Chapter 8

I4R for Circular Economy: Transition Trends and Readiness of Indonesia – Textile and Electronic Sectors

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CHAPTER 8

Industry 4.0 Readiness for the Circular Economy: Transition Trends and Readiness of Indonesia's Textile and Electronics Sectors

Arie Rahmadi

Indonesia is the largest economy in the Association of Southeast Asian Nations (ASEAN) and responsible for one-third of its total gross domestic product (GDP). Around 257 million people live in the island nation. The population growth rate was 1.35% in 2014 but is expected to be lower in the future as the Government of Indonesia resumes its national family planning programme (BPS, 2015). The country comprises 17,508 islands and stretches over 5,000 kilometres, with Java and Sumatra as the main islands where the majority of the population resides. It has a large domestic consumption base that along with investment and government spending have been the main drivers of Indonesia's continued growth, which was estimated at 5.05 % for 2017 by the Bank of Indonesia. GDP was estimated at US$878.3 billion in 2014 (BPS, 2017), and economic activity tends to be focused in the Java-Bali region. Though endowed by abundant natural resources, the country is transitioning from being a commodity-exporting economy (majority oil and gas based) into one supported by domestic manufacturing and investment. Sound reforms and ambitious initiatives from the government to boost the growth of the manufacturing sector as well as achieve competitive labour costs in the manufacturing sector have been the main attractions for many foreign investors. Indonesia is, therefore, considered to be one of the region's investment destinations, with almost 75% of the Indonesian manufacturing output in 2017 coming from six main industries (Swedish trade and Investment Council, 2018). The largest industry is still the food and beverage industry, which accounted for almost one-third of the country's manufacturing output last year. This was followed by an 11% contribution from petroleum-related products; around 9% came from the automotive, chemical, and electronics industries; while the textile and apparel industry accounted for 6% of total output.

In the advent of the Industry 4.0 revolution, the use of advanced technologies, including cloud computing, cognitive computing, and the Internet of Things (IoT) has become a necessity. Countries with powerful manufacturing capabilities, such as China, have become more powerful. Many countries that are already struggling with manufacturing and relying heavily on outsourced work, are unfortunately going to fall even further behind. Developing countries such as Indonesia must become more proactive to avoid any adverse effects. In April 2018, the government therefore launched 'Making Indonesia 4.0', a roadmap to improve labour productivity and shift to value-added manufacturing in priority industries. By implementing Industry 4.0, the government aspires to accelerate Indonesia to become a global top-10 economy by 2030. This will allow the country to regain its net export advantage, drive the share of manufacturing in GDP and compete in terms of productivity, as a result of the advancement in technology and innovation (AT Kearney, 2017).

Amongst ASEAN countries, unfortunately, Indonesia is currently in the 'nascent', or third, stage of adoption of the Fourth Industrial Revolution – at the same level as Viet Nam and Cambodia. Thailand and the Philippines are in the 'legacy', or second, stage, while Singapore and Malaysia are already in the 'leading' stage. The Indonesian government has decided to focus on five main industries, selected based on two criteria. The first criterion is the feasibility of implementation with respect to infrastructure conditions within the industry, as well as manufacturers' readiness to adopt new technologies. The second criterion is based on the projected impact defined by the contribution to GDP growth that the implementation of Industry 4.0 reforms would have on the industry. Based on these two criteria, the food and beverage, chemical, automotive, electronics, and textile and apparel industries have been selected as the focus industries for the roadmap. Together, these industries accounted for almost two-thirds of the total manufacturing output in 2017.
In the meantime, Indonesia has committed to achieving the Sustainable Development Goals by initiating the implementation of the 'circular economy' (Ministry of

Environment and Forestry, 2018). This type of economy in general terms is used for industrial process and business models that optimally improve resource efficiency and reducing waste. The principle thinking is commonly known as 5R: reuse, repair, redistribute, refurbish, and remanufacture. The circular economy is, therefore, considered a driver for envisioning sustainable industry while Industry 4.0 provides the driver for circular innovation (Venkatachalam and Kimura, 2018, p.12). This is being carried out by developing policies to encourage a circular economy that ensures that sustainable consumption and production are implemented in business cycles and business processes.

While the circular economy remains relatively outside the mainstream, the seeds of the circular economy have been manifested in various notable activities, including sustainable oil palm production and solid waste management (GAPKI, 2016). As in other ASEAN countries, Indonesia's resource-use policy is still typically based on 3R: reuse, reduce, recycle. The circular economy is expected to add upstream measures (in product design, for example) to this 3R principle. The case of implementing circular economy principles in the palm oil industry is also limited to this 3R principle, and it is simply about economics and competitiveness as well as international pressure and cooperation from both concerned countries and multinational companies. The activity of palm oil production during its life cycle has the potential to use resources for producing valuable products while minimising waste and even converting waste into energy.

For solid waste management, the full life cycle from cradle to cradle is possible in the case of auto scrap for the steel industry, tires and upholstery (plastic materials), and glass materials for the glass industry, as well as campaigns for the re-use of plastic bags and municipal solid waste management (Ministry of Industry Environment and Forestry, 2018). Although awareness of recycling is not very high in Indonesia, the recycling business is thriving and employs a significant number of people. Again, the circular economy thrives when there is significant profit that can be gained in the life cycle process of goods. It is unsurprising that the countries and regions that have developed circular economy policies and programmes have done so largely because of natural resource scarcity and/or environmental pressures.

Developing a circular economy is essential in order to foster sustainable economic growth and generate new jobs. The attractiveness and the necessity of the circular economy model lie in the fact that it offers solutions to volatile material costs, issues of security of supply for certain crucial raw materials, and increasing costs of managing waste appropriately while minimising the negative environmental impacts associated with the current linear production model. As in the case of palm oil production, increased resource efficiency and circular economy solutions will improve the competitiveness of companies and create new growth opportunities in green markets domestically and abroad.

This arguably contributes to the current lack of recognition of the opportunities for Industry 4.0 to catalyse circular growth. While ASEAN countries are no doubt developing progressive policies with respect to environmental management and resource efficiency, policymakers are not yet seriously regarding the circular economy as a new industrial paradigm. In the absence of such compelling external policy drivers, elevating the circular economy discourse to a national or regional priority may be a challenge, particularly as Indonesia is concerned more with its economic growth. According to Ramanathan (2018), the four clusters of ASEAN nations to enter the Industry 4.0 ecosystem would be as follows: Singapore and Malaysia are considered as 'potential innovators'; while Indonesia, the Philippines, and Thailand are placed in the 'efficiency seekers' category; Viet Nam is a transitional nation; and countries such as Cambodia, the Lao People's Democratic Republic (Lao PDR) and Myanmar are considered as 'slow movers'.

Connecting Industry 4.0 and the concept of the circular economy is, therefore, a vision that could potentially achieve new gains in productivity and efficiency (Wyes, 2018). As such, the Government of Indonesia should connect the frameworks of Industry 4.0 and circular economy principles in theory, practice, policy initiatives, and research programmes. Given these opportunities, it is, therefore, important to evaluate the Industry 4.0 readiness profile at the level of the firm and the sector. As Indonesia is focusing on five sectors, this study is limited to cover two sectors, i.e. the electronics and textiles industries.

1. What is the Industry 4.0 Readiness Profile of the Firm and the Sector?

Using the framework developed in the previous chapters and later presented in Appendix 1 and Appendix 2, a survey of the Industry 4.0 readiness profile of the firms and sectors was conducted. The results are presented in the next sub-sections, with PT Siemens Indonesia representing the electronics industry, while various textile experts were considered to represent the textile industry.

1.1. Siemens Indonesia – the Energy Management Division

PT Siemens Indonesia dates back to 1855, when the company supplied 10 telegraph machines. Their first office was established in Surabaya, East Java, in 1909 (Siemens, 2018a). Today, the company continues to be a reliable technology partner in Indonesia, offering a wide range of solutions and services with a focus on the areas of electrification, automation, and digitalisation. The company also offers a comprehensive portfolio of seamlessly integrated hardware, software, and technology-based services to enhance the flexibility and efficiency of manufacturing processes and reduce time-to-market.

As the trusted partner for the development and extension of an efficient and reliable power infrastructure, the Energy Management Division provides utility companies and industries in Indonesia with a portfolio that meets their needs. This includes facilities and systems for the low-voltage and distribution power grid level, smart grid and energy automation solutions, power supply for industrial plants, and high-voltage transmission systems (Siemens, 2018b).

The Energy Management Division of PT Siemens Indonesia serves Indonesia and the whole ASEAN region with more than 500 employees and 100 engineers. Their capabilities include:

- Project management all over the Siemens Energy Management Division value chain
- ASEAN Center of Competence for Engineering of High-Voltage Substations, Energy Automation, Relay Control System, Medium and Low Voltage Systems

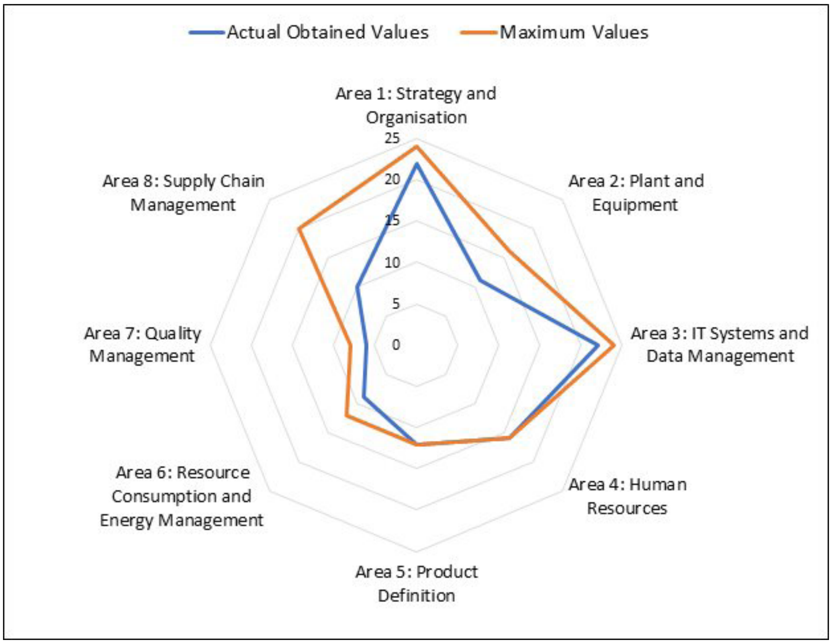
- ASEAN Proposal and Project Execution Hub from Low Voltage to High Voltage.
- Installation, commissioning, and after-sales service for the whole Siemens Energy
- The division has its factory at Pulomas Jakarta and it was established in 1975. The Pulomas factory is the oldest manufacturing facility of Siemens in Indonesia, and it is used for manufacturing, assembly, wiring, testing, and maintenance workshops. It has a total area of 24,300 square metres with a 7,500 square metre production facility and employs more than 360 employees with around 80 engineers. The factory has now become the Siemens regional production hub for air-insulated medium voltage systems of up to 24 kilovolts and for low voltage systems serving the international and Indonesian markets.
- As part of the Siemens International subsidiary, PT Siemens Indonesia has been implementing the Industry 4.0 programme. The drive is mainly to align with the overall corporate strategy of Siemens, and the Pulomas factory is obliged to follow suit. The interview was conducted in the factory and two duty managers were available for that session. The results are presented in the following Table 8.1, Figure 8.1, and Figure 8.2.

