufactured product (USD/unit)

Price

Price is defined as the amount of money paid for a product or service by considering the life cycle cost of a product and expected profit margin as illustrated in the following equation:

$$P = LCC \times (1 + PM)$$

Equation 4.15

Where,

P : Price of remanufactured product (USD/unit)

LCC : Life cycle cost (USD/unit)

PM : Profit margin (%)

Recovered material value

The recovered material value of the remanufacturing activity is calculated using the following equation (Nasr 2012):

$$RV = (UMC - URC) + C_{RC} - C_{DS}$$

Equation 4.16

Where,

$$URC = \sum_{i=1}^{n} (1/Y_I) \times C_i$$

RV : Recovered material value (USD/unit)

UMC : Unit manufacturing cost (i.e. cost of new product) (USD/unit)

URC : Unit remanufacturing cost (USD/unit)

C_i : Remanufacturing process i (unit)

Y_I : Yield of process I (unit)

C_{RC} : Recovered material value (kg/material)

C_{DS} : Disposal cost (USD/unit)

Return on investment

The return on investment (ROI) analysis of the remanufacturing activity for a certain number of remanufacturing operations is given by following equation (Ferrer 1997b):

$$ROI = EC/ER$$

Equation 4.17

$$ER = NPR + RR \times ENR_n$$

$$EC = NPC + RC \times ENR_n$$

Where,

ROI	: Return on investment (USD)
EC	: Expected cost (USD)
ER	: Expected revenue (USD)
NPR	: New product revenue (USD)
NPC	: New product cost (USD)
RR	: Remanufacturing revenue (USD)
RC	: Remanufacturing cost (USD)
ENR	: Expected number of remanufacturing operations (n times)

Import dependency

Qualitative values (e.g. dependent or independent) have been used to determine the import dependency indicator for the sustainable manufacturing framework. If the SMEs are importing or using imported items, then they are import dependent; otherwise, they are import independent.

4.4.4 Social assessment tools

The social analysis tools for assessing employment creation, health and safety, education and health service development, labour wages, customer satisfaction and youth and entrepreneurship development are discussed in this section.

Employment creation

The employment analysis is categorized into direct employment and indirect employment. Direct employment concerns the employment created by the remanufacturing industry, while indirect employment is the employment created by the businesses providing services to the remanufacturing industry.

In the case of remanufacturing SMEs, the first employment source is provided by the total direct employment generated from product recovery, disassembly, testing and sorting, cleaning, reconditioning, reassembly and packaging. The requirement for direct employment is affected by the total quantity of remanufactured products produced. The equation used for determining the total number of employees required per year is a modified version of Mishra (2006) as presented in the following equation:

$$TDE = \sum (STi \; x \; RP)/(AWT)$$

Equation 4.18

Where,

TDE	: Total number of direct employees (persons)
STi	: Standard time per remanufacturing process (minutes)
RP	: Total production of remanufactured products per year (unit/year)
AWT	: Average work time available per employee per year (minute/year)

The second indirect employment source is determined by the total number of jobs created by the distributors, stores, scavengers, packaging industry, suppliers, collection centres and recycling industries. The estimation of the indirect employment created by the remanufacturing industry is based on direct observation and investigation during the field visit as illustrated in the following section.

The distributors are the first indirect employees in the remanufacturing supply chain. About one to two distributors usually distribute the remanufactured products to sellers and collect cores by van with a maximum capacity of 0.4 tonne to deliver to remanufacturers.

Stores are another employment source arising from remanufacturing activities. In the stores, remanufactured products are sold to customers. It is predicted that about two to three people are required to work in a store. If sales increase, there is an opportunity to open new stores in different locations, creating new jobs. The number of jobs created has been calculated on the basis of the estimation of number of existing and new stores.

Remanufactured products require packaging, which could be provided by local new or recycled packaging materials manufacturers, thus creating new jobs..

Remanufacturers may require the supply of new components from suppliers for replacements when used components cannot be reused. The supplier in this case employs about two to three people to sell new parts to the remanufacturers. This number will increase with sales as usable parts may not be readily available.

The scavenger plays a significant role in collecting end of life (EoL) products. Once products fail, scavengers collect them and take them to a collection centre. Each scavenger collects on average about 15 kg EoL parts a day (Birolini 2010). This helped to estimate the number of scavengers required to collect EoL products for the recovery/recycling industry.

The collection centre is the hub for EoL products, where they are collected and then sent for processing (i.e. recycling). The collection centre usually employs five to seven workers.

The recycling industry is the last stage in the remanufacturing supply chain, where about eight to 10 people are usually employed. A recycling operation may produce about 0.4 tonne EoL products per day (Agustina 2007).

Equation 4.30 has been developed to determine the number of indirect employees, as follows:

$$IE = \sum_{i=1}^{6} JRA_i$$

Equation 4.19

Where,

IE	:	Total number of indirect employees (persons)
JRA_i	:	Job for activity i
i	:	Distribution, stores, scavengers, suppliers, collection centre, packaging industry

Youth and entrepreneurship development

The estimation of youth entrepreneurship development was based on the total number of youth participating in entrepreneurial activities associated with remanufacturing in the last, present and future year. The equation is expressed as follows:

$$YED_1 = ((\Sigma YE_{(n)} - \Sigma YE_{(n-1)})/\Sigma YE_{(n)}) \times 100\%$$ Equation 4.20

$$YED_2 = ((\Sigma YE_{(n)} - \Sigma YE_{(n+1)})/ \Sigma YE_{(n)}) \times 100\%$$ Equation 4.21

Where,

YED_1 : Youth entrepreneurship development (current and past year) (%)

YED_2 : Youth entrepreneurship development (current and future year) (%)

$YE_{(n)}$: Total number of youth enterprises in present year (unit)

$YE_{(n-1)}$: Total number of youth enterprises in past year (unit)

$YE_{(n+1)}$: Total number of youth enterprises in future year (unit)

Corporate social responsibility (CSR)

CSR was evaluated in terms of whether it had been undertaken or not. Those remanufacturers producing higher quality products with reduced environmental impact were considered to have performed CSR.

Labour wages

Labour wages are considered to be the cost of paying the labourers who actually carry out the remanufacturing. Wages were calculated on the basis of labour cost per hour (USD/hour) and working hours per month (hours/month), as expressed by the following equation:

$$LW = LC \times WH$$

Equation 4.22

Where,

LW : Labour wages (USD/month)

LC : Labour cost (USD/hour)

WH : Working hours (hours/month)

Intergenerational equity

The intergenerational equity of the remanufactured product is represented as the savings in material and energy estimated over 20 years. The material and energy saving equations are expressed as follows:

Energy savings (ES) are expressed as:

$$ES = (EC_n \times NN - EC_r \times NR)n$$

Equation 4.23

Material savings (MS) are expressed as:

$$MS = (MC_n \times NN - MC_r \times NR)n$$

Equation 4.24

Where,

ES	: Energy savings (kWh/20 years)
MS	: Material savings (tonnes/20 years)
ECn	: Energy consumption of a new product (kWh/unit)
NN	: Total number of new products in a year (unit/years)
ECr	: Energy consumption of a remanufactured product (kWh/unit)
NR	: Total number of remanufactured products in a year (unit/years)
MCn	: Material consumption of a new product (kg/unit)
MCr	: Material consumption of a remanufactured product (kg/unit)
n	: Expected period (20 years)

Company reputation

The value of a company's reputation is considered to be either strong or weak based on the number of sales, profit margin and market share. When all of these criterion are attained, then the reputation is regarded as strong, otherwise it is weak.

4.4.5 Threshold value determination

The threshold values were chosen because they are achievable by remanufacturing SMEs in developing countries while maintaining standard remanufacturing operations. Standard remanufacturing operations are those that use quality cores, a reasonable quantity of used components, and follow all required remanufacturing steps (e.g. disassembly, cleaning and testing) and testing procedures. The remanufacturing operations are conducted by skilled workers.

Table 4.8 Available indicator values for technical aspects

Indicators	Available values		Description
	Value	Reference	
Reliability	≥ 90%	(Anityasari 2009)	This represents the optimum value for the reliability of remanufactured mechanical devices (e.g. compressors, TVs and tires) in Indonesia.
	100%	(Andrew et al. 2006, Steinhilper and Brent 2003)	This represents the reliability of remanufactured products which are considered as good as new in developed countries.
Durability	≥ 90% over two years	(Anityasari 2009)	This represents the optimum value for the durability of remanufactured mechanical devices (e.g. compressor) for the local situation.
	Three years	(Nasr 2012, Remy International 2014)	The durability of remanufactured products is considered to be the same as for new products (i.e. three years) mainly from developed countries' perspective.
Warranty	Two years	(BBB Industries 2014, Kim et al. 2008)	This represents the optimum warranty value for remanufactured products in the Indonesian market. This warranty is applied to the majority of the remanufactured products in developed countries.
Safety standards	Meet the standards	(Brent and Steinhilper 2004)	This represents the safety standards (e.g. temperature, speed, noise and vibration) that need to be satisfied by the remanufactured products.
Availability of cores	5,600 units	Case study observation	This represents the optimum number of cores which need to be available in order to meet the demand for remanufactured products.

The threshold values for technical aspects have been chosen from the available values in Table 4.8.

An optimum value of ≥ 90% for reliability was chosen as it is suitable for local Indonesian remanufacturing industries and can be achieved within the technical and economic constraints of Indonesian remanufacturing SMEs. Similarly, the optimum values for durability (two years) and warranty (two years) for remanufactured alternators are applicable to Indonesian remanufacturing industries for maintaining product quality. In the case of safety performance, four criteria (temperature, speed, noise and vibration) are to be satisfied in order to meet the threshold value. The threshold values for the availability of cores are based on the observations of the SMEs in the case study.

The threshold values for environmental aspects have been chosen from the available values in Table 4.9.

The threshold value chosen for energy savings is 75%, as it is the average value for remanufacturing in developing and developed countries while maintaining standard remanufacturing operation. The threshold value chosen for material savings is 65%. Although it is the lower limit for remanufacturing in developing countries, but falls within the energy saving range for the use of remanufactured products in developed countries. The chosen threshold value for GHG emissions reduction is 77%, as this is the average value from remanufactured products in developing and developed countries where standard remanufacturing practices have been implemented.

A MIPS of 0.067g/kWh has been found from the literature of developed countries, which can be an achievable value for developing countries such as Indonesia when the components and recovered materials of EoL are extensively used for suitable application. The threshold value chosen for solid waste avoided is 88% as it is achievable in developing countries by improving existing remanufacturing practices. ‘Zero waste’ has not been considered as it could go beyond the financial and technological capacities of developing countries. A reduction in landfill size by 88% has been considered as a threshold value for landfill as it could be achievable by standard remanufacturing practices in developing countries due to aforementioned reasons.

Table 4.9 Available indicator values for environmental aspects

Indicators	Different value		Description
	Value	Reference	
Energy savings	78–89%,	(Liu et al. 2005)	This represents the energy savings for remanufactured alternators and auto parts in China.
	68–83%	(Smith and Keoleian 2004)	This represents the energy savings due to the use of remanufactured engines in USA.
Material savings	80–86%	(Gallo, Romano, and Santilo 2012, Asif et al. 2010, Steinhilper 1998b)	These material savings arose from the remanufacturing operations of SMEs in European countries (e.g. Germany and Sweden).
	65%	(Mukherjee and Mondal 2008)	These material savings were possible in developing countries like India, within their technical and social constraints.
GHG emissions reduction	88%	(Liu et al. 2005)	This value represents the optimum GHG emissions of remanufactured auto parts (i.e. engines) in China.
	73%–87%	(Smith and Keoleian 2004, Kim et al. 2008)	These values represent the GHG emissions savings for remanufactured engines and alternators in developed countries (e.g. the US, Germany).
MIPS	0.067 kg/kWh	(Kim et al. 2008)	This estimation is based on the material consumption figures for a remanufactured alternator.
Solid waste avoided	100%, 95%, 88%, 65%,	(Smith and Keoleian 2004, Kim et al. 2008, Asif et al. 2010)	This reduction in solid waste was recorded in developed countries (e.g. Germany, US and Sweden) due to remanufacturing operations.
Landfill avoided	88%–100% (zero landfill)	(Asif et al. 2010, Wollongong City Council 2010, Fuji Xerox 2011)	These values represent the landfill impact for remanufactured alternators in both developed (e.g. Sweden, Australia) and developing countries (e.g. Indonesia)

The threshold values for economic aspects have been chosen from the available values in Table 4.10.

Table 4.10 Available indicator values for economic aspects

Indicators	Different value		Description
	Value	Reference	
Life cycle cost	20–80%	(Severengiz et al. 2008, Ijomah, Childe, and McMahon 2004)	Life cycle cost saving by replacing new alternators and auto parts with remanufactured ones in Germany and USA.
	40–60%	(Mukherjee and Mondal 2008)	These values represent the life cycle cost savings for remanufactured auto parts in India.
Profit margin	20%	(Nasr et al. 1998, Matsumoto and Umeda 2011)	The value represents the profit margin for remanufactured auto parts in the US and Japan.
	20–40%	(Mukherjee and Mondal 2008)	This value represents the profit margin for remanufactured auto parts in developing countries (e.g. India)
Price	30–50%,	(Nasr et al. 1998, Smith and Keoleian 2004, Asif et al. 2010)	The price of remanufactured alternators in USA and Sweden is between 30% and 80% of the price of the new ones.
	30–50%	(Mukherjee and Mondal 2008, Saavendra et al. 2013)	The same level of price savings as in developed countries is attainable in India..
Recovered material value	Based on 65% material saving	(Mukherjee and Mondal 2008)	This value represents the optimum recovered material value for remanufactured alternators in India.
Return on investment (ROI)	92% of new	(Ferrer 1997b)	This value represents the optimum value for ROI for the Indonesian remanufacturing industry based on experiences in developed countries.

A threshold value of 40% for LCC has been chosen. This is the average limit for developing countries but it falls within the cost saving values for developed countries. A threshold value of 20% has been chosen for the profit margin as this value still meets the lower limits of the expected profit margin in both developed and developing countries while selling the reasonable quality (≥90% reliability) remanufactured product in the market. A threshold value of 50% has been chosen for price savings as it represents the situation in developing countries and falls within the savings values for developed countries.

Based on the information for material savings, a threshold value of 40% was chosen for recovered material as it is representative of the situation in developing countries. The chosen return of investment threshold value is 92% as it represents the situation in developing countries where an alternator can be remanufactured three to four times during the life cycle of a car.

The threshold values for social aspects have been chosen from the available values in Table 4.11.

The chosen threshold value for the labour wage is USD 89 per month as it represents the average wage of an Indonesian SME worker. Since the lifetime of an alternator could be 20 years after a number of rounds of recycling in developing countries, the threshold values for energy and material savings of 75% and 65% respectively have been considered to be achievable.

Table 4.11 Available indicator values for social aspects

Indicators	**Different value**		**Description**
	Value	**Reference**	
Labour wages	USD 89 per month	(Wage Indicator Foundation 2011)	This value represents the average labour wage in the Java region.
Inter-generational equity	65%	(Mukherjee and Mondal 2008)	Based on the optimum value for material savings in developing countries.
	75%	(Liu et al. 2005, Smith and Keoleian 2004)	Based on the average value for energy savings in developed and developing countries

There are some qualitative indicators (e.g. safety performance, sales, import dependency, employment creation, company social responsibility (CSR) and company reputation) for which there are no numerical values. In the case of safety standards, it is ‘standard met’, ‘increase’ for sales, ‘dependent’ for import dependency, ‘increase’ for employment creation, and ‘performed’ for CSR and ‘strong’ for company reputation.

4.5 Mitigation strategies

The first objective for achieving sustainable manufacturing in a remanufacturing scenario is to determine whether the remanufactured products are technically and environmentally sustainable. Mitigation strategies including waste minimization, cleaner production, material efficiency and the 6Rs are the most broadly applied strategies (Cordoba and Veshagh 2013), and were considered to constitute the first screening process for delivering a sustainable remanufacturing strategy.

The 6Rs strategy, including reuse, repair, reconditioning, recycling, remodification and remanufacturing, is recognized as an effective way of achieving future remanufacturing sustainability. In this research, the key strategy for achieving sustainable manufacturing is remanufacturing. Table 4.12 outlines the ways in which remanufacturing takes place through the other 5Rs, reuse, repair, reconditioning, recycling and remodification.

Table 4.12 The mitigation strategies through the 6Rs approach

Remanufacturing by reusing	Cores/parts are reused without any repair or reconditioning. This is applicable for valuable cores (i.e. parts) which have met the quality requirements (i.e. functionality and appearance) for the remanufacturing process.
Remanufacturing by repairing	Cores/parts are repaired and any damaged parts are replaced with new ones. The cores/parts are then remanufactured after meeting the functionality and quality requirements.
Remanufacturing by reconditioning	Cores/parts are reconditioned and returned to obtain better functionality and performance. Function and performance are often upgraded.
Remanufacturing by recycling	Vital cores are usually recycled and then reused as substitutes for out of order parts in the remanufacturing process.
Remanufacturing modification	Cores/parts are modified to meet the functionality and performance requirements.

4.6 Enabling mechanism

The technically and environmentally sound options may not be economically and socially viable, so an enabling mechanism needs to be established involving both direct and indirect stakeholders, including the Indonesian government and its legal and advisory institutions, and collaboration with relevant research institutions and non-government organizations, remanufacturers, suppliers, consumers and other indirect stakeholders.

The following section presents an enabling mechanism for achieving sustainable manufacturing among remanufacturing SMEs in Indonesia.

Firstly, barriers and opportunities are identified through the sustainable manufacturing framework suggested by Fatimah et al (2013). All information related to the barriers to and potential opportunities for developing a remanufacturing industry among Indonesian SMEs were obtained from the analysis carried out using the sustainable manufacturing framework, and are classified as follows:

1. Level of knowledge and technical skill of SME workers;
2. Availability of technology, efficient and effective processes;
3. Opportunities at government policy and regulatory levels;
4. Financial issues and potential for investment;
5. Opportunity for market development;
6. Existing standardization processes;
7. Environmentally conscious development.

Secondly, the stakeholders' roles and the existing mechanism are identified, where the stakeholders are government institutions, original equipment manufacturers, suppliers, universities, non-governmental organizations, financial institutions, end of life manufacturers (recyclers, reusers, refurbishers) and customers, within the implementation of sustainable manufacturing through remanufacturing.

Finally, an institutional framework as illustrated in Figure 4.8 needs to be developed based on the previous identifications. The figure illustrates the interconnection between the organizations which are expected to contribute to attaining the successful implementation of sustainable manufacturing programs for remanufacturing SMEs in Indonesia. The institutions involved at various levels of the implementation process have also been presented in this framework (Figure 4.8).

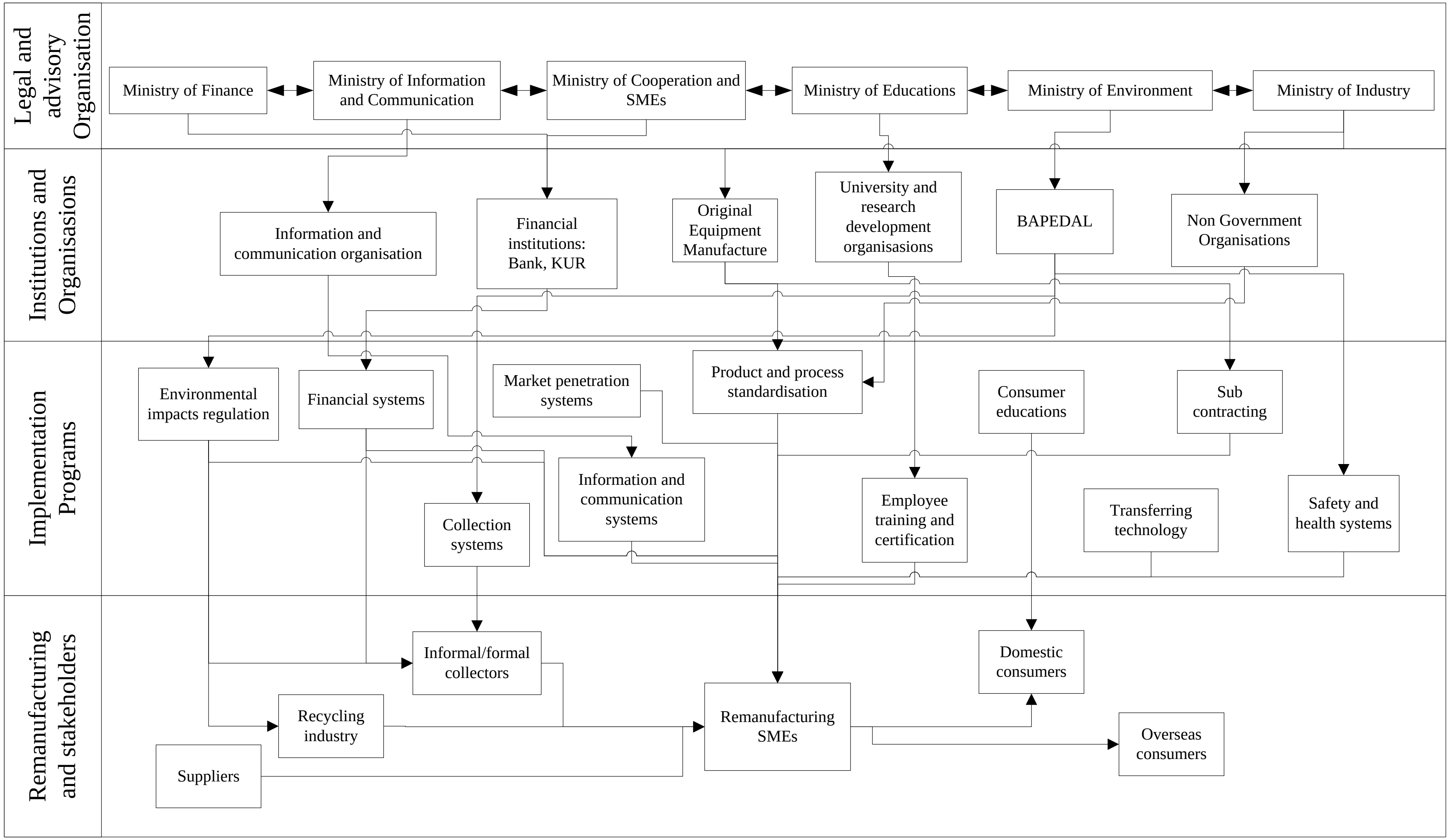

Figure 4.8 Institutional framework for developing remanufacturing SMEs

Figure 4.8 above shows that the government, with assistance from a number of legal advisory organizations under the Indonesian ministries, including the Ministry of Finance, Ministry of Information and Technology, Ministry of Cooperation and SMEs, Ministry of Education, Ministry of Environment and Ministry of Industry, could assume a number of responsibilities in assisting remanufacturing SMEs to achieve sustainability, such as:

- Providing comprehensive environmental impact regulations that are more transparent, fair and relevant to the remanufacturing requirements of SMEs.
- Providing access to exclusive financial information and communication support to both remanufacturing SMEs and informal sectors.
- Enhancing market penetration and campaign activities for boosting SMEs' remanufactured products and consumer awareness workshops
- Developing used and second-hand products and waste collection systems which are more advanced and environmentally sustainable.
- Improving information and communication systems to support the development of remanufacturing SMEs.
- Promoting product and process standardization, safety and health systems and staff training and certification for remanufacturing SMEs.
- Promoting sub-contracting and transferring technology.

In order to perform these responsibilities, there needs to be effective collaboration and coordination between financial institutions (i.e. banks), OEMs, universities and research development organizations, environmental organizations (i.e. BAPEDAL), information and communication organizations (i.e. PT TELKOM) and non-governmental organizations. Last but not least, it is essential to have the participation and involvement of remanufacturing SMEs with the abovementioned stakeholders.

Chapter 6 presents the enabling mechanism for the implementation of strategies for the remanufacture of alternators by Indonesian SMEs.

4.7 Conclusion

This chapter provided detailed information on the process for testing the sustainable manufacturing framework, including data collection, tools and threshold values. Accordingly, the sustainable manufacturing indicators for remanufacturing assessment based on four important dimensions of sustainable manufacturing, including technical, environmental, economic and social aspects, have been extensively discussed.

Field information was collected from SMEs on Java Island in Indonesia for the calculation of sustainable manufacturing indicators for assessing the sustainable manufacturing framework in Chapter 5.

In particular, a number of tools (i.e. suitable formulas) for calculating sustainable manufacturing indicators were discussed in detail, as well as their threshold values, as these values are required for comparing with the indicators to assess sustainable manufacturing.

Chapter 5

Sustainable manufacturing assessment of the existing scenario

5.1 Introduction

This chapter presents an assessment of the sustainability of Indonesian Small Enterprises (SEs) for the remanufacture of alternators using the technical, economic, environmental and social indicators discussed in Chapter 4. Firstly, the case study describes the existing scenario for SEs producing remanufactured alternators on Java Island. Secondly, information on the remanufacturing process and the management and business of these SEs has been gathered in order to assess the sustainability of the existing remanufacturing situation using the technical, environmental, social and economic indicators discussed in Chapter 4. Thirdly, all of the technical, environmental, social and economic indicators are compared with the threshold values for sustainable manufacturing. Finally, those indicators not meeting the threshold values are identified in order to develop a strategy for achieving the sustainable manufacture of remanufactured alternators.

5.2 Existing scenario for remanufactured alternator

This case study is based on fieldwork carried out in three SEs[7], Firm A, Firm B and Firm C located in Jakarta, Magelang and Semarang respectively which are involved in the repairing, refurbishment and remanufacturing of car alternators. They have been categorized as small enterprises because their total assets are worth less than USD 50 million and they have an annual turnover of USD 250 million and a total number of employees less than 20 (Indonesian Central Bureau of Statistics 2008, 2009).

All three SEs, which are owned by local people, started out either as small workshops or repair services. The Asian financial crisis of 1997, which led to the devastating Indonesian economic downturn, initiated the development of SEs for reconditioning, refurbishing and remanufacturing.

The market (aftersales market) for affordable new and reconditioned auto parts grew dramatically over 10 years and the illegal import of these products from China and Taiwan increased significantly. It was estimated that only about 30% of products in the aftersales market were authorized components, while the remaining 70% were not authorized and were illegally sold on the black market (Pasha and Setiati 2011) (Pasha and Setiati 2011). This became a serious problem for Indonesian SMEs as the aftersales market was tighter. Cheap prices were the main orientation in this market, which made it difficult for Indonesian industry (especially SMEs) to compete in the market. Table 5.1 presents the category, quality, warranty, sales price, number of employees and market coverage for each of the three SEs surveyed for this research.

[7] Firm names have not been disclosed for confidentially reasons. Since the number of employees is less than 20 in this enterprises, they are regarded as small enterprises (SEs) (Indonesian Central Bureau of Statistics 2008).

Table 5.1 Alternator remanufacturing SEs in Java, Indonesia

	Firm A	Firm B	Firm C
Category	Remanufacturing, reconditioning, repairing	Remanufacturing, reconditioning, repairing	Reconditioning, repairing
Quality	OEM standardization	Own standardization	Own standardization
Warranty	1–2 years	3 months	1 month
Price (Approx)	USD 75	USD 38	USD 30
Employee (Approx)	20	16	7
Market coverage	National and local market	Aftersales and local market	Aftersales and local market

Note: 1 USD = IDR 10,000; OEM standardization is likely to satisfy the standards and specifications of the original products (Inc. 2014); own standardization is likely to satisfy the functionality or quality established by enterprise.

Firm A not only produces OEM-quality remanufactured alternators, but also offers a relatively long-term warranty, thus enabling them to sell products at the price of new alternators (USD 75) on the local market. Firm A also sells its remanufactured alternators on the national market (e.g. Jakarta, Surabaya and Semarang). The manager of Firm A, who is also the owner of the SE, had more than 20 years' experience in the automotive industry before he established the firm in 1991. Firm A is thus well managed, profitable and employs relatively skilled engineers, technicians and bookkeepers, compared to the other two remanufacturing SEs (Firms B and C). Importantly, their staff were recruited locally, thus contributing to local employment.

Firm B represents a conventional Indonesian alternator remanufacturing, reconditioning and repairing enterprise. The quality of their product is not as good as that of Firm A, so they can offer a warranty period of only three months which is four to eight times less than that of Firm A. Therefore, Firm B's alternators sell at a lower price (USD 38) than those of Firm A (USD 75). This price does not provide enough income to expand the business and so its number of employees (16 people) is also lower than for Firm A (20 people). The manager of this firm is also the owner, but this person does not have the same experience (less than 10 years) as the manager of Firm A. The manager of Firm B inherited this SE, which was established in 1991.

Firm C also follows its own product standardization (Table 5.1). The standardization is based on enterprise knowledge, which is different for firms B. It requires minimal expenditure so the quality is less assured, which allows the firm to offer an even shorter warranty period than Firm B. As a result, the alternators produced by Firm C are sold even cheaper (USD 30) than those of Firm B. Here also, the manager is the owner of the SE, but only holds a junior high school qualification. This firm was established in 1991, the same year that Firms B and Farm A were established. However, these enterprises only entered full scale production in 1997 when the demand for used products grew significantly due to the economic crisis. The number of employees in Firm C is half that of Firm B, and the former has offered internships to a number of technical school students.

The continuity of business is an enormous challenge for Firms B and C due to a lack of adequate financial support, which is in fact a key barrier to the introduction of new technology, equipment and efficient production methods in these SEs. Although some commercial banks e.g. the People's Bank of Indonesia (BRI) and the National Bank of Indonesia (BNI)) have small enterprise credit (*Kredit Usaha Kecil*) programs to provide loans to SEs, they have not extended their programs to these weakened remanufacturing SEs. Field observation revealed that this situation was primarily due to the inability of these SEs to meet the terms and conditions imposed by the financial institutions due to a lack of financial knowledge (i.e. non-transparent and unclear financial reports) and management support (i.e. no financial initiative/plan from the manager). Some SE owners had initially received informal financial support from their families and friends to establish the business on a trust and mutual understanding basis, while others inherited the family business.

In the case of Firms B and C, the reconditioning and remanufacturing processes were mostly conducted using old and outdated tools such as compressors and lathe machines which are less automated, energy intensive and require frequent maintenance. The implementation of efficient technology and equipment appears to be very expensive for these SEs. Over the past five years, neither equipment nor technology has been upgraded in these SEs. Most of the machine tools, including lathes, grinding, milling, washing, cleaning and drying machines, hand tools (hand drill) and test benches were found to be old. This could potentially affect the technical performance, including cutting energy, surface roughness, and tool life for producing remanufactured alternators, which could in turn increase the embodied energy consumption and environmental emissions. Poor technical performance could also result in shorter product life, hence the short-term warranty periods and lower prices. In addition to the technology gap, there appeared to be no specialized skill training programs for the employees to improve their machine operating skills and industrial management performance.

These SEs are unaware of environmental management as survival is their daily concern, while controlling environmental pollution remains a luxury item. For example, the waste water from Firm B contains used oil, detergent and solvent from the washing and cleaning processes, and is deposited directly in a small river near by (one km away from the SE) without pre-treatment. In addition, oily and greasy rags are not disposed of properly, which could be a health hazard to the employees.

The number of employees in the SEs (especially Firm B and C), including technicians and workers, fluctuates with the demand for and supply of remanufactured alternators, thus these businesses cannot provide secure employment. Most of the workers have completed their education in local high schools known as

Sekolah Menegah Atas, some in technical schools known as *Sekolah Menengah Kejuruan*, and some are school dropouts. Because of their low educational qualifications, these people are poorly paid by the SEs. For both Firm B and C, the average monthly wage for the labourers is USD 75, which is lower than the average minimum monthly wage (USD 89) in Central Java and Jakarta (Wage Indicator Foundation 2011). Firm A, which is located in the Indonesian capital city of Jakarta, provided higher wages in comparison with Central Java.. No incentives were offered to employees except for an annual bonus which is usually given as a religious holiday allowance, locally known as *Tunjangan Hari Raya*. With regard to gender, employment was dominated by males (90%) apart from a few female employees who were mainly employed in administrative and bookkeeping roles.

The employment situation is gradually worsening in the SEs due to financial constraints resulting from a decrease in production capacity and other financial hurdles to maintaining their businesses. For example, it was found that only a few employees (seven workers) worked on a full time basis, while the remainder were part-time employees on average.

Except for Firm A, the alternators remanufactured by these SEs are sold predominantly on the local market. This is primarily due to a lack of networks, which prevents access to external markets. Most of the customers are private vehicle owners and public transportation agents. Whilst the auto parts market has expanded significantly due to the rapid growth of the automotive market between 2010 and 2012 (Ipsos Business Consulting 2013), these SEs struggle to improve sales due to the following reasons:

- There is competition with other local retailers who import new but cheap alternators from China. The Asia China Free Trade Area (ACFTA) has created competition between these local SEs and the sellers of imported products (Tambunan and Liu 2006).

- There is uncertainty associated with the collection of adequate numbers of cores from local customers, workshops, collection centres and cannibalizing centres (Damanhuri and Padmi 2012).

- The prohibition of used auto parts imports (Indonesia Regulation No. 610/MPP/Kep/2004 and Ministry of Trade Decree No.39/M-DAG/PER/12/2005) (BCRC China 2009, BCRCs 2009) is also a key barrier to the growth of local remanufactured products.

- The lack of supply of old cores at an acceptable standard (i.e. free of cracks, corrosion resistant, cleanable) affects the production and so the turnover of the businesses. A continuous and regular supply of quality cores is necessary to maintain production levels, to respond to market demand and to maintain a profit margin.

As discussed above, issues such as the absence of sufficient financing mechanisms, a shortage of skilled workers, inadequate supplies of quality cores and a lack of sophisticated technology and equipment (e.g. automatic testing machines) have restricted the ability of the SEs, especially Firms B and C, to improve the quality of their remanufactured alternators. In addition, the surveys revealed that the employees do not have adequate up-to-date knowledge (e.g. machining, testing processes and financial management) of reconditioning and remanufacturing processes.

5.2.1 The remanufacturing process

The remanufacturing processes in these Javanese SEs generally include the following eight stages (Figure 5.2):

- core collection;
- initial inspection and disassembly;
- cleaning;
- testing and sorting;

- reconditioning;
- replacement;
- reassembly;
- final testing.

The typical person-hours taken to complete each of these stages was determined using a work sampling method (Wikipedia 2014). The time taken for each remanufacturing activity was recorded from start to end during the field survey. Time was also recorded for external activities such as core collection. The remanufacturing processes, detailing the activities and person-hours, are illustrated in Figure 5.1.

5.2.2 Core collection

The alternator cores are used alternators collected from collection centres, workshops and scavengers for these Javanese SEs. The cores include all parts and components of the alternator, and the main type found on the Indonesian market is a typical lightweight Denso alternator. This alternator is mainly used in Indonesian passenger and commercial vehicles such as Toyotas, Hondas and Suzukis. It is commonly remanufactured by the SEs in this study, and is therefore the subject of a thorough technical and environmental analysis. The technical specifications for the alternator are presented in Table 5.2. The alternator is a critical component of a vehicle as it generates electricity for the battery, lighting and ignition systems. The purpose of the alternator is to transform mechanical energy into electrical energy through electromagnetism (Woo et al. 2008).

Table 5.2 Technical specifications of a typical remanufactured alternator (field survey)

Output voltage, current	12 volts (V), 60 Amp (A)
Power rating	720 Watts
Number of poles, revolution per minute (RPM), frequency	5-Grove Pulley, 1,800–5000 RPM, 50Hz
Mechanical and electrical specifications	2.2 kg in weight, 158 mm in length and 105 mm in diameter, internal voltage regulator fans (IR–IF series), internal rectifier, clockwise (CW) rotation

Cores, or used alternators, are the major material inputs for the SEs. Since the government banned the import of used auto parts from overseas in 2004, the majority of collection activities are conducted through direct pickup from car workshops and brokers, and cannibalizing and collection centres located in Semarang, Solo, Jogjakarta, Surabaya and Jakarta in the Java area. Once collected, the alternators are transported to the remanufacturer by small 0.4 tonne trucks. The distance between the collection centres and the remanufacturing factories ranges from 200 km to 400 km.

Additionally, some cores are received from scavengers while others come from customers who exchange their old alternators for remanufactured ones, for which remanufacturers receive a cash equivalent of USD 2.50 from the customers. The quality of cores received from scavengers and customers is lower than those collected from workshops, brokers and cannibalizing and collection centres. A large proportion of these exchanged alternator parts are broken and therefore often difficult to remanufacture.