Table 8.1: Industry 4.0 Readiness Survey Results for the PT Siemens Indonesia Pulomas Factory

Rating Classification	Actual Obtained Value	Maximum Value	Readiness Classification	Rating
Industry 4.0 readiness	108	132	Expert front runners	0.82
Industry 4.0 readiness for the circular economy	48	56	Circular economy leaders	0.86
Circular economy-adjusted Industry 4.0 readiness rating				0.70

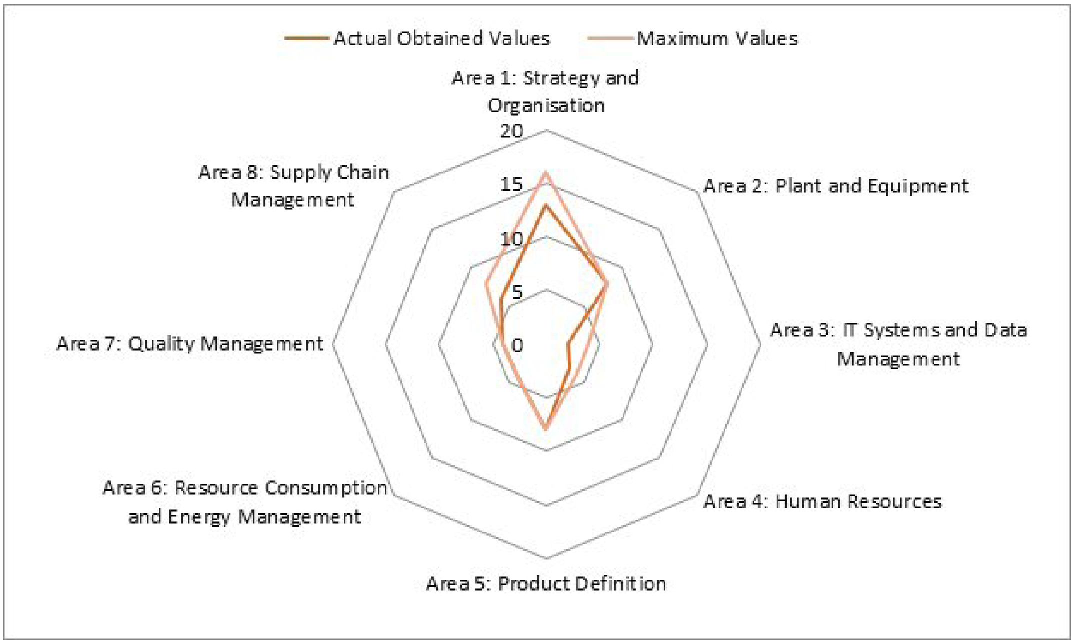
Source: Author.

Figure 8.1: Industry 4.0 Readiness for the PT Siemens Indonesia Pulomas Factory



Source: Author.

Figure 8.2: Industry 4.0 Readiness for Circular Economy for the PT Siemens Indonesia Pulomas Factory



Source: Author.

The Siemens factory is considered to be an expert front runner in terms of readiness for preparing for Industry 4.0. This is not surprising as Siemens International is amongst the companies championing the Industry 4.0 movement around the world. Siemens Indonesia has in fact offered Indonesian manufacturers to implement Industry 4.0 by offering their digitalisation enterprise services, which comprise software, industrial communication networks, security in automation, and business-specific industrial services. Through its digital factory division, PT Siemens Indonesia is promoting digital transformation using Siemens' open cloud platform, called MindSphere, particularly to the Indonesian food and beverage industry (Siemens, 2018c).

This will enable food and beverage enterprises to connect their machines and physical infrastructure to the digital world. It lets them harness big data from many intelligent devices, enabling the company to uncover transformational insights across the entire business. It also provides their customers and developers with the capability to develop applications and digital services, apply them, and make them available to other users to enable new services and business models.

Survey indicated that PT Siemens Indonesia has been classified as a circular economy leader, suggesting its Industry 4.0 readiness for the circular economy. It has strong points in the areas of resource consumption and energy management, in its product definition and facility plant and equipment. The human resources in the company are also well prepared for implementing Industry 4.0 for achieving the circular economy. They realise that implementing Industry 4.0 in their operations would save energy and reduce waste.

1.2. Textile Industry

The textile and textile products industry saw high growth from 2000 to 2013. The total Indonesian textile industry produced about 6.2 million tons of textile with a value equivalent to US$18.7 billion in 2014 (Susanti, 2017). It is an important industry in Indonesia as it contributed 1.2% to GDP, with exports valued at US$12.28 billion or 8.2% of the total Indonesian export value (API, 2016). A total of 5,273 companies in 2015 were recorded to work in the sector, and this accounted for the employment of about 1.51 million people. This has made Indonesia one of the leading textile exporters in the world (WTO, 2015) with the bulk of exports going to the United States

(32%), followed by Europe (14.6%), and Japan (9.8%) (API, 2015). The industry, however, remains labour intensive despite efforts to automate the manufacturing process.

Broadly speaking, the textile industry supply chain is comprised of three parts: the upstream sector, intermediate sector, and downstream sector. The upstream involves several industries, including fibres and threads. The characteristics of the upstream sector are relatively capital-intensive industries; high technological content; large in scale; using automatic machines; and having the greatest added value. Included in the intermediate sector are industries that produce fabrics, including weaving, knitting, printing, finishing industries that process semi-finished fabrics into finished fabrics, and the non-woven industry that processes fibres or yarn into cloth other than through the process of weaving or knitting. This sector is also capital intensive but employs more labour than the upstream sector with aspects of creativity in the printing segment, while adequate waste management is required in the dyeing segment. The downstream sector, meanwhile, includes industries that produce textile products for public consumption, including the apparel industry (garment), embroidery, garment manufacturing that includes the process of cutting, sewing, washing, and finishing that produces ready-made garments. This sector, in particular, is labour intensive.

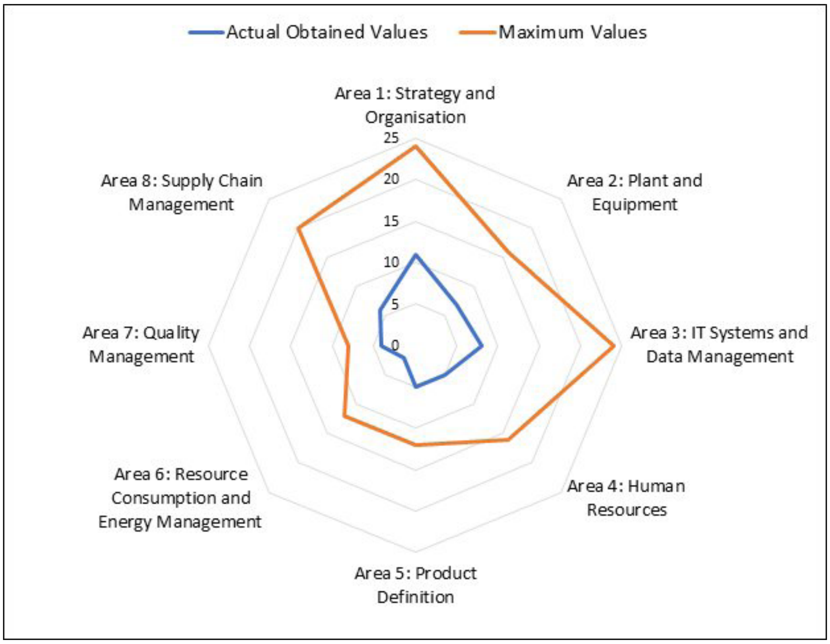
To evaluate the readiness of this industry toward Industry 4.0 for the circular economy, interviews were conducted with two textile industry experts in an office environment. The results are presented in the following Table 8.2, Figure 8.3, and Figure 8.4.

Table 8.2: Industry 4.0 Readiness Survey Results for the Indonesian Textile Industry

Rating Classification	Actual Obtained Value	Maximum Value	Readiness Classification	Rating
Industry 4.0 readiness	48	132	Potentialists	0.36
Industry 4.0 readiness for the circular economy	15	56	Circular economy beginners	0.27
Circular economy-adjusted Industry 4.0 readiness rating				0.097

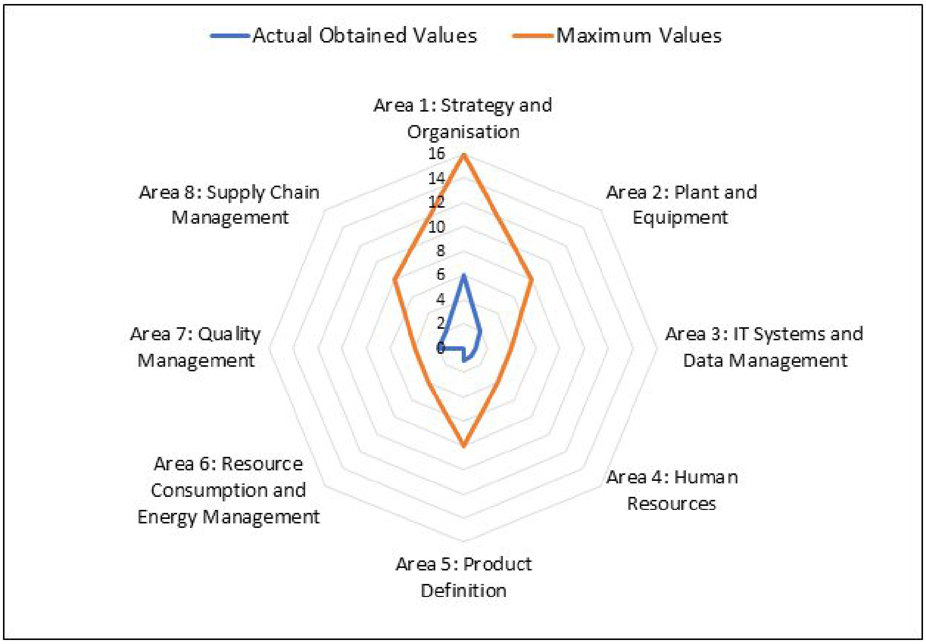
Source: Author.

Figure 8.3: Industry 4.0 Readiness for the Textile Industry



Source: Author.

Figure 8.4: Industry 4.0 Readiness for Circular Economy for the Textile Industry



Source: Author.

The textile industry is considered to be a 'potentialist' in terms of readiness to prepare for Industry 4.0. It has a score of 48 of a maximum value of 132. This is not surprising as the textile industry in general treats Industry 4.0 as of interest at the departmental level, but it is not explicitly incorporated into corporate strategy yet. The relatively low-level readiness was apparent in the interview when it came to information technology systems and data management. Digital data are only available in some departments and are only used for the purpose of evaluating the company's performance measurement system and selectively for remedial action (e.g. quality improvement). The readiness of this sector in terms of Industry 4.0 for the circular economy is classified as being a circular economy beginner, with a score of 15 from a maximum potential score of 56. The survey indicated that this sector has weak points in the areas of product definition, managing operations in term of resource consumption and energy consumption management, and the general facilities of the plant and equipment. The management and general employees in the textile industry are generally aware of the circular economy imperative, such as eco-innovations and textile design for the environment. They also have adopted new ways of working to support the industry's initiatives in adopting circular economy-based approaches. However, such awareness has not been extended to the suppliers, let alone the distributors and retailers of the textile industry. The drive in circular economy principles is to meet the regulatory requirements of the Green Industrial Standard (GIS) set by the Indonesian government. The standard is mainly to help textile and apparel manufacturers to meet demands and increase their competitiveness in global markets. Although GIS is voluntary in nature, the textile industry must treat it as a high priority for using natural resources to harmonise industrial development with environmental conservation.

2 . Why are there Gaps?

The gap in general lies in the lack of necessary digital infrastructure, such as high-speed fibre optics and cloud solutions to support new technologies. Although several potential benefits generated as a result of the Industry 4.0 concept have been recognised by management at the firm level and amongst government institutions, some supporting prerequisites must be fulfilled by the industry. The supporting needs include the availability of abundant, cheap, and continuous electricity sources, as well as the availability of internet network infrastructure with substantial bandwidth and wide coverage.

A lack of efficient transportation infrastructure exacerbates the implementation of Industry 4.0. This is partly due to Indonesia being a large archipelago country. This is a big problem for Indonesian logistics because the transfer of large goods between islands takes a long time and costs a lot. This certainly places additional shipping costs. Other problems arise due to inadequate infrastructure from damaged roads and the lack of ports for logistics ship docking. This risks the delivery of goods to distant destinations.

This inadequate infrastructure hampers PT Siemens Indonesia in fully preparing to adopt Industry 4.0 in its operations and become a full circular economy leader. It creates gaps specifically related to preparedness in the area of information technology system and data management and the area of supply chain management. Only some information within the IT system is available and easily accessible for incorporating CE principles. A lack of necessary digital infrastructure in general, such as high-speed fibre optics and cloud solutions to support new technologies, is the main cause for this gap. This has caused automation related to warehouse management, local supply chains, and local transportation that hinders the electronics industry in fully adopting the Industry 4.0 revolution and achieving its potential in the circular economy.

These gaps are not merely caused by PT Siemen Indonesia itself, but are caused more by the unprepared supporting infrastructure of its suppliers. This means their suppliers are not ready to implement fully Digital of Things. For the transportation of finished goods and raw materials, for example, the transport ordering is still done manually and carried out by a second-party supplier. Another reason is related to digital data management, which is only partially used for circular economy purposes. This is largely due to the principles of energy and material conservation, which are not popular and there are few incentives to follow them from both the government and the private sectors. Energy and materials conservation is usually driven by financial aspects. If there are sufficient incentives generated from the use of data for circular economy purposes, such efforts can easily be implemented.

Another gap in realising the circular economy in electronics is due to the non-existence of economically viable reuse and recycling infrastructure. The value of the materials in waste electrical and electronic equipment is unfortunately very low.

The quality and safety of the electrical and electronic products produced by PT Siemens Indonesia are paramount as they are widely used for power generation and transmission. Hence, they usually cannot use recycled materials, which are normally of a reduced quality.

In addition, the use of renewable energy is found to be expensive in the Indonesian case. Therefore, at the firm level, incentives to save more energy or buy electricity from renewable energy sources are rather elusive. Even though PT PLN as a local electricity supplier facilitates the scheme of power wheeling for those who want it, only some multi-national companies that are concerned with good corporate sustainability take advantage of the offer. However, if there were a financial advantage to be found in the scheme, then the use of renewable energy could easily be realised.

The specific gaps found in the textile industry are mostly related. A particular problem in the textile industry besides the problem of a lack of digital infrastructure and transportation is the fact that for certain sectors, especially the intermediate and downstream sectors, The manufacturing processis labour intensive. Human intervention is still very much needed, so automation work is rather difficult to implement.

In addition, there is concern from the leaders of textile companies about adopting Industry 4.0 for the circular economy in their operations. This is related to concerns that these efforts would significantly reduce the need for labour. Therefore, the leaders of textile companies always assure the public that adopting Industry 4.0 will not cause a reduction in employees, and even increase the efficiency and output of the manufacturing processes of companies engaged in the textile industry. Moreover, it is expected to generate new job opportunities, specifically those that need high competencies. This includes new types of worker, such as managers and digital data analysts, as well as professionals that can operate robot technology for industrial production processes.

3. What Trends Will Shape Future Opportunities?

There are several trends that will facilitate opportunities in the future. The first one is improvement in the infrastructure in the form of information and telecommunications infrastructure as well as transportation and energy infrastructure. The price of telecommunication bandwidth will become cheaper and the internet will be more accessible. In addition to improvements in the digital infrastructure, the Indonesian government is building many roads, seaports, and airports to improve freight logistics and people movement. A 35,000 megawatt electric power plant and transmission programme has been underway to provide electricity access. The Indonesian government has realised that providing opportunities for manufacturing companies in Indonesia to adopt Industry 4.0 will be possible if a basic infrastructure and environment are available and affordable.

Another trend is the growing financial technology in Indonesia. The number of internet users is growing, especially amongst young people. Indonesia now has the biggest number of internet users and the fastest growth amongst ASEAN countries (Asian Banking and Finance, 2018). This opens opportunities for e-commerce, online travel, online rides, and online media. These demographic and behavioural changes can be considered the most influential of all. The young, consuming middle-class in Indonesia should be receptive to digital banking and even fintech products. Moreover, a supporting regulatory framework to increase interoperability and interconnectivity between transaction channels has been in place. This can accelerate electronic payment adoption that later could facilitate the implementation of Industry 4.0 in Indonesia

In the textile industry, specifically in the segment of apparel production, there is a trend of made-to-order goods. Technological advances have created another alternative of the mass customisation for clothing. Sizing algorithms and e-commerce enable companies to offer a variety of designs and fits at only slightly more than similar off-the-rack prices. Levi Strauss & Co. helped lead the way with its 'personalized pair' programme in 1995 (Forte, 2018). 'Fast Fashion by Amazon' also offered a manufacturing system to support on-demand apparel-making (Danziger, 2018). Similarly, with artificial intelligence-based operations, Maison Me (Digital Trends, 2018) initiates services for clothing to order via video call, where later the order is produced in Maison Me's manufacturing facility in Arizona and the sartorial item is promptly shipped off to the customer in about two weeks. This trend along with an increase in demand for functional apparel, such as sports clothing, will require more advanced production methods.

In addition to these trends, the enactment of the Green Industrial Standard (GIS) for the textile industry is believed to encourage more companies to devise strategies to adopt the circular economy business model in stages. This came into effect under the Ministry of Industry decree no. 515/M-IND/Kep/12/2015 in December 2015. Moreover, textile companies that implement sustainability practices could open up bigger opportunities to expand markets globally as they attract customers and other stakeholders who are interested in environmentally sustainable products (Rusinko, 2007). The combination of GIS regulation and sustainability requirements from overseas textile buyers could create a future trend for business models that explicitly incorporate eco-innovation principles and demonstrate positive contributions towards the circular economy.

4. How Can Indonesia Prepare for the Transition?

As Indonesia currently does not possess adequate manufacturing capacity and relies on cheap labour to attract foreign investment, the topic of preparing for the transition is quite relevant. Several steps are therefore needed to be taken so that Indonesia can prepare to adopt Industry 4.0 for the circular economy. The first one would be increasing government funding to meet the increasing need to invest in digital and telecommunication infrastructure as well as infrastructure related to transportation and energy. For the electronic industry specifically, an improvement area would be research and development related to the design of electronic products, digital prototyping, and automation systems. In the textile industry would be improvements in the technology for sensor-based waste control systems, digital prototyping, and real-time productivity monitoring systems. Moreover, constructing data centres with sufficient storage capacity that are also safe and affordable will be essential for Industry 4.0. In addition, small and medium industries should also be encouraged to participate in capturing opportunities in the era of Industry 4.0.