5.2.3 Steps of remanufacturing

Once the cores have been collected, the first step in the remanufacturing process is inspection and disassembly (Figure 5.1). The alternator core is inspected visually by a technician who decides whether the core of the alternator will be reused, recycled or discarded. The visualization indicators are used to determine whether the alternator cores are broken, cracked or corroded. The alternator is then disassembled into single components and the disassembled components are inspected to determine which will require repairing, replacement or remanufacturing. The disassembly process in these SEs usually takes about 0.5 person-hours to complete. During this time the pulley, fan and nuts will be taken out using an impact gun which unscrews the bolts, and a hand wrench to split the case from the core. A number of components are cannibalized to supply components for other remanufactured alternators.

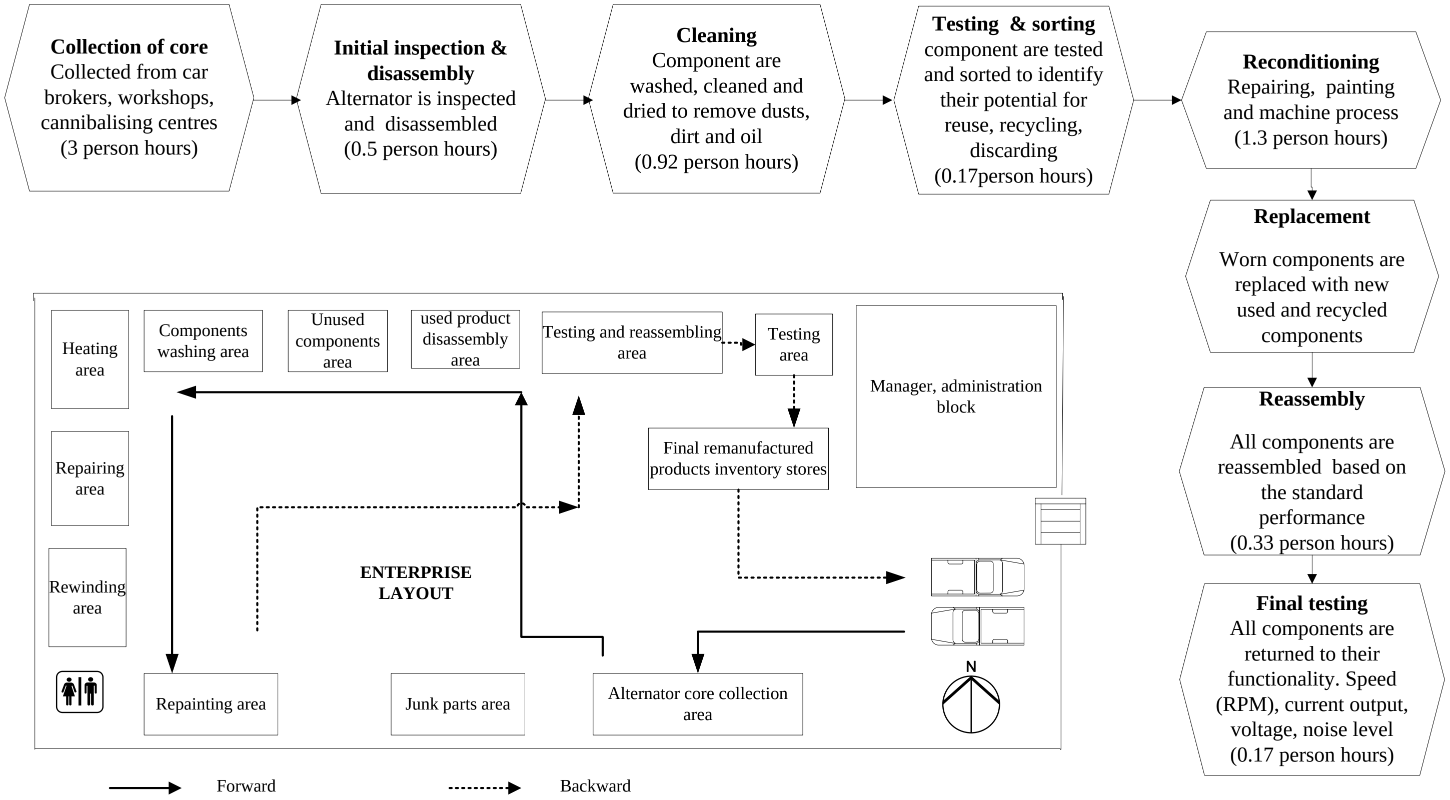

Figure 5.1 Layout of typical Indonesia SE incorporating remanufacturing process and time spent on the process (observed from field survey)

The components of the disassembled Denso alternator are illustrated in Figure 5.2. Some alternator component pictures are obtained from Sullivan (2013). The alternator weighs 2.2kg and its main components are the pulley, rear and front cases, brushes, rectifier, rotor assembly, stator assembly, voltage regulator, bearing, fan and slip rings. The alternator is constructed using different materials. About 95% of the alternator is made of energy intensive materials including cast iron (34%), cast aluminium (29%), steel (14.2%), and copper (17.5%). The material content and weight of each component was determined through direct observation at the SE, discussion with the SE engineers, and also through the literature review (Schau, Traverso, and Finkbeiner 2012).

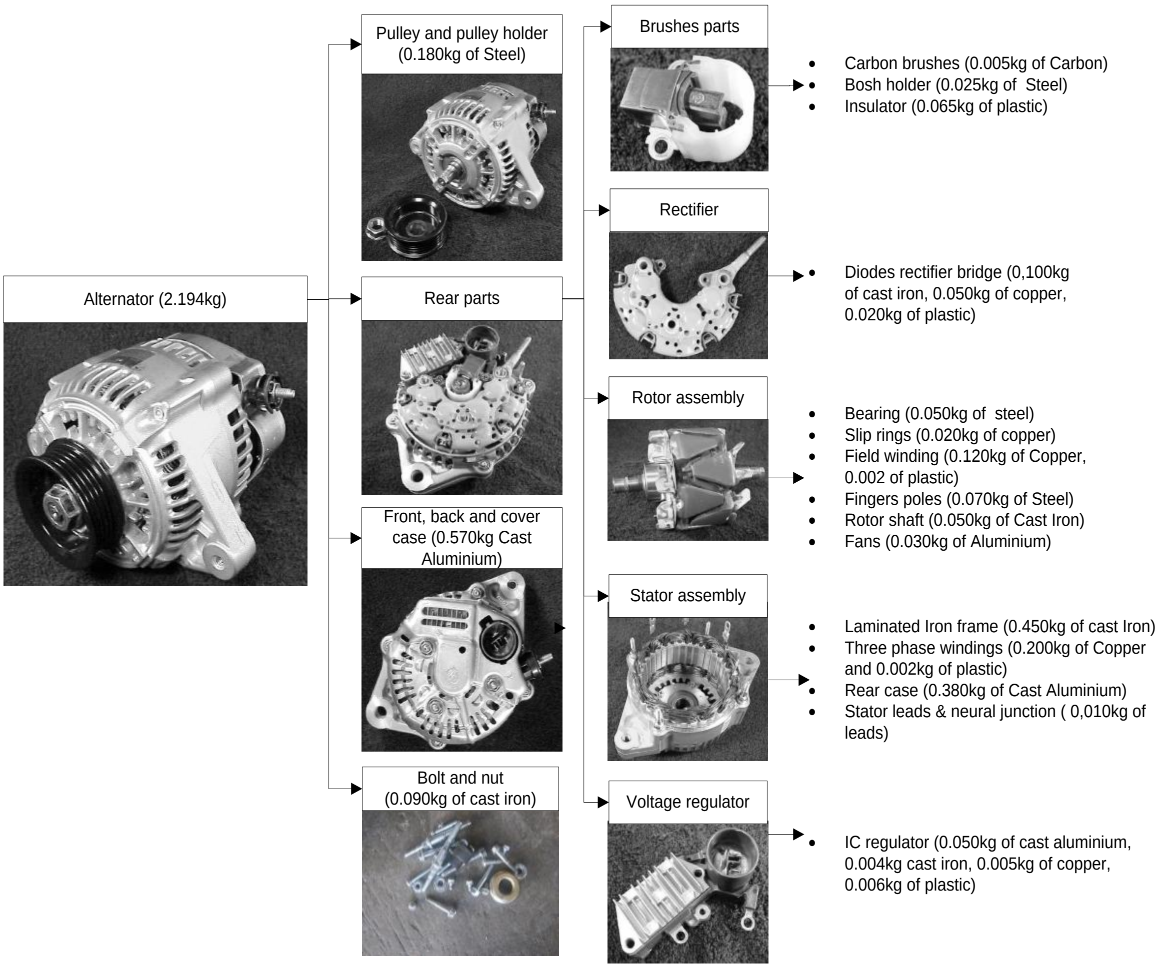

Figure 5.2 Components and source materials of a disassembled alternator

Following the disassembly process, all components are thoroughly cleaned to remove dust, dirt, old paint and oil using conventional high pressure hot water. The water is pumped from a hot water tank and mixed with solvents (e.g. sodium hydroxide, hydrochloric acid) and detergents. Once the components have been cleaned, the water, oil and dirt are removed from them by using a gas flame room oven. The cleaning process requires about 0.92 person-hours per alternator. As mentioned earlier, the used oil, detergent and solvent from the washing and cleaning processes are deposited directly in a nearby small river (one km away from the SEs) without pre-treatment.

All cleaned components, including cases, rotors, IC regulators, rectifiers and brushes are then inspected and sorted for reuse, remanufacture or replacement. Reusable components are sent for reconditioning, while non-reusable components including those which are cracked, damaged, unserviceable and worn are replaced with new, reused or recycled components. The reconditioning process for each component is discussed in the following section.

Prior to reconditioning, the housing is checked twice to ascertain whether there is any corrosion, distortion or cracks. The mounting surface is inspected and subsequently polished and painted to improve performance. The replacement of an old case with a new one is required when the housing is broken, damaged and unsuitable for repair.

The rotor assembly components (11% of total weight) (Figure 5.3), including bearing, shaft, body, slip rings, fans and field winding, are also inspected during the reconditioning process. If the brush size is less than ¼ inches of the housing and the bearing is noisy, then both are usually replaced with new components. A soldering gun is used to install the new brushes. The brushes can be found on the local market for USD 1 per pair. The bearing is also inspected for rust, bending and roughness. If any of these faults are found, then the bearing is replaced with a new one. If it only requires a little grease, then the shield is usually drilled and greased with new lubricant. After completion of these tasks, the rotor is balanced to reduce any unwanted vibration.

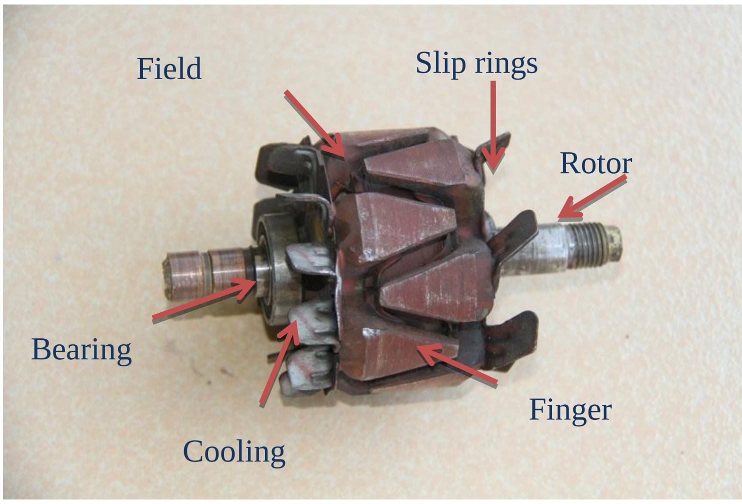

Figure 5.3 The remanufactured rotor assembly and its components

In the case of the stator assembly (32% of total weight) (Figure 5.4), the iron frame, phase winding, stator lead and neural junction are inspected. The phase winding is either replaced, rewound or varnished, while the stator lead and neural junction are inspected using an ohmmeter and then soldered using a solder gun. For the pulley, varnish is applied to ensure the same performance as a new one. If the pulley is faulty (e.g. cracked), it is often replaced with a used one rather than a new one as an old pulley can perform as well as a new one when revarnished.

The fans are inspected for any cracks, defects and missing components while the voltage regulator is inspected visually for any distortions, corrosions and cracks. If the used voltage regulator displays any of these problems, it is necessary to replace it with used or new components in order to avoid over-charging which can damage the alternator. The cast iron diode rectifier is usually replaced with a new one because it is cheaper to buy a new one (i.e. USD 1) than to repair it. The inspection process requires about 0.17 person-hours per alternator. The reconditioning process, involving grinding, turning, polishing and painting of components requires about 1.3 person-hours per alternator.

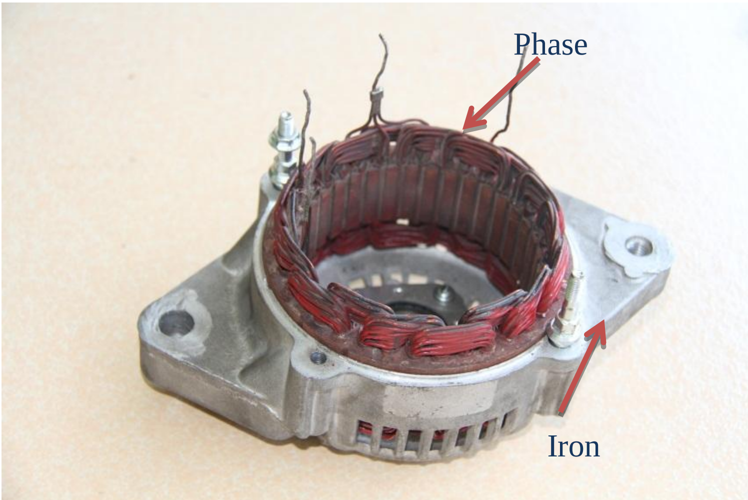

Figure 5.4 The remanufactured stator assembly and its parts

Table 5.3 presents the usual materials, weights and probabilities of reuse of remanufactured alternator components in these SEs. Typically, around 57% of the parts are reused, 21% are replaced with new parts and 22% are replaced with old parts from other alternators.

The new components for replacement (i.e. bearings, brushes, bearing clamps, bolts and nuts, copper) are generally Chinese- and Taiwanese-made products. These products are affordable and can be sourced from local markets and auto parts distributors. All residual valuable materials and scraps (i.e. aluminium, copper, iron etc.) are usually collected by metal collectors or are sent to nearby recyclers. It is estimated that only about 2% to 5% of the replaced materials (e.g. carbon) are disposed to landfill. These materials cannot be recycled in an economically viable manner as their weight is negligible (0.05kg).

Table 5.3 The material sources, weights and probabilities of reuse of remanufactured alternator components.

Part	Material	Weight (% of total weight)	Unit	Probability of reuse (a)	Remanufacturing strategy (b)
Housing	Aluminium	570 (26%)	g	80%	R
Stator	Steel	450 (20.5%)	g	90%	R
	Lead	10 (0.5%)	g	50%	R
	Plastic	2 (0.1%)	g	20%	RwN
	Copper winding	200 (9%)	g	20%	RwN
Rotor	Cast iron	70 (3%)	g	60%	R
	Steel	50 (2.3%)	g	60%	R
	Plastic	2 (0.1%)	g	20%	RwN
	Copper winding	120 (5.5%)	g	20%	RwN
Fans	Aluminium	30 (1.4%)	g	60%	R
Slip ring	Copper	20 (0.9%)	g	60%	R
Pulley holder	Steel	30 (1.4%)	g	60%	R
Bosh holder	Steel	25 (1.1%)	g	80%	R
IC regulator	Plastic	5 (0.2%)	g	60%	RwU
	Copper	5 (0.2%)	g	60%	RwU
	Cast iron	5 (0.2%)	g	60%	RwU
	Aluminium	50 (2.3%)	g	60%	RwU
Pulley	Steel	150 (6.8%)	g	80%	RwU
Rectifier	Cast iron	100 (4.5%)	g	60%	RwU
	Copper	50 (2.3%)	g	60%	RwU
	Plastic	20 (0.9%)	g	60%	RwU
Insulator	Plastic	65 (3%)	g	60%	RwU
Bolt and nut	Cast iron	90 (4.1%)	g	70%	RwN
Brush	Carbon	5 (0.2%)	g	10%	RwN
Bearings	Steel	50 (2.3%)	g	20%	RwN
Bearing clamps	Cast iron	20 (0.9%)	g	40%	RwN

R = reused (existing component is reused), RwN = replaced with new (the replacement of old components with new components), RwU = replaced with used (the replacement of component with other alternator components). RwR = replaced with recycled (represents the replacement of old component with recycled material).

5.2.4 Material reuse and replacement strategies

The probability of reuse (i.e. 10–90%, Table 5.3) is the likelihood that a remanufactured component can be used by remanufacturers at the end of its lifetime. This probability was determined by discussion with the managers of the SEs in the case study. For example, 60% means that the core component has a 60% probability to being reused in the remanufacturing process. The weight is the proportion of the material (i.e. steel, copper etc.) in the total 2.2kg weight of the remanufactured alternator. The remanufacturing strategies in Table 5.3 represent the reusability potential of the components.

If new components are used in the remanufactured alternator, it is necessary to consider all of the upstream emissions and wastes associated with the material and energy consumption of the raw material extraction, production, transportation and foundry processes required to produce these new components. The replacement of an old component with a new component is thus energy and material intensive. The combined weight of a new stator and rotor winding coils, bolts and nuts, brushes, bearings and bearing clamps is about 0.39 kg. Firm A, which is located in the Indonesian capital city of Jakarta, provided higher wages in comparison with Central Java. In addition, these components are imported from China and Taiwan, meaning that transportation must be included in the analysis to capture the associated environmental impact. The transport of 39.5E-05 tons of alternator components from China and Taiwan to Indonesia over a distance of 7,966 km equates to around 1.52 tonne-kilometres or tkm (39.5E-05 tons x 7,966 km = 1.52 tkm), which was used for the environmental and economic analysis (Table 5.4).

Table 5.4 Tons-kilometres (tkm) for new alternator components

Components	Locations	Distance (approx.)	Tons	Tkm
Copper, bolts, nuts	Jiangsu, China to Semarang, Indonesia	4,184 km	32.0E-05	1.35
Brushes, bearings, bearing clamps	Taipai, Taiwan to Semarang, Indonesia	3,782 km	7.5E-05	0.18

The reassembly process is then carried out by assembling the reused, reconditioned and new components into a remanufactured alternator. It was found during the field observation that this process requires about 0.33 person-hours per alternator and is manually performed using basic tools and equipment.

Following the reassembly process, the remanufactured alternator undergoes final testing, which consists of testing the revolutions per minute (RPM), current output, voltage, cut in speed[8] and noise level to ensure the functionally of the alternator. The testing process is very basic and applies conventional testing equipment such as multimeters and 10 HP motors for running the alternator. The case study surveys found that the tester is not able to conduct all of the required testing. For example, in a vehicle, an alternator often operates at high temperatures, thus the reliability and durability of the alternators under such conditions need to be tested. However, the existing testing equipment does not permit such tests. The field observation shows that the final testing process requires about 0.17 person-hours per alternator.

Once the final testing has been conducted, a certain warranty period (three months) is offered to the customers to cover the replacement components. The warranty period is the same for private and business purposes, but this is actually not reasonable for

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[8] The speed at which the internal sense circuitry connects the battery to the voltage regulator (SAE International 1999).

business customers who often experience product failure faster than individual customers, as the warranty is not based on the vehicle mileage. The field interviews revealed that, although the lifetime of a remanufactured alternator varies for different types of vehicles operating under different environmental conditions, they are expected to run for at least 19,000 km (the average annual mileage of an Indonesian vehicle) or about 12 months before servicing is required. The short warranty period offered by Firms B and C often discourages customers from purchasing these alternators. On the other hand, the extended warranty period on remanufactured alternators produced by Firm A increased the price to beyond customers' expectations.

There are many factors that affect the lifetime of an alternator, including the performance of the engine and the number of electrical devices involved in the vehicle operation. Other factors that can potentially shorten the lifetime of a remanufactured alternator include the age of the components, damaged components, improper installation and assembly process and environmental stress (e.g. corrosion) (SAE International 2001). However, these factors often receive less attention due to the inability of SE workers to collect high quality cores, follow appropriate testing procedures and standardization processes, and maintain suitable working conditions.

5.3 Sustainability assessment of the existing scenario

As discussed in the previous section, SEs specializing in remanufactured alternator production experience problems associated with poor quality cores, poor serviceability (warranty periods), low profitability resulting from high remanufacturing costs and low market prices, lack of qualified workers, unattractive salaries and adverse environmental conditions (i.e. dirty oil sent to rivers), and many other problems, which could considerably affect the sustainability of these SEs. Therefore, the framework devised by Fatimah et al (2013), based on this PhD research, has been applied to determine the opportunities for improvement and for achieving sustainability in remanufacturing. The first step is to identify the sustainable manufacturing indicators not meeting the threshold values as discussed in Chapter 4. Next, the technical, environmental, social and economic indicators are used to assess the existing scenario for remanufactured alternators against their threshold values.

5.3.1 Technical assessment

The technical indicators are reliability, durability, safety, warranty and availability of cores. The basis for choosing these indicators and the procedure for determining them were discussed in Chapter 4. To assess the technical indicators of the existing scenario, time series data covering the period from 2008 to 2010 was collected from the SEs involved in this study.

Reliability

The alternator reliability analysis was conducted by using information on the number of products sold (8,490 alternators), the number of failed alternators (3,838), the number of suspended products (4,652 alternators), the time to failure of the products (230 days), and the suspension time of products (360 days) from the SEs in this case study.

Since cars are not used for the whole day, the average number of daily driving hours for Indonesian people (6 hours) was used to determine the time to failure (TTF) value of the alternator. This value was obtained through interviews with randomly selected motorists in Java. The sample calculation in Appendix C1 shows how these aforementioned inputs were used to calculate the reliability of remanufactured alternators.

The TTF data was then analyzed using Reliasoft ++ software version 8 (Reliasoft 2013). Once all the data had been entered into the software, the reliability of the remanufactured alternator was analyzed using the Weibull distribution. The reliability analysis was calculated using the maximum likelihood estimation (MLE), Fisher Matrix and median rank methods. The results obtained from the Weibull distribution showed that the shape parameters (β), which were failure mode, were around 2.4, while the scale parameters (α), which were alternator life, were about 1,288 days. The Weibull reliability plot displaying the relationship between reliability and the time for remanufactured alternators is presented in Figure 5.5.

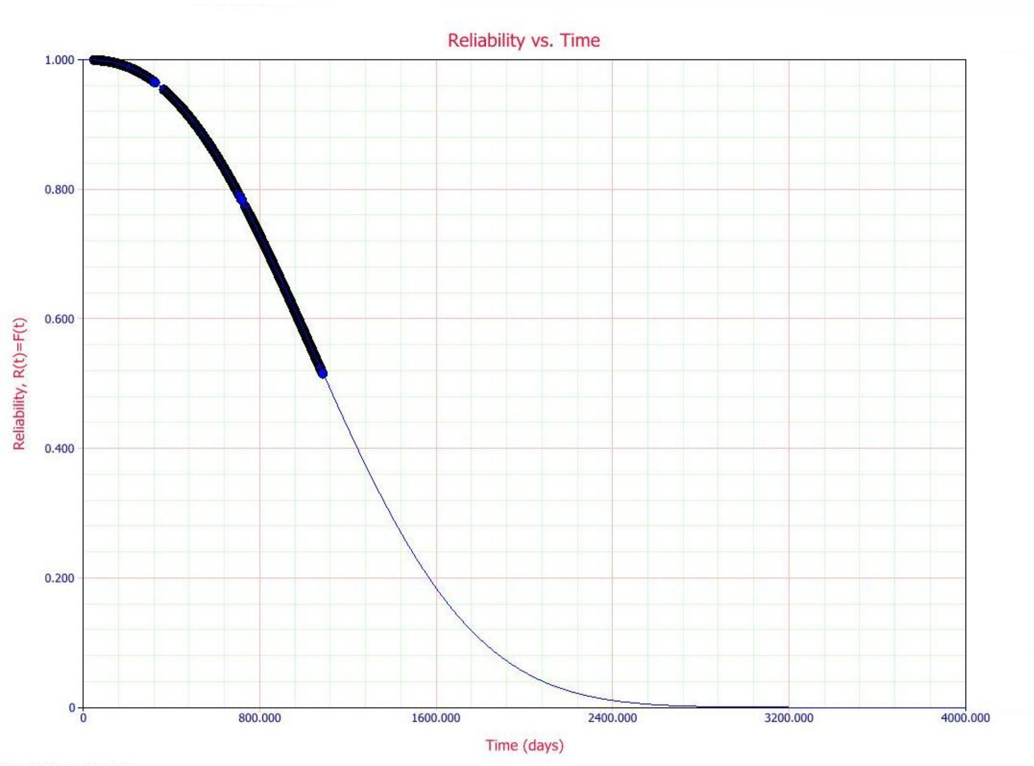

Figure 5.5 The Weibull reliability plots for remanufactured alternators

Following Equation 4.1 in Chapter 4, the mean time to failure for the remanufactured alternators was estimated to be 1,142 days. The reliability of the remanufactured alternators was compared with the threshold value of ≥90%. This level of reliability was regarded as the minimum standard for manufacturing products which could be achieved by the remanufactured alternators (Anityasari 2009). However, the reliability of the remanufactured alternators produced by these SEs (78% in two years) was even lower than the lower limit (90%) of the threshold value.

Durability

The durability analysis includes the estimation of the failure free life period of the remanufactured alternators. This period is estimated to be 12 months, during which the remanufactured alternator is expected to run for 19,000 km under typical Indonesian vehicle operating conditions (i.e. hot temperature of 105°C, speeds of 1,800 RPM, sound level of 85 decibels and vibrations of 1.2A).

According to the existing scenario, no proper durability testing has been conducted by these SEs. The current alternator testing procedure is only performed at very a basic level including testing speed, sound level and vibrations using conventional equipment (i.e. multimeter, sound level meter), as mentioned earlier.

The Weibull analysis which was used to determine the reliability of the remanufactured alternators was also utilized to determine the durability. The results showed that the durability of the remanufactured alternators was only 78% over two year, far less than the lower limit of the threshold value (≥90%) (Anityasari 2009). The lower limit of the threshold value was determined on the basis of the durability of an alternator under high temperatures, speeds, sound level and vibrations (SAE International 2001, Jung et al. 2008, Woo et al. 2008).

Warranty

Warranty has become an important part of consumer and commercial transactions, particularly in the remanufacturing industry. This is because it helps to provide protection for both producers and consumers in terms of product quality guarantee and sales improvement. According to the results of the reliability analysis, if 1% of the components failed during the warranty period, the remanufactured alternator could survive at least six months in order to achieve 99% reliability.

As it is assumed that a vehicle will be used for an average for six hours a day, the six months would be equal to 1,080 hours of use (three years). Accordingly, the SEs could have offered a maximum warranty of three years which is more than the warranty periods currently offered in the market (i.e. two years). However, in a real-market situation, the SEs provide only three months warranty, which has resulted in a 20% fall in remanufactured alternator sales on the market. Reasonable costs to honour the warranty are required in order to survive in a competitive market.

Safety Performance

Along with the reliability and durability of remanufactured alternators, safety is another essential concern that needs to be addressed. The direct connection between the alternator and battery requires safety measures in order to avoid injuries to people as well as damage to engine components. Information on power generation, currents and sound levels (WEG Equimantos Electricos S. A. 2013, SAE International 1999) were collected to determine the safety parameters in this case study. SEs usually carry out these safety tests at the final stage of the remanufacturing process.

Table 5.5 shows the results of the safety analysis of the remanufactured alternator on the basis of power generation, current and sound level. A ‘yes’ result means that the testing is conducted in the existing scenario, while a ‘no’ means that the test is not performed under the existing scenario due to a lack of testing facilities.

Table 5.5 Safety analysis of the remanufactured alternator

Performance	**Unit**	**Safety requirement**	**Testing equipment**	**Knowledge required**	**Final testing**
Power generation	RPM – Amp	1,800 RPM – >53A	Multimeter	Basic	Yes
Current	Volt	12V +/- 0.3V	Multimeter	Basic	Yes
Sound level	dB	<85 dB	Sound level meter	Basic	Yes

From the table, it appears that all of the safety requirements have been met. However, both durability and safety testing have to be conducted under different conditions (i.e. temperatures, speeds and vibrations), and this has not occurred in these testing processes due to a lack of sophisticated equipment and a lack of the knowledge required to conduct the testing. Using advanced testing technology such as an alternator tester that provides multiple testing functions (i.e. fully automated and computer controlled testing of current and stator balance) and standards could be an effective solution to maintain the required level of reliability and durability.

Availability of cores

The availability of reasonable quality cores or used products is one of the primary issues in sustaining the remanufacturing activities of the SEs. The availability of cores has been estimated by using the information on the total recovered rate of the alternator cores based on the remanufacturing capability of the SEs. The area enclosed by a circle in Figure 5.6 presents the location and the cities where the cores were currently collected.

Figure 5.6 The location of core recovery activities in Java Island

The field survey revealed that the average quantity of recovered alternator cores was about 9.9 tons/year (4,500 used alternators). These cores were collected from cities in Java including Semarang, Solo, Magelang, Purwokerto, Salaman, Yogyakarta, Jakarta, Bogor and Bandung, which were categorized as large cities with a great number of private vehicles. In comparison with the remanufacturing capability of the SE which was set as the threshold value (i.e. 5,600 alternators), the recovery rate was estimated to be 80% of the total core requirement annually. Thus the recovery rate did not meet the threshold value, and the product recovery rate of the SEs needs to be increased in order to balance the supply and demand in the remanufacturing process and maintain the required level of sales. Expansion of the collection area, collaboration with cannibalization SEs and OEM need to be considered as potential strategies for increasing the recovery rate of alternator cores.

5.3.2 Environmental assessment

Environmental assessment is an integral part of the technical assessment. Once the technical assessment is completed, the environmental impact associated with the production of remanufactured alternators needs to be assessed. The relevant environmental indicators are embodied energy saving, GHG emissions reduction, material conservation, solid waste minimization, and landfill size reduction.

Streamlined life cycle assessment

A streamlined life cycle assessment (SLCA) was conducted to estimate the GHG emissions and embodied energy consumption. It is streamlined because it ignores all downstream activities such as use, disposal and maintenance (Todd and Curran 1999). The SLCA followed the four steps of ISO 14040-44; goal and scope, life cycle inventory, impact assessment and interpretation (ISO 2006).

The goal of the assessment was to calculate the potential global warming impact of the GHG emissions (kg CO_2-eq) and embodied energy (MJ) for a typical remanufactured alternator resulting from the production of alternative materials (kg) and energy consumption (MJ) during remanufacturing operations (Figure 5.7).

The goal of this assessment is to assess the global warming impact (kg CO_2-e) and embodied energy (MJ) of a typical remanufactured alternator during its life cycle. The scope of this assessment was limited to the factory gate only and packaging was excluded. The system boundary includes cores collection, initial inspection and disassembly, cleaning, testing and sorting, reconditioning, reassembly and final testing (Figure 5.7).

The life cycle inventory (LCI) is a prerequisite for carrying out an LCA analysis. It includes a listing of the quantitative values of the materials, chemicals and energy used in all stages of the remanufacturing operation from core collection to final testing. Figure 5.7 shows the life cycle inventory, consisting of all inputs, processes and outputs (e.g. materials, energy, resources, emissions, and waste) for a 2.2 kg remanufactured alternator.

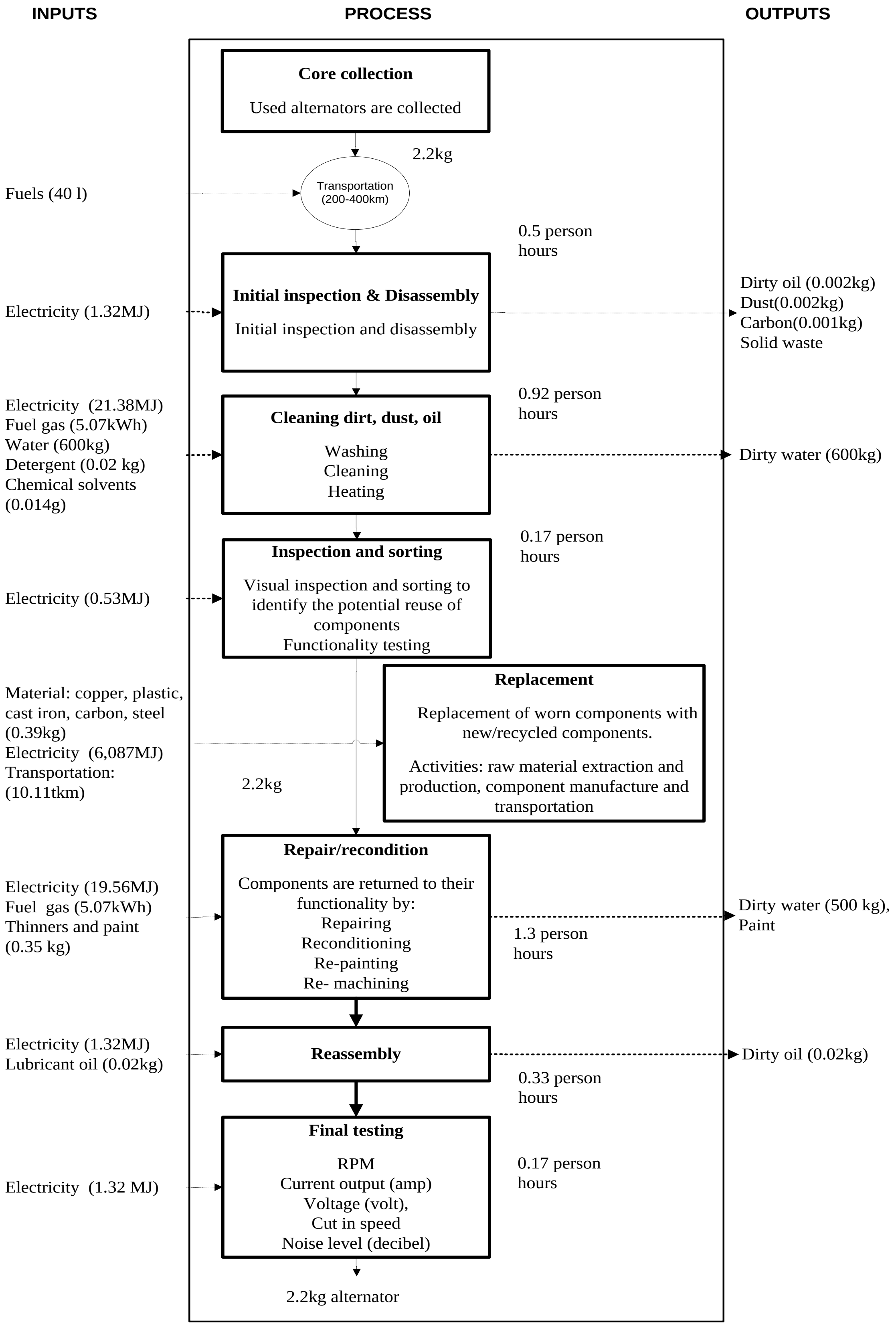

Figure 5.7 The life cycle inventory of a remanufactured alternator

Once the LCI was developed, the input and output data were entered into Simapro 7.3.3 software (PRe Consultants 2013). The data was linked to relevant libraries or emission databases within the software to estimate GHG emissions. The IPCC global warming potential (GWP) for a 100-year timescale was applied to determine the GHG emissions, and the cumulative energy demand method in the Simapro software was used to calculate the embodied energy (PRe Consultants 2013). Since some Chinese parts were used and the remanufacturing operation was conducted in Indonesia, the Indonesian electricity mix, consisting of lignite (41%), petroleum (29%) and natural gas (17%), and the Chinese electricity mix consisting primarily of hard coal (77%) were considered for electricity generation.

Embodied energy saving

The embodied energy of a typical remanufactured alternator was calculated to be 76.5 MJ. This is 71% less than the embodied energy associated with the production of a new alternator (265 MJ). However, this energy saving did not meet the corresponding threshold value which is 75% less energy for a remanufactured alternator than for a new one. As a result, a 'hot spot' accounting for the most energy has been identified as the reason for the increased embodied energy consumption. The energy consumption associated with the replacement of out-of-order parts with new parts accounts for a significant portion (52.4%) of the embodied energy consumption, followed by reconditioning activities such as repainting the case (16.7%) and cleaning and washing used components (21.8%) (Figure 5.8).