Secondly, it is important to improve the quality of human resources as a lack of skilled labour combined with low productivity could cause Indonesia to lose its competitive edge. As was found in the survey, particularly in the textile industry, the lack of preparedness to embrace Industrial Revolution 4.0 is mainly due to a shortage of skills to compete in the digital age.It requires a transformation of the skills of Indonesian industrial human resources for the information technology sector. And a reorientation of the curriculum in higher education in which new literature (data, technology, and humanities) is developed and taught. Extra-curricular activities to develop leadership skills and team work should be implemented. Entrepreneurship and internships with relevant stakeholders to work together in a collaborative infrastructure should also be compulsory to establish life-long learning to realise the circular economy model. This infrastructure must include product designers and manufacturers, product users and asset managers, and participants in the reverse supply chain at the end of product use.

To facilitate the transition, the government has established a committee with responsibility for the implementation of the different measures. It has also been tasked with designing a programme for quick wins (Swedish Trade and Investment Council, 2018). One of them is the creation of an innovation development centre to integrated with the Apple Innovation Centre to enable the government to develop a strategic policy to spur the growth and competitiveness of the national industry. This would include creating suitable incentives and possible non-fiscal measures (Ministry of Industry, Indonesia, 2018).

In the electronics industry, the government is encouraging leading global manufacturers to invest in Indonesia so that they can gain advanced manufacturing capabilities beyond the assembling process. Thus, more skilled and innovative workers could be produced so that local companies can improve as new champions of Industry 4.0 for the circular economy. In the textile industry, this will be carried out by building upstream capabilities in high-quality materials, improving cost competitiveness through increased labour productivity and industrial zoning, being a leader in functional clothing, and scaling up production to meet the export and domestic markets. This is relevant as the majority of firms in the manufacturing sector are local small and medium-sized enterprises with limited technological adoption and underdeveloped domestic raw material processing facilities, which has resulted in a high dependency on imported raw materials for manufacturers.

In addition to those efforts, continued implementation of the GIS (Green Industrial Standard) in the electronics and textile industry is recommended. A study by Susanti (2017) on the Indonesian textile industry suggests that optimising efficiency in raw material consumption and energy can significantly reduce production costs and lead to an increase in company profitability in the long term. The immediate benefits of implementing sustainability programmes are increases in sales in global and domestic markets. Several top tier companies, such as PT Pan Brothers and PT Sritex, have a genuine interest in this revolution. The leadership in the electronics and textile industry has been convinced of the potential benefits that can be gained through the adoption of Industry 4.0 and has commenced piloting and developing an implementation plan

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Appendix 1-1:Framework for Assessing Industry 4.0 Readiness from Framework for Assessing the Status of Industry 4.0 Readiness in Manufacturing – PT Siemens Indonesia

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 1: Strategy and Organisation					
Extent of Industry 4.0 emphasis in strategy formulation and implementation	Industry 4.0 has not been considered at all	Industry 4.0 is of interest at the departmental level but is not explicitly incorporated into corporate strategy	Industry 4.0 is recognised as important and is being introduced at an elementary level into the strategy formulation process	An Industry 4.0 strategy has been developed and implementation is in progress in stages	An enterprise-wide Industry 4.0 strategy has been implemented and is being continuously reviewed and updated
Interfirm collaboration	There is no cross-functional collaboration, and the various departments adopt a 'functional silo' mentality	Some limited cooperation exists between the departments in areas such as sales and operations planning	Departments are willing to work together and share information, and the use of IT has facilitated this	Departments realize the value of cross-functional collaboration to improve performance and use IT-based interventions, such as ERP systems	Cross-functional collaboration is the norm and the use of IT-based interventions has enabled the extensive sharing of information
Critical allocation of funds for Industry 4.0 investment	Has not been considered at all	Funds are allocated selectively, and incrementally, when requested by a department	Seed funding has been allocated at a basic level	Investments have been made in selected areas	Enterprise-wide investments have been made
Measuring the impact of Industry 4.0 implementation	No key performance indictors (KPIs) exist	No KPIs exist that assess the status of Industry 4.0 implementation and/or the enhanced performance arising out of Industry 4.0 introduction	A preliminary set of KPIs exists that assesses the status of Industry 4.0 implementation and the enhanced performance arising out of Industry 4.0 introduction	A comprehensive set of KPIs is used to assess the status of Industry 4.0 implementation and the enhanced performance arising out of Industry 4.0 introduction	A comprehensive set of KPIs to assess Industry 4.0 implementation and impact has been formulated, is used enterprise-wide, and is integrated into the strategic planning process

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 1: Strategy and Organisation					
Leadership	Top management has not recognised the value of Industry 4.0 and adopts a 'business-as-usual' attitude	The leadership is making preliminary investigations into the feasibility of adopting Industry 4.0 and the potential benefits to be gained	The leadership is convinced of the potential benefits to be gained through the adoption of Industry 4.0 and has commenced piloting and developing an implementation plan	The leadership shows total commitment by being involved in implementation and following up through reviews and providing additional resources as needed	There is enterprise-wide support for Industry 4.0, and a culture of sharing lessons learned and disseminating the knowledge gained is prevalent
Innovation orientation	Traditional method of using a 'funnel of ideas' and selecting projects	Adoption of a technology-push model along the lines of the linear model of innovation	Identification of customer needs triggers innovation – adoption of a demand-pull approach	Adoption of 'open innovation' that incorporates knowledge from within the organisation and selected external entities	Supply chain-wide adoption of 'open innovation' incorporating knowledge from suppliers, customers, and other technology partners
Determinant 2: Plant and Equipment					
Plant and equipment readiness for Industry 4.0	Not suitable for an Industry 4.0 model	Will need substantial overhaul for Industry 4.0 readiness	Some of the plant and equipment can be upgraded for Industry 4.0 without disruption	Most of the plant and equipment meet Industry 4.0 requirements and the rest can be upgraded	Plant and equipment meet Industry 4.0 requirements
Machine and system infrastructure	Machines and systems cannot be controlled through IT	Some machines can be controlled through IT but there is no machine-to-machine (M2M) connectivity	Some machines can be controlled through IT and have M2M capability	All machinery can be controlled through IT and there is partial M2M	All machinery can be completely controlled through IT and have full M2M capability
Autonomously guided workpieces	No autonomously guided workpieces in use	Autonomously guided workpieces are not in use, but business cases for their adoption are being prepared for consideration	Autonomously guided workpieces are being piloted	Autonomously guided workpieces are used in selected areas	Autonomously guided workpieces are widely adopted with continuous improvements being made in their use

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 2: Plant and Equipment					
Maintenance of plant and equipment	Only breakdown maintenance	Breakdown maintenance kept to a minimum through preventive and periodic (time-based) maintenance	Predictive maintenance carried out along with retrofitting and/or modifying equipment to facilitate effective preventive maintenance	Maintenance prevention that focuses on the design of new equipment based on evidence-based studies of the weaknesses of existing machines	Total productive maintenance fully implemented and controlled by a cyber-physical system
Determinant 3: Information Technology Systems and Data Management					
Seamless system – integrated information sharing	No system-integrated information sharing	Some information sharing amongst departments through the use of IT	In-company information sharing through the use of IT and the selective use of enterprise resource planning (ERP) systems	There is comprehensive in-company system-integrated information sharing along with some external system integration	Complete and seamless in-company system-integrated information sharing along with substantial external system integration
Cloud usage	Not in a position to consider it due to lack of infrastructure and skills	Cloud solutions not used even though opportunities exist for use	Plans have been developed and some partial testing has been carried out using cloud-based software, data storage, and analysis	Cloud-based solutions have been implemented successfully in some areas of the business	Cloud-based solutions have been implemented successfully across most or all areas of the business
IT and data security	Not a concern and nothing has been planned	IT security as an important issue is recognised and preliminary steps have been taken for protection	IT security solutions have been implemented in multiple areas of the business	IT security solutions have been comprehensively implemented across the business and are constantly monitored for bridging gaps that arise with time	IT security solutions, with continuous upgrading, have been comprehensively implemented across the business and have been extended to cover data and information sharing with all relevant external partners

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 3: Information Technology Systems and Data Management					
Operations data collection for internal process improvement	No formal data collection system. Data are collected manually by departments for their own usage as needed.	Required data are collected digitally by some departments and data available are current.	Data are collected digitally by most departments	Comprehensive and automated structure across the enterprise for digital data collection; arrangements in place to acquire and share data digitally with some important supply chain partners	Comprehensive and automated structure across the enterprise and with all key supply chain partners to acquire and share data digitally
Operations data usage	Collected data are not integrated with the company's performance measurement system and are used mainly for reporting.	Collected data are made available for integration with the company's performance measurement system and are used selectively for remedial action (e.g. quality improvement)	Data are integrated with the company's performance measurement system and used for performance improvement (e.g. to reduce downtime, reduce inventory, improve capacity utilisation etc.)	Comprehensive integration with the company's performance measurement system; used for performance improvement, performance optimisation, and improving supply chain performance	Effective integration with the company's performance measurement system, thereby enabling a dashboard perspective of all operations that enables performance improvement and optimisation across the supply chain
Virtualisation	There is awareness but no plans to develop capacity	Use of some operational processes management software	Use of operational processes management software along with supervisory control and data acquisition (SCADA)	Comprehensive use of operational processes management software, including manufacturing execution systems (MES), computerised maintenance management systems (CMMS), and SCADA	Complete virtualisation through cyber-physical production systems complete with the use of a digital twin (computerised duplication of physical assets that enable simulation and testing to be carried out prior to actual operations)

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 4: Human Resources					
IT Capabilities	Only basic IT skills scattered throughout the enterprise	IT skills at reasonable levels available in administrative areas (e.g. finance, stock keeping, etc.)	Technology focused areas of the business have employees with reasonable IT skills (e.g. computer-aided design (CAD), some aspects of manufacturing, etc.)	Well-developed digital and data analysis skills across most areas of the enterprise (e.g. CAD, computer integrated manufacturing (CIM), warehouse management systems (WMS), etc.)	State-of-the-art digital and analytics skills across the business that also enables real-time interaction across the supply chain
Industry 4.0 digital training	Basic or no knowledge of Industry 4.0 technologies amongst management and operations staff	Management and operations staff have been provided basic training on Industry 4.0, its benefits, and the new ways of working needed	New skills needed have been identified in relation to an Industry 4.0 strategy; relevant staff have been provided training and new staff with required skills have been recruited	Advanced IT skills needed for Industry 4.0 IT systems and data usage (in areas such as ERP, MES, SCADA, PLM, CIMM, and digital twins), and business analytics (descriptive, diagnostic, predictive, and prescriptive) are now available within the enterprise	Complete digital enablers as in Level 3 are available within the firm and with key partners outside the enterprise
Human-machine interface	Only direct human – machine interaction	Staff use remote control devices for routine machine interaction	Routine machine interaction no longer needed; capabilities are built into the machines	Ubiquitous access to all machines and devices through user-friendly interfaces	Independent monitoring built into the cyber-physical production systems
Skills for people–system collaboration	Traditional system of collaboration and communication between people and systems through meetings and exchange of hard copy information	Horizontal integration of information systems along the horizontal value chain (sales, outbound logistics, manufacturing, inbound logistics, procurement)	Digital integration of engineering processes (product lifecycle management (PLM))	Integration of information systems to enable the creation and use of digital twins	Fully integrated cyber-physical production systems that monitor and control physical processes autonomously and intelligently

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 5: Product Definition					
Product customisation	Product is a standard offering; no customization is possible	Products are made in large batches. Some limited, late customization possible in some products (e.g. changing the color)	Products have standardized bases, but limited features can be customized in many products (assemble to order - ATO))	Mass customisation (ATO) possible in all products but possibilities are constrained by inability of suppliers to quickly deliver the components needed for customisation	Late differentiation available for all make-to-order (MTO) products (batch size is 1)
Digital features of the product	Product is common and has many substitutes	Product is competitive but shows only physical value	Product value arises only due to the protected intellectual property used	Product value arises from the protected intellectual property used and some digital features	Product value arises from the protected intellectual property used and extensive digital features
Management of the product life cycle	Traditional approach based on a supply-push approach with limited or no inputs from other functional areas within the firm and downstream entities in the supply chain	A product data management (PDM) system is used	Engineering product lifecycle management (PLM) solution is used in design, manufacturing, and after-sales)	PLM solution is fully implemented within the enterprise and along the supply chain, both downstream and upstream	A digital twin is used for the development of the product and the designing of the production processes needed to produce the designed product, so that simulation and testing can be carried out prior to carrying out actual operations

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 6: Managing Operations – Resource Consumption and Energy Management					
Monitoring energy consumption, resource use, and emissions	Resource use and energy consumption information are provided by the service provider	Sensors are used to record energy and resource consumption for later review and the development of emission reduction and energy saving measures	Resource and energy consumption are monitored in real time to take corrective action where needed	Consumption patterns are compared, and disturbing patterns lead to an alarm generation to enable prompt action to be taken	Automated systems monitor energy and resource consumption as well as carbon emissions, identify inefficiencies, and propose corrective action
Increase share of renewables, recyclable resources, and energy	Conventional power management	Regular energy audits carried out for developing resource efficiency initiatives	Advanced renewable energy use and resource conservation saving systems have been installed	Renewable energy and resource consumption aspects are built into product and process design to proactively reduce energy and raw material usage	IT-based circular and green energy technology systems are fully implemented
Increased use of recyclable and recycled materials that can replace raw materials	Energy and resource consumption on demand	Control of energy demand by increased share of recyclable material	Power generation from waste	Resource recycling and energy storage systems have been installed and the energy demand curve is well-balanced	The enterprise has minimal demand for external energy and raw materials providers, and through its own self-generation has a positive net balance on raw material use

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 7: Managing Operations – Quality Management					
Quality assurance	Heavy reliance on inspection at incoming and finished stages	Use of total quality management (TQM) frameworks and tools (ISO 9000, Six-Sigma, etc.) to promote a zero-defect approach	Quality is integrated into the design and production during product lifecycle management (PLM)	Use of advanced control systems (e.g. artificial vision) along with machine learning systems and automatic adjustment of machine parameters to achieve zero defects	Total digital quality management is achieved through the design of effective cyber-physical production systems
Quality traceability in the supply chain	Quality issues are handled by accepting rejects and providing replacements; causes of problems cannot be traced	Quality issues are traceable down to the batch based on product parameters	Quality issues are traceable down to the batch based on both product and production process parameters	Quality issues can be detected at the unit level within the production system	Quality issues can be detected at the unit level within the supply chain
Determinant 8: Managing Operations – Supply Chain Management					
Customer demand management and supply chain integration	Based on historical demand patterns and forecasts	Some customers share their sales and requirements electronically	Demand is conveyed by customers in real time through electronic point-of-sale (e-POS) systems	Demand information from customers in real time through e-POS is used to analyse time-based material and component requirements from upstream partners (suppliers), and this information is communicated to them electronically	The entire supply chain is linked electronically to convey demand information in real time, and partners in the supply chain participate in collaborative planning, forecasting, and replenishment exercises (CPFR)
Supply chain visibility and integration	Each entity in the supply chain deals with the other at arm's length	Requirements and delivery information shared selectively with critical suppliers and customers respectively	Site location, capacity, inventory, and operations are visible between selected critical suppliers and customers	Site location, capacity, inventory, and operations are visible to all Tier 1 suppliers and customers	Site location, capacity, inventory, and operations are visible throughout the supply chain and are used in real time for monitoring and optimisation

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Determinant 8: Managing Operations – Supply Chain Management					
Inventory management	Manual systems used to update inventory levels at periodic intervals	Computerised database for recording inventory levels, which is updated manually at periodic intervals	ERP system is used to update inventory levels	The inventory database is updated through the use of smart devices at the point of use	The inventory database is updated in real time through the use of smart devices at the point of use
Warehouse management	Manual warehousing practices – receiving, storage, picking, and staging	Partial automation of receiving, storage, picking, and staging	Automated storage and retrieval systems	Automated warehouse integrated within the supply chain	Only few automated warehouses in the supply chain due to complete synchronisation with only consolidation points
Transportation	Own or customer vehicles used to deliver to customers	Use of second-party logistics service providers for defined deliveries	Use of third-party logistics service providers to manage transportation within the supply chain	Use of fourth-party logistics service providers to integrate logistics within the supply chain and reduce lead times	Use of fourth-party logistics service providers and autonomous transportation

Appendix 1-2:Assessing Industry 4.0 Readiness for the Circular Economy – PT Siemens Indonesia

Determinant 1: Strategy and Organisation					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which the business model of the firm allows for the leasing or renting out of the outputs so that it can be ensured that materials are returned for reuse	Top management has no interest in a CE, a business model that focuses on minimised exploitation of raw materials while delivering more value from few materials	Top management has expressed interest, and preliminary ideas are being exchanged	The organisation has worked out a strategy to adopt the CE business model in stages	The new business model is being implemented for some market segments and is being updated based on experience gained	The new business model is completely implemented across all market segments
Extent to which the firm requires its suppliers and subcontractors to provide parts and components that can be easily repaired, instead of fixed and single-use parts	Relationships with suppliers and subcontractors are at arm's length and are based only on price	Supplier and subcontractor relationships are good but there is no focus on easy repair and reuse aspects, with respect to supplies	The firm designs parts and components with a focus on easy repair and reuse and passes on the specifications to suppliers and subcontractors	There is 'early supplier involvement' (ESI) from the concept development, design, and specification development stages to produce parts and components with a focus on easy repair, redistribution, and reuse	Comprehensive ESI from concept development, design, and specification stages and to create a business model that will support circularity in product designs

Determinant 1: Strategy and Organisation					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which the firm has developed profit sharing models and incentives to encourage partners to work with the firm to adopt CE principles, to ensure that multiple cycles of disassembly, redistribution, and reuse are adhered to instead of fixed and single-use parts.	None have been developed and top management does not subscribe to the need for such a circular business model	There is interest but work on the development of such a model is still at a preliminary stage	Models have been developed and pilot tested with some critical partners but are not ready for full implementation	Models have been developed and implemented successfully with some critical partners based on trust, information exchange, and shared understanding of the value of adopting CE practices of reuse	Comprehensive models have been developed and implemented successfully with all partners based on trust, information exchange, and shared understanding of the value of adopting CE practices
Extent emphasis on eco-innovation principles is considered, including the design of products for longer life, enabling reuse, use of natural non-toxic materials and de-materialisation (e.g. use of the Internet and reduced packaging)	No consideration of eco-innovation and design for environment principles; the focus is mainly on cost reduction and improved performance, even if this means sacrificing the circularity principles of sustainability	Incorporation of eco-innovation aspects are incidental (e.g. use of modular parts or reduced packaging) and are due to reasons of cost reduction	Eco-innovations and design for the environment aspects are incorporated explicitly only to meet regulatory requirements	There is conviction that eco-innovation is a priority and that it can make positive contributions to profitability	All innovation is explicitly required to incorporate eco-innovation principles and demonstrate positive contributions towards a CE

Determinant 2: Plant and Equipment					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Capability of plant and equipment and facilities layout to adopt the principle of 'repair, refurbishment, and remanufacturing'	Adoption of the repair, refurbishment, and remanufacturing principles will not be possible with the current facilities layout and production processes	Some sections of the production process can be converted to adopt repair, refurbishment, remanufacturing, but the organisation has not initiated the move	The sections of the production process that can be converted to adopt repair, refurbishment, remanufacturing principles are being suitably redesigned and renovated	Repair, refurbishment, and remanufacturing principles are adopted in several sections of the production process	The entire manufacturing facility is capable of adopting repair, remanufacturing, and refurbishment principles
Capability of plant and equipment and facilities layout to adopt resource conservative manufacturing (ResCoM, viz; high-quality recycling of as much waste, material and energy as possible, enabling emission and pollution reduction)	Minimal or no capability to adopt ResCoM	Some sections of the production process can be converted to adopt ResCoM, but the organisation has not initiated the move	The sections of the production process that can be converted to adopt ResCoM are being suitably redesigned and renovated	ResCoM can adopted in several sections of the production process	The entire manufacturing facility is capable of adopting ResCoM