The replacement of old components with new ones consumed a significant amount of energy (40.1MJ) because this activity takes into account the energy consumption of all upstream activities including mining, processing and production of energy intensive new components such as copper. The second most energy-consuming stage is reconditioning (16.7 MJ) and is largely due to the painting process which combusts gas for the heating process.

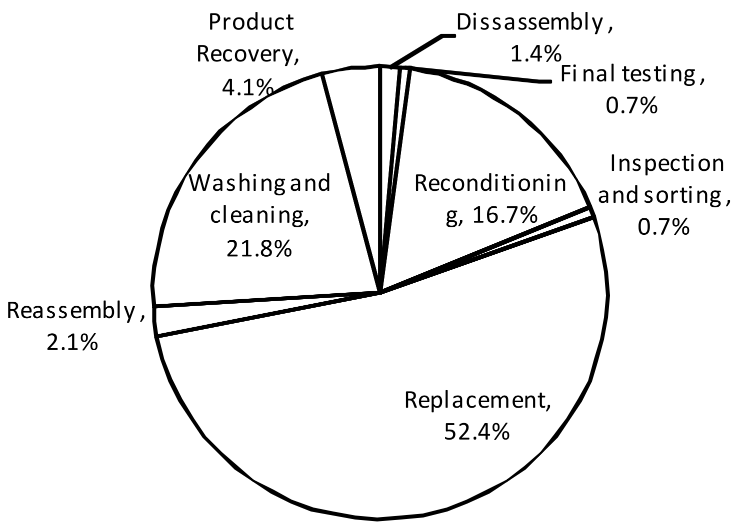

Figure 5.8 Breakdown of embodied energy consumption in terms of inputs for the existing scenario

The identification of energy 'hot spots' could help to generate improvement strategies for alternator remanufacture. For example, the use of new materials can be avoided by increasing the use of reconditioned, recycled and remanufactured components, which could in turn reduce the associated upstream energy consumption. In addition, replacing the painting process with cleaning technologies (i.e. shot blasting) (Nasr et al. 2003) could potentially improve the environmental performance, particularly in terms of embodied energy.

GHG emissions

The total GHG emissions resulting from the production of a 2.2 kg remanufactured alternator were estimated to be 4.1 kg CO_2-e. Referring to this value, it has been estimated that the replacement of new alternators with remanufactured ones could reduce GHG emissions by about 75%. Comparing the GHG reduction with the threshold values of 77% shows that the remanufacturing process in the existing scenario do not meet the GHG emissions reduction indicator. The LCA of each stage in the remanufactured alternator identified where most of the GHG emissions occurred in the existing scenario (Figure 5.9)

Similar to embodied energy consumption, the replacement of out-of-order parts with new components contributed a significant portion (55.8%) of total GHG emissions (2.3 kg CO_2-eq), followed by reconditioning (i.e. repainting) (20.4%, 0.8 kg CO_2-eq) and washing and cleaning (0.1 kg CO_2-eq). As mentioned before, this is mainly because of the use of new components. Although these new components make up only 22.2% of the total weight of the alternator, they are comprised of energy and carbon intensive materials such as copper (65 MJ/kg) and iron (25MJ/kg) (Energetics and Incorporated E3M 2004).

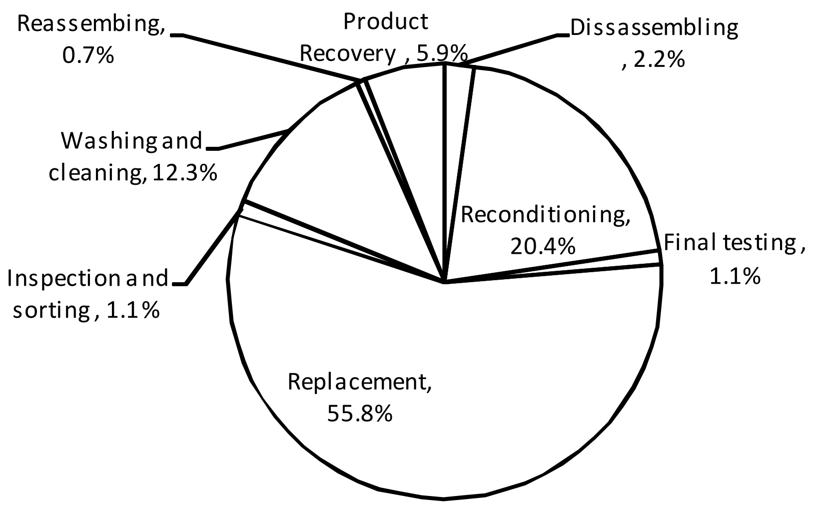

Figure 5.9 Breakdown of GHG emissions from the existing scenario in alternator remanufacturing

Material consumption

The material conservation in the existing scenario has been analyzed on the basis of the total amount of material required to remanufacture a 2.2 kg alternator. The materials in the remanufactured alternator have been classified into five categories; virgin (i.e. new parts), old (i.e. old parts), recycled (i.e. recycled parts), used and auxiliary materials (Table 5.6).

Table 5.6 The material consumption and predominant materials for the existing scenario

Component		**Predominant materials**	
Used components	1.26 kg (57%)	Steel (44%)	Aluminium (48%)
Unused components	0.94 kg (42.8%)	Copper (40%)	Cast iron (23%) Steel (20%)
Old components	0.45 kg (20.5%)	Steel (33%)	Cast iron (24%)
New components	0.49 kg (22.3 %)	Cast iron (23%)	Copper (65%)

Table 5.6 shows that the used components (1.26 kg, 57%) predominantly contain energy intensive materials like steel (44%) and aluminium (48%). The materials in the old components (0.45 kg, 20.5%) are mainly steel (33%) and cast iron (24%), while the unused components (0.94 kg, 42.8%) are mainly of copper (40%), cast iron (23%) and steel (21%). The new components (0.49 kg, 22.3 %) used to replace the old or out-of-order parts mainly consist of cast iron (0.11 kg, 23%) and copper (0.32 kg, 65%). Auxiliary materials account for 19.2% of total weight of the remanufactured alternator and include lubricant, varnish, thinner and paint.

In terms of material conservation, the use of a remanufactured alternator in this scenario would conserve about 57% of the material used in a new alternator. However, the material recovery value in this scenario is below the lower limit of the threshold value (65%) (Mukherjee and Mondal 2008, Gallo, Romano, and Santilo 2012, Asif et al. 2010) due to the generation of a large amount of unused materials (42.8%) for remanufacturing operations.

Material intensity per service unit (MIPS)

The material intensity per service unit (MIPS) of the alternator was estimated to be about 0.079kg/kWh of alternator use. This result was calculated on the basis of the weight of new material (0.49kg), the alternator lifetime (four years), daily usage (six hours/day) and the power (watt) generated by the alternator (0.7 kWh). MIPS represents the material flow associated with the delivery of service (kWh) during the life of the remanufactured alternator. Decreasing the MIPS of a remanufactured alternator by reducing new material consumption could be a potential option for improvement. In comparison with the threshold value (0.067kg/kWh) (Kim et al. 2008), the MIPS of the existing scenario did not meet the threshold value.

Solid waste avoided

The unused material generated from the remanufacturing of alternators has been estimated to be about 0.94 kg or 43% of the overall weight of a remanufactured alternator. Aluminium accounted for 23% of total unused materials followed by copper (17.1%), cast iron (9.8%), steel (9.1%), plastic (4.3%) and carbon (0.2%). These materials were replaced with both new and used materials. Around 99% of the unused materials are sent to recyclers, resulting in only 1% of solid waste which meets the threshold value of waste reduction (88%) (Smith and Keoleian 2004, Keoleian et al. 1997, Kim et al. 2008, Asif et al. 2010). This solid waste is usually sent to landfill by waste collectors who are paid around USD 5 a month.

Due to the low waste disposal cost, the SEs do not take solid waste management issues seriously. Interestingly, the revenue that these SEs generate from selling recyclable materials from the remanufacturing operation appears to be the main reason for avoiding landfilling activities. In fact, the supply of unused materials for recycling not only generated financial profits (i.e. take back revenues, disposal cost reductions) but also indirectly improved the environmental performance (i.e. waste, landfill reduction and resource conservation).

Landfill impact

The area of landfill occupied by solid waste from remanufactured alternatorwas estimated to be very low. As stated previously, only 1% of the used materials (0.14 tons of cores) are sent to landfill annually by the SEs. The replacement of a new alternator with a remanufactured one, however, could avoid about 10.5 tons of waste per year, which would occupy 2.2 m^2 of landfill area. This landfill impact (1%) meets the threshold value (20%) (Asif et al. 2010, Wollongong City Council 2010, Fuji Xerox 2011).

5.3.3 Economic assessment

In order to assess the economic feasibility of the remanufactured alternator in the existing scenario, an economic analysis including sales, life cycle cost (LCC), recovered material values and return on investment was conducted and is discussed in this section.

Life cycle cost (LCC)

The LCC of a remanufactured alternator under the existing scenario was calculated on the basis of the capital cost (USD 139,500) and operating and remanufacturing cost (USD 74,830) collected during the field visit to SEs. By using a 4% discount rate, 20 year project life and 25% tax provision, the LCC of remanufactured alternators has been estimated to be about USD 32.5. In comparison with new alternators, the LCC of a remanufactured alternator under the existing scenario is about 62% that of a new one (USD 52.3). This value does not meet the threshold value which is 40% of the LCC saving of a new alternator, but it still falls within the cost saving values for developed countries (Severengiz et al. 2008, Ijomah, Childe, and McMahon 2004, Smith and Keoleian 2004, Mukherjee and Mondal 2008).

The LCC is closely related to the reliability of a product. The more reliable the remanufactured products are, the greater the LCC and smaller the maintenance cost (i.e. direct and repairing costs). On the other hand, the less reliable remanufactured products are, the lower the LCC, and the greater the product failure. Accordingly, a future improvement scenario would include optimum reliability, a minimal LCC and reduced alternator failure.

Profit margin and price

Using a profit margin of 15%, the price of a remanufactured alternator under the existing scenario was estimated to be USD 37.5, cheaper than the price of remanufactured alternators (USD 40–50) on the local market.

Profit margin indicates the health of a business. It represents the ability of the enterprise to cover all direct costs and create a profit. This considers gross profit and the sales revenue of a product (Queensland Government 2014). The profit margin for the remanufactured alternators was determined to be about 15%, which did not meet the threshold value (20%) (Mukherjee and Mondal 2008, Nasr et al. 1998, Matsumoto and Umeda 2011). However, the selling price of a remanufactured alternator, which was estimated to be about USD 37.5 (50% of the price of the new product), did meet the threshold value of 50% (Smith and Keoleian 2004, Nasr et al. 1998, Saavendra et al. 2013).

Sales

Sales trends fluctuated during the period 2008–2010 with sales decreasing by 7% in 2009 and then further dropping by 22% in 2010 due to a decrease in reliability, quality and warranty (Figure 5.10). The total annual sales of remanufactured alternators are equivalent to around USD 107,957 (i.e. USD 37.5 per unit). This low figure has resulted in poor employee wages and lower profit. Therefore, strategies such as the expansion of the cores collection area, effective and efficient remanufacturing processes and promotional activities need to be implemented, not only to decrease the life cycle cost, but also to increase the reliability, durability and warranties of remanufactured alternators.

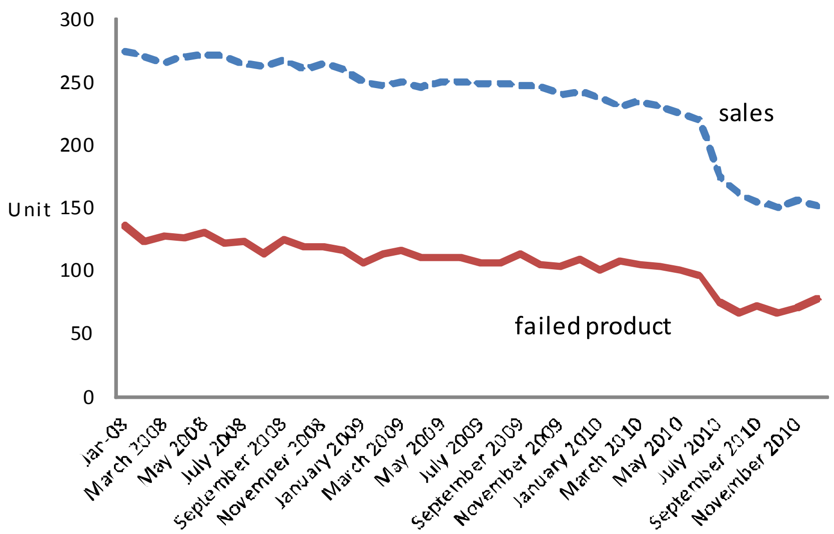

Figure 5.10 Remanufactured alternators sold during the period 2008 to 2010

Recovered material value

Recovered material value considers the price and cost of new and remanufactured alternators. A typical new alternator is worth about USD 75 on the local market. The material cost for manufacturing a new alternator has been estimated to be about USD

31.5 which is 60% of the total manufacturing cost (USD 52.3). Thus, the aggregate value added of the original material cost for a 2.2 kg alternator is USD 31.5/2.2 kg = USD 14.4/kg of alternator.

At the end of life of the alternator, the remanufacturing process saves about USD 18.4 (or USD 31.5 x 57.2%), which is equivalent to 57.2% of the original materials (1.26 kg). The unused materials (0.99 kg) which are usually sold to recyclers contribute about USD 0.4 per kg alternator. The monetary value at the end of life of an alternator is USD 18.4 + 0.4 = USD 18.8 which is 25.1% of a new alternator price. However, this did not meet the estimated threshold value of 35.7% based on recovered material value (Mukherjee and Mondal 2008).

Return on investment

Return on investment (ROI) is represented as a percentage comparison between revenue and cost. The information required for determining ROI is as follows: the price of a new alternator (USD 75), the cost of manufacturing the new alternator (USD 52.3), the price of a remanufactured alternator (USD 37.5), the cost of remanufacturing (USD 32.5) and the reusability of the alternator (four times) until it reaches till it reaches a level of fatigue where it cannot be used any more (Table 5.7). It was taken into consideration that used auto parts are commonly remanufactured two to four times, on the basis of the study undertaken by Matsumoto and Umeda (2011). Accordingly, it is estimated that an alternator can be remanufactured four times before it becomes technically and economically redundant.

Table 5.7 The return on investment (%) of the remanufacturing strategy

	Reusability	Solid waste	Revenue	Cost	Life time
New	0%	100%	USD 75.0	USD 52.3	4 years
Reman I	57%	43%	USD 37.5	USD 32.5	4 years
Reman 2	53%	47%	USD 37.5	USD 32.5	4 years
Reman 3	48%	52%	USD 37.5	USD 32.5	4 years
Reman 4	43%	57%	USD 37.5	USD 32.5	4 years
Total			USD 225.0	USD 182.5	4 years
			Total ROI	182.5/225 = 81%	

Following Table 5.7, the ROI has been estimated to be 81% of the total revenue. The ROI did not meet the threshold value of 92% (Ferrer 1997b), but it met the ROI for a new product (69.7%).

Import dependency

The import dependency of the remanufacturing SEs takes into consideration the demand for and supply of new auto parts which are used to replace old parts. New auto parts (i.e. rectifiers, bearings) mainly came from China (70%) and none of them were produced locally. The high level of import dependency of the remanufacturing SEs is due to the local unavailability of required quality products, and the price of imported items is higher than for local products. Therefore, strategies need to be developed to promote the production of parts locally, which will help to reduce the price of these parts or components due to economy of scale.

5.3.4 Social assessment

Both tangible and intangible social indicators were considered for assessing the social performance of the existing alternator remanufacturing scenario following the sustainable manufacturing framework devised by Fatimah et al (2013).

Employment creation

As discussed in the previous section, employee wages are not attractive, which creates high labour turnover. Intragenerational social equity can be enhanced through employment creation for both direct and indirect jobs by the remanufacturing industry.

During the observation period, the production and sale of remanufactured alternators decreased by 16.7% annually, resulting in a 7% decrease in direct jobs in the remanufacturing SEs. The following section illustrates the direct jobs associated with remanufacturing activities.

The field observation shows that some indirect jobs rely on the scale of production by remanufacturing SEs and can potentially be affected. These indirect jobs which were observed during the field survey, are discussed briefly below:

- *Suppliers* are responsible for the supply of new materials (i.e. copper wire for coil winding) and components (i.e. bearings, brushes) for replacement purposes. The number of suppliers for a remanufacturing SE varies between two to four employees.

- *Distributors* distribute remanufactured alternators from the remanufacturing factory to auto parts shops and some workshops in local markets. The remanufacturing SEs employed four local distributors who were usually self-employed and worked as a helping hand.

- *Scavengers* are involved in the collection of used alternators from vehicle owners and waste collection centres. These jobs are readily available and do not require any specialized skills or formal training. The SE has up to 12 scavengers.

- Each SE employs on average up to seven *collectors* for collecting waste metals (e.g. aluminium, steel, iron). The collection of scrap metal for recycling is another indirect job created by remanufacturing industries. The recycling industries, which collect used material and components from SEs, employ about seven workers for their activities.

These indirect jobs are not discussed further because they are beyond the scope of this research.

Labour wages

A typical Indonesian salary package includes a monthly average wage of USD 140 (1,481,100 IDR), which is 20% to 24% lower than other Asian countries such as Malaysia and Thailand (Hewlett Packard 2012). However, the labourers in the SEs earn only about USD 3 (30,000 IDR) per day or USD 75 (750,000 IDR) per month, which is even lower than the provincial average minimum wage for the Java area (USD 89 or 890,000 IDR) in 2010.

The monthly average wage can vary depending on hourly wage rates and the number of work hours as determined by the SEs. The uncertainty associated with the supply and demand for remanufactured alternators often means that there is an increase in part-time jobs which replace full-time jobs. Even if employees are not satisfied with the wages offered by the SEs, they have no negotiation power due to their lack of technical skills and financial security or assets. An increase in sales could increase the SEs' profits, which could in turn increase wages and attract skilled workers. As discussed in the previous section, the increase in sales also depends on the technical performance of the remanufactured alternators. Thus, both a technically sound product and an effective promotional initiative are required to boost revenue and to increase wages.

Intergenerational equity

Intergenerational equity is the equity which arises between generations by conserving resources and enhancing environmental performance. The conservation of resources (i.e. energy, material etc.) allow future generations to maintain the same lifestyle as the current generation (Biswas and Cooling 2013). The replacement of OEM with remanufactured alternators could potentially conserve materials, including the rare earth metals (i.e. neodymium) used in the coil part of the alternator, for future generations. It can thus enhance the carrying capacity of the earth and reduce the ecological footprint.

The LCA analysis in the previous section was used to estimate energy and material consumption for future generations over a period of 20 years. It was estimated that the material consumption required for remanufacturing 4,500 units of alternators was about 2.2 tons/year and the energy consumption was about 0.34 TJ/year. On the other hand, it was calculated that the manufacture of 4,500 units of new alternators requires about 9.9 tons of materials per year, consumes about 1.20 TJ/year of embodied energy.

Comparing OEM with remanufactured alternators revealed that material consumption of about 7.7 tons/year could be avoided due to the replacement of new alternators with remanufactured alternators and the embodied energy saving arising from this replacement would be 0.85 TJ/year. The extraction and use of rare earth materials including neodymium and dysprosium, metals and petroleum products could be avoided. The intergenerational equity in terms of material and energy conservation due to the replacement of new alternators with remanufactured alternators over the next 20 years would be 154 tons and 16.9 TJ respectively. The threshold values for material and embodied energy savings which were sourced from Kim et al. (2008) and Smith and Keoleian (2004) were 160 tons and 17.9 TJ respectively. As a result, the remanufacture of alternators by the SEs do not meet the threshold value for intergenerational equity.

Company reputation

A company's reputation can increase customer interest in purchasing a product and thus can assist in the increase of sales. Reputation is 'a collective representation of a firm's past actions and results that describes the firms' ability to deliver valued outcomes to multiple stakeholders' (Fombrun and van Riel 1997, p. 5). The relation between direct and indirect stakeholders is presented in Figure 5.11.

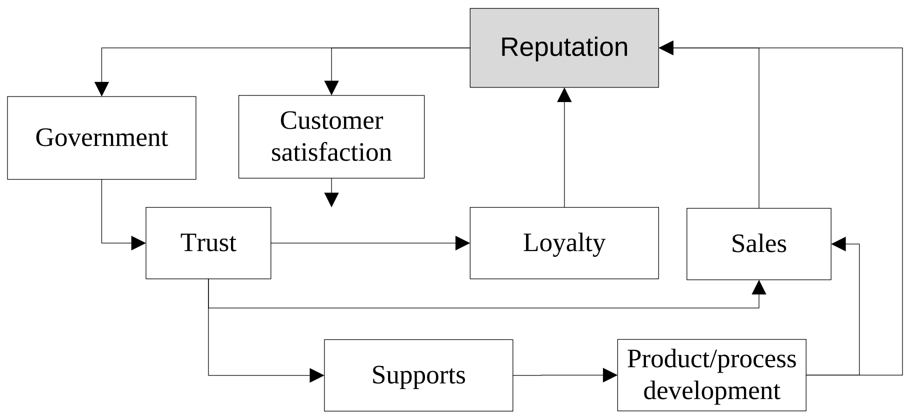

Figure 5.11 The corporate social responsibility model for the remanufacturing SEs

Figure 5.11, which is based on observations made in the field survey, shows how the reputation of the existing remanufacturing SEs could increase the trust and loyalty of customers, leading to a positive effect on sales. Price is considered a key factor to increasing sales. Thus, an appropriate strategy needs to be developed for SEs in order to provide high quality products at affordable prices. This could increase sales which in turn would improve the promotion of these SEs. However, the existing situation is that the reputation of the enterprises remains weak due to a lack of promotion. Sustainable remanufacturing producing a quality product with a competitive price and a reasonable warranty could help to strengthen the reputation of the SEs.

Corporate social responsibility (CSR)

Corporate social responsibility (CSR) is important for a business as it refers to how remanufacturing will provide enormous economic, social and environmental advantages by remanufacturing of end of life products (Matsumoto and Umeda 2011, Gallo, Romano, and Santilo 2012). However, the promotion of corporate social responsibility in the Indonesian industry has not been effective, resulting in a lack of motivation among SEs to remanufacture of the end of life products (Koestoer 2007).

Youth and enterprise development

Remanufacturing SEs would encourage the development of youth and enterprise. In 2013, the number of youth involved in enterprise reached about 3.7 million (1.5% of the Indonesian population), which was dominated by SMEs in a number of important sectors including industrial electronics, the automotive parts industry, agriculture and some other businesses. In 2014, the number is expected to reach about 4.7 million, and remanufacturing SEs could play a potential role in achieving this target.

5.4 Summary of the existing scenario and the threshold values

The threshold values for the technical, environmental, social and economic pillars were used to assess the sustainability of the remanufacturing SEs. The sustainable manufacturing indicators were compared with the threshold values as presented in Tables 5.8 and 5.9.

Table 5.8 Technical-environmental sustainability assessment of the existing scenario

No	Sustainable indicators	Existing scenario	Threshold value
1	Reliability	78.0%	≥90%
2	Durability	78.0% over 2 years	≥90% over 2 years
3	Warranty	3 months	2 years
4	Safety performance	Do not meet standard	Meet standard
5	Availability of cores	4,500 units	5,600 units
6	Embodied energy saving	71.1%	75.0%
7	GHG emission reduction	75.0%	77.0%
8	Material saving	57.0%	65.0%
9	MIPS	0.079 kg/kWh	0.067 kg/kWh
10	Solid waste avoided	99.0%	88.0%
11	Landfill	1.0%	20.0%

Based on the above comparison, it appears that most of the indicators have not met the threshold values. The technical performance (i.e. reliability, durability, safety performance, warranty and availability of core) of the alternator remanufacturing SEs seemed very low compared to the threshold value. This was due to poor quality cores, lack of skilled workers and inefficient remanufacturing processes.

Except for solid waste and landfill indicators, the environmental indicators for the existing scenario including GHG emissions and material and energy conservation did not meet the threshold values. These results indicate that the alternator remanufacturing SEs are material and energy intensive industries and contribute to significant environmental impact due to the use of a large number of new components, inefficient resource consumption, the absence of environmentally friendly equipment (e.g. water saving washing machines) and lack of environmental awareness. On the other hand, the recycling process, which is conducted by local recyclers, helped to avoid the solid waste and landfill impact.

Table 5.9 Socio-economic sustainability assessment of the existing scenario

No	Sustainable indicators	Existing scenario	Threshold value
1	Life cycle cost saving	38%	40.0%
2	Profit margin	15.0%	20.0%
3	Price	50.0% of new	50.0% of new
4	Sales	Decrease 7%	Increase
5	Recovered value	25.1% of new	36.7% of new
6	Return on investment	81% of new	92.0% of new
7	Import dependency	Dependent	Independent
8	Intragenerational equity		
	Employee creation	Decrease	Increase
9	Labour wages	USD 75	USD 89
10	Intergenerational equity		
	Energy saving	16.9 TJ	17.9 TJ
	Material saving	154 tons	160 tons
11	Company reputation	Weak	Strong
12	Intangible asset finance		
	Corporate social responsibility	Decrease	Increase
13	Youth and enterprise development	Not developed	Developed

Similarly to the technical and environmental analysis, remanufactured alternators were not found to be economically feasible because all of the indicators did not meet the threshold values. The analysis of the social objectives, including employee creation, intergenerational equity and corporate social responsibility, revealed that the existing scenario also has not met the threshold values.

These results show that the SEs have not yet generated technically, environmentally, economically and socially feasible remanufactured alternators. Thus, this analysis, utilizing the sustainable manufacturing framework devised by Fatimah et al. (2013), has shown that existing Indonesian SEs producing remanufactured alternators are not sustainable.

Based on the above analysis, the weaknesses in the existing scenario have been identified and these issues are addressed by considering a number of remanufacturing strategies in Chapter 6. The factors which have been identified as impediments to attaining sustainable remanufacturing are as follows:

- The number of failed products was high (approximately 45%) during the observation, which resulted in a low reliability score for the remanufactured products (78%). The failed components included regulators (64% of the total failed products), rectifiers (13%) and brushes (12%), which are considered to be critical components. Therefore, alternative remanufacturing strategies will be considered to enhance the quality of the product.

- The composition of materials in the existing situation showed that reused materials (57%) dominated the remanufactured alternators, followed by new parts (21%) and old parts (22%). This often leads to poor performance of the final products.

- The testing process was not properly conducted due to limited access to appropriate technologies and equipment and testing procedures.

- The supply of the required number of quality cores on a regular basis by. scavengers, customers, collection centres, cannibalizing centres and workshops is insufficient due to the small size of the cores collection area. The lack of supply chain management also causes an imbalance between supply and demand.

- There is a lack of skilled workers due to a lack in education, knowledge, training and salary, which negatively affects the productivity of employees.

- There is a lack of attractive promotional activities, so sales did not increase. This situation does not allow the generation of enough revenue to expand the business and employment.

Three remanufacturing strategies are considered in Chapter 6 to overcome the aforementioned impediments to achieving a sustainable manufacturing framework, by improving the technical and environmental performance of the remanufactured alternators.

Chapter 6

Achieving sustainability in alternator remanufacturing

6.1 Introduction

As explained in Chapter 5, the technical, environmental, economic and social performance of the existing scenario was not sustainable due to the high number of failed components, large proportion of poor quality used parts, absence of modern testing facilities, inadequate supply of quality cores, lack of skilled workers and lack of marketing strategies. This chapter presents an improvement framework (discussed in Chapter 3) with remanufacturing strategies for achieving sustainable manufacturing in Indonesian SMEs. In remanufacturing strategy I, the quantity of new materials was increased in order to decrease the quantity of poor quality used parts in the production of remanufactured alternators. This strategy was found to be technically viable but not environmentally feasible. The second remanufacturing strategy decreased the quantity of new materials and increased the proportion of recycled materials.Again, the strategy was not found to satisfy with all environmental criteria. Hence, remanufacturing strategy III employed a greater quantity of high quality used materials which proved to be a technically feasible and environmentally friendly solution. Following this, the economic and social implications of remanufacturing strategy III were assessed to develop policies for implementing this strategy. Finally, this chapter discusses the enabling mechanisms for policy implementation to promote sustainable remanufacturing strategies in Indonesia.

6.2 Remanufacturing strategy for improvement scenario I

As discussed in Chapter 5, the existing scenario was found to be unsustainable mainly due to technical weakness resulting from a large number of failed products. These failed items included three critical components (regulator, rectifier and brush) which decreased the reliability of the remanufactured alternator. Other reasons were the use of large quantities of used materials without any quality assurance being performed, improper testing processes due to the absence of appropriate technology and equipment, a core collection area too limited to be able to provide for the required level of production, lack of skilled workers or promotional strategies.

All of these factors were taken into account in the improvement framework devised by Fatimah et al. (2013) that has been utilized to assess the remanufacturing strategy. The improvement scenario I remanufacturing strategy for SEs was required to meet the threshold values of the technical indicators, including reliability, durability, safety, warranty and availability of cores, as these are considered to be the key factors for improving the performance of remanufactured alternators. Table 6.1 illustrates the way in which the improvement scenario I remanufacturing strategy aims to overcome the drawbacks of the existing scenario..

A failure analysis conducted in the current study considered all of the failure data collected during three consecutive years (2008–2010). The results showed that the majority of failure was caused by the regulator (64%) followed by the rectifier

(13%), brush (12%) and other components (11%), such as the stator and rotor. One prominent way of making a very high quality remanufactured alternator could be by replacing most of the old components with new ones except for the housing, and the stator and rotor casings which are reconditioned and do not affect the quality and performance of the remanufactured alternator. Based on this strategy, improvement scenario I considered replacement of all critical components with new ones. The old critical components and materials included the regulator, rectifier, brush and other worn components including the coil winding stator and rotor, pulley, insulation, bolt and nut, bearings and clamps, which were to be replaced with new ones that were usually imported from China and Taiwan.

Table 6.1 Improvement scenario I: remanufacturing strategy for overcoming the drawbacks of the existing scenario.

Unsustainable factors of the existing scenario	Feedback arrow	Strategy approaches
Large number of failed products	→	Increase the quantity of virgin materials
Large proportion of used material and lack of quality	→	Reduce the quantity of used materials
Lack of testing process	→	Use new technology for testing processes
Limited core collection area	→	Expand the core collection area
Lack of skilled workers	→	Implement skills and management training for workers
Lack of marketing promotion	→	Increase the marketing promotion

→ illustrates an improvement approach

The IC regulator, rectifier and brush contributed the most (84%) to the failure of the remanufactured alternators. Replacing them with new ones was expected to reduce the chance of failure of the remanufactured alternator. Other small components including the insulator, pulley, bolt and nut, bearing and bearing clamps were also considered for replacement, as the field survey showed it was cheaper to buy new parts than to recondition the used ones. Due to poor core quality, the burnt out rotor and stator were also to be replaced with new ones in this scenario. Table 6.2 shows the components that were considered to be replaced with new (43%) and reused parts (57%) to improve the technical performance.

Table 6.2 Remanufacturing strategies for scenario I

Part	Material	Weight	Unit	Existing Scenario	Scenario I
Housing	Aluminium	570 (26%)	g	R	R
Stator	Steel	450 (20.5%)	g	R	R
	Lead	10 (0.5%)	g	R	R
	Plastic	2 (0.1%)	g	RwN	RwN
	Copper winding	200 (9%)	g	RwN	RwN
Rotor	Cast iron	70 (3%)	g	R	R
	Steel	50 (2.3%)	g	R	R
	Plastic	2 (0.1%)	g	RwN	RwN
	Copper winding	120 (5.5%)	g	RwN	RwN
Fans	Aluminium	30 (1.4%)	g	R	R
Slip ring	Copper	20 (0.9%)	g	R	R
Pulley holder	Steel	30 (1.4%)	g	R	R
Bosh holder	Steel	25 (1.1%)	g	R	R
IC regulator	*Plastic*	*5 (0.2%)*	*g*	*RwU*	*RwN*
	Copper	*5 (0.2%)*	*g*	*RwU*	*RwN*
	Cast iron	*5 (0.2%)*	*g*	*RwU*	*RwN*
	Aluminium	*50 (2.3%)*	*g*	*RwU*	*RwN*
Pulley	*Steel*	*150 (6.8%)*	*g*	*RwU*	*RwN*
Rectifier	*Cast iron*	*100 (4.5%)*	*g*	*RwU*	*RwN*
	Copper	*50 (2.3%)*	*g*	*RwU*	*RwN*
	Plastic	*20 (0.9%)*	*g*	*RwU*	*RwN*
Insulator	*Plastic*	*65 (3%)*	*g*	*RwU*	*RwN*
Bolt and nut	Cast iron	90 (4.1%)	g	RwN	RwN
Brush	Carbon	5 (0.2%)	g	RwN	RwN
Bearings	Steel	50 (2.3%)	g	RwN	RwN
Bearing clamps	*Cast iron*	*20 (0.9%)*	*g*	*RwN*	*RwN*

R = Reuse of component, RwN = Replaced with New, RwU = Replaced with Used

6.2.1 Technical analysis

Reliability

A reliability parameter was allocated to all new components replacing existing parts and materials (i.e. regulator, rectifier, brush, slip rings, stator winding, rotor winding, bearing and pulley). Other components, including the bosh holder, insulator, rotor shaft, finger poles, laminated iron frame, stator lead and neural junction, front case, back case and fan bolt and nuts were found not to have failed and the reliability of these components was thus determined using exponential distribution.[9] The failure rate of these components (0.1%) was discerned by consulting with the surveyed SEs which was cross-checked with the Military Standardization and Reliability Handbooks (Weibull Com 2014)

The reliability analysis was then conducted by applying series and parallel relationships between the components of the remanufactured alternator to estimate the reliability of the remanufactured alternator for improvement scenario I as shown in Figure 6.1.

The steps followed to discern the reliability by using the series-parallel relationship between component reliabilities are as follows:

- Firstly, reliability values for all series connections including the rotor assembly, stator assembly and carbon brush assembly were determined using Equation 4.4 (see Chapter 4) S

- Secondly, following Figure 6.1, the reliability value for the parallel connections was determined using Equation 4.5 (see Chapter 4).

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[9] The exponential distribution in this research is the distribution of failure probability that illustrate the time between failure in a poisson process (i.e. failure occurs continuisly at costant average rate.

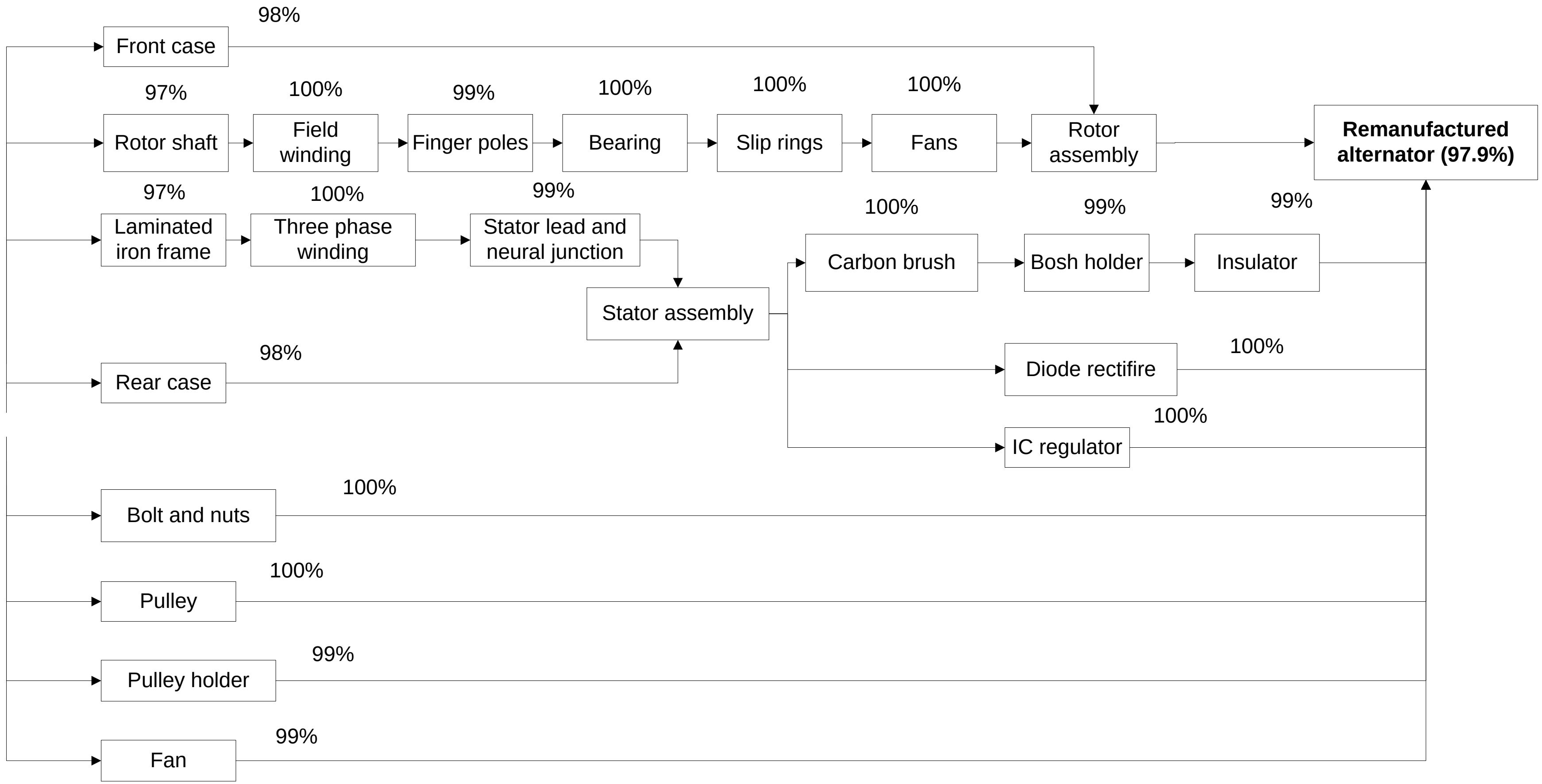


Figure 6.1 Series and parallel relationships between the components of the remanufactured alternator for Improvement Scenario I

(43% new components, 57 % used components)

- Finally, using parallel and series connections, the reliability of the remanufactured alternator for improvement scenario I was estimated to be about 97.9%. The detailed calculation of the reliability is presented in Appendix C2.