Determinant 3: Information Technology Systems and Data Management					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent of design of the information technology system, big data analytics, IoT platforms to quickly generate information needed for incorporating CE principles (e.g. reuse, repair, redistribute, repair and remanufacturing) explicitly into the firm's operations	No consideration has been given to the generation of such CE information and principles	The data needed may be available in a raw form, but the IT system software and planning tools will have to be redesigned and upgraded to generate the information needed for incorporating CE principles	Some information is available and easily accessible for incorporating CE principles	Information within the firm can be easily accessed to assist in incorporating CE principles, but only partial information is available from partners in the supply chain	Comprehensive information can be easily accessed both internally and from partners in the supply chain to assist in incorporating CE principles

Determinant 4: Human Resources					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which CE value networks have been built amongst staff, stakeholders, and consumers, using required human-machine interfaces	No explicit efforts have been made	Employees of the firm are aware of the CE imperative and have adopted new ways of working to support the firm's initiatives in adopting CE-based approaches	Employees of the firm and critical suppliers, distributors, and retailers are aware of the CE imperative and have adopted new Industry 4.0 ways of working to support the firm's CE initiatives	Employees of the firm and all suppliers, distributors, and retailers are aware of the CE imperative and have adopted new Industry 4.0 ways of working to adopt CE-based approaches through the entire supply chain; initiatives are underway to convince and inform customers about it	Employees of the firm and all suppliers, distributors, and retailers are aware of the CE imperative and have adopted new Industry 4.0 ways of working to adopt CE-based approaches through the entire supply chain; consumers reinforce the CE-based approaches by demanding eco-products, the efficient use of raw materials, and minimised waste

Determinant 5: Product Definition					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent of 'regenerative design' considerations are being made with distinction of biological materials (materials that can safely enter the biosystems) and technical materials (materials that can be refurbished, reused, or recycled).	No explicit consideration; design is based on raw material cost and availability. Any regenerative design aspects that appear are incidental	Regenerative design aspects are focused mainly on technical nutrients. Biological nutrient focus is restricted to those needed because of regulatory requirements	Regenerative design is restricted to only what is designed by the firm; there is no requirement on suppliers to incorporate these design requirements into the parts and components that they supply	Some products are designed with comprehensive regenerative design considerations with the participation of some critical suppliers who incorporate these considerations into the parts and components that they supply	Comprehensive information can be easily accessed both internally and from partners in the supply chain to assist in incorporating CE principles
Extent of product design considerations based on sustainable and minimal use of resources and enabling high-quality recycling	No explicit consideration; design is based on raw material cost and availability; any CE material design aspects that appear are incidental	Product design aspects are focused on just a few considerations on circularity; the focus is restricted to those needed because of regulatory requirements	Critical eco-product design is restricted to only what is designed by the firm; there is no requirement on suppliers to incorporate circularity design requirements into the parts and components that they supply	Some products are designed with comprehensive eco-material design considerations with the participation of some critical suppliers who incorporate those considerations	

Determinant 6: Managing Operations – Resource Consumption and Energy Management					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which 'waste-to-energy (WtE)' approaches, such as thermochemical conversion (combustion, gasification, pyrolysis, and refuse derived fuel), physicochemical conversion (transesterification), and biochemical conversion (fermentation and anaerobic digestion) are used as a secondary resource to reduce the carbon emissions as business in action	None used	Thermochemical conversion approaches, such as combustion, hot gases, and refuse-derived fuel (RDF) are used in an ad-hoc way	Thermochemical conversion approaches, such as combustion (hot gases) and RDF, are used in a consistent and regular basis and plans are underway to examine the feasibility of adopting other WtE approaches	Comprehensively used based on a sophisticated understanding of the nature of waste generated and its convertibility into energy	Comprehensively used across the supply chain based on a sophisticated understanding of the nature of the waste generated by the supply chain and access to technologies like 3D printing

Determinant 7: Managing Operations – Quality Management					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which a 'zero-defect (ZD)' approach is being used to eliminate waste; incineration is avoided, and landfill use is limited to a minimum	Defects are regarded as inevitable and the emphasis is on reducing the extent; incineration and land fill use continues as usual	There is interest in moving towards a ZD target, and plans are being made to avoid incineration and landfill use	Formal ZD programmes have been initiated within the firm and some are being piloted; progressive avoidance of incineration and landfill use	Formal ZD programmes have been initiated comprehensively within the firm with continuous monitoring and improvement; significant progress made in the avoidance of incineration and landfill use	Formal ZD programmes have been initiated comprehensively within the firm and with all key partners in the supply chain; landfill use and incineration are completely avoided

Determinant 8: Managing Operations – Supply Chain Management					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Level of sophistication of the reverse logistics system from a CE perspective	No formal reverse logistics capability; any collection from the downstream end of the supply chain is done on a needs basis	The firm is planning/ developing arrangements with its downstream supply chain partners to develop a collection, sorting, refurbishment, and remanufacturing mechanism to bring materials and used products only up to the firm	The firm, in collaboration with its downstream supply chain partners has put in place a collection, sorting, refurbishment, and remanufacturing mechanism to bring materials and used products only up to the firm	The firm, in collaboration with some of its critical supply chain partners (both upstream and downstream), has put in place a collection, sorting, refurbishment, and remanufacturing mechanism to bring materials and used products upstream to the relevant critical entity nodes in the supply chain	The firm, in collaboration with all its supply chain partners (both upstream and downstream), has put in place a collection, sorting, refurbishment and remanufacturing mechanism to bring materials and used products upstream to the relevant nodes in the supply chain
Extent of collaborative consumption in action, wherein inter-firm network capabilities and location detection technologies are brought in the market place for resource sharing and recycling	The firm has no Industry 4.0 capabilities to track the location and condition of used devices and recyclable components and gather bills-of-material (BOM) information	The firm is in the process of developing basic digital capabilities to track the location and condition of used devices and recyclable components, and gather BOM information for multi-level customer interaction	Through the use of advanced IT-based interventions, the firm can track the location and condition of some used devices and components, as well as BOM information, which are relevant only for its own use and multi-level customer profiling	Through the use of advanced IT-based cloud computing, the firm and some of its critical supply chain partners can track the location and condition of used devices and reusable components, as well as BOM information for their use and multi-level consumer market authentication	Through the use of advanced IT-based detection systems, the firm and its supply chain partners can track the location and condition of needed recyclable raw materials, used devices, and recyclable components, and also BOM information facilitates inter-firm collaboration whereby the waste of one becomes a resource for another

Appendix 2-1: Framework for Assessing the Status of Industry 4.0 Readiness in Manufacturing – Textile Industry in Indonesia

Determinant 1: Strategy and Organisation					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent of Industry 4.0 emphasis in strategy formulation and implementation	Industry 4.0 has not been considered at all	Industry 4.0 is of interest at the departmental level but is not explicitly incorporated into corporate strategy	Industry 4.0 is recognised as important and is being introduced at an elementary level into the strategy formulation process	An Industry 4.0 strategy has been developed and implementation is in progress in stages	An enterprise-wide Industry 4.0 strategy has been implemented and is being continuously reviewed and updated.
Interfirm collaboration	There is no cross-functional collaboration, and the various departments adopt a 'functional silo' mentality	Some limited cooperation exists between the departments in areas such as sales and operations planning	Departments are willing to work together and share information, and the use of IT has facilitated this	Departments realise the value of cross-functional collaboration to improve performance and use IT-based interventions, such as ERP systems	Cross-functional collaboration is the norm, and the use of IT-based interventions has enabled extensive sharing of information
Critical allocation of funds for Industry 4.0 investment	Has not been considered at all	Funds are allocated selectively, and incrementally, when requested by a department	Seed funding has been allocated at a basic level	Investments have been made in selected areas	Enterprise-wide investments have been made
Measuring the impact of Industry 4.0 implementation	No key performance indictors (KPIs) exist	No KPIs exist that assess the status of Industry 4.0 implementation and/or the enhanced performance arising from the introduction of Industry 4.0	A preliminary set of KPIs exist that assess the status of Industry 4.0 implementation and the enhanced performance arising from the introduction of Industry 4.0	A comprehensive set of KPIs is used to assess the status of Industry 4.0 implementation and the enhanced performance arising out of Industry 4.0 introduction	A comprehensive set of KPIs to assess Industry 4.0 implementation and impact has been formulated, is used enterprise-wide, and is integrated into the strategic planning process

Determinant 1: Strategy and Organisation					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Leadership	Top management has not recognised the value of Industry 4.0 and adopts a 'business-as-usual' attitude	The leadership is making preliminary investigations into the feasibility of adopting Industry 4.0 and the potential benefits to be gained	The leadership is convinced of the potential benefits to be gained through the adoption of Industry 4.0 and has commenced piloting and developing an implementation plan	The leadership shows total commitment by being involved in implementation and following up through reviews and providing additional resources as needed	There is enterprise-wide support for Industry 4.0; a culture of sharing lessons learned and disseminating the knowledge gained is prevalent
Innovation orientation	Traditional method of using a 'funnel of ideas' and selecting projects	Adoption of a technology-push model along the lines of the linear model of innovation	Identification of customer needs triggers innovation – adoption of a demand-pull approach	Adoption of 'open innovation' that incorporates knowledge from within the organisation and selected external entities	Supply chain-wide adoption of 'open innovation' incorporating knowledge from suppliers, customers, and other technology partners