The reliability of the remanufactured alternator in improvement scenario I (97.9%) is not only higher than it is in the existing scenario (78% over two years), but is also much higher than the lowest limit of the threshold value (≥90%). This increased reliability is due to the replacement of old components with new ones. However, this could increase the life cycle cost of the remanufactured alternator and the environmental impact resulting from the mining and manufacturing processes associated with the production of the new components (Biswas and Rosano 2011).

Durability

The durability of the remanufactured alternator in improvement scenario I was estimated to be 97.9% due to the increase in reliability to 97.9% over two years. In order to ensure a durability higher than that in the existing scenario, a durability testing framework was used in this scenario (Figure 6.2).

It was determined that the durability testing should be conducted using a 15HP alternator tester. The first test is to measure the durability of the alternator at high temperature (i.e. 105°C) for a period of 20 seconds. An efficiency of 90% or more has to be achieved for a standard durability testing.

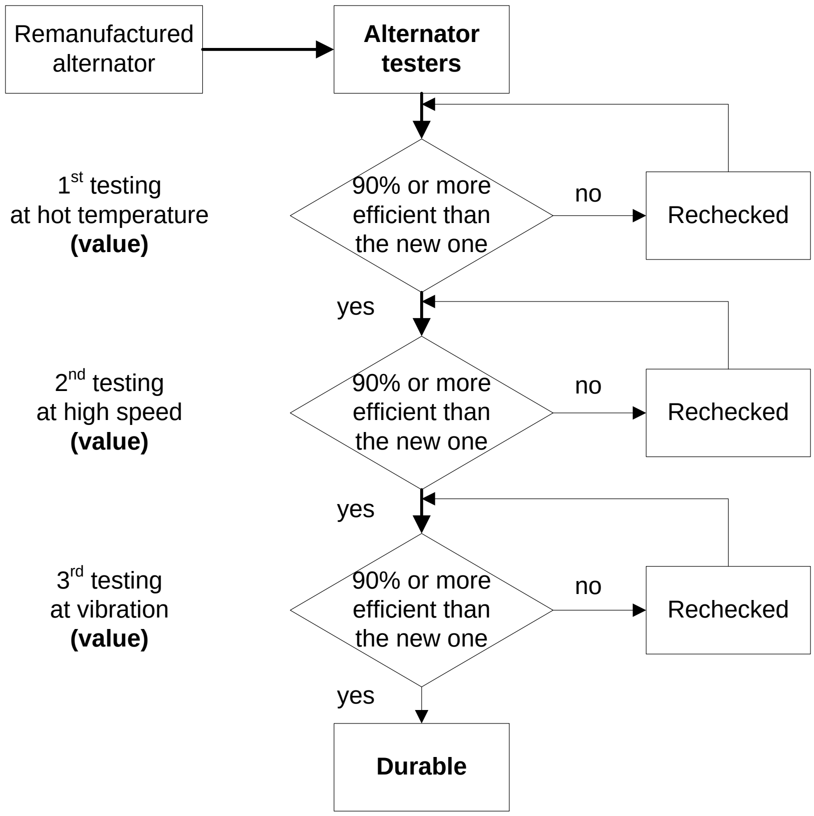


Figure 6.2 A durability testing framework for remanufactured alternators

If the durability testing result does not meet the 90% efficiency value,[10] the remanufactured alternator needs to be rechecked and then retested to meet the durability requirement. Once the remanufactured alternator has met the lower limit of the threshold value for durability (≥90%), a similar testing procedure is applied twice more under high speed and vibration to check whether the durability is maintained at ≥90%. Therefore, it is recommended that Javanese SEs adopt these advanced alternator testers in order to maintain a technical performance that will provide customer satisfactions.

[10] An efficiency of 90% or more means that the remanufactured alternator would have 90% or more of the durability requirement.

Warranty

The reliability value and the mean time to failure (MTTF) of the remanufactured alternator were then used to determine the warranty period for the remanufactured alternator. Some information including the warranty period of the new alternator (t_{w1} = two years), a nominal customer risk (NCR) (0.0361) of two years, average life of a new alternator (t_0= four years), and the reliability of the remanufactured alternator (R_{tw2} = 97.9%) were used to estimate the warranty period (W_2) and the end of life estimation of the remanufactured alternator (t_{w2}) for improvement scenario I by using Equation 4.14 (Chapter 4). The warranty period of the remanufactured alternator under this scenario was estimated to be two years with a life expectancy of about four years, which is very high compared to the existing scenario.

Safety performance

The safety performance test, consists of three basic tests, including power generation at high temperature, current and sound measurements. The ability of the remanufactured alternator to generate power at high temperature is determined at the maximum load (50 to 70 amps at 12V). For this type of alternator, the speed should be between 1,800 rpm and 3,000 rpm (2,000 to 5,000 rpm) to increase the alternator efficiency and the current should be above 50 amps (SAE International 1999). The performance of the IC regulator should be around 12.2V +/- 0.3V while the noise level performance should not be above 85dB (SAE International 1999). This testing was expected to maintain the safety performance of the remanufactured alternator. If the alternator meets all of the safety criteria, it is considered to satisfy the standard safety performance. Thus it is assumed that the improvement scenario successfully met the requirements for safety testing and thus ensured that the safety standards were met availability of cores

It was expected that increasing the availability of cores by expanding the core collection area would help the SEs to achieve the required remanufacturing capacity.

It was proposed to expand the collection area to the east and west of Java, including Jakarta, Bekasi, Bandung, Surabaya, Banyuwangi, and Malang(represented by the dotted circles), in order to maintain the supply of the required number of cores (Figure 6.3) to sustain the desired level of production. The number of quality cores supplied increased by 41% due to this expansion. However, the travelling distances from these cities to the remanufacturing SE factories was estimated to be about 400–800 km by road.

Figure 6.3 The expansion of the core collection area

The collection of cores will affect the economic and technical viability of the alternator remanufacturing SEs, plus social sustainability in terms of job creation. It was estimated that the expansion of this collection area could increase the remanufacturing capacity of SEs by up to 7,900 units per year, which could result in the reduction of the unit cost due to economy of scale. The establishment of a collection centre (centralized collection area) in a suitable location would thus facilitate core collection and reduce collection costs. Indirect purchasing through online order and collaboration with some cannibalization SMEs could be additional strategies for increasing the supply of quality cores to sustain production at the required level.

Summary of the technical analysis

The technical criteria for improvement scenario I are compared with the respective threshold values in Table 6.3. Interestingly, all technical criteria including reliability, durability, safety, availability of cores and warranty met the threshold values, which was due to the increase in the use of new materials, introduction of new testing technology and the expansion of the collection area.

Table 6.3 Technical criteria for the sustainability assessment of improvement scenario I

No	Technical criterion	Threshold value	Improvement scenario I
1	Reliability	≥90	97.9%
2	Durability	≥90	97.9%
3	Safety	standard met	standard met
4	Availability of core	5,600 units	7,900 units
5	Serviceability (warranty)	1–2 years	2 years

6.2.2 Environmental impact analysis

Once the technical criteria have been met, the environmental criteria need to be satisfied before the socio-economic analysis is carried out (Fatimah et al. 2013). The environmental implications of the modified remanufactured alternator under this scenario have been assessed to investigate whether the environmental performance was affected by the use of virgin materials and new components. Some environmental indicators, which were used for the existing scenario, including GHG emissions, embodied energy, material conservation, material intensity per service unit (MIPS), solid waste avoided and landfill size, were used for assessing the environmental friendliness of the technically feasible remanufactured alternator.

Embodied energy saving

Following the same approach (cumulative energy demand method) as for the existing scenario, the embodied energy of the remanufactured alternator in improvement scenario I was estimated to be 116 MJ. This embodied energy value is much higher than the threshold value or that of the existing scenario due to the use of a large portion (68.7%) of virgin materials as shown in Figure 6.4. Specifically, the use of energy intensive materials including copper (17.1%), cast iron (9.8%) and steel (9.1%) increased the embodied energy consumption significantly. The use of any new components takes into account all energy consumption in the mining, processing, transportation and manufacturing stages of new components, thus increasing the amount of embodied energy in improvement scenario I. Therefore, the embodied energy saving benefits were only 56.2% of the total embodied energy (148.9MJ) for a new alternator. This value is less than the threshold value which is about 75% of the total embodied energy of a new alternator.

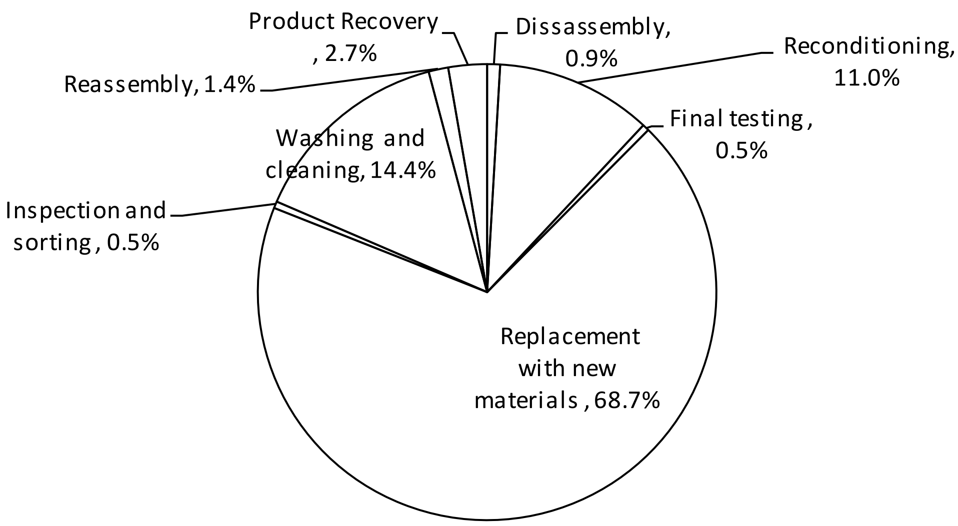


Figure 6.4 The breakdown of embodied energy in improvement scenario I

GHG emissions

The IPCC 2007 global warming potential which was used in the existing scenario, has also been employed in improvement scenario I to determine the GHG emissions for a remanufactured alternator. The GHG emissions from the remanufacturing of an alternator in improvement scenario I were estimated to be about 6.4 kg CO_2-eq. The GHG saving associated with the replacement of new alternators with remanufactured ones was estimated to be 10.1 kg CO_2-eq (61.5%) per remanufactured alternator. This percentage (61.5%) of GHG saving is far less than in the existing scenario (75%) and the threshold value (77%).

Like the embodied energy hotspot, the GHG emissions associated with the replacement of old materials with new materials also contributed to a significant portion (71.4%) of the GHG emissions in this scenario (Table 6.4). Thus, as discussed in the previous energy analysis, the composition of recycled materials, and reused and new components, needs to be determined in a way that will reduce both GHG emissions and embodied energy consumption while meeting the requirement for technical viability. As stated earlier, the mining, processing and manufacturing processes in the upstream activities for new component production have added a significant quantity of GHG emissions to the life cycle of a remanufactured alternator.

Table 6.4 The breakdown of GHG emissions in terms of inputs in improvement scenario I

Process	**GHG emissions**	**Process**	**GHG emissions**
Product recovery	3.8%	Reconditioning	13%
Disassembly	1.4%	Replacement	71.4%
Inspection	0.7%	Reassembly	0.4%
Washing & cleaning	7.8%	Final testing	0.7%

Material saving

The quantity of virgin materials in the remanufactured alternator in improvement scenario I has been estimated to be 0.94 kg (43% of the total weight of the remanufactured alternator). As a result, the advantage of material conservation in this scenario is same as in the existing scenario (57%), resulting in only 57% saving of virgin material compared to the threshold value of 65%.

Therefore, the next remanufacturing strategy should reduce the number of new components and increase the number of recycled or reused materials in a way that both technical and environmental criteria are met. For example, the embodied energy for virgin copper alone is about 140MJ/kg, while for recycled copper is only about 35MJ/kg (Gaines 1995, Stodolsky et al. 1995). Therefore, the embodied energy of recycled copper is 25% of the embodied energy of virgin copper, which could reduce GHG emissions significantly (Ashby 2009). The level of reduction of GHG emissions depends on where the copper was mined and processed and the quality of the copper cores.

Material intensity per service unit (MIPS)

The material intensity per service unit (MIPS) for this scenario was calculated to be 0.151 kg/kWh. The calculation was on the basis of the weight of new materials (0.94 kg), the alternator life (four years), the car operating hours (six hours/day) and the energy (watt) produced by the alternator (0.72 kWh). The MIPS in improvement scenario I is higher than that in the existing scenario (0.079 kg/kWh) and also much higher than the threshold value (0.067 kg/kWh), which means that the remanufactured alternator under improvement scenario I can be regarded as an eco-efficient remanufactured alternator, which helps to enhances the carrying capacity and reduce the ecological footprint. The calculation of the MIPS is presented in Appendix C4.

Solid waste avoided

The remanufacturing scrap in improvement scenario I was estimated to be about 0.94 kg (43% of the overall weight of a remanufactured alternator), about the same as for the existing scenario (0.94kg, 43%), which is mainly due to the replacement of old critical components and small parts with new ones. The total number of new materials used for replacement in improvement scenario I (43%) is higher than in the existing scenario (23%). The scrap produced due to the use of new materials which are mainly dominated by copper (0.375kg, 17.1%), cast iron (0.215kg, 9.8%) and steel (0.200kg, 9.1%) have potentially increased the amount of solid waste.

Most of the scraps produced in SMEs for improvement scenario I do not go to landfill as they are picked up by the scavengers for use or recycling in other applications (e.g. cookware). As a result, it has been estimated that Javanese SEs avoid a significant amount of solid waste (99%), which is much higher than the threshold value (88%).

Landfill impact

Based on the results from the solid waste analysis above, the total scrap that could be generated annually has been estimated to be about 16.3 tonnes. If the scrap were to go to landfill, it would require about 3.1 m^2 of landfill area. As 99% of the unused materials or scraps are collected by recyclers, the alternator remanufacturer in improvement scenario I could save about 3.06 m^2 of landfill area, which would potentially reduce the amount of landfill that would be required for the disposal of EoL alternators.

Summary of the technical analysis

Table 6.5 summarizes the environmental criteria in improvement scenario I in comparison with the threshold values. The environmental criteria show that the embodied energy, GHG emissions, material conservation and MIPS did not meet the corresponding threshold values. Only two environmental indicators, including solid waste and landfill, met the threshold value, mainly due to the reuse of these scraps for producing alternator products, and the income generated by the SE from selling these scraps to recyclers. In the case of developing countries such as Indonesia, economy is a driver for recycling, while environmental regulations and landfill tax are the drivers of recycling among remanufacturing SMEs in developed countries (Damanhuri and Padmi 2012, Wilson 2007).

Table 6.5 The environmental criteria for improvement scenario I and the threshold values

	Environmental	Improvement scenario I	Threshold values
1	Embodied energy saving	56.2%	75%
2	GHG emissions	61.5%	77%
3	Material saving	57%	65%
4	MIPS	0.151 kg/kWh	0.069 kg/kWh
5	Solid waste avoided	99%	88%
6	Landfill	1%	20%

Although the technical criteria were met, improvement scenario I is not entirely environmentally friendly. From the technical and environmental analysis presented above, the following factors have been identified as constraints to achieving the threshold values for embodied energy consumption, GHG emissions, material consumption and MIPS reduction. The main reason for not meeting the threshold values is the increased quantity of virgin materials, and the reduction in used components and materials, as well as the increase in transportation needed for importing new components.

According to Fatimah et al. (2013), this scenario cannot be considered for a socio-economic analysis as the technical and environmental indicators have not been met. Therefore, different remanufacturing strategies have been considered in improvement scenario II to assess whether the technical and environmental indicators could be met.

6.3 Remanufacturing strategy for improvement scenario II

Improvement scenario II, which involves the use of both recycled and used material, was considered for the technical and environmental analysis in the following section on the basis of the remanufacturing strategy as presented in Table 6.6.

Table 6.6 Remanufacturing strategies for overcoming the drawbacks in scenarios I and II

Unsustainable factors of improvement scenario I	**Feedback arrow**	Strategy approaches
Large quantity of virgin materials	⟶	Use recycled materials
Lack of used materials	⟶	Increase the quantity of used materials
High level of transportation activities	⟶	Reduce the importation of new components
Employ new technology for the testing process	-·-·-·-·-→	Employ new technology for the testing process
Expand the core collection area	-·-·-·-·-→	Expand the core collection area
Introduce training for workers and managers	-·-·-·-·-→	Training on remanufacturing standards
Increase marketing promotion	-·-·-·-·-→	Increase marketing promotion

⟶ new strategies -·-→ no change, remain as is

- It is proposed that the old material and components in the existing scenario, including rotor and stator winding copper, be replaced with recycled material for the following reasons: From the technical and economic points of view, recycled copper has been found to have the same quality (i.e. reliability, durability) as virgin copper and it is cheaper and readily available on the market (Copper Recycling and Sustainability 2014)
- From an environmental point of view, the replacement of new copper with the recycled copper could save up to 90% of embodied energy (West 2014).

Other alternator components including the housing, laminated iron stator, rotor shaft, slip ring, fan, bolt and nut and pulley were reconditioned for reuse in this scenario. These reconditioned parts were found not to have failed and they are found reusable at the end of the alternator life (SAE International 2001).

It was proposed that critical components including the regulator, rectifier, brush and bearing be replaced with new ones, since these components have been found to contribute to the failure of remanufactured alternators in the existing scenario. In addition, it is cheaper to buy new regulator, rectifier and brush than to spend money on reconditioning old components. The bearing has never been found to be suitable for either repairing or remanufacturing (Biswas and Rosano 2011).

Table 6.7 shows the parts and materials which were replaced with recycled materials, new and reused components in improvement scenario II. Based on the materials and components analysis in Table 6.7, it was estimated that approximately 62.2% of the materials and components were reused, and the rest were intended to be replaced with recycled materials (15%), old materials (3%), and new materials (13%). The main difference between improvement scenario I and improvement scenario II is that recycled copper is used instead of new copper.

Table 6.7 Remanufacturing strategy for improvement scenario II: composition of recycled, reused and new components

Part	Material	Weight	Unit	Existing Scenario	Scenario I	Improvement scenario II
Housing	Aluminium	570 (26%)	g	R	R	R
Stator	Steel	450 (20.5%)	g	R	R	R
	Lead	10 (0.5%)	g	R	R	R
	Plastic	*2 (0.1%)*	*g*	*RwN*	*RwN*	*RwR*
	Copper winding	*200 (9%)*	*g*	*RwN*	*RwN*	*RwR*
Rotor	Cast iron	70 (3%)	g	R	R	R
	Steel	50 (2.3%)	g	R	R	R
	Plastic	*2 (0.1%)*	*g*	*RwN*	*RwN*	*RwR*
	Copper winding	*120 (5.5%)*	*g*	*RwN*	*RwN*	*RwR*
Fans	Aluminium	30 (1.4%)	g	R	R	R
Slip ring	Copper	20 (0.9%)	g	R	R	R
Pulley holder	Steel	30 (1.4%)	g	R	R	R
Bosh holder	Steel	25 (1.1%)	g	R	R	R
IC regulator	Plastic	5 (0.2%)	g	*RwU*	*RwN*	*RwN*
	Copper	5 (0.2%)	g	*RwU*	*RwN*	*RwN*
	Cast iron	5 (0.2%)	g	*RwU*	*RwN*	*RwN*
	Aluminium	50 (2.3%)	g	*RwU*	*RwN*	*RwN*
Pulley	*Steel*	*150 (6.8%)*	*g*	*RwU*	*RwN*	*RwU*
Rectifier	Cast iron	100 (4.5%)	g	*RwU*	*RwN*	*RwN*
	Copper	50 (2.3%)	g	*RwU*	*RwN*	*RwN*
	Plastic	20 (0.9%)	g	*RwU*	*RwN*	*RwN*
Insulator	*Plastic*	*65 (3%)*	*g*	*RwU*	*RwN*	*RwU*
Bolt and nut	Cast iron	90 (4.1%)	g	*RwN*	*RwN*	R
Brush	Carbon	5 (0.2%)	g	*RwN*	*RwN*	*RwN*
Bearings	Steel	50 (2.3%)	g	*RwN*	*RwN*	*RwN*
Bearing clamps	*Cast iron*	*20 (0.9%)*	*g*	*RwN*	*RwN*	*R*

R = Reuse of component, RwN = Replaced with New, RwU = Replaced with Used, RwR = replaced with recycled

The use of recycled, old and reused materials in remanufactured alternators has reduced the use of new materials to 13% (0.29 kg), which is expected to improve environmental performance by reducing upstream GHG emissions and embodied energy consumption. The following technical assessment will show whether the reduction in use of new materials affects the quality of the remanufactured alternators.

6.3.1 Technical analysis

Reliability

Firstly, the reliability of all of the components of the remanufactured alternator was determined. The reliability of the recycled materials was considered to be the same as the new components (100%), which implies that the failure rate of the new components has been assigned zero. The reused components, including front case, rear case, slip rings, fan, bosh holder, insulator, rotor shaft, finger poles, laminated frame, stator lead and neural junction, were not found to demonstrate any failure in the existing scenario as discussed in section 5.1.1.

The reliability of the remanufactured alternator was calculated by integrating the overall reliability of the components (Figure 6.5). The reliability calculation used Equations 4.6 and 4.7 for calculating the overall reliability of components connected through series and parallel connections (Figure 6.5). The series system included the rotor assembly, stator assembly, diode rectifier, regulator and carbon brush while the parallel system included the rest of the components (i.e. rear case, fan, pulley, pulley clamp, bolt and nut).

Following the above approach, the reliability of the remanufactured alternator improvement scenario II was estimated to be 95.8%. Even though the reliability of remanufactured alternators in this improvement scenario is lower than in improvement scenario I, this scenario has met the threshold values.

Durability

The durability of remanufactured alternators has been estimated to be 95.8% which is higher than for the existing scenario due to the increase in reliability (95.8%) of the remanufactured alternators (Figure 6.5) in improvement scenario II. The use of recycled copper does not affect the reliability and durability of alternators as confirmed by Copper Recycling and Sustainability (2014). .

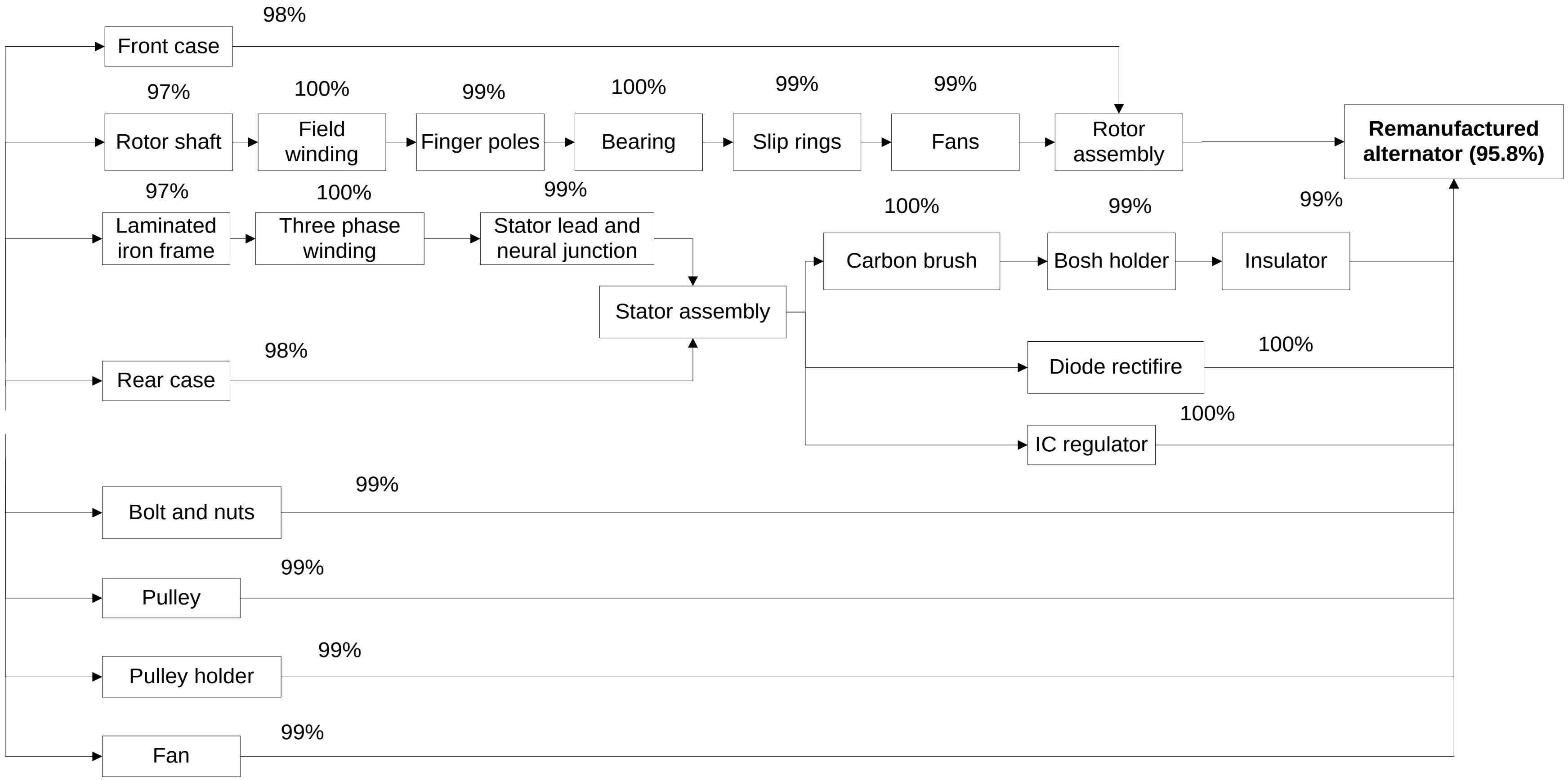


Figure 6.5 Series and parallel relationship between components of the remanufactured alternator for improvement scenario II (15% recycled components, 69 % used component)

Warranty

The warranty analysis of the remanufactured alternator was conducted by using the reliability value of 95.8%. The warranty period was estimated to be at least two years while the end of life of the remanufactured alternator was estimated to be four years. The warranty period therefore meets the threshold value of two years.

Safety performance and availability of cores

The increased collection of cores, introduction to new technology for testing reliability, durability and safety, and training for employees were also considered in improvement scenario II. The safety performance of the remanufactured alternator and the availability of cores were expected to be the same as for improvement scenario I.

Summary of the technical analysis for improvement scenario II

The technical criteria for improvement scenario II are compared with the respective threshold values which are presented in Table 6.8.

Table 6.8 Technical assessment of improvement scenario II

No	Technical criterion	Threshold value	Improvement scenario II
1	Reliability	≥90%	95.87%
2	Durability in two years	≥90%	95.87%
3	Safety	standard met	standard met
4	Availability of cores	5,600 units	7,900 units
5	Serviceability (warranty)	2 years	2 years

Table 6.8 shows that the remanufactured alternators in improvement scenario II demonstrated almost the same performance as those in improvement scenario I in terms of reliability, durability, safety, availability of cores and warranty. The replacement of some new materials and components (43%) with recycled materials (15%) plus the increase in used components (69%) did not affect the technical performance of the remanufactured alternator. This confirms that the remanufacturing strategy for improvement scenario II met the technical indicators; it now needs to be assessed with regard to whether it has met the environmental criteria.

6.3.2 Environmental impact analysis

Following the technical assessment, the environmental feasibility of remanufactured alternators under improvement scenario II was assessed.

Embodied energy

The total embodied energy for remanufacturing an alternator in improvement scenario II was estimated to be 93.8 MJ. The use of recycled materials and used components significantly reduced the total energy consumption of alternator production from 116 MJ (44%) in improvement scenario I to 93.8 MJ (35%) in improvement scenario II. This is mainly because of the use of recycled copper in the rewinding process as the recycling of copper requires 90% less energy than making new copper.

The total embodied energy for remanufacturing an alternator has been compared with that for the manufacturing of a new one to determine the potential energy recovery of this improvement. The results showed that the remanufacturing of alternators using improvement scenario II could conserve a significant amount of energy (65%) compared to improvement scenario I, but that the scenario does not yet meet the threshold values (Table 6.9).

Table 6.9 The embodied energy conservation for improvement scenario II

	Existing scenario	Scenario I	Improvement scenario II	Threshold value
Percentage of saving	71%	56.2%	65%	75%
Energy consumption	76.5 MJ	116.1 MJ	93.8 MJ	66.3 MJ

The replacement of new material with recycled material was initially expected to save a significant amount of energy (20%) in comparison with the replacement of old materials with new.

GHG emissions

The GHG emissions of 2.2 kg for the remanufacture of alternators in improvement scenario II were estimated to be 5.1 kg CO_2-eq. The replacement of a new alternator with a remanufactured alternator using improvement scenario II could reduce GHG emissions by 69%.

This reduction is mainly because the percentage of new components has been reduced from 43% in improvement scenario I to 13% in improvement scenario II, thereby reducing the upstream GHG emissions from the mining, processing and manufacturing of virgin materials for new components. Whilst the use of new components decreased significantly by 30%, the replacement of old materials with new materials is still a GHG hotspots (65.1%) in this scenario due to the use of recycled materials (Figure 6.6).

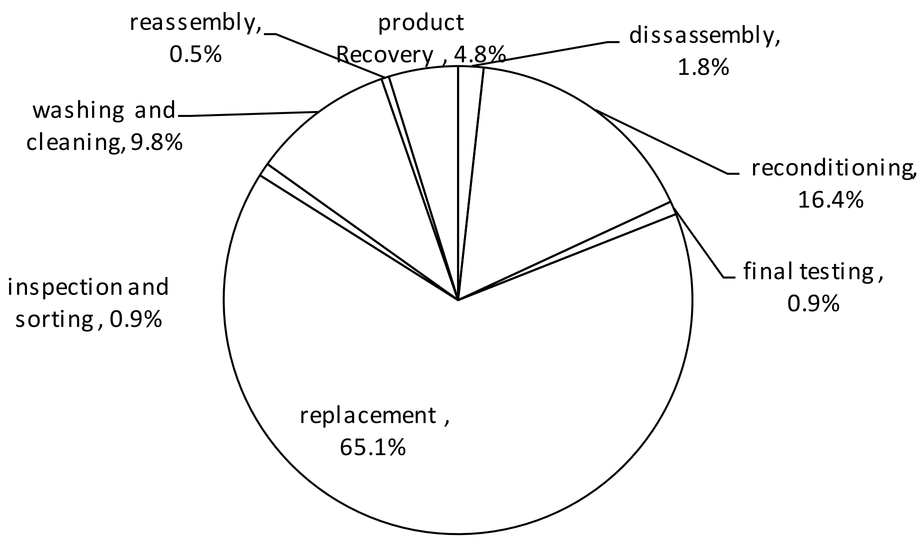


Figure 6.6 The breakdown of GHG emissions for improvement scenario II

Further investigation shows that the cast iron foundry for rectifier production would consume a significant amount of energy (8.23 MJ), which could be reduced by using used rectifiers (Figure 6.7). To facilitate this, it is important that high quality used rectifiers be used. Furthermore, to maintain the rectifier quality, the part should be tested using a standard procedure to achieve the best performance.

Figure 6.7 The upstream activities for improvement scenario II

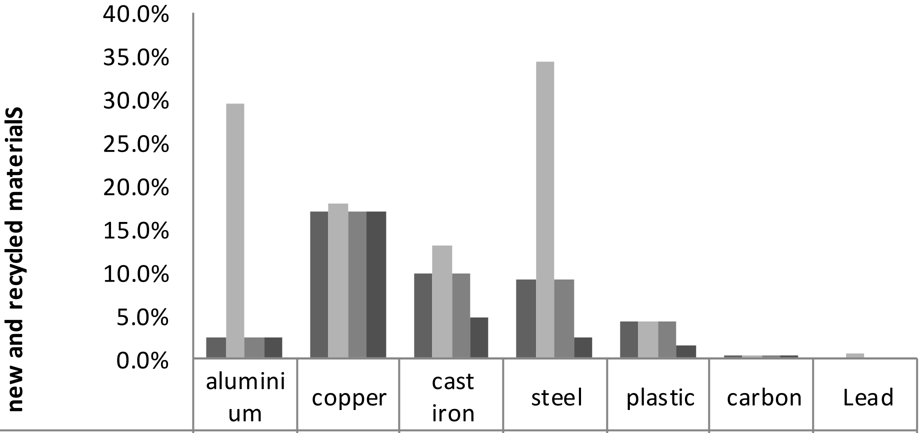
Material saving

The material consumption analysis for improvement scenario II took into account the total quantity of materials consumed in the process of remanufacturing alternators. The results showed that the material consumption consisted of new material (13.2%), used material (62.2%), recycled materials (14.2%) and old material (9.8%). Therefore, this improvement scenario conserved about 62.2% of material consumption.

The used materials mostly consisted of energy intensive materials such as steel, aluminium and cast iron, followed by recycled materials, mainly copper (14.6%), and then a small proportion of new materials including cast iron (4.8%), and old materials consisting of plastic.

Improvement scenario II was then compared with the existing scenario, new alternator scenario and improvement scenario I in order to investigate whether there was any significant reduction in material consumption due to the technical modifications suggested in improvement scenario II. The results showed that the material consumption for improvement scenario II (38%) consumed a very small portion of virgin materials (13%) compared to improvement scenario I (43%), and the existing scenario (43%) (Figure 6.8). Despite the higher usage of used components, the material consumption was still higher than the threshold value (35%).

The breakdown of the new and recycled materials presented in Figure 6.8 shows that copper accounts for quite a significant portion (17.1%) of the new and recycled materials. The next remanufacturing strategy could thus consider using reused copper instead of recycled copper as the recycling process consumes 10% more energy than if it is reused (Copper Recycling and Sustainability 2014).



	aluminium	copper	cast iron	steel	plastic	carbon	Lead
Scenario I	2.3%	17.1%	9.8%	9.1%	4.3%	0.2%	0.0%
New alternator	29.6%	18.0%	13.0%	34.4%	4.3%	0.2%	0.5%
Existing situation	2.3%	17.1%	9.8%	9.1%	4.3%	0.2%	0.0%
Scenario II	2.3%	17.1%	4.8%	2.3%	1.3%	0.2%	0.0%

Figure 6.8 New and recycled material consumption in new, existing, and improved scenarios

Material intensity per unit service unit (MIPS)

The material intensity per service unit in improvement scenario II was estimated to be about 0.099 kg/kWh. This MIPS value is still higher than the threshold value (0.067 kg/kWh) and also higher than the MIPS value in the existing scenario (0.079kg/kWh). Therefore, the MIPS value for improvement scenario II is much better than for improvement scenario I (0.151 kg/kWh) (Table 6.10).