Determinant 2: Plant and Equipment					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Plant and equipment readiness for Industry 4.0	Not suitable for an Industry 4.0 model	Will need substantial overhaul for Industry 4.0 readiness	Some of the plant and equipment can be upgraded for Industry 4.0 without disruption	Most of the plant and equipment meet Industry 4.0 requirements and the rest can be upgraded	Plant and equipment meet Industry 4.0 requirements
Machine and system infrastructure	Machines and systems cannot be controlled through IT	Some machines can be controlled through IT but there is no machine-to-machine (M2M) connectivity	Some machines can be controlled through IT and have M2M capability	All machinery can be controlled through IT and there is partial M2M	All machinery can be completely controlled through IT and have full M2M capability
Autonomously guided workpieces	No autonomously guided workpieces in use	Autonomously guided workpieces are not in use, but business cases for their adoption are being prepared for consideration	Autonomously guided workpieces are being piloted	Autonomously guided workpieces are used in selected areas	Autonomously guided workpieces are widely adopted with continuous improvements being made in their use
Maintenance of plant and equipment	Only breakdown maintenance	Breakdown maintenance kept to a minimum through preventive and periodic (time-based) maintenance	Predictive maintenance carried out along with retrofitting and/or modifying equipment to facilitate effective preventive maintenance	Maintenance prevention that focuses on the design of new equipment based on evidence-based studies of the weaknesses of existing machines	Total productive maintenance fully implemented and controlled by a cyber-physical system

Determinant 3: Information Technology Systems and Data Management					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Seamless system-integrated information sharing	No system-integrated information sharing	Some information sharing amongst departments through the use of IT	In-company information sharing through the use of IT and the selective use of enterprise resource planning (ERP) systems	There is comprehensive in-company system-integrated information sharing along with some external system integration	Complete and seamless in-company system-integrated information sharing along with substantial external system integration
Cloud usage	Not in a position to consider it due to lack of infrastructure and skills	Cloud solutions not used even though opportunities exist for use	Plans have been developed and some partial testing has been carried out using cloud-based software, data storage, and analysis	Cloud-based solutions have been implemented successfully in some areas of the business	Cloud-based solutions have been implemented successfully across most or all areas of the business
IT and data security	Not a concern and nothing has been planned	IT security as an important issue is recognised and preliminary steps have been taken for protection	IT security solutions have been implemented in multiple areas of the business	IT security solutions have been comprehensively implemented across the business and are constantly monitored for bridging gaps that arise with time	IT security solutions, with continuous upgrading, have been comprehensively implemented across the business and have been extended to cover data and information sharing with all relevant external partners

Determinant 3: Information Technology Systems and Data Management					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Operations data collection for internal process improvement	No formal data collection system; data are collected manually by departments for their own usage as needed	Required data are collected digitally by some departments and the data available are current	Data are collected digitally by most departments	Comprehensive and automated structure across the enterprise for digital data collection; arrangements in place to acquire and share data digitally with some important supply chain partners	Comprehensive and automated structure across the enterprise and with all key supply chain partners to acquire and share data digitally
Operations data usage	Collected data are not integrated with the company's performance measurement system and are used mainly for reporting	Collected data are made available for integration with the company's performance measurement system and are used selectively for remedial action (e.g. quality improvement)	Data are integrated with the company's performance measurement system and used for performance improvement (e.g. to reduce downtime, reduce inventory, improve capacity utilisation, etc.)	Comprehensive integration with the company's performance measurement system;. Used for performance improvement, performance optimization, and improving supply chain performance.	Effective integration with the company's performance measurement system thereby enabling a dashboard perspective of all operations that enables performance improvement and optimization across the supply chain
Virtualization	There is awareness but no plans to develop the capacity	Use of some operational processes' management software	Use of operational processes management software along with SCADA (Supervisory Control and Data Acquisition)	Comprehensive use of operational processes management software including MES (manufacturing execution system), CMMS (computerized maintenance management system), and SCADA	Complete virtualisation through cyber-physical production systems complete with the use of a digital twin (computerised duplication of physical assets that enables simulation and testing to be carried out prior to actual operations)

Determinant 4: Human Resources					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
IT capabilities	Only basic IT skills scattered throughout the enterprise	IT skills at reasonable levels available in administrative areas (e.g. finance, stock keeping, etc.)	Technology-focused areas of the business have employees with reasonable IT skills (e.g. computer-aided design (CAD), some aspects of manufacturing, etc.)	Well-developed digital and data analysis skills across most areas of the enterprise (e.g. CAD, computer integrated manufacturing (CIM), warehouse management systems (WMS), etc.)	State-of-the-art digital and analytics skills across the business that also enables real time interaction across the supply chain
Industry 4.0 digital training	Basic or no knowledge of Industry 4.0 technologies amongst management and operations staff	Management and operations staff have been provided basic training on Industry 4.0, its benefits, and the new ways of working needed	New skills needed have been identified in relation to an Industry 4.0 strategy; relevant staff have been provided training and new staff with required skills have been recruited	Advanced IT skills needed for Industry 4.0 IT systems and data usage (in areas such as ERP, MES, SCADA, PLM, CIMM, and digital twins), and business analytics (descriptive, diagnostic, predictive, and prescriptive) are now available within the enterprise	Complete digital enablers as in Level 3 are available within the firm and with key partners outside the enterprise
Human-machine interface	Only direct human-machine interaction	Staff use remote control devices for routine machine interaction	Routine machine interaction no longer needed; capabilities are built into the machines	Ubiquitous access to all machines and devices through user-friendly interfaces	Independent monitoring built into the cyber-physical production systems
Skills for people–system collaboration	Traditional system of collaboration and communication between people and systems through meetings and exchange of hard copy information	Horizontal integration of information systems along the horizontal value chain (sales, outbound logistics, manufacturing, inbound logistics, procurement)	Digital integration of engineering processes (product lifecycle management (PLM))	Integration of information systems to enable the creation	Total productive maintenance fully implemented and controlled by a cyber-physical system

Determinant 5: Product Definition					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Product customisation	Product is a standard offering; no customisation is possible	Products are made in large batches; some limited, late customisation possible in some products (e.g. changing the colour)	Products have standardised bases, but limited features can be customised in many products (assemble to order (ATO))	Mass customisation (ATO) possible in all products, but possibilities are constrained by the inability of suppliers to quickly deliver the components needed for customisation	Late differentiation available for all make-to-order (MTO) products (batch size is 1)
Digital features of the product	Product is common and has many substitutes	Product is competitive but shows only physical value	Product value arises only due to the protected intellectual property used	Product value arises from the protected intellectual property used and some digital features	Product value arises from the protected intellectual property used and extensive digital features
Management of the product life cycle	Traditional approach based on a supply push approach with limited or no inputs from other functional areas within the firm and downstream entities in the supply chain	A product data management (PDM) system is used	Engineering product lifecycle management (PLM) solution is used in design, manufacturing, and after-sales	PLM solution is fully implemented within the enterprise and along the supply chain, both downstream and upstream	A digital twin is used for the development of the product and the designing of the production processes needed to produce the designed product, so that simulation and testing can be carried out prior to carrying out actual operations

Determinant 6: Managing Operations – Resource Consumption and Energy Management					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Monitoring energy consumption, resource use, and emissions	Resource use and energy consumption information are provided by the service provider	Sensors are used to record energy and resource consumption for later review and the development of emission reduction and energy saving measures	Resource and energy consumption are monitored in real time to take corrective action where needed	Consumption patterns are compared, and disturbing patterns lead to an alarm generation to enable prompt action to be taken	Automated systems monitor energy and resource consumption as well as carbon emissions, identify inefficiencies, and propose corrective action
Increase share of renewables, recyclable resources, and energy	Conventional power management	Regular energy audits carried out for developing resource efficiency initiatives	Advanced renewable energy use and resource conservation-saving systems have been installed	Renewable energy and resource consumption aspects are built into product and process design to proactively reduce energy and raw material usage	IT-based circular and green energy technology systems are fully implemented
Increased use of recyclable and recycled materials that can replace raw materials	Energy and resource consumption on demand	Control of energy demand by increased share of recyclable material	Power generation from waste	Resource recycling and energy storage systems have been installed and the energy demand curve is well-balanced	The enterprise has minimal demand for external energy and raw materials providers, and through its own self-generation has a positive net balance on raw material use

Determinant 7: Managing Operations – Quality Management					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Quality assurance	Heavy reliance on inspection at incoming and finished stages	Use of total quality management (TQM) frameworks and tools (ISO 9000, Six-Sigma, etc.) to promote a zero-defect approach	Quality is integrated into the design and production during product lifecycle management (PLM)	Use of advanced control systems (e.g. artificial vision) along with machine learning systems and automatic adjustment of machine parameters to achieve zero defects	Total digital quality management is achieved through the design of effective cyber-physical production systems
Quality traceability in the supply chain	Quality issues are handled by accepting rejects and providing replacements; causes of problems cannot be traced	Quality issues are traceable down to the batch based on product parameters	Quality issues are traceable down to the batch based on both product and production process parameters	Quality issues can be detected at the unit level within the production system	Quality issues can be detected at the unit level within the supply chain

Determinant 8: Managing Operations – Supply Chain Management					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Customer demand management and supply chain integration	Based on historical demand patterns and forecasts	Some customers share their sales and requirements electronically	Demand is conveyed by customers in real time through electronic point-of-sales (e-POS) systems	Demand information from customers in real time through e-POS is used to analyse time-based material and component requirements from upstream partners (suppliers), and this information is communicated to them electronically	The entire supply chain is linked electronically to convey demand information in real time, and partners in the supply chain participate in collaborative planning, forecasting, and replenishment exercises (CPFR)
Supply chain visibility and integration	Each entity in the supply chain deals with the other at arm's length	Requirements and delivery information shared selectively with critical suppliers and customers respectively	Site location, capacity, inventory, and operations are visible between selected critical suppliers and customers	Site location, capacity, inventory, and operations are visible to all Tier 1 suppliers and customers	Site location, capacity, inventory, and operations are visible throughout the supply chain and are used in real time for monitoring and optimisation
Inventory management	Manual systems used to update inventory levels at periodic intervals	Computerised database for recording inventory levels, which is updated manually at periodic intervals	ERP system is used to update inventory levels	The inventory database is updated through the use of smart devices at the point of use	The inventory database is updated in real time through the use of smart devices at the point of use
Warehouse management	Manual warehousing practices – receiving, storage, picking, and staging	Partial automation of receiving, storage, picking, and staging	Automated storage and retrieval systems	Automated warehouse integrated within the supply chain	Only few automated warehouses in the supply chain due to complete synchronisation with only consolidation points
Transportation	Own or customer vehicles used to deliver to customers	Use of second-party logistics service providers for defined deliveries	Use of third-party logistics service providers to manage transportation within the supply chain	Use of fourth-party logistics service providers to integrate logistics within the supply chain and reduce lead times	Use of fourth-party logistics service providers and autonomous transportation