Table 6.10 The MIPS of improvement scenario II in comparison with other scenarios and the threshold value

Scenario	Existing scenario	Improvement scenario I	Improvement scenario II	Threshold value
MIPS (kg/kWh)	0.079	0. 151	0.099	0.067

The above table demonstrates that improvement scenario II is more eco-efficient than the existing scenario and improvement scenario I.

Solid waste avoided

The unused material associated with the remanufacturing of an alternator in improvement scenario II was estimated to be 38% (0.829 kg) of the total weight of the remanufactured alternator. This percentage of unused material is lower than that for both the existing scenario and improvement scenario I (43%). However, as about 99% of the unused material was espected to be recycled, the solid waste avoided is higher that threshold value (Table 6.11).

Table 6.11 Solid waste avoided in improvement scenario II compared with other scenarios

	Existing scenario	Improvement scenario I	Improvement scenario II	Threshold value
Unused material (%)	43%	43%	38%	35%
Solid waste avoided	99%	99%	99%	88%

Landfill impact

The total amount of unused material consumed for the recycling process has been estimated to be about 10.8 tons annually, which could reduce about 2.1 m^2 of landfill. This shows that landfill requirement could potentially be reduced to 1% by remanufacturing operations which have met the threshold value of 20%.

Summary of the environmental impact analysis for improvement scenario II

The following Table 6.12 summarizes the environmental impact associated with the remanufacturing of an alternator in improvement scenario II.

Table 6.12 The environmental criteria for improvement scenario I compared with the threshold values

	Environmental	Improvement scenario II	Threshold value
1	Embodied energy saving	65%	78%
2	GHG emissions	69%	88%
3	Material saving	62.2%	65%
4	MIPS	0.099 kg/kWh	0.069 kg/kWh
5	Solid waste avoided	99%	88%
6	Landfill	1%	20%

Whilst technical criteria were met, improvement scenario II was not found to meet the threshold values for major environmental impacts criteria, including material and energy consumption and GHG emissions, due to the use of a large quantity of recycled materials that were energy and carbon intensive. Furthermore, the material intensity per service unit for remanufactured alternators needs to be decreased in order to increase the resource eco-efficiency. However, solid waste and the landfill avoided due to the use of recycled materials did meet the threshold values. The following remanufacturing strategy will use a different composition of used, recycled and new materials in order to address both technical and environmental viabilities.

6.4 Remanufacturing strategy for improvement scenario III

On the basis of the above technical and environmental analysis, the factors which have been recognized as obstacles to achieving sustainable manufacturing are as follows.

- The use of recycled copper in rotor and stator winding still contributed to a significant portion of the total GHG emissions and embodied energy due to the recycling process involving collection, cleaning, melting, and manufacturing.

- The use of new materials including bearings, regulators, brushes and rectifiers still contributed to high embodied energy consumption and GHG emissions due to the manufacturing process (i.e. refining, manufacturing, casting, machining) and transportation activities.

The following Table 6.13 illustrates the improvement approaches in improvement scenario III.

Table 6.13 Remanufacturing strategies for overcoming the drawbacks in improvement scenario II

Unsustainable factors of the existing scenario	**Feedback arrow**	**Strategy approaches**
Conduct the recycled materials Increase the quantity of used materials Reduce the imported new components	⟶ ⟶ ⟶	Increase the quantity of used materials with good supply of quality alternator cores (critical parts excluded)
Employ new technology for testing process	- · - · - · - · →	Employ new technology for testing process
Expand the core collection area	- · - · - · - · →	Expand the core collection area
Introduce training for workers and managers		Introduce training for workers and managers
Increase marketing promotion	- · - · - · - · →	Increase marketing promotion

⟶ new strategies - · - → no change, remain as it is

In improvement scenario III, the reuse option has been considered where both stator and rotor were reused to improve the environmental performance of alternator remanufacture. Once the stator and rotor were fitted, they were balanced and then varnished.

Since critical components including the bearing, regulator, rectifier and brush that account for 13% of the total weight of the alternator cause the majority of failure, they are required to be replaced with new parts. In addition, the use of a new bearing is an economically viable option for increasing reliability because it is cheaper to buy than to recondition. The bearing is a sensitive component as its failure could lead to the breaking down and failure of the entire alternator.

The remaining used components including the housing (front and rear case), fan, slip ring and pulley were reconditioned by painting the housing, using a grinding machine to remove abrasions on the fan, and a lathe for turning the rough slip ring. The quantity of used parts was increased from 62% in improvement scenario II to 87% in improvement scenario III.

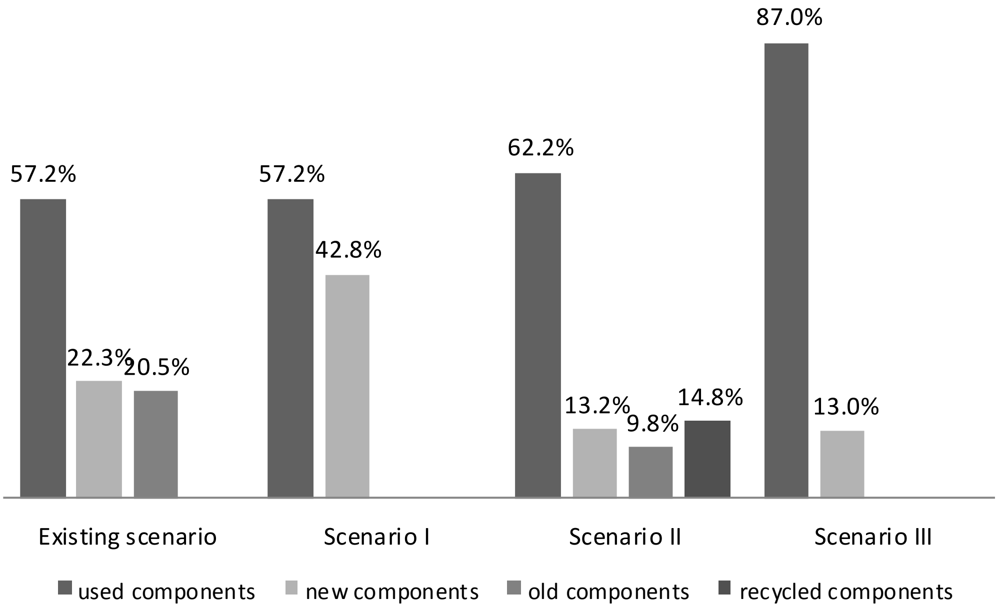


Figure 6.9 The breakdown proportions of used, recycled, new and old parts of a remanufactured alternator for existing and improvement scenarios I, II and III

Table 6.14 presents the details of the materials in the parts and their weights for exising scenario and scenario III. The modification that was incorporated into improvement scenario III has been highlighted in italics.

Table 6.14 Remanufacturing strategy in improvement scenario III

Part	Material	Weight	Unit	Existing scenario	Improvement scenario III
Housing	Aluminium	570 (26%)	g	R	R
Stator	Steel	450 (20.5%)	g	R	R
	Lead	10 (0.5%)	g	R	R
	Plastic	2 (0.1%)	g	RwN	*R*
	Copper winding	200 (9%)	g	RwN	*R*
Rotor	Cast iron	70 (3%)	g	R	R
	Steel	50 (2.3%)	g	R	Re
	Plastic	2 (0.1%)	g	RwN	*R*
	Copper winding	120 (5.5%)	g	RwN	*R*
Fans	Aluminium	30 (1.4%)	g	R	R
Slip ring	Copper	20 (0.9%)	g	R	R
Pulley holder	Steel	30 (1.4%)	g	R	R
Bosh holder	Steel	25 (1.1%)	g	R	R
IC regulator	*Plastic*	*5 (0.2%)*	*g*	*RwU*	RwN
	Copper	*5 (0.2%)*	*g*	*RwU*	RwN
	Cast iron	*5 (0.2%)*	*g*	*RwU*	RwN
	Aluminium	*50 (2.3%)*	*g*	*RwU*	RwN
Pulley	*Steel*	*150 (6.8%)*	*g*	*RwU*	*R*
Rectifier	*Cast iron*	*100 (4.5%)*	*g*	*RwU*	RwN
	Copper	*50 (2.3%)*	*g*	*RwU*	RwN
	Plastic	*20 (0.9%)*	*g*	*RwU*	RwN
Insulator	*Plastic*	*65 (3%)*	*g*	*RwU*	*R*
Bolt and nut	Cast iron	90 (4.1%)	g	RwN	r
Brush	Carbon	5 (0.2%)	g	RwN	*RwN*
Bearings	Steel	50 (2.3%)	g	RwN	*RwN*
Bearing clamps	*Cast iron*	*20 (0.9%)*	*g*	*RwN*	R

R = reused component, RwN = Replaced with new RwU = Replaced with used

6.4.1 Technical analysis

Reliability

The reliability of new components including the IC regulator, rectifier, bearing and brush were considered the same as for improvement scenario II (100%). The reliability of the pulley, holder, bosh holder, insulator, bolt and nut and bearing clamps were determined by consulting with the SEs (Figure 6.10) and these reliability values were checked with the standardization book and literature (Weibull Com 2014).

Using the reliabilities for all of the individual components in Figure 6.10, the reliability of the remanufactured alternator was estimated to be about 95.6%. This was higher than the threshold value (Figure 6.11), which means that the proposed modification will not affect the performance of the alternator. The majority (87%) of the components were reused. The critical components, which make up 13% of the total weight of the alternator, have relatively higher failure rates (i.e. 65% for the IC regulator, 13% for the rectifier, 12% for the brush) and have been replaced with new ones to maintain the required reliability of the remanufactured alternator.

In addition, the majority of the reusable components are not expected to exhibit failure as they have undergone proper reconditioning and machining processes and higher quality cores have been considered for use. These factors will increase the reliability (Gray and Charter 2007). In addition, more accurate initial testing was considered to ensure the reduction of the failure rate and to maintain the reliability and durability of the remanufactured alternators.

In Figure 6.11, the reliability of improvement scenario III was found to be higher than that of the existing scenario and the threshold value. This means that the increased use of reused components, advanced testing methods and the use of quality cores could maintain the technical performance of the remanufactured alternator at threshold value level.

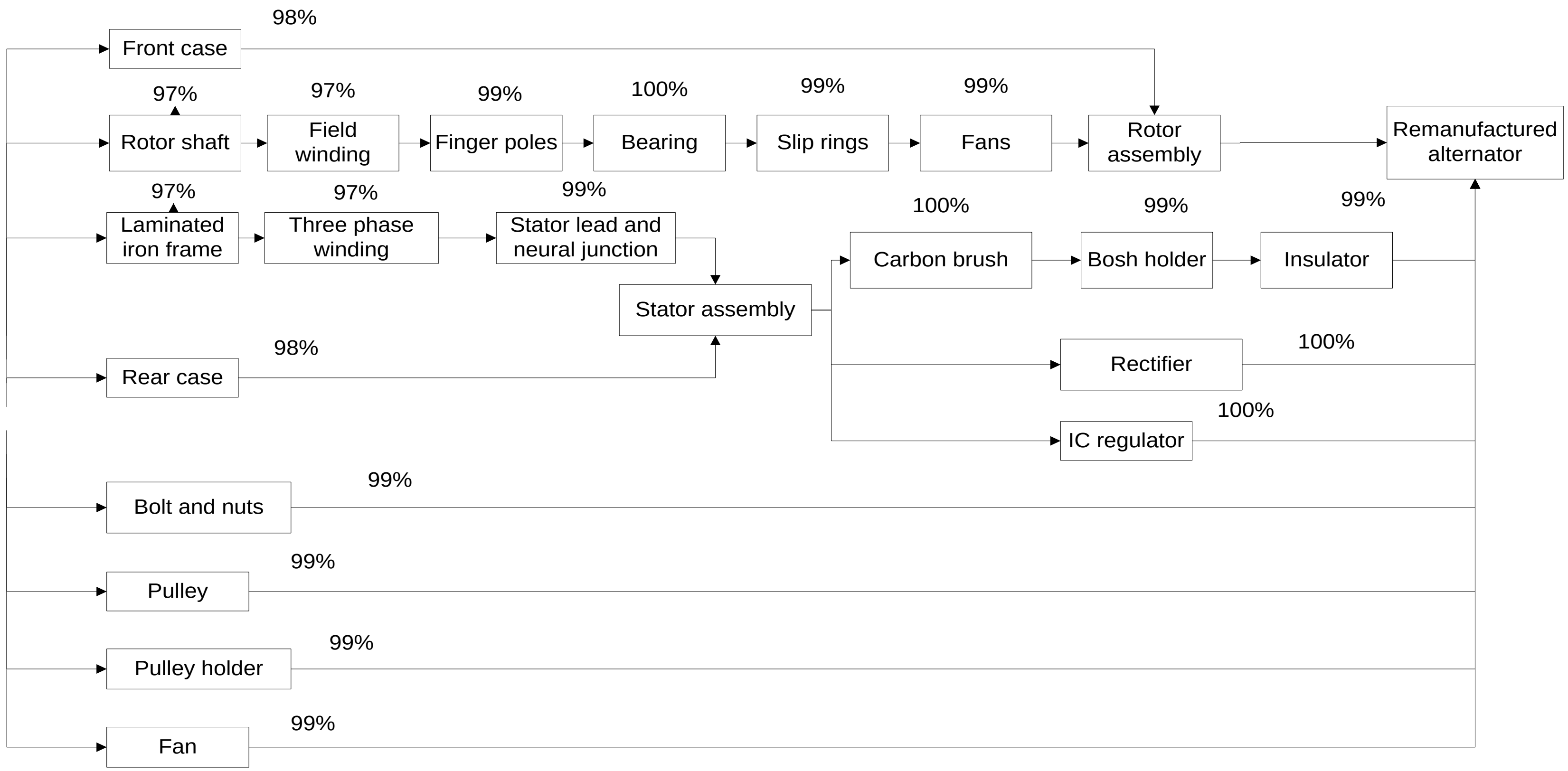


Figure 6.10 Series and parallel relationship between components of the remanufactured alternator in improvement scenario III

(13% new parts and 87% used parts)

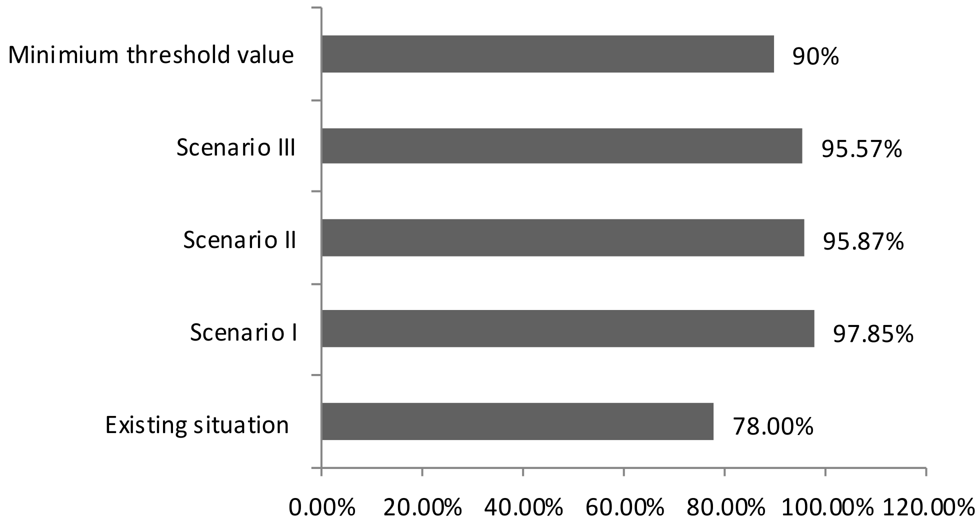


Figure 6.11 Reliability of remanufactured alternator improvement scenario III compared to other scenarios.

Durability

The higher reliability of the components which ranged between 97% and 100% in improvement scenario III (Figure 6.11) was expected to increase the durability of the remanufactured alternator (i.e. 95.87%). Therefore, the same durability tests used for improvement scenarios I and II (i.e. high temperature, high speed and vibration) were conducted for improvement scenario III, and it was found that the durability standard (90% or more) was maintained.

Warranty

Since the reliability of the remanufactured alternator under improvement scenario III is almost the same as that under improvement scenario II (95.6%), the warranty period for improvement scenario III remained unchanged (two years). The same life time of four years for the remanufactured alternators was considered for both scenarios.

The analysis of the warranty period for improvement scenario III produced the same result as for improvement scenario I and improvement scenario II, where the increase in reliability provided a greater opportunity for SEs to offer a longer warranty period (2 years). However, the economic challenges which are often experienced by SEs due to financial limitations need to be addressed in order to provide suitable warranty costs and optimal warranty protection. Moreover, an additional warranty period could be an attractive option for customers who want greater reliability.

Safety performance

A safety performance analysis was conducted on the basis of the remanufacturing strategy in improvement scenario III in order to assess whether the modifications met the safety requirements. It was expected that the introduction of advanced testing methods in the improved scenario would maintain the safety standards for the remanufactured alternators. The measurement of the alternator’s safety performance through the safety testing procedure is a key action to improve its safety performance.

Availability of cores

On the basis of the remanufacturing capacity and capability of the SEs, the required target is to obtain at least 7,900 used cores annually which could be made possible by expanding the core collection area, building a collection centre, and collaborating with cannibalizing SEs to increase the disassembly process. If these SMEs adopt these strategies, more quality alternator cores would become available, thus increasing their remanufacturing capacity. Therefore, awareness needs to increase among the stakeholders in the remanufacturing supply chain (i.e., collection centres, cannibalization SEs and scavengers) in order to increase the supply of quality cores through proper handling processes.

Summary of the technical analysis improvement scenario III

The technical indicators for improvement scenario III met the threshold values (Table 6.15). However, it needs to be determined whether the increase of used materials to 87% has met the environmental criterion.

Table 6.15 Sustainable assessment of improvement scenario III: technical criteria

No	Technical criterion	Improvement scenario III	Threshold value
1	Reliability	95.57%	≥90%
2	Durability over two years	95.57%	≥90%
3	Safety performance	standard met	standard met
4	Serviceability (warranty)	2 years	1–2 years
5	Availability of cores	7,900 units	5,600 units

6.4.2 Environmental impact analysis

An environmental impacts analysis was conducted for improvement scenario III as follows.

Embodied energy saving

The total embodied energy in improvement scenario III was estimated to be about 65.5 MJ. The replacement process was identified as the largest contributor, accounting for 49.3% of the total embodied energy, followed by the washing and cleaning process (25.5%) and reconditioning process (14.6%) (Figure 6.12).

The remanufacturing process in improvement scenario III only consumed about 24.7% of the total embodied energy required for manufacturing new alternators (265 MJ). About 75.3% (199.5 MJ) in embodied energy consumption can be saved by replacing a new alternator with a remanufactured one. Table 6.16 shows that improvement scenario III was not only able to save more energy than the other scenarios, but also met the threshold values.

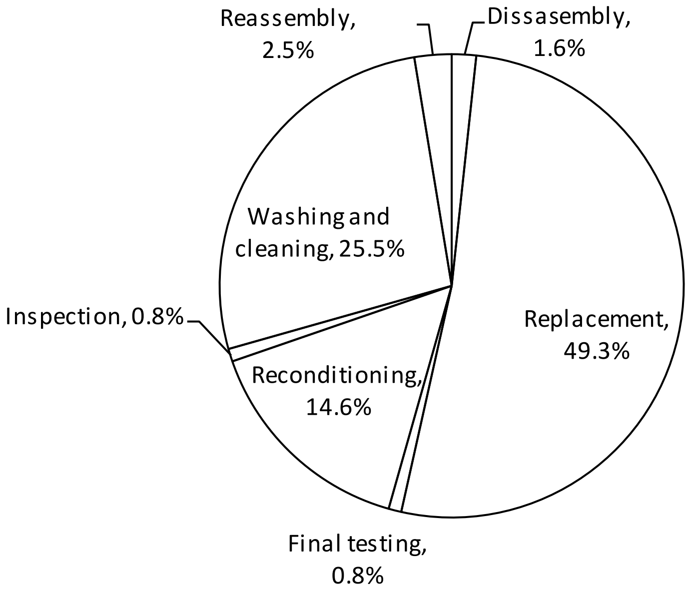


Figure 6.12 The breakdown of embodied energy in terms of the remanufacturing process in improvement scenario III

Table 6.16 Comparison of energy savings between different scenarios

	Existing scenario	Improvement scenario I	Improvement scenario II	Improvement scenario III	Threshold values
New component replacement	22.3%	42.8%	22.3%	13%	19%
Energy consumption	76.5 MJ	199.5 MJ	93.8 MJ	65.5 MJ	66.3MJ
Energy saving	71.1%	56.2%	64.6%	75.3%	75%

A significant energy saving is possible due to avoiding the energy consumption in upstream activities, including mining, processing and manufacturing associated with the production of new material, as well as by avoiding the recycling process.

GHG emissions

The carbon footprint of the remanufactured improvement scenario III was estimated to be 3.59 kg CO_2-eq, which is 21.8% of the total GHG emissions for a new alternator (16.5kg CO_2-eq). It was found that the remanufacturing process in improvement scenario III could offer significant GHG savings (78%) compared to the other scenarios, and it also supersedes the threshold value (77%).

The GHG emissions in improvement scenario III mainly result from replacement with new components (54%) followed by reconditioning (20%) and cleaning and washing (14%). The GHG emissions for new components including the bearing (9.2%), IC regulator (40%), rectifier (46%) and brush (5%) respectively are presented in Table 6.17.

Table 6.17 The breakdown embodied energy in terms of stages of the critical components in Improvement scenario III

Component	Material	Embodied energy supply (MJ)		
		Mining	Manufacturing	Transportation
IC regulator	Aluminium, copper, cast iron, plastic	0.64	0.13	0.10
Rectifier	Cast iron, copper, plastic	0.35	0.39	0.26
Bearing	Steel	0.07	0.12	0.01
Brush	Carbon	0.01	0.02	0.08

Table 6.17 shows that the rectifier contributed the largest quantity of GHG emissions as it is made of a number of virgin materials including aluminium, copper, cast iron and plastic, thus adding the energy consumption in the supply chains of mining, manufacturing and transportation of materials. As the rectifier has been found to be the hot spot component, the technical feasibility of the reuse of this component needs to be assessed in order to reduce the embodied energy.

Figure 6.13 shows the hot spot for upstream activities in improvement scenario III which mainly come from the use of new materials. It can be seen that the major sources of GHG emissions are energy consumption during the manufacturing of the rectifier, which is mainly generated by the production of material, and metal and non-metal production. The replacement of new rectifiers with used ones could be a means of significantly reducing energy consumption and minimizing GHG emissions.

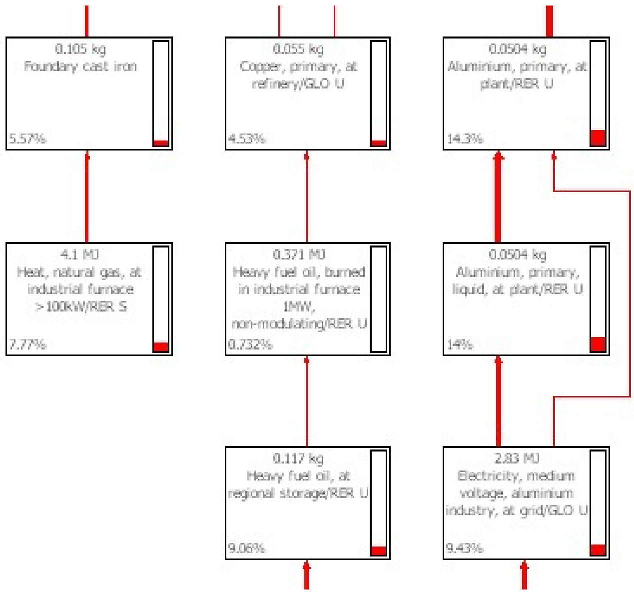


Figure 6.13 The upstream activities for improvement scenario III

Material consumption

The 15 major components used in alternator remanufacturing, in descending order of consumption, include about 87% (1.9kg) used materials, 13% (0.39kg) virgin materials (i.e. cast iron) and a trace amount of lubricant.

In this scenario, the replacement of a new alternator with a remanufactured one could potentially conserve 87% of virgin material consumption, thus safeguarding non-renewable resources for future generations. These materials, including steel (32%), aluminium (27%), copper (16%) and cast iron (8%) are energy and carbon intensive. Table 6.18 shows that improvement scenario III has the potential to conserve more materials than the other scenarios and has met the threshold values.

Table 6.18 Percentage of materials consumed and conserved

Scenario	Existing scenario	Improvement scenario I	Improvement scenario II	Improvement scenario III	Threshold value
Consumption	47%	47%	38%	13%	35%
Conservation	53%	53%	62%	87%	65%

It becomes clear that the increase in the use of used components not only reduces the requirement for new materials to 13%, but also reduces the associated embodied energy, emissions (e.g. CO_2, N_2O) and pollution (e.g. SO_2, NO_x). However, the useful life (lifetime) and serviceability of used components are often unpredictable, so it could make it difficult for SEs to maintain the technical performance (i.e. reliability) of the final product. Therefore, it is important to know the track record of each component accurately and to use new materials more efficiently to ensure the technical and environmental sustainability of the remanufacturing activity.

Material intensity per unit service (MIPS)

The MIPS was determined by measuring inputs including the weight of virgin materials (0.29kg) used for remanufacturing an alternator, the life of the alternator (four years), the operating hours of cars (six hours/day) and the power (watt) of the alternator (720 watt). Using Equation 4.16, the MIPS for the remanufactured alternator was calculated to be about 0.047kg/kWh (Table 6.19).

Table 6.19 MIPS of the existing scenario, the other scenarios and the threshold value

Scenario	Existing	Improvement scenario I	Improvement scenario II	Improvement scenario III	Threshold value
MIPS kg/kWh	0.079	0.151	0.099	0.047	0.067

The use of used components could increase the collection, washing and cleaning and machining activities carried out by the SEs, thus having the potential to create a variety of jobs. Improvement scenario III could not only offer a lower MIPS than the other scenarios, it also showed a better outcome with regard to the threshold value. Thus improvement scenario III can significantly contribute to the dematerialization needed for achieving sustainable consumption and production—an objective set at the World Summit for Sustainable Development in Johannesburg in 2002 (United Nations 2002).

Solid waste avoided

According to Table 6.20, about 99% (0.29 kg) of the unused components consisting of energy intensive materials (i.e. cast iron, steel, aluminium, and copper) for all scenarios were proposed to be sent to recyclers for other appliances (such as cans, computer casing, and cookware) (Damanhuri and Padmi 2012).

Table 6.20 Percentage of solid waste avoided for improvement scenario III and other scenarios

Scenario	Existing scenario	Improvement scenario I	Improvement scenario II	Improvement scenario III	Threshold value
Solid waste avoided	99%	99%	99%	99%	88%

This recycling process has created job opportunities. In addition, take back income for SEs has led to waste minimization, resource conservation and landfill area reduction.

Landfill impact

Only about 1% of the solid waste (i.e. carbon brushes) needs to be sent to landfill in all scenarios as it is not economically viable to recycle this tiny portion. Under the case study, if only 1% of solid waste is sent to landfill, it is estimated that about 15.1 tonnes of solid waste can be avoided due to the conversion of EoL alternators to remanufactured alternators by the SMEs. This translates into a saving of 2.9 m^2 of landfill area.

Summary of the environmental impacts analysis improvement scenario III

Finally, the overall environmental indicators of scenario III have been compared with the respective threshold values as summarized in Table 6.21.

Table 6.21 Summary of environmental sustainability for improvement scenario III

No	Environmental criterion	Improvement scenario III	Threshold value
1	Embodied energy saving	75.3%	75%
2	GHG emissions reduction	78%	77%
3	Material saving	87%	65%
4	MIPS	0.047kg/MWh	0.067kg/MWh
5	Solid waste avoided	99%	88%
6	Landfilling	1%	20%

The above results confirm that avoiding the use of new materials for replacement could significantly increase the environmental performance of the remanufactured alternator in a technically feasible way. In other words, it can be concluded that the remanufactured alternators in improvement scenario III have met the threshold values for both the technical and environmental criteria.

Once the technical and environmental sustainability in improvement scenario III was met, the economic and social analyses were conducted to determine the economic and social feasibility of the remanufacturing strategy for improvement scenario III according to Fatimah et al. (2013).

6.4.3 Economic analysis

Similar to the discussion of the existing scenario in Chapter 5, an economic analysis including life cycle cost, sales, recovered material value and return on investment was conducted to assess the economic feasibility of the remanufacturing strategy for improvement scenario III. The variables for improvement from scenario III were compared with those in the existing scenario and the threshold values for conducting an economic feasibility study.

Life cycle cost

The life cycle cost (LCC) of the remanufactured alternator in improvement scenario III was determined by utilizing both capital and operational costs including capital investments (i.e. buildings, machines and land), cost of staff development (technical training) to make quality products, energy costs, warranty costs, cost of core collection and disposal, and remanufacturing costs.

In order to determine the economic feasibility of improvement scenario III, a discounted cash flow analysis was conducted. The same information used for calculating the LCC in the existing scenario (Chapter 5), including the initial investment costs of building and old components (1997 prices), the inflation rate (2–12.6%) over 1997–2016 and the discount rate (4%), were also taken into account for the economic analysis of this improvement scenario III. In addition, the cost of new items and the incremental costs required to implement the remanufacturing strategies in improvement scenario III were utilized to calculate the LCC for improvement scenario III (Table 6.22).

Table 6.22 Cost of new items and incremental costs

Cost	Existing scenario	Improvement scenario III	Cost of new items/ incremental cost
Capital cost	USD 139,500	USD 158,000	USD 18,500
Core collection cost	USD 516,556	USD 707,089	USD 190,533
Remanufacturing cost	USD 419,469	USD 450,511	USD 31,042
Energy cost	USD 114,833	USD 144,689	USD 29.856
Warranty cost	USD 16,779	USD 46,644	USD 29,865
Overhead cost	USD 41,947	USD 45,051	USD 3,104
Training cost	-	USD 3,000	USD 3,000
Life cycle cost	USD 32.5	USD 40.6	USD 8.1

In the case of improvement scenario III, the capital cost was increased by USD 18,500 (13% of the capital cost under the existing scenario) due to the proposed purchase of alternator testers – Alt 186, and sandblasting and painting equipment to improve the quality of the remanufactured alternators. The expansion of the collection area to maintain the supply of high quality cores in improvement scenario III would increase inter-province transportation costs and it would require additional collection centres, increasing the cost by 37% (USD 190,533). The high quality cores needed to improve the quality of the remanufactured alternators are 14% more expensive than existing cores (USD 11.50 per alternator). The remanufacturing cost would be increased by 7% due to the purchase of new critical components (e.g. bearing, regulator, rectifier and brush) for replacement purposes. The replacement cost (USD 3.95 per alternator) contributed to the largest portion (9.7%) of the remanufacturing cost. If the prices of the new components could be reduced, there would be the potential to significantly minimize the remanufacturing cost. Therefore, a reduction in the import tax on the critical components could reduce the overall cost.

- The utility costs for electricity, gas and water are expected to increase by 26% due to the 20% increase in the production of remanufactured alternators. However, the energy costs of the remanufacturing operation are not expected to change significantly (5%) due to the use of new machine tools which are more energy efficient.

- The warranty cost in improvement scenario III is increased by 1.8% as the warranty periods have increased to 2 years.

- The overhead costs (i.e. taxes, utilities for factory) increased due to the increase in the remanufacturing cost. It was estimated that the overhead cost was about 10% of the remanufacturing cost.

- It is proposed that the cost of training be included, for remanufacturing strategies, inventory management, remanufacturing processes, financial management, marketing management and environmental awareness. In order to keep production going, the staff would be divided into two groups so that one group attends the training while the other continues production activities. The training cost has been estimated to be about USD 3,000. The inclusion of a reasonable of budget (USD 3,000) for training is expected to improve employee performance and therefore increase the productivity of the SE and the quality of the remanufactured products.

- The cost of disposing of solid waste to landfill in improvement scenario III remains the same as for the existing scenario (USD 5 per month for a regular waste collection).

Profit margin and price

Based on the above information, the LCC for improvement scenario III was estimated to be about USD 40.6, which was 7% higher than the existing scenario (USD 32.5) (Table 6.23). The technical benefits, including reliability and warranty, associated with the introduction of remanufacturing activity in improvement scenario III increased by three times more than the increase in the unit cost. The reliability of the remanufactured alternators under the scenario increased from 78% to 95% and the warranty period was increased from three months to 2 years, for an increase in the LCC of only 7%.

The price of the remanufactured alternator was expected to increase from USD 37.4 to USD 48.7 due to the remanufacturing strategy in improvement scenario III (Table 6.23). The profit margin for improvement scenario III was estimated to be 20%, which meets the threshold value. The technical benefits associated with the increase in the reliability and warranty of the remanufactured alternators in improvement scenario III, have far exceeded the incremental price (USD 11). The remanufactured alternators produced under this improvement scenario appear to offer the same technical benefits as a new alternator, for 65% of the price of the new alternator. Therefore, it can be concluded that customers will get more from this remanufactured alternator than they will pay.

Table 6.23 Economic analysis of a remanufactured alternator under existing scenario and improvement scenario III

	Sales (unit)	LCC (USD)	Profit margin (%)	Price (USD)
Existing scenario	2,326 units	32.5	15%	37.4
Improvement scenario III	2,792 units	40.6	20%	48.7

A sensitivity analysis was carried out to assess how the price of a remanufactured alternator varies with sales, size of enterprise, wage rate and market coverage.

Sales – Sales generate revenue for the enterprise, thus it is very important to increase sales throughout the business. Sales can be increased by increasing the production, which can be achieved by increasing the person hours without increasing the size of the SE. Therefore, a second shift has been introduced in order to maximize person hours and thus to increase sales. There were approximately 142 hours (16 hrs/day x 7 days/week) available for remanufacturing activity in a week, excluding sleeping time, while only about 40 hours (8 hour/day x 5 days/week) are currently used. This means that about 102 hours (71.8 %) can potentially be utilized by implementing another shift. The introduction of the additional shift could increase production and thus sales to approximately 6,448 alternators/year (124 alternators/week x 52 weeks), calculated on the basis of a production rate for one alternator (2.7 hours/alternator), and the available machine tool capacity of the enterprise.

However, it should be noted that the additional shift would not change the number of employees, and nor will it increase the number of machine tools and size of the SE. Accordingly, investment costs (e.g. building, equipment, overhead cost) would remain unchanged, while the operational costs (i.e. labour and materials cost) would increase due to the increase in work hours and the supply of cores. Table 6.24 illustrates how an additional shift in improvement scenario III could reduce LCC and the price of remanufactured alternators.

Table 6.24 Economic analysis of improvement scenario III for one and two shifts

Approach	Sales (unit)	LCC (USD)	Profit margin (%)	Price (USD)	Profit (USD)
Improvement scenario III (One shift – 40 person hours)	2,792	40.2	20%	48.6	22,671
Improvement scenario III (Second shift – 102 person hours)	6,448	36.2	20%	43.4	47,006

The LCC and price of the remanufactured alternators in improvement scenario III could be reduced to USD 36.2 and USD 43.4 respectively, due to an increase in sales by 56.7%, which requires an additional 62 person hours. Furthermore, the increase in sales of the remanufactured alternators (6,448 units) would not only increase the gross profit (51.8%) but it is estimated that the price would be reduced by 10%, and this price meets the threshold value. This approach confirms that the increase of sales through the incorporation of an additional shift could enhance the economic viability of the SE.

Increasing the size to medium enterprise (ME) – Based on the aforementioned analysis, it is proposed that considerable economic benefit could be gained by increasing sales. Since there is no opportunity to increase the person hours after the shift, the size of the enterprise needs to be extended in order to increase sales. Therefore, converting remanufacturing small enterprises (SEs) into medium sized enterprises (MEs) could be another promising strategy to increase the economic benefit of the enterprise.

According to Pemerintah Kabupaten Sleman (2006), the difference between SEs and MEs can be put in terms of sales, in that the sales of MEs are 3.64 times those of SEs. Accordingly, the sales for this ME is estimated to be about 23,470 remanufactured alternators per year. Since time, existing facilities and the resource availability for the SE are constraints to maintaining a ME level of production, the enterprise needs to be expanded by installing additional machine tools, which also requires the expansion of the building. Accordingly, it is expected that there will be about 30% additional machinery and equipment costs.

In addition, the LCC for the remanufactured alternators produced by a ME needs to take into account additional operational costs (e.g. labour and cores cost, energy costs) and additional investment costs (30%). As a result, the LCC for the remanufactured alternator was estimated to be about USD 34.09 which is much lower than that of alternators produced by an SE operating under single and double shifts. Table 6.25 presents an economic sensitivity analysis of small and medium sized enterprises showing how the size of the enterprise affects the economic viability of the remanufactured alternator under improvement scenario III.

Table 6.25 Economic sensitivity analysis of small and medium sized enterprises

Size of enterprise and number of employees	Sales (units)	LCC (USD/unit)	Price (USD/unit)	Gross profit (USD)
SE (improvement scenario III), 16 employees	2,792	40.5	48.6	22,671
SE (improvement scenario III – 2nd shift), 16 employees	6,448	36.2	43.4	47,006
SE to ME, 58 employees	23,470	37.8	45.4	177,668

The switches from an SE to an ME creates 58 jobs and increases the profit from USD 47,006 to USD 177,668. Since the LCC is lower than the threshold value, there is an opportunity for increasing wages until the LCC is equal to the threshold value.

Increasing wage rates – Since one of the objectives of the sustainable manufacturing framework is to enhance social equity by improving the quality of life of the employees, it was estimated that the wage rate could be increased until the LCC is less than or equal to the base case value (USD 40.5). If the wage rate for employees in the ME is raised by 100% with an increase from USD 4.5/hour to USD 9/hour, the LCC of the ME would be about USD 36.17, which is still lower than that of the SE under improved improvement scenario III.

The LCC analysis in Table 6.26 shows that the higher the number of remanufactured alternators sold on the market, the lower the LCC that could be achieved. This is how Indonesian remanufacturing SEs can reduce life cycle cost by increasing both sales and the size of the enterprise, which would allow the wages of the workers to increase, thus enhancing their quality of life. However, the expansion from SE to ME could be challenging for a remanufacturer without any government financial assistances. If the Indonesian government, through Indonesia's Cooperative and Small and Medium Enterprise Ministry, could provide a soft loan (i.e. People's Business Loan – KUR) to remanufacturing SEs, with an optimum interest rate of 9%, it might be possible to change the size of an enterprise from a SE to ME. Table 6.27 presents a soft loan sensitivity analysis showing how the change in interest rate and wage rate affects the LCC of a remanufactured alternator produced by an ME.

Table 6.26 Economic analysis of remanufactured alternator by SEs and MEs for existing and improved wages

Size of enterprise and employee	Sales (unit)	LCC (USD/unit)	Price (USD/unit)	Gross profit (USD)
SE (improvement scenario III), 16 employees	2,792	40.5	48.6	22,671
SE (improvement scenario III – 2nd shift), 16 employees	6,448	36.2	43.4	47,006
SE to ME, 58 employees	23,470	37.8	45.4	177,668
SE to ME, 58 employees (with doubled wages)	23,470	40.2	48.2	188,464

LCC has been estimated for an interest rate of 7.5% which is a base rate offered by banks. The LCC is still far below the threshold value (USD 40) with the inclusion of this interest rate. Table 6.27 shows the LCC matrix for different wage rates and interest rates. It appears that LCC is not very sensitive to interest rate, since it changes by only 0.02% following a decrease in the interest from 9% to 2%. However, the LCC is sensitive to wage rate, increasing by 6% due to a 100% increase in wage. This analysis concludes that a financial organization would not be at risk offering loans to remanufacturing SMEs, provided that an effective loan recovery approach is introduced. Even if the interest rate were to be increased to 9%, the LCC for the remanufactured alternator would remain below the threshold value (i.e. improvement scenario III – 40.52). Accordingly, a bank (e.g. Indonesian Peoples Bank – BRI) could offer loans to remanufacturing SMEs with a higher interest rate, which will in turn improve the bank's financial position.

Table 6.27 The impact of wages and loan interest rate on LCC

Wages	LCC for different interest rates				
	9%	7.5%	5%	3.5%	2%
Existing (USD 4.6/hour)	37.8369	37.8349	37.8317	37.8298	**37.8278**
25% increase	38.4150	38.4130	38.4098	38.4079	38.4059
50% increase	38.9931	38.9911	38.9879	38.9859	38.9840
75% increase	39.5712	39.5692	39.5596	39.564	39.5621
100% increase	40.1492	40.1473	40.1441	40.1421	**40.1402**

Market coverage – The fourth sensitivity analysis is associated with the portion of remanufactured products sold on the market. From the forecast made in the previous analysis, it appears that about 5.6 million alternators could be sold on the Indonesian market per year. According to interviews with a number of auto parts shops, reused and remanufactured alternators contribute about 10% of the total number of alternators on the market (0.56 million alternators). Given that there are opportunities to increase the market share of remanufactured products, Table 6.28 shows that there would be an increase in sales and number of employees associated with an increase in market coverage for the remanufactured alternators.

Table 6.28 shows that an increase in market share leads to an increase in the volume of sales and the number of jobs in the remanufacturing SMEs. Maximizing market share is an effective way to increase the profits of the remanufacturing SMEs (Wernerfelt 1986). However, if the remanufactured alternators' portion of the market share is too high, the availability of high quality cores may be an issue. Therefore, it is necessary to determine the optimum number of alternator cores that can realistically be supplied nationwide to produce remanufactured alternators.

Table 6.28 The impact of market coverage on the remanufacturing SMEs

Market share as %	Number of sales (units)	Employees (person)
10% market coverage	560,000	1,390
20% market coverage	1,120,000	2,779
30% market coverage	1,680,000	4,169
40% market coverage	2,240,000	5,559

It has been estimated that the number of cores sent to the remanufacturing process (i.e. disassembly) was at least one third of the cores inventory (i.e. collected cores) (Matsumoto and Umeda 2011). Therefore, this value has been used as the optimum share of the remanufactured alternators market. Table 6.29 shows the optimum market share, which is 20%. There will be shortage of cores if the market share for remanufactured alternators is greater than 20%.

Table 6.29 Determination of the optimum market share

% of market share of remanufactured alternators	Number of sales (units)	Potential number of new cores (units)	Cores required (units)	Cores left in market (units)
10%	560,000	5,040,000	1,680,000	3,360,000
20%	1,120,000	4,480,000	3,360,000	1,120,000
30%	1,680,000	3,920,000	5,040,000	-1,120,000
40%	2,240,000	3,360,000	6,720,000	-3,360,000

A 10% market share means that about 0.56 million remanufactured products could be sold on the market and about 5.04 million new alternators could potentially be remanufactured at the end of their lives. The demand for cores could reach up to 1.68 million (0.56 million x 3) in order to achieve the production target for a market coverage of 10% for remanufactured alternators. This demand could be easily satisfied by the cores gathered from the end of life of the new alternators (3.36 million). A 20% market share has been estimated to be the optimum option, because it would provide the highest profit with the maximum number of sales, cores and jobs.

Recovered value

The recovered value in improvement scenario III was estimated to be USD 27.6 which is 36.7% of the new alternator price. A comparison of the recovered material value for improvement scenario III with the existing scenario and the threshold value is presented in Table 6.30. The detailed calculations are presented in Appendix C5.

Table 6.30 The recovered material value (USD) for improvement scenario III in comparison with the existing scenario and threshold value

Scenario	Used materials[a]	Recycled materials[b]	Recovered material value (% of new)
Existing scenario	1.26 kg	0.99 kg x 99%	USD 18.8 (25.1%)
Improvement scenario III	1.90 kg	0.28 kg x 99%	USD 27.5 (36.7%)
Threshold value	1.43 kg	0.77 kg x 88%	USD 20.9 (27.9%)

[a] the value of new materials is USD14.4 per kg; [b] the value of recycled materials is USD 0.4 per kg.

From Table 6.30, it appears that improvement scenario III contributed the highest recovered material value (USD 27.5) due to the greater quantity of used materials used in the remanufactured alternator than for the existing scenario. The recovered material value also met the threshold value (27.9%).

Return on investment

A return on investment analysis for improvement scenario III was conducted following the same approach as for the existing scenario. The analysis considered the price of a new alternator (USD 75), the cost of manufacturing (USD 52.3), the price of a remanufactured alternator (USD 48.7), the cost of remanufacturing (USD 40.6) and a potential reusability of the alternator of up to four times (after that the alternator cannot be reused due to fatigue reasons) (Matsumoto and Umeda 2011).

Using this information, the return on investment was estimated to be 80% of the expected revenue (Table 6.31). This analysis shows the slowdown of cash outflow through the material economy associated with remanufacturing activities.

Table 6.31 Expected revenue and costs for improvement scenario III

	Reusability	Solid waste	Revenue	Cost	Lifetime
New	0%	100%	USD 75	USD 52.3	4 years
Reman I	57%	43%	USD 48.7	USD 40.6	4 years
Reman 2	53%	47%	USD 48.7	USD 40.6	4 years
Reman 3	48%	52%	USD 48.7	USD 40.6	4 years
Reman 4	43%	57%	USD 48.7	USD 40.6	4 years
Total			USD 269.8	USD 214.7	4 years
			Total return on investment	= 214.7/269.8 = 80%	

The increase in solid waste due to an increase in material fatigue is followed by an increase in the recycling rate, thus there is still value that can be obtained from the waste. Even though the return on investment of this scenario is less than the threshold value (92%), this value is still higher than the ROI for new one (69.7%).

Import dependency

SEs have experienced challenges with importing new parts for replacing out of order parts. The SEs prefer to buy imported parts and materials since it is within their purchasing power to do so. Therefore, the government could provide soft loans to promote the manufacturing of critical parts locally, and impose higher taxes on the foreign parts to sustain the local market. The purchase of local parts would also avoid the emissions associated with the transportation of imported parts.

6.4.4 Social Analysis

Employment creation

The intragenerational social equity resulting from employment creation (i.e. direct and indirect jobs) has been analysed for improvement scenario III. The number of jobs per enterprise can be doubled (i.e. 32) in an economically feasible way by creating an extra shift in to order to meet the high sales target (23,470). Increasing the size of the enterprise to an ME could increase the number of jobs to 58 per enterprise without affecting the economic viability.

The introduction of new technology, training and wage improvements would help capacity building (indirect social benefit) of the employees (e.g. allowing them to hold higher skilled positions) and to enhance employee morale. In addition to direct employment as highlighted above, the improved remanufacturing strategy could also create indirect employment opportunities in the supply chain, which are mainly collection activities, such as the cannibalizing industry, scavengers and recyclers.

Labour wages

In order to maintain the production capacity of SEs, these enterprises are expected to increase their production rate and to utilize highly skilled workers which will allow the enterprises to increase employee wages by 20% from USD 3.75 per hour to USD

4.5 per hour (or USD 87 per month), which is higher than the minimum monthly wage in Central Java (USD 82 per month). Interestingly, if these SEs could be expanded to MEs, the labour wages could be doubled (USD 9 per hour, USD 174 per month) without affecting the economic viability of the enterprise. This increase in wages would not only enable the SMEs to attract skilled workers but would also enhance the quality of life of the employees.

Quality of life – An increase in wages would improve the quality of life of a family by lifting its income. An average Indonesian family requires about USD 75 to fulfil the basic needs including food, clothes, health, children's education and shelter. Increasing the monthly income to USD 174 could help employees to obtain decent accommodation, healthy food, good health care and quality education for children.

Education – Providing children with a better education is a vital part of the Indonesian culture. With good academic qualifications, Indonesian people can access jobs with higher wages, improving both health and political stability, which could enhance intergenerational social equity and lead to global sustainable development.

Savings – Many Indonesian employees understand that savings are critical for their retirement due to insufficient social life assurance and lack of pension plans. However, current wages are insufficient to accommodate this requirement. An increase in wages in remanufacturing SEs could help employees to establish reasonable savings for their retirement. For example, if about 50% of the incremental income due to an increase in wages to USD 9/day was deposited into a bank for 20 years, there would be a saving of about USD 13,950 (310 days/year x 50% x USD 4.5/day x 20 years) which could be used in retirement.

Productivity of labour – The increase in wages could generate higher productivity (United Nations Industrial Development Organisation 2013). Other than wages, training and improved working conditions are expected to increase labour productivity. This is supported by evidence that the rise in wages could help a large number of industry workers by alleviating their poverty (Weiss 2011).

Intergenerational equity

An intergenerational equity analysis was conducted to determine whether this improved scenario could increase resource conservation in order to maintain equity between the generations. By using the same analysis as for the existing scenario, the intergenerational equity aspects of improvement scenario III were investigated as presented in Table 6.32.

Table 6.32 Replacement benefits of a remanufactured alternator over 20 years

	Material saving (tons)	Energy saving (TJ)
Existing scenario	154	16.9
Improvement scenario III	172	18.0
Threshold values	160	17.9

Table 6.32 shows that there is potential for resource conservation by replacing new alternators with remanufactured ones. It appears that about 172 tonnes of material and 18 TJ of energy could potentially be conserved due to a reduction in the use of virgin materials in improvement scenario III. The material and energy savings in this scenario are considerably higher than the threshold values due to the increase in material saving. These material and energy savings could reduce the ecological footprint while enhancing carrying capacity and biodiversity and reducing deforestation.

There is the potential for a massive saving in resource use if the existing remanufacturing SEs in Indonesia applies the remanufacturing strategies from improvement scenario III. More material consumption could potentially be avoided (8.6 tons/year) due to the replacement of new alternators with remanufactured alternators under this scenario than for the existing scenario (7.7 tons/year). Also, the embodied energy saving has been found to be about 1.1 TJ higher than for the existing scenario. The conservation of rare earth materials including neodymium and dysprosium, metal and petroleum, would be possible due to the use of large quantities of used materials in improvement scenario III.

Company reputation

The increase in technical performance (i.e. reliability, durability, warranty and safety) of the remanufactured alternators is expected to increase company reputation. A better company reputation can increase customer trust and loyalty, which ultimately could lead to an increase in sales. As discussed in the previous section, an increase in sales could drastically decrease the unit cost of remanufactured alternators and the SE could thus gain a competitive advantage by selling remanufactured alternators at affordable prices.

Improvement scenario III not only produced quality remanufactured alternators, but also offered reasonable prices which could definitely attract customers and establish trust in the remanufactured product over the new product. This is the means by which Indonesian SEs can reach the level seen in developed countries, where remanufactured products are viewed as being as good as new products. In addition, the technical, financial and environmental performance under improvement scenario III would encourage the Indonesian government to make appropriate investment strategies for extending technical and financial support to these SEs.

Corporate social responsibility

Corporate social responsibility involves fair and valuable industrial practices concerning employees, the community and the area where the industry is conducted (American Production and Inventory Control Society 2014). By implementing improvement scenario III, the Indonesian remanufacturing SMEs could assist government and non-government organizations to strengthen corporate social responsibility in an environmentally benign and socially equitable manner. These SMEs could help the Indonesian government to achieve triple bottom line benefits, and to showcase their remanufacturing activities to other similar industries in order to achieve the goal of sustainable development. These remanufacturing strategies could provide more environmentally friendly industries, new job opportunities and better wages to their employees. The job creation by these remanufacturing strategies could potentially address Indonesia's existing unemployment situation and could roughly reduce the employment problem from 5.94% to 4.99% per annum (Trading Economics 2014).

Youth and enterprise development

Job opportunities for youth have decreased significantly due to the economic crisis in 1997 which led to a dramatic increase in unemployment in 2009 (22.2%) (Ministry of Manpower and Transmigration , United Nations Industrial Development Organisation 2013). On the basis of this research, it has been estimated that the development of remanufacturing SMEs could create about 2,779 direct jobs per year.

6.5 Summary of sustainable manufacturing outcomes of improvement scenario III

The above alternator case study has clearly illustrated the use of the sustainable manufacturing assessment model to identify and develop remanufacturing strategies for achieving sustainable manufacturing among auto parts SEs. The three different scenarios for remanufactured alternators were assessed using the sustainable manufacturing framework in order to help SEs find the optimum remanufacturing strategies for achieving technical, environmental, economic and social sustainability.

The assessment of the existing scenario reveals that the technical criteria did not meet the threshold values due to low reliability, durability, safety, warranty and availability of cores. In addition, the environmental impact of the remanufactured alternators, including material and energy conservation, GHG emissions and material intensity per unit of service (MIPS) were not found to meet the threshold values for sustainable manufacturing. The economic aspect of the existing situation did not achieve sustainability due to a reduction in sales, high life cycle cost, low added value of remanufacturing and low return on investment. Furthermore, the social criteria, including employment, salary package and intergenerational equity were not met.

Three improvement scenarios involving three different remanufacturing strategies were investigated in this case study, and yielded useful insights in order to come up with a sustainable remanufacturing strategy. However, the improvement scenario III, which maximizes the use of used components, was found to offer a sustainable solution for achieving the technical, environmental, economic and social objectives of sustainability. Furthermore, a number of sensitivity analyses were conducted to examine the economic prosperity and social sustainability of the Indonesian remanufacturing SMEs. The expansion of small enterprises to medium enterprises and an increase in the number of shifts were found to strengthen both economic and social prosperity.

6.6 Enabling mechanism

A mechanism needs to be designed that will enable the small and medium enterprises (SMEs) to implement improvement scenario III. The implementation of this scenario would require the participation of the stakeholders including government, suppliers, NGOs, OEM, the community and customers. The coordination and assistance (e.g. financial, facility, expertise) of and collaboration with these stakeholders could potentially play an important role to develop an institutional framework for remanufacturing SEs and MEs in more economically, socially, technically and environmentally viable ways.

Accordingly, a number of programs and strategies for establishing collaboration between the Indonesia government (e.g. the Ministry of Finance, Trade) and stakeholders (e.g. OEM, NGO, universities, suppliers and customers) have been presented in the following sections. The roles of stakeholders (i.e. responsibility) and regulation and policies in overcoming the barriers to the implementation of the remanufacturing strategies in the improvement scenario III are explained in detail below with the aid of Figures 6.15, 6.16, 6.17 and 6.18.

6.6.1 Technical aspects

In order to implement improvement scenario III, an enabling mechanism has been developed concerning the technical improvement of remanufacturing SMEs. This enabling mechanism requires the comprehensive identification of all stakeholders related to the activities of remanufacturing SMEs, including direct and indirect stakeholders.

The direct stakeholders who will be directly responsible for this improvement are the National Standardization Agency, banking organizations (e.g. BRI, BNI), original equipment manufacturers (OEM), the state-owned electricity company (PT PLN), the state-owned telecommunication company (PT Telkom), universities and research centres and the Indonesian Chamber of Commerce and Industry.

The indirect stakeholders who will be indirectly responsible for this improvement but play an important part in successfully implementing the remanufacturing strategies are the Ministry of Cooperative and Small Medium Enterprise, Ministry of Industry, Ministry of Public Work, Ministry of State Owned Enterprise, Ministry of Communication and Information and Ministry of Trade.

Figure 6.14 illustrates the relationship between direct and indirect stakeholders in establishing the enabling mechanism for implementing the technical aspects of the remanufacturing strategy.

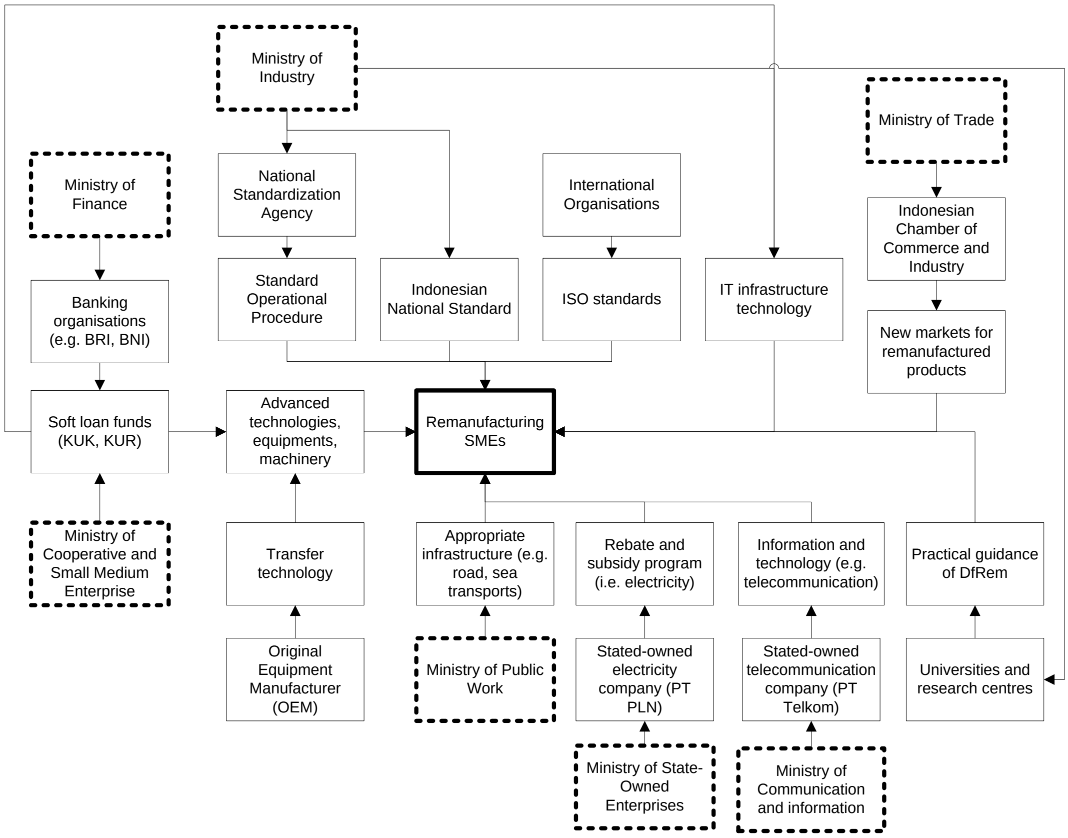


Figure 6.14 Enabling mechanisms for achieving technical sustainability

The technical programs consist of a number of possible strategic actions as presented in the following sections.

Standards

The first step in achieving good remanufacturing practices is to have a standard operational procedure (SOP) for remanufacturing activities. The SOP is applied to all remanufacturing steps including core collection, initial inspection, disassembly, cleaning and washing, testing, reconditioning, reassembly and final checking. Other

SOP including safe handling processes, safe work loads, environmental protection processes and waste management processes also need to be considered. These procedures should be documented and placed in workshop areas to help employees understand the standard remanufacturing processes and offer quality products with minimal environmental degradation.

The Indonesian National Standards (SNI) for the remanufacturing industry need to be developed for certification purposes that will help to maintain the quality and reliability of remanufactured products. For example, the SNI will certify those remanufactured products which meet at least 90% reliability.

In addition, regionally based remanufacturing standards could be proposed for remanufactured products through agreements with South East Asian countries, as was done in standardizing 199 products in 2011 (Hanafi et al. 2011). There are also a number of international standardization processes for quality management including ISO 13485:2003, resource management (ISO 13485: 2003, 6.1) and refurbishment labelling (ISO 13485:2003. 7.3.3), which could also be considered for increasing the quality and reliability of remanufactured products.

Advanced technology

Innovative technology, advanced equipment and automated machinery, which focus on the reduction of resources and foster the sustainability of end of life products, need to be developed by remanufacturing SMEs. Financial assistance is urgently required from the government to invest in new technology, equipment and machinery in order to push the improvement of the remanufacturing SMEs. Therefore, the Ministry of Cooperative and Small Medium Enterprise needs to increase the soft loan fund (e.g. Kredit Usaha Kecil – KUK, People’s Business Loan – KUR) to the SMEs.

Infrastructure

Another obstacle to the flourishing of the remanufacturing industry in Indonesia is the under-developed infrastructure (e.g. road, sea transportation and electricity). The looming power shortage is a critical issue experienced by Indonesian SMEs. Disrupted production processes in remanufacturing activities, especially for the processes requiring electricity (e.g. machining, washing and testing), makes it difficult for SMEs to maintain the production process.

Therefore, the development of the electricity infrastructure needs to receive more attention if remanufacturing SMEs are to achieve sustainability. In addition, the improvement of road and transportation facilities (i.e. air, sea) and the provision of infrastructure strengthening the connectivity among cities and regions needs to be considered in order to increase the uninterrupted supply of cores to boost production rate and competiveness.

In addition, information technology (IT) infrastructure (e.g. telecommunication, internet, software) also needs to be constructed to improve the communication associated with the distribution and transportation processes and the storage of information on supply of used cores, different cannibalizing centres, etc. The use of e-Bay for used an EoL remanufactured products also needs to be developed The Ministry of Public Work and the Ministry of Communication and Technology have to work together with remanufacturing SMEs and stakeholders to achieve the improvement of robust infrastructures.

Supply chains

IT infrastructure (e.g. radio frequency identification (RFID) technology) is an important factor in the remanufacturing supply chain. It helps remanufacturers to manage the supply of and demand for returned products (i.e. cores) and new materials from suppliers. However, this technology can only be accessed if there is sufficient support (e.g. financial, training or facilities) from the government through the Ministry of Industry.

Another important factor in improving the remanufacturing supply chain is product legal and trade acknowledgement. The Ministry of Trade, through the Indonesian Chamber of Commerce and Industry (*Kamar dagang dan industry* – KADIN) and under the Law No.1/1987 (KADIN Indonesia 2011) could help establish legal and trade acknowledgement for remanufactured product. This will help remanufacturing industries to produce exportable items (American Production and Inventory Control Society 2014).

In addition, the drivers who are responsible for collecting cores and other used components for the remanufacturers require training for a take back scheme for collecting used products (i.e. standard operational procedure (SOP) of take back activity) efficiently and to strengthen the remanufacturing supply chain activities. To satisfy the demand for quality and quantity of cores, incentive programmes could be established with suppliers.

Design for remanufacture (DfRem)

Practical guidance on DfRem (e.g. disassembly methods and material selection) (Hatcher, Ijomah, and Windmill 2013) needs to be developed in collaboration with experts or researchers at universities and research centres. The Indonesian Government, through the integration of the Ministry of Industry, provides financial and technical assistance to support universities and research centres to offer guidance to remanufacturers.

6.6.2 Environmental aspects

The stakeholders who will be directly responsible for this improvement are the schools and training centres, BAPEDAL and information media. The indirect stakeholders who will be indirectly responsible for this improvement but play an important part in successfully implementing the remanufacturing strategies are the Ministry of Finance, Ministry of Cooperative and Small Medium Enterprise, Ministry of Industry, Ministry of Communication and Information, Ministry of the Environment and Ministry of Education. Figure 6.15 illustrates the relationships between the direct and indirect stakeholders in achieving the enabling mechanism.

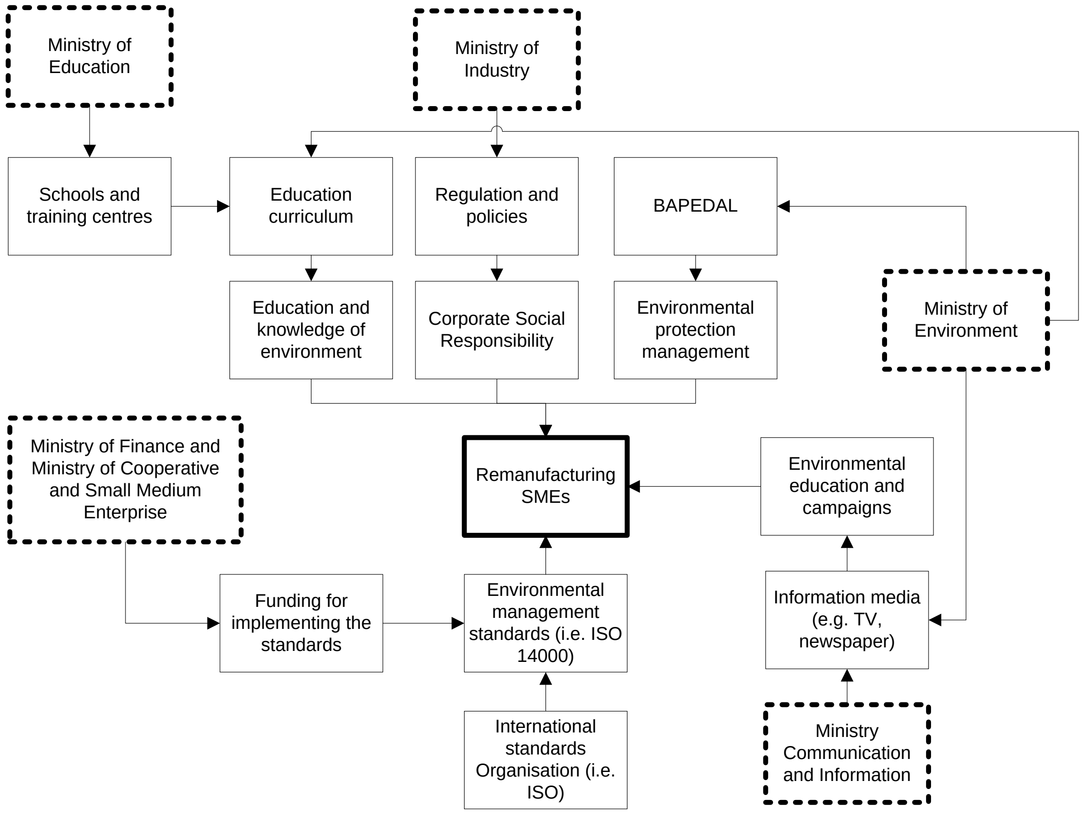


Figure 6.15 Enabling mechanisms for achieving environmental sustainability

The environmental strategies to implement the improved scenario are as follows.

Eco-labelling program

Environmental labelling programs need to be introduced in Indonesian markets and industries. These programs would promote the use of eco-labelling to provide customers with environmentally friendly product information. Recently, Indonesia has implemented eco-label type 1 for limited products (e.g. detergents, textiles), while eco-label type 2 (e.g. electronic and electrical equipment, dry-cell battery) is still to be developed (Hanafi et al. 2011). It is important to establish an eco-label for remanufactured auto parts in order to increase product competiveness internationally. The current research calculated the carbon footprint, embodied energy, solid waste and MIPS associated with the production of remanufactured alternators, which can be used for eco-labelling the alternators under improvement scenario III. This will then have met the environmental criteria and this will help remanufacturers to comply with eco-labelling and the Indonesian government to implement environmental policies.

Corporate social responsibility

The implementation of corporate social responsibility (CSR) by industries as specified in Indonesian Government Law No 40/2007 on Limited Corporations (Indonesia Investments) need to be consistently focussed on in order to improve environmental sustainability.

Environmental education and campaigns

The environmental awareness (e.g. e-waste, recycling and remanufacturing) of Indonesian customers and society is still low. A previous study found that about 77% of 180 respondents in Jakarta were aware of environmental issues (i.e. e-waste). However, only about 8% of them has practiced environmentally friendly actions, for example by selling their used products to be recycled through a ‘trade in program’ (Hanafi et al. 2011). Accordingly, a number of environmental educational campaigns are critically required to increase the awareness of customers and the community. Information media (e.g. radio, television, newspaper), under the control of the

Ministry of Communication and Informatics, plays an important role in implementing these environmental education programs and campaigns.

Waste management and technology

Waste (i.e. e-waste) is rapidly growing in Indonesia and is creating more critical problems for the environment. Accordingly, international environmental legislation associated with waste (e.g. the Waste Electrical and Electronic Equipment (WEEE), the EU's Restriction of Hazardous Substance (RoHs), as discussed in Chapter 2) (Hatcher, Ijomah, and Windmill 2013) needs to be adopted by the Ministry of Environment. Based on this legislation, new waste regulations and directives could be introduced. The current Indonesian waste regulations (e.g. Act No.32/2009 Environmental protection and management, Government regulation No27/2007 Environmental impact assessment) (Ministry of Environment Republic of Indonesia 2013) need to be fully implemented in order to further reduce waste and to ensure that the waste is managed in an environmentally friendly manner.

In addition, a 'producer compliment scheme' for financing waste management (i.e. take back process) and recycling centres need to be established. Original equipment manufacturers (OEM) need to be motivated to contribute financially to this remanufacturing scheme through an extended producer responsibility (EPR) policy.

Environmental management standards

The implementation of environmental management standards (i.e. ISO 14000) would be an effective strategy to reduce the environmental impact associated with all processes in remanufacturing and to improve environmental performance. The implementation of this environmental standard is a challenging task for SMEs due to financial constraints. Therefore, the government through the Ministry of Finance and Ministry of Cooperative and Small Medium Enterprise could provide financial assistance to the SMEs.

6.6.3 Economic aspects

The direct stakeholders who will be directly responsible for this economic improvement are banking organizations (e.g. BRI, BNI), original equipment manufacturers (OEM), community/independent organizations (i.e. Muhammadiyah Organization) and the Indonesian Chamber of Commerce and Industry.

The indirect stakeholders who will be indirectly responsible for this improvement but play an important part in successfully implementing the strategies are the Ministry of Finance and the Ministry of Trade. Figure 6.16 illustrates the relationships between the direct and indirect stakeholders in achieving the enabling mechanism.

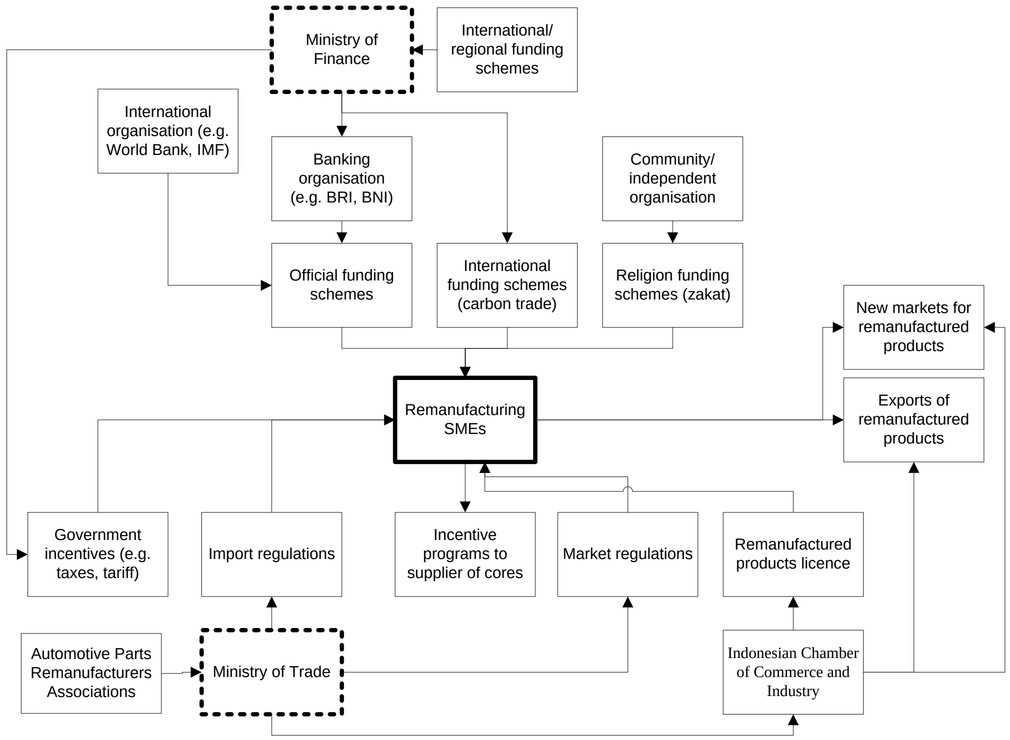


Figure 6.16 Enabling mechanisms for achieving economic sustainability

The economic strategies to implement the improved scenario III are as follows.

Funding programs

Investment in funding schemes (i.e. soft loans) provided by the government could come from a number of sources, including national funding organizations (i.e. Bank Rakyat Indonesia), international funding organizations (i.e. World Bank) or religious funding schemes (i.e. zakat) (Indonesia Investments). These financing organizations should have a transparent, effective and efficient procedure for providing loans to remanufacturing SMEs. However, previous analysis has shown that the remanufacturing industry could maintain its financial viability even if they were to receive the loans at a 9% interest rate.

A number of international funding schemes (i.e. carbon trade) could potentially be implemented in Indonesia. Government policies and industrial capacity need to be strengthened and improved to utilize the funding. In addition, financial schemes need to be developed which are more transparent, sophisticated and effective in promoting financial feasibility of the remanufacturing industries.

Import activities

The implementation of import regulations associated with remanufacturing activities (e.g. Table 6.33) need to be reviewed. Indonesia does not permit imports of second-hand products without an industry licence (e.g. refurbishing industry). In addition, government incentives (e.g. taxes, tariffs, import duties and licences) need to be structured in such a way as to promote remanufacturing activities. The cost of some critical components, such as bearings, rectifiers, brushes and regulators, which are imported from overseas, could potentially decrease if the government withdraws import taxes.

Table 6.33 Indonesian regulations associated with remanufacturing activities

Regulation	Concerns
Decree of Ministerial Trade No. 63/M-DAG/PER/12/2009	Imports of used products for reconditioning, remanufacturing and reuse purposes.
Decree of Ministerial Trade No. 39/M-DAG/PER/12/2009	Imports of non-dangerous waste (scraps).
Decree of Ministerial Trade and Industry No. 520/2003	Dangerous waste import prohibition.

Potential fiscal policies adopted from the Ministry of Finance (2009) need to be developed including tax (i.e. tax differentiation/holiday), import tax breaks, and subsidies (Ministry of Finance 2009a).

Market penetration

The lack of market penetration is an issue requiring urgent attention. The creation of new markets for remanufacturing and the establishment of connectivity are crucial to improve local and national markets for remanufactured products. Export activity for selling remanufactured products on the international market (e.g. Asia and Europe) also needs to be improved to increase the competiveness of products. The Automotive Parts Remanufacturers Associations (APRA) could assist SMEs by giving advice on international trade and import strategies. The formulation of effective policies (i.e. licencing of remanufactured products) and a number of market regulations are urgently required to reduce market failure of the remanufactured products. Coordination with peripheral governments needs to be improved to ensure uniformity between local and national regulations. A service trade centre for developing the remanufacturing sector is important to gain more public attention and concern. In addition, training of effective marketing strategists is urgently needed to improve the marketing skills of remanufacturing staff.

6.6.4 Social aspects

Even though the Indonesian Human Development Index (HDI) impressively increased in 2010 (Ministry of Manpower and Transmigration), the quality of Indonesian labour is still far below a High-HDI due to a lack of education and poor quality of life (Indonesia Investments). This situation will have an impact on the quality of Indonesian remanufactured alternators. The current research has demonstrated that a sustainable manufacturing scenario could even double wages to the labourers, which could allow them to access modern health benefits and improve their skills. Accordingly, social soft infrastructures (e.g. health care and education systems) need to be improved to achieve healthier and more skilled labourers as discussed in the following section.

The direct stakeholders who will be directly responsible for this improvement are the schools and training centres, the National Agency for Professional Certification, universities and higher education through the Centre of Research and Community Service Development, OEM, Information Media and Government Social Security Agency.

The indirect stakeholders who will be indirectly responsible for this improvement but play an important part in successfully implementing the strategies are the Ministry of Finance, Ministry of Cooperative and Small Medium Enterprise, Ministry of Industry, Ministry of Communication and Information, Ministry of Health, and the Ministry of Education. Figure 6.17 illustrates the relationships between the direct and indirect stakeholders in achieving the enabling mechanism.

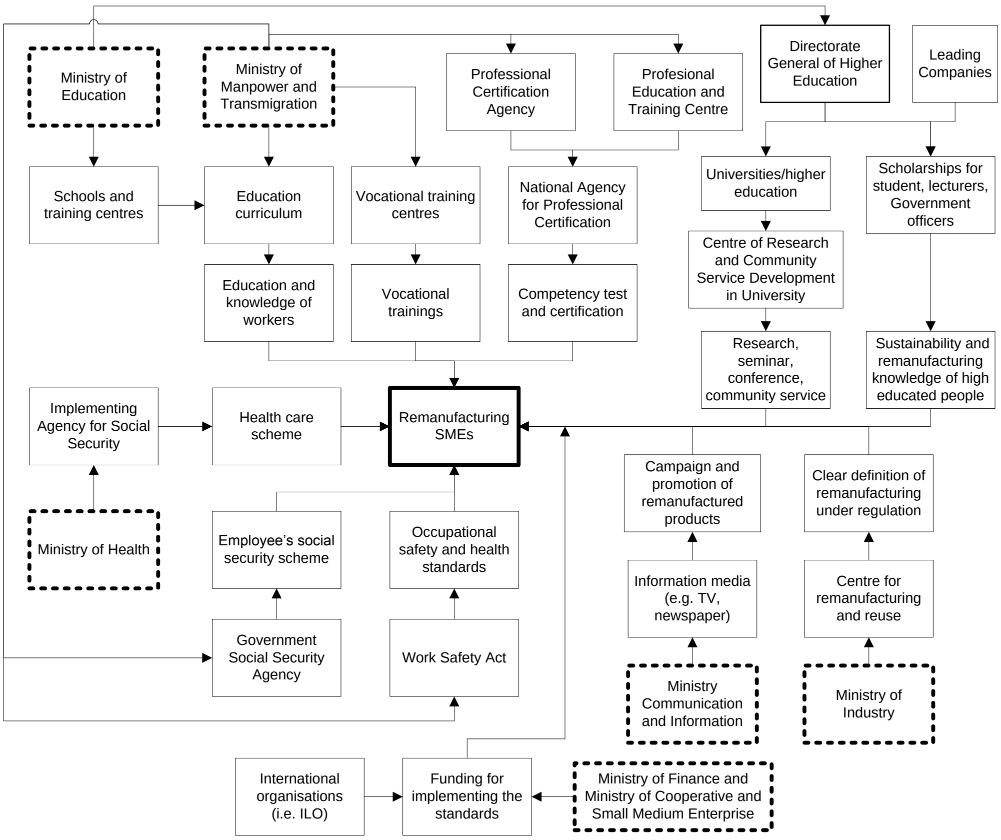


Figure 6.17 Enabling mechanisms for achieving social sustainability

The social strategies for achieving the improved scenario are as follows.

Education system

Education curricula should be designed on the basis of work demands (Ministry of Manpower and Transmigration). Currently, the Ministry of Manpower and Transmigration has established 201 National Work Competency Standards (SKKNI) as a basis for the development of education curricula in schools and training centres. A number of social, economic and environmental issues related to sustainable manufacturing, remanufacturing and sustainability need to be integrated in this SKKNI. Collaboration with the Ministry of Education is urgently required to develop the curriculum.

The lack of knowledge on product design is an important barrier to the ability of remanufacturing labourers to produce high quality products (Hatcher, Ijomah, and Windmill 2013). For example, in the disassembly process which is mainly conducted manually, the used products need to be carefully disassembled by skilled labourers in order to provide valuable used products (i.e. non-damaged products). Accordingly, vocational training in some successful enterprises could be a useful opportunity for improving the quality and competiveness of skilled labourers. This vocational training in remanufacturing could be introduced by the Vocational Training Centre (VTC) which works under the supervision of the Ministry of Manpower and Transmigration (MoMT).

Developing competency tests and certification for remanufacturing activities could also be conducted by the National Agency for Professional Certification (BNSP) in collaboration with the MoMT, the Professional Certification Agency (LSP) and the Professional Education and Training Centre (LDP). In addition, International Labour Organization (ILO)through a number of programs (e.g. skill promotion and training centres) could also help in developing the skills of labourers.

Universities, through the Centre of Research and Community Service Development (Lembaga Penelitian dan Pengabdian Masyarakat - LPPM), could conduct more research, seminars, conferences and community services to share their technical and knowledge expertise with stakeholders (i.e. customers, communities and enterprises). For example, the Global Conference on Sustainable Manufacturing could be an appropriate platform for exchanging new ideas between researchers and the industries. The Ministry of Education through the Indonesian Directorate General of Higher Education (Direktorat Penelitian dan Pengabdian Ditjen Pendidikan Tinggi – DIKTI) could offer funding to implement these programs.

Scholarship programs in developing sustainability and remanufacturing knowledge could be offered to university lecturers, students, government officers and senior

SME employees. These scholarship programs could be provided by leading companies (i.e. PT Komatsu Indonesia), government institutions (i.e. DIKTI) and other organizations (i.e. PT Toyota Manufacturing Indonesia). Government support and assistance is required to encourage the implementation of these programs.

Campaign and promotion programs

Effective campaigns and promotions including waste return campaigns, remanufacturing exhibitions, brochures (i.e. waste collection programs), posters and advertisements need to be created to increase the awareness of the Indonesian people about remanufacturing activities. These programs could be conducted in collaboration with remanufacturers, the government, OEM and other stakeholders.

Through its policies and regulations, the government needs to provide a clear definition of recovery systems (e.g. remanufacturing, refurbishing) in order to avoid misinterpretation among remanufacturers, stakeholders and customers. A clear definition would also increase customer confidence in remanufactured products as discussed in Chapter 2.

The concept of a remanufacturing centre as established in developed countries (i.e. UK CRR – Centre for Remanufacturing and Reuse) (Centre for Remanufacturing and Reuse 2014) could be adopted and developed to promote and encourage remanufacturing and reuse activities in Indonesia. This centre would be an independent organization which could work with government and business clients to provide services, promotion and advice associated with remanufacturing and reuse activities (i.e. training, consultancy, certification and standardization).

Health care

The social security of Indonesian labour is still low due to a lack of safety procedures and inadequate equipment (Darisman 2011). Remanufacturing SMEs use potentially hazardous processes and materials which could injure employees due to a lack of safety equipment and protection of labourers from hazardous materials through the use of waste/used materials. Strategies to develop safe workplaces and reduce labour-related injuries are a crucial concern. The current improvement scenario could make a considerable amount of profit (USD 46,000), some of which could be spent on the health and safety aspect of remanufacturing.

Accordingly, under Law No.40/2004 on the National Social Security System (SJSN), health care development should be implemented to improve the social security of labourers. The priority development concerns the implementation of health care schemes provided by the Implementing Agency for Social Security (Badan Pelaksana Jaminan Sosial (BPJS)). This scheme covers hospital costs associated with illness and injures among BPJS members. All employees should be encouraged to be BPJS members in order to receive the benefits of this program.

Another social program to protect employees is provided through the employee social security scheme (Jamsostek) conducted by PT Jamsostek (the government Social Security Agency), which provides health, injury and safety compensation to employees who are registered in the social program (Darisman 2011). In this case, industries are responsible for providing their employees with the Jamsostek program which is financed by the employers.

Workplace health and safety

A number of regulations associated with workplace and labour conditions, such as Law No.1 of 1970 The work safety act (PortalK3.Com 2013), need to be followed up with strategic actions to provide social security and labour protection. For example, sufficient safety procedures, safety equipment, tools and personal protective equipment (PPE) (i.e. boot, glasses, mask and gloves) should be provided to labourers engaging in remanufacturing activities which are usually conducted manually.

The implementation of occupational safety and health (OSH) standards developed by the MoMT would help industries to effectively implement these actions. Funding is critically needed from the government and stakeholders (i.e. ILO) in order to successfully implement this program. This health and safety funding could strengthen and transform the application of the regulatory approaches.

Chapter 7

Conclusion

7.1 Introduction

This study set out to investigate sustainable manufacturing through the remanufacturing strategies used by Indonesian small medium enterprises (SMEs). A holistic sustainable manufacturing framework was developed out of a comprehensive literature review and was then tested on existing Indonesian SMEs remanufacturing alternators.

Firstly, an extensive literature review identified the knowledge gap between the past and existing situations regarding sustainable manufacturing, remanufacturing and global sustainability in developed and developing countries. Whilst there is a huge potential for the remanufacturing industry to achieve sustainable manufacturing in developing countries, it is not actually happening due to an absence of legislation, policies, financing mechanisms, institutional frameworks, supporting mechanisms, including the availability of good quality cores and used parts, computerized information databases, training opportunities and promotional activities.

Secondly, the study developed a comprehensive sustainable manufacturing framework for assessing remanufacturing in developing countries. Next, an inclusive case study was conducted specifically in the context of Indonesian remanufacturing SMEs in order to utilize the sustainable manufacturing framework. Fourthly, three subsequent improvement scenarios specified the enormous potential for technical, environmental, economic and social sustainability among Indonesian remanufacturing SMEs. Finally, inclusive enabling mechanisms were suggested for successfully implementing the remanufacturing improvement strategies.

7.2 Sustainable manufacturing knowledge in past and existing research

A comprehensive review was made of the general theoretical literature from a variety of resources (e.g. credible international and national journals, conference proceeding, books and dissertations) on manufacturing, sustainable manufacturing, remanufacturing and sustainability in the context of developed and developing countries.

As mentioned in Chapter 2, manufacturing has been found to be a wealth producing sector and an essential contributor to the economy in both developed and developing countries (Bi 2011, Bureau of East Asian and Pacific Affairs 2012, Jawahir, Badurdeen, and Rouch 2013, United Nations Industrial Development Organisation 2013). However, the rapid development of manufacturing industries has been followed by an increase in waste and pollution, climate change, health problems, poverty, social bearing, decrease in biodiversity and resource depletion which has raised the awareness of sustainability (Jovane et al. 2008),

The need for sustainability has become abundantly clear. In developed countries, the main drivers of sustainability are policy regulation, standards and protocols, environmental regulation and schemes, community concern, risk and liabilities with investment, costs associated with meeting regulatory constraints, marketing viability and opportunities, environmentally benign technologies and corporate commitment (Badurdeen et al. 2009, Cordoba and Veshagh 2013, Commonwealth Scientific and Industrial Research Organisation 2013, Manufacturing Skills Australia 2008, Mittal et al. 2012, Sabapathy 2007). In developing countries, the major drivers of sustainability are environmental initiatives and regulations, supply chain pressure, availability of funds for green projects, economic benefits, company competitiveness, customer demand, green technology dissemination programs and marketing tools (Amrina and Yusof 2012, Fatimah et al. 2013, Kulatunga, Jayatilaka, and Jayawickrama 2013, Mittal et al. 2012).

Overall, sustainable manufacturing requires 'the design and manufacture of high quality/performance products with improved/enhanced functionality using energy-efficient, toxic-free, hazardless, safe and secure technologies and manufacturing methods utilizing optimal resources and energy by producing minimum wastes and emissions, and providing maximum recovery, recyclability, reusability, remanufacturability, with redesign features, and all aimed at enhanced societal benefits and economic impact' (Jawahir 2008, p. 37). Sustainable manufacturing has no longer become 'nice to have' but has become a business imperative (OECD 2011).

Recently, the 6Rs have been considered as an important strategy in achieving sustainable manufacturing especially in developed countries (e.g. the United States, United Kingdom, Germany, Australia and Japan). The 6Rs constitute a science-grounded, comprehensive and assessable strategy and include reduce, reuse, recycle, recover, redesign and remanufacture (Cordoba and Veshagh 2013, Joshi et al. 2006) . These strategies have been successfully implemented to solve economic, social and environmental burdens in the abovementioned countries. However, sustainable manufacturing is still in the nascent stages in developing countries (e.g. China, India and Indonesia). The implementation of the 6Rs strategies in developing countries is less effective and efficient than in developed countries (Damanhuri and Padmi 2012, Guo and Marinova 2007, Mariëtte and Esther 2009).

Of the 6Rs strategies, remanufacturing has been highlighted as a potential means of achieving global sustainability (Xiang and Ming 2011). Remanufacturing is the transformation of used products to a state similar to new, with warranty to match, and may bring more economic, social and environmental benefits than conventional manufacturing because it offers greater potential profits, employment opportunities and reduction of environmental impact (Giuntini and Gauddette 2003, Gray and Charter 2007, Hatcher, Ijomah, and Windmill 2011, Lund and Hauser 2009, Steinhilper 1998b).

However, although remanufacturing has contributed to potential profits, employment opportunities and environmental impact reduction in developed countries (e.g. the United States, Germany, Japan) (Giuntini and Gauddette 2003, Gray and Charter 2007, Hatcher, Ijomah, and Windmill 2011, Lund and Hauser 2009, Steinhilper 1998b), it has been found to be underdeveloped in developing countries (e.g. China, India, Nigeria and Indonesia) (Fatimah et al. 2013, Vasudevan et al. 2014, Wu 2012, Zhang et al. 2011). Whilst remanufactured products have been treated as 'good as new' items in the market of developed countries, the main hurdle for remanufactured products to flourish in developing countries is the quality issue which tremendously affects the attaining of socio-economic sustainability for these products. This is a result of the absence of legislation, policies, financing mechanisms, institutional frameworks and supporting mechanisms, insufficient good quality cores and used parts, and a lack of technology, training opportunities and promotional activities,

Accordingly, this study has developed a sustainability manufacturing framework (SMF) through remanufacturing strategies for achieving sustainable manufacturing in developing countries.

7.3 Sustainable manufacturing framework for assessing remanufacturing in a developing country

In order to develop the sustainable manufacturing framework, a number of thematic aspects of sustainability manufacturing frameworks were identified from previous research (Jawahir, Rouch, et al. 2006, Seliger, Kernbaum, and Zettl 2006, Nasr and Thurston 2006), which mainly concerned the specific economic, social and environmental aspects. This is because these studies have already defined remanufactured products as products that offer about the same quality as new products, reflecting the situation in developed countries. In the case of developing countries, remanufactured items are treated as second-hand products which are mainly used by people who do not have the purchasing power to buy new items. In addition, reliability and warranty periods are very low compared to the products produced by remanufacturing SMEs in developed nations.

Consideration of the technical aspects as one of the pillars of sustainable manufacturing is thus inevitable for remanufacturing SMEs in developing countries. However, there is no available sustainable manufacturing framework (SMFs) which take the technical aspects (e.g. reliability, durability) into account as integral parts of sustainability in remanufacturing strategies especially for developing countries. Therefore, this study has proposed a different, holistic, sustainable manufacturing assessment framework which integrates the technical aspect into the environmental, economic and social aspects in order to assess the implementation of remanufacturing strategies in SMEs.

A number of premises were then taken into account as the basis for constructing SMF, including strengthening the local market, profitability, landfill impact, capacity building for the SMEs, policy infrastructural aspects, international pressure on sustainability and reliability, durability and safety.

In order to construct the SMF, the concept of nested egg sustainability was considered the best way to successfully implement a remanufacturing strategy. The reason for this is that this concept emphasizes ecologically focussed development of human activities whereby the social demand that drives the economy has to be within the carrying capacity of the earth.

Using the nested approach, a sustainable manufacturing framework was developed and then established in two steps:

In the first step, the technical, environmental, economic and social performance of the remanufacturing SMEs in their current situation was assessed utilizing the relevant indicators. The performance indicators were measured using statistical calculations (e.g. LCC estimation) and software (Reliasoft ++, Simapro and Excel).

The results were then compared with sustainable manufacturing threshold values obtained from the literature discussing remanufactured products in similar areas (e.g. auto parts, alternators), both in developed and developing countries. The selection of threshold values was a challenging task as they needed to be achievable and relevant to the situation in developing countries. Some threshold values were very difficult to obtain (e.g. reliability) for the product under investigation, in which case a surrogate value was considered. This meant that the data available for the remanufactured product(s) with similar remanufacturing procedures were chosen as the threshold value (i.e. remanufactured television). A number of optimum threshold values were chosen because they are achievable by remanufacturing SMEs in developing countries while still maintaining standard remanufacturing operations.

For some indicators (e.g. safety performance, import dependency and CSR) which cannot have numerical values, qualitative values (e.g. increase/decrease, performed/unperformed and independent/dependent) were considered as threshold values.

Once the threshold values were determined, they were compared with the corresponding sustainable manufacturing indicators for the remanufactured product. If all indicators did not meet the threshold values, the remanufactured product was considered to be unsustainable and requiring further improvement. The objective of the improvement framework is first to achieve technically and environmentally feasible solutions and then to achieve economic and social performance.

A number of sustainable development and manufacturing frameworks were sourced from international documents (i.e. the OECD's Core Environmental Indicator), national reports (i.e. Design for Sustainability (DFS)), standards organizations (i.e. the EEA's Core Set of Indicators), research organizations (i.e. UNAND's Sustainable Manufacturing Performance Measures for Automotive Companies) and established company sustainability reports (i.e. Ford's Product Sustainability Index). These were comprehensively reviewed in order to select the technical, economic, environmental, and social indicators for a remanufactured product (Amrina and Yusof 2011, EEA 2005, Jawahir, Dillon, et al. 2006, OECD CEI 2003, Schmidt and Taylor 2006).

Based on the reviews, the indicators were established for the proposed sustainable manufacturing framework. Technical indicators included reliability, durability, warranty, safety performance and availability of cores, while environmental indicators included embodied energy savings, GHG emissions, material savings, material intensity per unit service (MIPS), solid waste avoided and landfill impact.

Economic indicators included LCC, profit margin, price, sales, value added, return on investment and import dependency. Social indicators consisted of employment creation, labour wages, intergenerational equity, CRS, company reputation and youth and enterprise development.

7.4 Existing situation for Indonesia remanufacturing SMEs utilizing a sustainable manufacturing framework

The remanufacturing SMEs on Java Island in Indonesia were used as a case study for applying the sustainable manufacturing framework. Accordingly, a survey was carried out to collect information associated with remanufacturing processes, products, costs, materials, labour, energy and machinery in the remanufacturing SMEs.

In order to perform the first step of the sustainable manufacturing framework, a survey was carried out to gather information for use in determining the indicators for technical performance, environmental performance, economic performance, and social performance.

These indicators were compared with the threshold values to assess the sustainability of the existing remanufacturing SMEs.

The technical indicators including reliability (78%), durability (78% over two years), warranty (three months), safety performance (safety testing) and availability of cores (4,500 units) did not meet the threshold values. The environmental impact associated with embodied energy savings (71.1%), GHG emissions reduction (75%), material savings (57%) and material intensity per service of unit (MIPS) (0.079) did not meet the threshold values. Only solid waste avoided (99%) and landfill impact (1.0%) adequately met the threshold values. The economic indicators including LCC saving (38%), profit margin (15%), price (50%), sales (decrease 7%), recovered value (25.1%), return on investment (81%) and import dependency did not seem to meet the threshold values. The social performance indicators including employment creation (decrease), labour wages (USD 75), intergenerational equity (14.5 TJ), CSR (133.54 tons), company reputation (weak) and youth and entrepreneurship development (not developed) also did not meet the threshold values.

These results confirmed that the existing situation did not meet the threshold values for the majority of the sustainable manufacturing indicators, mainly due to the increased number of failed components, large quantity of used parts, absence of modern testing facilities, inadequate quality cores, lack of skilled workers and lack of marketing strategies. Technical weaknesses were found to be the predominant factors affecting other aspects of sustainable manufacturing. Therefore, a number of remanufacturing strategies were considered in order to develop a technically and environmentally sound solution while maintaining the socio-economic performance.

7.5 Determination of improvement scenario for achieving sustainable manufacturing

In order to determine the optimum technically, environmentally, economically and socially feasible solution, three improvements to the remanufacturing strategy were tested.

The first improvement scenario considered increasing the quantity of new materials used for all critical components (e.g. rectifiers, regulators), the implementation of advanced technology for testing processes, the introduction of training to improve workers' skills and the expansion of core collection areas in order to guarantee the supply of sufficient quality cores. The result found that this improvement scenario was technically viable due to its high reliability (97.9%), durability (97.9% in two years), qualified safety performance (good), warranty (two years) and availability of cores (7,900 units). However, this improvement scenario was not environmentally sustainable due to the lower embodied energy saving (56.2%), GHG emissions reduction (61.5%), material saving (57%) and the higher MIPS (0.151 kg/kWh), which did not meet the threshold values. Since this SMF follows the nested egg concept of sustainability by providing the ecological aspect with greater priority than the social and economic aspects, this remanufacturing strategy was not further considered for socio-economic assessment.

Similarly, a second improvement scenario was considered where the quantity of new materials was reduced and the quantity of recycled materials was increased. In addition, this remanufacturing strategy considered the same approach as the first one, with the implementation of advanced technology for testing processes and the improvement of worker skills through training. This improvement scenario was also found to meet the threshold values for technical performance, including reliability (95.87%), durability (95.87% in two years), qualified safety performance, warranty (two years) and availability of cores (7,900 units). However, this remanufacturing strategy did not provide an environmentally friendly solution as seen by the embodied energy saving (65%), GHG emissions reduction (69%), material saving (62.2%) and MIPS (0.099 kg/kWh) which did not meet the threshold values.

As a result, a third remanufacturing scenario was considered whereby the use of an increased quantity of high quality used materials helped to attain both technically and environmentally feasible solutions. The technical performance indicators for this improvement scenario met the threshold values for reliability (95.57%), durability (95.57% in two years), safety performance (meet the standard), warranty (two years) and availability of cores (7,900 units). The environmental performance also met the threshold values for energy consumption (75.3%), GHG emissions (78%), material saving (87%) and MIPS (0.047 kg/kWh).

Once these technical and environmental criteria were met, the third remanufacturing strategy was considered for economic and social analysis as outlined by Fatimah et al. (2013) and a sensitivity analysis was carried out to determine the effect of changes in scale of production, interest rate and size of the SMEs on the economic viability of the remanufactured alternators. An interesting outcome from this sensitivity analysis was that an increase in the size of the remanufacturing enterprise could not only reduce the life cycle cost and price, but could also help increase wages, thus enhancing intergenerational social equity.

In the case of the third remanufacturing strategy, the sales of remanufactured alternators were estimated to increase by 20% from 2,326 units in the existing scenario to 2,792 units in the improvement scenario. The profit margin was also estimated to increase from 15% to 20%. However, the price was found to increase by about 30% from USD 37.4 to USD 48.7 due to the additional costs associated with the purchase of high quality used materials, advanced testing technology and training for improving the skill of workers.

The results of the sensitivity analysis show how increases in the size of the SME, the sales and the wage rate could increase the economic and social benefits for the remanufacturing SMEs. The results from the sensitivity analyses are as follows:

- The inclusion of an additional shift in the third remanufacturing scenario could increase sales by about 56.7%, which in turn would reduce the price significantly by about 10% (i.e. from USD 48.62 to USD 43.43) and increase the profit by 52% (i.e. from USD 22,671 to USD 47,006). The additional shift therefore would increase the income of the workers which could help increase their standard of living.

- Increasing the size of the industry to medium sized enterprises could increase production to 23,470 remanufactured alternators per year, which would significantly increase the profit from USD 47,006 to USD 177,668. Even though the price would be estimated to increase by 30% due to this expansion, the increase in profit would be expected to ameliorate this.

- The lower price associated with the expansion of the enterprise would allow wages to be doubled (from USD 4.5 to USD 9 per day) until the price reached the threshold value. This expansion therefore would increase the gross profit to USD 188,464, and would provide more job opportunities.

- In the case of market coverage, the proportion of remanufactured products sold on the market has been estimated to be 20% of the total number of alternators, based on the maximum number of cores that could be potentially provided by Indonesian suppliers. This coverage could make 1.12 million remanufactured alternators available on the market and create about 2,779 jobs, resulting in the reduction of the unemployment rate (7,661,482 persons) (Indonesia Investments 2014b) by 0.04% every year.

The other economic benefit accrued from the improvement scenario is associated with the recovered value. The recovered value was estimated to be about 36.7% of the price of a new alternator, which is higher than the threshold value. Similarly, the return on investment was estimated to be 80% of the expected revenue which is better than the return on investment from the new product. Import dependency could be reduced by providing soft loans to SEs manufacturing critical components locally.

The social analysis showed that the improvement scenario could provide potentially enormous social benefits as follows. The number of jobs was estimated to double (from 16 to 32 employees) with the incorporation of an additional shift. Therefore, the number of jobs could increase significantly even up to 58 by a small enterprise becoming a medium enterprise. In addition, the number of skilled workers is expected to increase due to training programs which could potentially be conducted by the SEs through financial support from the government.

As mentioned in the economic analysis, the improvement scenario could increase the wages of labourers by 100% which would significantly improve the quality of life of the SE workers. Furthermore, the additional wages could help to access better education and health services, and save for the future.

This remanufacturing scenario could help achieve intergenerational equity by conserving a large quantity of material (172 tons) and energy (18 TJ) for future generations. The corporate social responsibility is expected to increase through environmentally benign and socially equitable manner. Furthermore, company reputation is predicted to increase due to the increase in technical performance and reasonable prices.

From the technical, environmental, economic and social points of view, it is clear that the implementation of sustainable manufacturing through remanufacturing strategies could create enormous advantages, not only in the economic sector but also in the technical, environmental and social sectors. However, the successful implementation of this strategy needs support from the government and other stakeholders.

7.6 Enabling mechanisms

A number of mechanisms have been designed to enable the implementation of this improvement scenario utilizing the third remanufacturing strategy. Coordination, assistance (e.g. financial, facilities) and collaboration with stakeholders (e.g. government, OEM, NGOs) were proposed through a number of mechanisms to achieve specific technical, environmental, economic and social objectives. In addition, a number of programs and strategies for collaboration with these stakeholders are explained in detail, highlighting the roles of all direct and indirect stakeholders, and relevant regulations and policies to overcome the barriers to the implementation of the remanufacturing strategies.

In the case of the technical enabling mechanism (i.e. standards), a number of stakeholders (e.g. the National Standardization Agency) were considered who would be directly responsible for improving technical performance by establishing a number of remanufacturing standards to meet the technical requirements of the remanufactured products (e.g. the reliability of the remanufactured product has to be $\geq$90% in order to meet the standard). In addition, the Ministry for Industry could be indirectly responsible for successfully implementing the standards. For the economic enabling mechanism (i.e. funding program), a number of stakeholders (e.g. Bank National Indonesia) were considered who would be directly responsible for improving funding programs to make them more transparent, effective and efficient in providing loans to remanufacturing industries. The Ministry of Finance has the indirect responsibility for controlling the implementation of the funding program. Other associated activities are the amendment of import regulations and market promotion to achieve economic viability.

For the environmental enabling mechanism (i.e. education and environmental knowledge), there are a number of stakeholders (schools and training centres) who have direct responsibility for raising environmental awareness by offering courses on sustainable manufacturing. The Ministry of Education could play an important role in successfully implementing this improvement through the establishment of an education curriculum on the basis of manufacturing and the environment. An eco-labelling program, and programs or workshops on CSR, waste management and technology and environmental management standards could be other modes of delivery for sustainable manufacturing knowledge.

For the social enabling mechanism (e.g. health care programs), a number of stakeholders (e.g. the Government Social Security Agency) could be directly responsible for enhancing the employees' social security scheme by providing appropriate health insurance and safety compensation. The Ministry of Manpower and Transmigration, through the implementation of Law No.40/2004, are indirectly responsible for successfully implementing the third remanufacturing strategy.

7.7 Future development

Some proposals for future research, which were beyond the scope of this current project, are as follows:

- This research only considered a few SMEs in Java Island and Jakarta, and it would have been useful to consider more examples from other Indonesian provinces and even other developing countries with a similar sort of background in order to come up with more realistic conclusions. Since the main objective of the current research was to develop and then test a sustainable manufacturing framework, the consideration of a larger sample size was beyond the scope of this project.
- The framework proposed by Fatimah et al (2013) could be applied to other remanufacturing SMEs including electronic (e.g. computers), agriculture equipment (e.g. tractors), and transportation (e.g. trucks) since they are, like remanufactured alternators, widely used items due to affordability reasons.
- Funding needs to be sought for the practical implementation of the framework (Fatimah et al. 2013) among Indonesian remanufacturing SMEs. The feedback that could be received from the implementation of the framework could help to further refine it.
- Similarly the enabling mechanisms need to be tested and applied by the relevant government departments.
- The same framework can be applied for the other Rs in the 6Rs strategy, including recycling, recovery and reconditioning, both from the theoretical and practical implementation points of view.
- Research needs to be conducted on the other activities in the supply chain for remanufactured products in order to identify broader supply chain strategies for enhancing sustainable remanufacturing activity.

- This research project only considered those remanufacturing strategies involving the use of new, used and recycled components, however, there are other avenues, including machining performance, energy efficiency, water conservation and input substitution, which can be considered for making remanufacturing SMEs more sustainable, lower carbon and energy intensive.
- The inclusion of water pollution associated with remanufacturing activities was beyond the scope of this research. Future remanufacturing research could take water pollution into account in the environmental assessment process.

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Appendix A - Journal publication

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CASE STUDY — Open Access

Sustainable manufacturing for Indonesian small- and medium-sized enterprises (SMEs): the case of remanufactured alternators

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Abstract

Achieving sustainability is a great challenge for most of the Indonesian manufacturing small- and medium-sized enterprises (SMEs). Remanufacturing has been considered to be a key strategy to attain sustainable manufacturing by maximising the use of old components and minimising landfill size and energy usage. However, SMEs, which are undoubtedly the engine of the Indonesian manufacturing industry, do not have adequate experience, skill, resource, technology and financial support in the remanufacturing area. This paper proposes a new concept for sustainable manufacturing assessment framework through remanufacturing strategies in Indonesian SMEs. In this sustainable manufacturing assessment framework, the existing remanufactured products are assessed using sustainable manufacturing criterion (e.g. reliability, life cycle cost, employment opportunity and greenhouse gases). This framework identifies improvement opportunities, including eco-efficiency, cleaner production and green technology to make existing remanufactured products technically, economically, environmentally and socially sustainable. The sustainability of remanufactured alternators produced by Indonesian SMEs has been assessed to validate the aforementioned sustainable manufacturing assessment framework.

Keywords: Remanufacturing; SMEs; Sustainable manufacturing

Introduction

The manufacturing industry is a wealth-producing sector of the Indonesian economy accounting for 24% of gross domestic product (GDP) followed by agriculture (15%) and other economic sectors [1]. Large enterprises and small- and medium-sized enterprises (SMEs) accounted for 43.28% and 56.72% of the total GDP in the manufacturing sector, respectively, while SMEs alone represent 99.96% of total number of manufacturing industries (3.27 million companies) and also absorb employment for 87.47% of the total industry workers [2].

However, the proportion of SMEs for total manufacturing export and GDP is still low compared to the large number of enterprises due to a lack of innovative technology, inefficient production processes, limited skilled workers, insufficient capital investments and unqualified and unclassified standardisation products [3]. Most of SME exports are dependent on large enterprises, and their contributions are usually unrecorded and undermined. As a result, SMEs cannot expand their market independently

[4]. Furthermore, many Indonesian manufacturing SMEs are not environmentally conscious and contribute a large amount of pollution and resource depletion due to inefficient equipment usage [5].

Thus, Indonesian manufacturing SMEs do not comply with the economic, social and environmental objectives of sustainable development. This is because the objective of sustainable manufacturing is to develop and improve human life continually over time through the optimization of production and consumption activities by conducting efficiency on material and energy consumptions, focusing on poverty reduction and maintaining the resources for human beneficial reasons [6].

The main strategies for attaining sustainable manufacturing are remanufacturing, reuse, recondition and recycling [7]. Remanufacturing which is defined as a series of manufacturing steps acting on an end-of-life part or product in order to return it to like-new or better performance, with warranty to match [8], appears to be the most appropriate strategy to attain sustainable manufacturing in Indonesia due to the following reasons.

Firstly, it fulfils three objectives of sustainable manufacturing. Remanufacturing is economically viable by maximising the use of old components or product, and it is environmentally friendly by reducing the size of landfill, minimising the energy usage, and it is socially viable by providing employment opportunities and developing prosperity flows [9-11]. For example, an automotive engine remanufacturing company reduced metal consumption by 7,650 tonnes, conserved energy of 16 million kW h and decreased emission of about 11,300 to 15,300 tonnes CO_2 equivalent (CO_2eq) [12]. In the UK, remanufacturing contributes to the workforce around 50,000 employees and provides £2.4 billion GDP in 2009 [13], while in the USA, 73,000 remanufacturing industries employed about 480,000 people [14]. In addition, the increased employment opportunity, job satisfaction, income and clean environment will improve the quality of human life. These advantages significantly place remanufacturing as the main contributor to the sustainability of prosperity [10].

Secondly, since 1997 - when the economic crisis took place Indonesia - the new products became unaffordable and expensive for majority of the Indonesian people. Consequently, refurbished, reconditioned, cannibalised, reused and remanufactured products such as electronic, household appliances, automotive components and office furniture have become the usual products in the Indonesian market [15].

Unfortunately, the development of the remanufacturing industry which is mainly held by SMEs is still undercover, neglected and environmentally unfriendly. Many SMEs feel doubtful that their remanufacturing business will continue to grow due to high competency in the global market. Only few giant companies (e.g. PT Sanggar Sarana Jaya, PT Komatsu Remanufacturing Asia) have recognised the value of remanufacturing strategies in Indonesia as they can offer economic, social and environmental benefits to the manufacturing sector of Indonesia [16,17].

State of the art of Indonesian-remanufactured auto parts

The automotive industry sector is growing alarmingly in Indonesia in the recent years. The production growth was about 35.21% from 2009 to 2011, while the market growth was 37.54% [18]. The total number of automotive industries was around 445 which are mainly held by SMEs absorbing around 185,000 to 204,596 employees [19]. In the case of motor vehicle industries, sales were 894,164 units in the last 2011, and the prediction shows that the percentage will be increased to 50% in the next 5 years [18,20]. As a result, the use of auto parts such as engine, transmission, steering gear, starter and alternator will increase.

Alternator is part of the automotive components which can potentially be remanufactured. The remanufactured alternator dominates the remanufacturing market around 22% [21]. The remanufactured alternator offers 50% cheaper costs than the new ones and consumes 60% less energy and 70% less material compared to the new product. Also about 80% of the alternator parts can potentially be reused [22,23].

The legislations (e.g. End-of-Life Vehicle Directive and Energy-Using-Product Directive), which are crucial drivers for a successful implementation of the remanufactured products in developed countries (e.g. UK, Japan) [10], have been found absent in Indonesia. The next important driver is market demand. The Indonesian automotive component market is divided into original equipment market and market for low-cost and minimum standard product which are manufactured mainly by SMEs. Due to the affordable price of remanufactured products [24], the remanufactured alternators are expected to dominate the market.

Except for a few (e.g. Galeri alternator), most SMEs are not effectively producing remanufactured alternators. The Indonesian SMEs producing remanufactured alternators experienced a number of challenges. Firstly, the lack of financial mechanism has been perceived to be an obstacle to expand SMEs. Although the Indonesian government offers business credit programme (KUR-Kredit Usaha Kecil) for SMEs, it is mostly applied to few specific locations in Indonesia (e.g. Java, Bali) [25]. Secondly, the lack of knowledge and skilled worker has led to ineffective and inefficient production activities. Thirdly, the orientation of product standardisation based on the domestic market generates low quality, less reliability and short warranty period which reduce the attractiveness of the remanufactured alternators in the market. Fourthly, most of the SMEs are not environmentally efficient and produce more pollution due to lack of advanced technology and waste management.

Thus, this paper provides a remanufactured alternator as a case study to test the sustainable manufacturing framework for both assessing and improving the SMEs' remanufacturing auto parts in Indonesia and seeks to come up with the best solutions and strategies to overcome the aforementioned problems.

The model for sustainable manufacturing

Based on Figure 1, the steps for assessing the sustainability of remanufactured products are stated.

Firstly, the existing remanufactured products are assessed using the sustainable manufacturing criterion, including technical (i.e. reliability), economic (i.e. life cycle cost, sales) environmental (i.e. solid waste, GHG emission) and social aspects (i.e. employment opportunity, warranty). Secondly, the calculated values of these criterions are compared with the threshold values of the sustainability criterion. These threshold values are derived from the standard Indonesian and international literature discussing Indonesian and global remanufacturing issues. Examples of the threshold values of technical, economic, social and environmental aspects are reliability (99%), life cycle cost (50% cost of new product), warranty period (2 to 3 years) and greenhouse gas

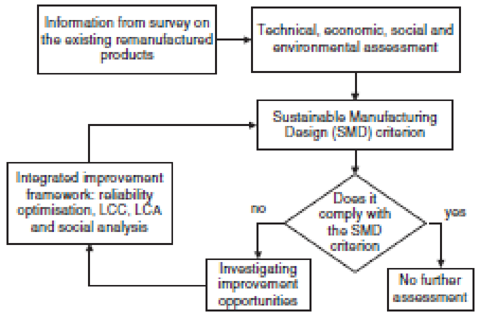

Figure 1 Model for sustainable manufacturing assessment.

emission (2.58 kg CO_2eq) which appeared in the remanufacturing sectors [23,24]. Remanufactured products not complying with any of these sustainability criteria are considered as unsustainable remanufactured product and are then redefined by investigating improvement opportunities through an integrated improvement framework involving reliability optimization, life cycle cost (LCC), life cycle assessment (LCA) and social assessment. The objective of this integrated improvement is to determine technically feasible solutions which are economically, socially and environmentally feasible and meet the sustainable manufacturing criterion. Figure 2 shows the detailed version of the integrated improvement framework.

Firstly, technical criterion involving reliability of the remanufactured products is assessed. Using this criterion, the material, method, man, machine, energy and information are analysed, and appropriate technical feasible solutions involving the best available technologies, processes, technical skills and energy and material consumption are proposed. Along with technical feasibility studies, LCA analysis of the technically feasible solutions is carried out following the ISO 14040–43 guideline [26] to determine environmental criteria including greenhouse gas (GHG) emissions and solid waste. If technically feasible solutions are not environmentally viable, 'hotspot' or the process producing the most pollution is identified to apply mitigation strategies (e.g. cleaner production, eco-efficiency, green technology and industrial symbiosis).

These two analyses are carried out simultaneously until both technically feasible and environmentally friendly solutions are obtained. Once technically and environmentally feasible solutions are obtained, the socio-economic viabilities of these options are

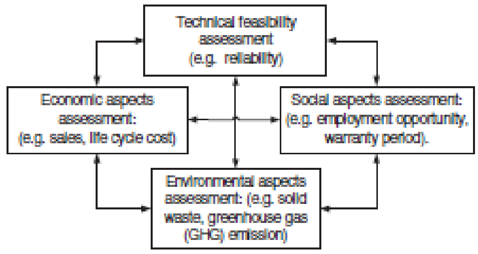

Figure 2 An integrated improvement framework.

assessed involving sales and life cycle cost assessments. The economic viability is attained when sales and life cycle cost are equal or greater than the threshold values. Similarly, social criteria such as employment opportunity and warranty period are required to meet the threshold value. If the revised version of technical option is not socio-economically viable, different socio-economic policies including rebate, subsidy and education are considered to attain socio-economic feasibilities.

Once technically, economically, socially and environmentally feasible solutions are determined, some appropriate institutional framework, including policy instruments, stakeholder responsibilities, key actions, targets and key performance indicator, are developed to implement sustainable manufacturing in SMEs. The institutional framework takes into account the constitution of direct (e.g. remanufacturer, supplier and consumer) and indirect (e.g. government, research institution and bank) stakeholders who participate in the decision-making process for sustainable remanufacturing.

The case study of remanufactured alternators

The existing situation of SME remanufactured alternators

A survey has been conducted in an SME producing remanufactured alternators in Central Java, Indonesia to test the proposed model and the framework. Remanufacturing operations have begun with a recovery process where alternators were collected directly from used alternator collection centres (e.g. service centre and auto junkyard). It should be notable that this research is limited to factory gate, and therefore, downstream activities such as customer satisfaction have been excluded.

In the factory line, disassembly is the first step where housing, stator, rotor, regulator, rectifier, brush and bearings are dismantled using simple tools and manual methods, and then all parts have been cleaned and dried by gas heating. Following this, testing including inspection and sorting of parts has been done for reconditioning on the basis of the reusability of parts. The reconditioned and new parts have been reassembled to make the remanufactured alternator. The alternator was tested before they were packed and ready to be delivered to the customer. The assessments of the existing remanufactured alternators have been done in the following ways.

Technical assessment

In this case study, the number of alternators that failed in 3 years (2008 to 2010) was 3,838. Failure of alternator components happened mainly due to failure of regulator (63.68%), followed by rectifier (13.25%), brush (11.97%) and other components such as stator and rotor (11.11%).

The reliability of the remanufactured alternator was calculated using the Weibull ++8 software. Intensive data including failure identification of the alternator, time of failure of the alternator and sales of the alternator were identified. The purchasing date, failure date and failed parts were collected to determine the time to failure. Data related to the number of failed alternators, suspended alternators and status (e.g. failure/F or suspended/S) were also involved to get the valid reliability result of the remanufactured alternator. Based on the calculation using Weibull distribution, the Weibull reliability plot in Figure 3 presents the shape parameter (β) which was 2.4 and the scale parameter (η) which was 1,288 days.

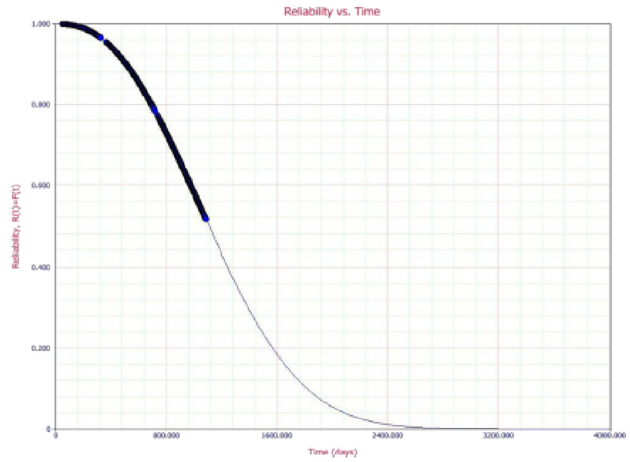

Figure 3 The reliability vs. time of the remanufactured alternators.

However, the reliability of new product is 100% in the early part of its life and gradually declines during its lifetime [8]. The mean time to failure of the alternator was 1,142 days, and the reliability model of the remanufactured alternator is presented in the following equation:

$$R(t) = exp\left[-\left(\frac{t}{1288}\right)^{2.4}\right] \quad (1)$$

The threshold value of the remanufactured alternator reliability is estimated to be about 99% which is close to 194 days (6.5 months), while the reliability of the remanufactured product in 1 year is 95%.

Economic assessment

The lack of investment on SMEs, inefficiency and ineffective production and the lack of quality and reliability made difficult situations for the SMEs to compete in the global market. This can be seen in the sales performance of the SMEs which showed that the number of sales decreased gradually from 2008 to 2010. In 2009, the sales decreased by 7.20% and dropped again in 2010 by 21.7% which led to a financial crisis in the SMEs.

The life cycle cost analysis of the remanufacturing process that includes the cost of product recovery, disassembly, cleaning and washing, inspection and sorting, reconditioning, replacement, reassembling, final testing, packaging and warranty have been performed. The acquisition cost was not considered in this LCC because the remanufacturing process used old infrastructure and machinery.

Based on the calculation done, the unit cost of the remanufactured alternator product was 183,000.00 IDR (USD = 9,700 Indonesian Rupiah (IDR) in 2010). The threshold value of LCC that was used to evaluate the economic criterion of the remanufactured product was 50% of the new product [25]. The breakdown of the remanufacturing operation costs of the alternator is shown in Figure 4. The product recovery cost contributed the largest portion (34.84%) of total unit cost, followed by replenishment cost

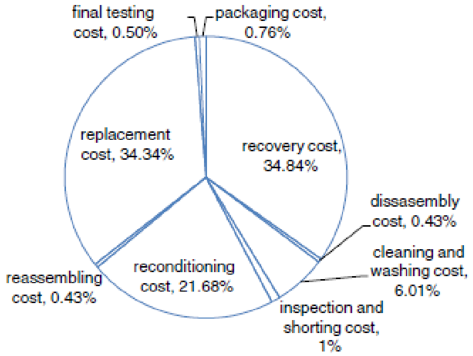

Figure 4 The life cycle cost of the remanufactured alternator.

(34.34%), reconditioning cost (21.68%), cleaning and washing cost (6.01%), inspection and shorting cost (1%), packaging cost (0.76%), final testing cost (0.50%), reassembling cost (0.43%) and disassembling cost (0.43%).

Social assessment

Warranty is one of the key social indicators of remanufactured product which represents an industry for its corporate social responsibilities [27]. The warranty of remanufactured product is proposed to maintain the performance of the product to be as good as new, which offers a social benefit to the customer. However, the remanufactured alternator SMEs could only provide a 1-year warranty against a 2- to 3-year warranty for new alternators. The next social indicator is employment opportunity because a higher employment opportunity could alleviate poverty and enhance social equity by reducing the gap between the rich and the poor [28]. The survey conducted in the SMEs' remanufacturing alternators found that they could hire nine to ten employees per year. However, the financial crisis faced by the SME has decreased the number of employee to about 24% per year in 2008 to 2010.

Environmental assessment

Environmental assessment includes the determination of solid waste and GHG emissions. After the disassembling, washing and testing processes, 59% of components are reused, 22% of components are replaced with used component and 19% of components are replaced with new components. Therefore, the remaining parts have been categorised as solid waste. About 41% (0.83 kg) of the parts have been replaced with used and new parts consisting of steel (24%), cast iron (26%), copper (33%), plastic (11%) and carbon (1%). The threshold value used to evaluate the solid waste contributed from the remanufactured alternator was 21% [24].

The GHG emission was calculated using an LCA software known as Simapro 7.3 [29]. As the remanufacturing processes were conducted in Indonesian SMEs, Indonesia's emission factors for electricity generation were used to determine the CO_2 equivalent emission from the remanufacturing process. The emission from the production of new components which replaced the worn-out components had also been

Table 1 The existing situation and the threshold value

Assessment	KPI	Threshold value	Existing situation	Yes/No
Technical	Reliability	99%	95%	No
Economic	LCC	172,500 IDR	183,000 IDR	No
	Sales	Increase	Decrease 21.70%	No
Social	Employment opportunity	Increase	Decrease 24%	No
	Warranty	2 to 3 years	1 year	No
Environment	Solid waste	0.43 kg	0.83 kg	No
	GHG emission	2.58 kg CO_2eq	5.98 kg CO_2eq	No

considered. GHG emissions associated with transportation for product recovery and shipment of new components from China to Indonesia were estimated using emission factors obtained from the Simapro 7.3 software database. The results show that the remanufactured alternator contributed 5.98 kg CO_2eq of GHG emissions, while the threshold value of the GHG emissions was 2.58 kg CO_2eq for a remanufactured alternator [24]. Table 1 represents the existing scenario of the remanufactured alternator in comparison with the threshold values.

The result indicates that the remanufactured alternator industry does not comply with the SMD criterion as all key performance indicators do not satisfy the threshold value.

The integrated improvement framework

The processes, material, labour and machinery from the existing situation were assessed using the sustainable manufacturing framework to determine the best possible technical solution meeting the sustainability criteria (or threshold values).

Scenario I

In this scenario, the technical feasibility of the replacement of all worn-out components (41%), including voltage regulator, rectifier, insulator, brush, bearings, pulley and rotor, with original equipment components was assessed in order to increase the reliability of the alternator. This means that 22% of the components, which were previously replaced with the used components, have now been replaced with new components.

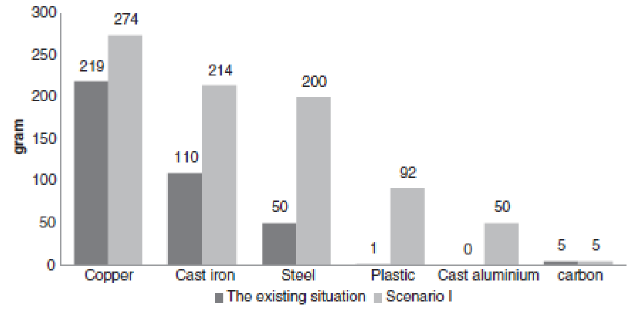

Figure 5 The materials used in the existing situation and scenario I.

Table 2 The environmental impacts of scenario I

	GHG emission (kg CO_2eq)	Solid waste (kg)
Existing situation	5.98	0.83
Threshold values	2.58	0.43
Scenario I: replacement with new components	14.6	0.83

The reliability of the alternator in scenario I was assumed to be the same as a new alternator because this scenario had considered the use of new parts instead of reconditioned parts. However, some key information such as time to failure, failure data and suspension data associated with the use of new components could have been considered in order to calculate the exact value of reliability of the improved version, but this was beyond the scope of this paper. Figure 5 shows the comparison of material intensities between the existing situation and scenario I.

The environmental impact assessment for scenario I in Table 2 shows that the replacements of worn-out components with new ones do not satisfy the threshold value of the environmental indicators, so an alternative scenario (scenario II) was conducted.

Scenario II

This scenario involves the use of recycled components. The following assumptions and considerations were applied to this scenario:

- The components including housing and pulleys have been reconditioned. The only recycled item considered was the coil of stator and rotor.
- The use of recycled components could reduce the GHG emission to about 83% and waste to about 88% [24].
- Since the brush and plastic cannot be recycled in an economically viable way, they were assumed to be sent to a landfill.
- The electricity consumption for reconditioning, recycling and transportation was considered for assessing environmental aspects of this mitigation strategy [24,30].
- It was assumed that there is a collaboration between the remanufacturing SMEs and the recycling industry to exchange worn-out and recycled components.

Table 3 shows that the technical and environmental criteria have been met by applying scenario II. The next step was to assess the socio-economic viabilities of the remanufactured alternator.

Table 4 shows that the LCC (170,600 IDR) of scenario II had met the threshold value (172,500 IDR). Following Cook and Ali [31], the reliability of the remanufactured alternator was assumed to increase the customer's satisfaction by 0.2%. This means that the increase in market response was predicted to increase the sales of the remanufactured

Table 3 The technical aspect and environmental impact assessment of scenario II

	Reliability (%)	GHG emission (kg CO_2eq)	Solid waste (kg)
Existing situation	95	5.98	0.83
Threshold values	99	2.58	0.43
Scenario II: replacement with recycled components	99	2.48	0.10

Table 4 The socio-economic analysis of scenario II

Indicator	Existing situation	Scenario II	Threshold value
LCC[a]	183,000 IDR	170,600 IDR	172,500 IDR
Sales	Decrease by 21.7%	Increase by 0.2%	Increase
Warranty	1 year	2 years	2 to 3 years
Employment opportunity	Decrease 24%	Increase 0.3%	Increase

[a]LCC analysis was calculated based on the additional variable cost for replacement (15,000 IDR), sustaining cost (237,000 IDR) and cost saving (61,000 IDR).

alternator by about 0.2%, which had in turn increased the employment opportunity by around 0.3%. The warranty period of a remanufactured alternator was considered to be the same as that of a new alternator. The increase in reliability was expected to extend the warranty period and to reduce warranty cost. Nominal customer's risk analysis was used to assess the warranty of the remanufactured alternator. Based on this analysis, the warranty of the proposed scenario was about 2 years which is the same as the threshold values.

However, these strategies can only be applied through the implementation of appropriate policies by the Government of Indonesia and stakeholders' involvement. Socio-economic policies, including rebate, subsidy and education, are some possible policy instruments. In addition, the stakeholder responsibilities, key actions, targets and key performance indicators can be developed to implement the mitigation scenario for attaining sustainable manufacturing.

Conclusions

The development of sustainable manufacturing is a great challenge for Indonesian SMEs. Remanufacturing has the potential to achieve sustainable manufacturing in Indonesian SMEs. This research proposes a sustainable manufacturing assessment model and integrated improvement framework to address socio-economic and environmental objectives of remanufacturing SMEs. Following the integrated sustainable framework, it was found that the existing remanufacturing operation in Indonesian SMEs is unsustainable. The use of recycled components in the remanufactured alternator could help attain the threshold values for sustainable manufacturing, including reliability (99%), GHG emission (2.48 kg CO_2eq), solid waste (0.10 kg), LCC (170,600.00 IDR), sales (increase 0.2%), warranty period (2 years) and employment opportunity (increase 0.3%). Last but not least, an institutional framework, including remanufacturers, suppliers, consumers, government, research institutions and financial institutions, needs to be established in order to promote sustainable manufacturing strategies in Indonesian SMEs.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
YAF collected data, carried out literature review, conducted technical, environmental, economic and social analyses and finally completed this manuscript. WB reviewed the environmental, economic and social analyses. IM and MNI reviewed the technical analysis and participated in the consultation process. All authors read and approved the final manuscript.

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Appendix B – Research ethic approval

Curtin University

Memorandum

To	Yun Arifatul Fatimah, Civil & Mechanical Engineering
From	Pauline Howat, Administrator, Human Research Ethics Science and Mathematics Education Centre
Subject	Protocol Approval **SMEC-17-11**
Date	14 April 2011
Copy	Wahidul Biswas, Civil & Mechanical Engineering

Office of Research and Development

Human Research Ethics Committee

Telephone 9266 2784
Facsimile 9266 3793
Email hrec@curtin.edu.au

Thank you for your "Form C Application for Approval of Research with Low Risk (Ethical Requirements)" for the project titled *"The prospect of remanufacturing for attaining sustainable industrial development in Indonesia"*. On behalf of the Human Research Ethics Committee, I am authorised to inform you that the project is approved.

Approval of this project is for a period of twelve months **1st April 2011** to **31st March 2012**.

The approval number for your project is **SMEC-17-11**. *Please quote this number in any future correspondence*. If at any time during the twelve months changes/amendments occur, or if a serious or unexpected adverse event occurs, please advise me immediately.

Pauline

PAULINE HOWAT
Administrator
Human Research Ethics
Science and Mathematics Education Centre

Please Note: The following standard statement must be included in the information sheet to participants:
This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number SMEC-17-11). If needed, verification of approval can be obtained either by writing to the Curtin University Human Research Ethics Committee, c/- Office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth, 6845 or by telephoning 9266 2784 or hrec@curtin.edu.au

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CRICOS Provider Code 00301J

Appendix C – Sample calculation of indicators

C1: Sample calculation of technical indicators

Step 1: The first step was to collect information including purchasing date, failure date, failed components, failure identification and state in time (days) from the Javanese SEs to determine reliability and durability of the remanufactured alternator. The types of raw data are presented in Table C1.

Table C1 Raw data required to calculate reliability and durability

Model	Purchasing date	Failure date	Failed component	Failure Identification	State in time (days)
A-IRIF70	01/1/2008	05/4/ 2008	Regulator	Doesn't work	95
A-IRIF70	01/1/2008	1/4/ 2009	Rectifier	Doesn't work	457
A-IRIF70	01/1/2008	31/12/2011	-	-	1461
A-IRIF70	01/1/2008	31/12/2011	-	-	1461
A-IRIF70	01/1/2008	08/3/2010	Brush	Wear out	798
A-IRIF70	01/1/2008	10/6/2010	Rectifier	Doesn't work	922

Step 2: The number of state (unit), state (failure or suspended) and time (days) were determined using the raw data in Table C1, and then they were inserted into Relia ++ software to calculate reliability. Table C2 only shows 6 sets of data as examples. However, in an actual case, more than 8,000 sets of data were used to calculate the reliability.

Table C2 Type of data required for the Relia ++ software

ID	Number of state (unit)	State (Failure or Suspended)	Time (day)
A-IRIF70	1	F	95
A-IRIF70	1	F	457
A-IRIF70	1	S	1461
A-IRIF70	1	S	1461
A-IRIF70	1	F	798
A-IRIF70	1	F	922

Step 3: Once all failure and suspended data were inserted into the Relia ++ software, the maximum likelihood estimation (MLE), Fisher Matrix and median rank methods were applied to calculate the failure rate and reliability (Figures C1 and C2).

Figure C1 Failure rate of remanufactured alternator

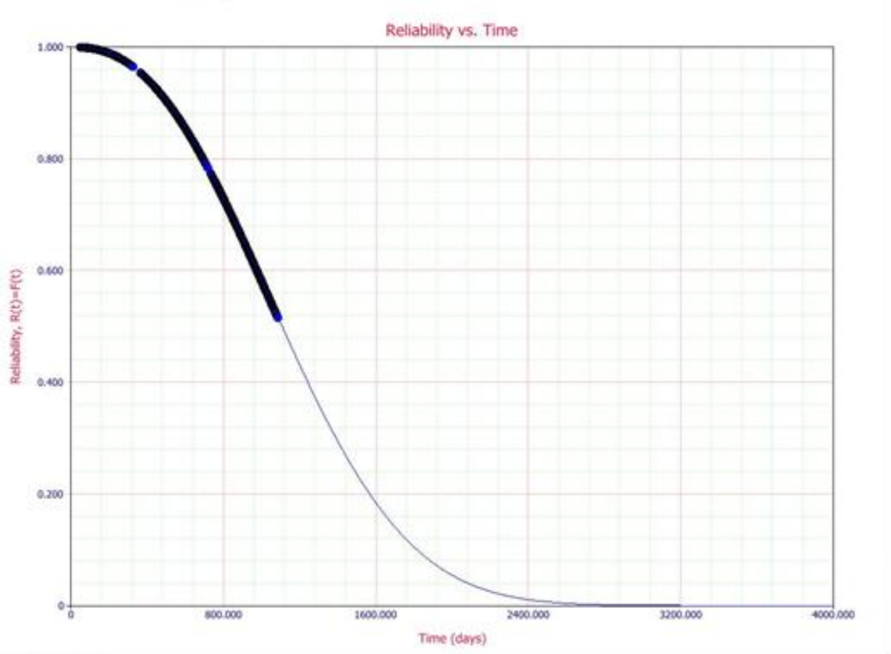

Figure C2 Reliability of remanufactured alternators

Step 4: The results obtained from the relia ++ software showed that the shape parameters (β), which were failure mode, were around 2.4, while the scale parameters (α), which were alternator life, were about 1,288 days. From this result, the mean time to failure of the remanufactured alterantor was found as 1,142 days which result to about 78% of reliability. Following this, the information on the reliability (78%) was incorporated into the software to determine the value of durability which was 2 years.

C2: Integration of series and paralel systems for determining reliability

The reliability of the improvement scenario was estimated based on the series and paralel relationships using different reliability for each component of alternators. Using Figure 6.1 in Chapter 6, a sample of reliabiliy calculation of the remanufactured alterantor has been presented below.

Step 1: The reliability of series subsystems have been calculated in the following way

$R_{series1}$= R(rotor shaft) * R(field winding) * R(finger poles) * R(bearing) * R(slip) * R(rings) * R(fans)

R(0.97)*R(1)* R(0.99) * R(1) * R(1) * R(1) * R(1) = 0.96

$R_{series\ 2}$= R(laminated iron frame) * R(three phase winding) * R(stator lead and neural junction)

R(0.97) * R(1) * R(0.99) = 0.96

$R_{series\ 3}$= R(carbon brush) * R(bosh holder) * R(insulator)

R(1) * R(0.99) * R(0.99) =0.98

Steps 2: Using the calculated values of series subsystems, a number of parallel sub systems have been calculated in the following way

$R_{paralel\ 1}$=	R(front case) and $R_{series1}$ = R(front case) + $R_{series1}$ (R(front case) * $R_{series1}$) = 0.98 +0 .96 (0.98 * 0.96) = 0,999
$R_{paralel\ 2}$=	$R_{series\ 2}$ and R(rear case) = $R_{series2}$ +R(rare case) - ($R_{series2}$ * R(rare case)) =0.96 + 098 – (96 * 98) = 0.999
$R_{paralel\ 3}$=	$R_{series\ 3}$, R (rectifier) and R(IC regulator) = $R_{series\ 3}$ + R(rectifier) + R(IC regulator) – ($R_{series\ 3}$ * R(rectifier)) - ($R_{series\ 3}$ * R(IC regulator)) – (R(rectifier) * R(IC regulator) + $R_{series\ 3}$ * R(rectifier) * R(IC regulator)

	= 0.98 + 1 + 1- (.98*1) - (.98*1) – (1*1) + 98%*1*1 = 1
R($R_{series\ 3}$ and $R_{paralel\ 2}$) =	= $R_{series\ 3}$ * $R_{paralel\ 2}$ = (0.1%)*(0.99%) = 99%

Finally the reliability of the alternator system have been calculated below

$Q_{paralel\ total}$ = $R_{paralel\ 1}$ * R($R_{series\ 3}$ and $R_{paralel\ 2}$) * R(bolt and nuts) * R(pulley) * R(pulley holder) * R(fan)

= 0.999 * 0.99 * 1 * 1 * 99 * 99 = 97.9

C3: Determination of GHG emissions and embodied energy consumption

The values of environmental indicators (i.e. embodied energy saving, GHG emission).have been calculated using life cycle assessment (LCA) analysis. The outputs of the Simparo 7.33 software have been presented in Tables C3 and C4.

Table C3 The embodied energy consumption outputs from Simapro 7.33 software

Calculation:	Analyse
Results:	Impact assessment
Product:	2.2 kg LCA - remanufactured alternator
Method:	Cumulative Energy Demand - with breakdowns V2.00 / Energy by fuel source
Indicator:	Single score
Unit:	MJ

Impact category	Unit	Total	LCA remar	Disaasembly	Final testing	Inspection and so	Recondition	Replacement	Washing	Reassembly	Product recovery
Total	MJ	116.10267	0	1.0566252	0.55472823	0.55472823	12.796116	79.657512	16.713673	1.6096536	3.1596361
Electric. (del)	MJ	0	0	0	0	0	0	0	0	0	0
Elec Conv Losss	MJ	0	0	0	0	0	0	0	0	0	0
Fuel extra& del	MJ	0	0	0	0	0	0	0	0	0	0
Process heat	MJ	0	0	0	0	0	0	0	0	0	0
Transport	MJ	0	0	0	0	0	0	0	0	0	0
Mechanical	MJ	0	0	0	0	0	0	0	0	0	0
Feedstock	MJ	0	0	0	0	0	0	0	0	0	0
_	MJ	0	0	0	0	0	0	0	0	0	0
Renewables	MJ	7.856177	0	0.060871728	0.031957657	0.031957657	0.30918736	7.1149303	0.29604342	0.011228871	0
Fossil fuels - oil	MJ	40.221777	0	0.38914338	0.20430027	0.20430027	5.666816	16.567516	12.872419	1.3569594	2.960322
Fossil fuels - gas	MJ	28.089752	0	0.096051272	0.050426918	0.050426918	1.9174459	25.235986	0.46760894	0.11391415	0.15789197
Fossil Fuels - coal	MJ	31.257067	0	0.50467741	0.26495564	0.26495564	2.6268353	25.044019	2.4570702	0.094553727	0
Fossil fuels - other	MJ	0.016688682	0	0	0	0	0.016688682	3.25E-13	0	0	0
Biomass	MJ	0.25923047	0	0.000205579	0.000107929	0.000107929	0.013333728	0.24314931	0.00106518	0.001108631	0.000152187
Nuclear	MJ	7.6747695	0	0.005675845	0.002979819	0.002979819	2.1760812	5.3844286	0.029465477	0.031888743	0.041269988
Other/Unknown	MJ	0.72721098	0	0	0	0	0.069727946	0.067483036	0.59	0	0
__	MJ	0	0	0	0	0	0	0	0	0	0
Embodied energy LHV	MJ	0	0	0	0	0	0	0	0	0	0
Embodied energy HHV	MJ	0	0	0	0	0	0	0	0	0	0

Table C4 The GHG emissions outputs from Simapro 7.33 software

Calculation:	Analyse										
Results:	Impact assessment										
Product:	2.194 kg LCA remanufacturing SCENARIO I OK (of project LCA of remanufactured alternator)										
Method:	IPCC 2007 GWP 100a V1.02										
Indicator:	Characterisation										
Unit:	%										
Skip categories:	Never										
Exclude infrastructure	Yes										
Exclude long-term em	No										
Sorted on item:	Impact category										
Sort order:	Ascending										
Impact category	Unit	Total	LCA remar	Disaasembly	Final testing	Inspection and so	Recondition	Replacement	Washing	Reassembly	Product recovery
IPCC GWP 100a	kg CO2 eq	6.360546	0	0.089359227	0.046913594	0.046913594	0.83495144	4.5696594	0.50194254	0.026648632	0.24415754

C4: The calculation of Material intensity per service unit (MIPS) indicator

$$MIPS = \frac{\sum WNM}{SR \times \sum T}$$

Where,

WNM : Weight of new material (kg) = 0.939 kg

SR : Service provided by remanufactured product (kWh) = 0.72 kWh

T : Total time for using the service (hours) = (6*360*4) = 8,640 hours

Therefore, MIPS (kg/kWh) = 0.151 kg/kWh

C5: The calculation of life cycle cost and recovered material value

Table C5 Life cycle cost analysis for existing scenario

Year	capital cost	inflation	training	energy	warranty	recovery	remanufacturing	overhead cost	disposal	total	saving	total after saving
1	$ 139,500.00	0.11		$ 5,340.00	$ 778.73	$ 24,021.08	$ 19,506.33	$ 1,950.63	$ 53.40	$ 191,150.17	$ 781.20	$ 190,368.97
2	$ -	0.087		$ 5,478.00	$ 798.86	$ 24,641.85	$ 20,010.42	$ 2,001.04	$ 54.78	$ 52,984.95	$ 801.39	$ 52,183.56
3	$ -	0.02		$ 5,880.00	$ 857.48	$ 26,450.18	$ 21,478.88	$ 2,147.89	$ 58.80	$ 56,873.22	$ 860.20	$ 56,013.02
4	$ -	0.09		$ 5,460.00	$ 796.23	$ 24,560.88	$ 19,944.67	$ 1,994.47	$ 54.60	$ 52,810.85	$ 798.76	$ 52,012.09
5	$ -	0.126		$ 5,244.00	$ 764.73	$ 23,589.24	$ 19,155.65	$ 1,915.56	$ 52.44	$ 50,721.63	$ 767.16	$ 49,954.47
6	$ -	0.1		$ 5,400.00	$ 787.48	$ 24,290.98	$ 19,725.50	$ 1,972.55	$ 54.00	$ 52,230.51	$ 789.98	$ 51,440.53
7	$ -	0.051		$ 5,694.00	$ 830.36	$ 25,613.49	$ 20,799.44	$ 2,079.94	$ 56.94	$ 55,074.17	$ 832.99	$ 54,241.18
8	$ -	0.064		$ 5,616.00	$ 818.98	$ 25,262.62	$ 20,514.52	$ 2,051.45	$ 56.16	$ 54,319.73	$ 821.58	$ 53,498.15
9	$ -	0.17		$ 4,980.00	$ 726.23	$ 22,401.68	$ 18,191.29	$ 1,819.13	$ 49.80	$ 48,168.14	$ 728.54	$ 47,439.60
10	$ -	0.066		$ 5,604.00	$ 817.23	$ 25,208.64	$ 20,470.68	$ 2,047.07	$ 56.04	$ 54,203.66	$ 819.83	$ 53,383.84
11	$ -	0.066		$ 5,604.00	$ 817.23	$ 25,208.64	$ 20,470.68	$ 2,047.07	$ 56.04	$ 54,203.66	$ 819.83	$ 53,383.84
12	$ -	0.111		$ 5,334.00	$ 777.86	$ 23,994.09	$ 19,484.41	$ 1,948.44	$ 53.34	$ 51,592.14	$ 780.33	$ 50,811.81
13	$ -	0.028		$ 5,832.00	$ 850.48	$ 26,234.26	$ 21,303.54	$ 2,130.35	$ 58.32	$ 56,408.95	$ 853.18	$ 55,555.77
14	$ -	0.07		$ 5,580.00	$ 813.73	$ 25,100.68	$ 20,383.01	$ 2,038.30	$ 55.80	$ 53,971.53	$ 816.31	$ 53,155.21
15	$ -	0.038		$ 5,772.00	$ 874.98	$ 25,964.36	$ 21,084.37	$ 2,108.44	$ 57.72	$ 55,861.86	$ 844.40	$ 55,017.46
16				$ 6,000.00	$ 874.98	$ 26,989.98	$ 21,917.22	$ 2,191.72	$ 60.00	$ 58,033.90	$ 877.76	$ 57,156.14
17	$ -	0.0838		$ 6,502.80	$ 948.30	$ 29,251.74	$ 23,753.88	$ 2,375.39	$ 65.03	$ 62,897.14	$ 951.31	$ 61,945.83
18	$ -	0.084		$ 6,504.00	$ 948.48	$ 29,257.14	$ 23,758.27	$ 2,375.83	$ 65.04	$ 62,908.75	$ 951.49	$ 61,957.26
19	$ -	0.084		$ 6,504.00	$ 948.48	$ 29,257.14	$ 23,758.27	$ 2,375.83	$ 65.04	$ 62,908.75	$ 951.49	$ 61,957.26
20	$ -	0.084		$ 6,504.00	$ 948.48	$ 29,257.14	$ 23,758.27	$ 2,375.83	$ 65.04	$ 62,908.75	$ 951.49	$ 61,957.26
Present value	$ 139,500.00		$ -	$ 114,832.80	$ 16,779.33	$ 516,555.80	$ 419,469.28	$ 41,946.93	$ 1,148.33	$ 1,250,232.47	$ 16,799.23	$ 1,233,433.24
Project life	20											
Discount rate	4%											
Present value	$ 1,233,433.24											
CRF	7.36%											
ALCC	$ 90,758.18											
LCC	$ 32.52											

The recovered material value has been calculated as follows:

$$RV = (UMC - URC) + C_{RC} - \ C_{DS}$$

Where,

$$URC = \sum_{i=1}^{n} (1/Y_I) \times C_i$$

UMC : Unit manufacturing cost (i.e. cost of new product) = USD 52.3/unit)

URC : Unit remanufacturing cost (USD/unit) = USD 32.5/unit

C_i : Remanufacturing process i = 7 processes

Y_I : Yield of process i(unit)

C_{RC} : Recovered material value (USD/kg) = 0.98 kg* 0.4 USD/kg

C_{DS} : Disposal cost (USD/unit) = USD 1.4

$$RV = (UMC - URC) + C_{RC} - \ C_{DS} = (52.3 - 32.5) + 0.39 - 1.4 = \text{USD}18.8$$