Appendix 2-2: Assessing Industry 4.0 Readiness for the Circular Economy - Textile Industry in Indonesia

Determinant 1: Strategy and Organisation					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which the business model of the firm allows for the leasing or renting out of the outputs so that it can be ensured that the materials are returned for reuse	Top management has no interest in a CE, a business model that focuses on the minimised exploitation of raw materials while delivering more value from fewer materials	Top management has expressed interest and preliminary ideas are being exchanged	The organisation has worked out a strategy to adopt the CE business model in stages	The new business model is being implemented for some market segments and is being updated based on experience gained	The new business model is completely implemented across all market segments
Extent to which the firm requires its suppliers and subcontractors to provide parts and components that can be easily repaired, instead of fixed and single-use parts	Relationships with suppliers and subcontractors are at arm's length and are based only on price	Supplier and subcontractor relationships are good, but there is no focus on easy repair and reuse aspects, with respect to supplies	The firm designs parts and components with a focus on easy repair and reuse and passes on the specifications to suppliers and subcontractors	There is 'early supplier involvement' (ESI) from the concept development, design, and specification development stages to produce parts and components with a focus on easy repair, redistribution, and reuse.	Comprehensive ESI from the concept development, design, and specification stages to create a business model that will support circularity in product designs

Determinant 1: Strategy and Organisation					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which the firm has developed profit-sharing models and incentives to encourage partners to work with the firm to adopt CE principles, to ensure that multiple cycles of disassembly, redistribution, and reuse are adhered to, instead of fixed and single-use parts	None have been developed and top management does not subscribe to the need for such a circular business model	There is interest, but work on the development of such a model is still at a preliminary stage	Models have been developed and pilot-tested with some critical partners but are not ready for full implementation	Models have been developed and implemented successfully with some critical partners based on trust, information exchange, and shared understanding of the value of adopting CE practices of reuse	Comprehensive models have been developed and implemented successfully with all partners based on trust, information exchange, and shared understanding of the value of adopting CE practices
Extent emphasis on eco-innovation principles are considered, which include the design of products for longer life, enabling reuse, use of natural non-toxic materials, and de-materialisation (e.g. use of the Internet and reduced packaging)	No consideration of eco-innovation and design for environmental principles; the focus is mainly on cost reduction and improved performance even if this means sacrificing circularity principles of sustainability	Incorporation of eco-innovation aspects is incidental (e.g. use of modular parts or reduced packaging) and are due to reasons of cost reduction	Eco-innovations and design for environmental aspects are incorporated explicitly only to meet regulatory requirements	There is conviction that eco-innovation is a priority and that it can make positive contributions to profitability	All innovation is explicitly required to incorporate eco-innovation principles and demonstrate positive contributions towards a CE

Determinant 2: Plant and Equipment					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Capability of plant and equipment and facilities layout to adopt the principle of 'repair, refurbishment, and remanufacturing'	Adoption of the repair, refurbishment, and remanufacturing principles will not be possible with the current facilities layout and production processes	Some sections of the production process can be converted to adopt repair, refurbishment, remanufacturing, but the organisation has not initiated the move	The sections of the production process that can be converted to adopt repair, refurbishment, remanufacturing principles are being suitably redesigned and renovated	Repair, refurbishment, and remanufacturing principles are adopted in several sections of the production process	The entire manufacturing facility is capable of adopting repair, remanufacturing, and refurbishment principles
Capability of plant and equipment and facilities layout to adopt resource conservative manufacturing (ResCoM, viz; high-quality recycling of as much waste, material, and energy as possible, enabling emission and pollution reduction)	Minimal or no capability to adopt ResCoM	Some sections of the production process can be converted to adopt ResCoM, but the organisation has not initiated the move	The sections of the production process that can be converted to adopt ResCoM are being suitably redesigned and renovated	ResCoM can be adopted in several sections of the production process	The entire manufacturing facility is capable of adopting ResCoM

Determinant 3: Information Technology Systems and Data Management					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent of design of the information technology system, big data analytics, IoT platforms to quickly generate information needed for incorporating CE principles (e.g. reuse, repair, redistribute, repair, and remanufacturing) explicitly into the firm's operations	No consideration has been given to the generation of such CE information and principles	The data needed may be available in a raw form, but the IT system software and planning tools will have to be redesigned and upgraded to generate the information needed for incorporating CE principles	Some information is available and easily accessible for incorporating CE principles	Information within the firm can be easily accessed to assist in incorporating CE principles, but only partial information is available from partners in the supply chain	Comprehensive information can be easily accessed both internally and from partners in the supply chain to assist in incorporating CE principles

Determinant 4: Human Resources					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which CE value networks have been built amongst staff, stakeholders and consumers using required human-machine interfaces	No explicit efforts have been made	Employees of the firm are aware of the CE imperative and have adopted new ways of working to support the firm's initiatives in adopting CE-based approaches	Employees of the firm and critical suppliers, distributors, and retailers are aware of the CE imperative and have adopted new Industry 4.0 ways of working to support the firm's CE initiatives	Employees of the firm and all suppliers, distributors, and retailers are aware of the CE imperative and have adopted new Industry 4.0 ways of working to adopt CE-based approaches through the entire supply chain; initiatives are underway to convince and inform customers about it	Employees of the firm and all suppliers, distributors, and retailers are aware of the CE imperative and have adopted new Industry 4.0 ways of working to adopt CE-based approaches through the entire supply chain; consumers reinforce the CE-based approaches by demanding eco-products, the efficient use of raw materials, and minimised waste

Determinant 5: Product Definition					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent 'regenerative design' considerations are being made with distinction of biological materials (materials that can safely enter the biosystems) and technical materials (materials that can be refurbished, reused, or recycled).	No explicit consideration; design is based on raw material cost and availability; any regenerative design aspects that appear are incidental	Regenerative design aspects are focused mainly on technical nutrients; biological nutrient focus is restricted to those needed because of regulatory requirements	Regenerative design is restricted to only what is designed by the firm; there is no requirement on suppliers to incorporate these design requirements into the parts and components that they supply	Some products are designed with comprehensive regenerative design considerations with the participation of some critical suppliers who incorporate these considerations into the parts and components that they supply	All products are designed with comprehensive regenerative design considerations with the complete participation of all suppliers who incorporate these considerations into the parts and components that they supply
Extent of product design considerations based on sustainable and minimal use of resources and enabling high-quality recycling	No explicit consideration; design is based on raw material cost and availability; any CE material design aspects that appear are incidental	Product design aspects are focused on just a few considerations on circularity; the focus is restricted to those needed because of regulatory requirements	Critical eco-product design is restricted to only what is designed by the firm; there is no requirement on suppliers to incorporate circularity design requirements into the parts and components that they supply	Some products are designed with comprehensive eco-material design considerations with the participation of some critical suppliers who incorporate these considerations	All products are designed with circularity considerations with the complete participation of all suppliers who incorporate these considerations into the parts and components that they supply

Determinant 6: Managing Operations – Resource Consumption and Energy Management					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which 'waste-to-energy' (WtE) approaches, such as thermochemical conversion (combustion, gasification, pyrolysis, and refuse derived fuel), physicochemical conversion (transesterification), and biochemical conversion (fermentation and anaerobic digestion) are used as a secondary resource to reduce the carbon emissions as business in action	None used	Thermochemical conversion approaches, such as combustion, hot gases, and refuse-derived fuel (RDF) are used in an ad-hoc way	Thermochemical conversion approaches, such as combustion (hot gases) and RDF are used in a consistent and regular basis, and plans are underway to examine the feasibility of adopting other WtE approaches	Comprehensively used based on a sophisticated understanding of the nature of the waste generated and its convertibility into an energy form	Comprehensively used across the supply chain based on a sophisticated understanding of the nature of the waste generated by the supply chain and access to technologies like 3D printing

Determinant 7: Managing Operations – Quality Management					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which a 'zero-Defect' (ZD) approach is being used to eliminate waste; incineration is avoided, and landfill use is limited to a minimum	Defects are regarded as inevitable and the emphasis is on reducing the extent; incineration and land fill use continues as usual	There is interest in moving towards a 2D target, and plans are being made to avoid incineration and landfill use	Formal 2D programmes have been initiated within the firm, and some are being piloted; progressive avoidance of incineration and landfill use	Formal 2D programmes have been initiated comprehensively within the firm with continuous monitoring and improvement; significant progress made in the avoidance of incineration and landfill use	Formal 2D programmes have been initiated comprehensively within the firm and with all key partners in the supply chain; landfill use and incineration are completely avoided

Determinant 8: Managing Operations – Supply Chain Management					
I4R Assessment Criteria for Circular Economy (CE)	Focus Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Level of sophistication of the reverse logistics system from a CE perspective	No formal reverse logistics capability; any collection from the downstream end of the supply chain is done on a need basis	The firm is planning/ developing arrangements with its downstream supply chain partners to develop a collection, sorting, refurbishment, and remanufacturing mechanism to bring materials and used products only up to the firm	The firm, in collaboration with its downstream supply chain partners, has put in place a collection, sorting, refurbishment, and remanufacturing mechanism to bring materials and used products only up to the firm	The firm, in collaboration with some of its critical supply chain partners (both upstream and downstream), has put in place a collection, sorting, refurbishment, and remanufacturing mechanism to bring materials and used products upstream to the relevant critical entity nodes in the supply chain	The firm, in collaboration with all its supply chain partners (both upstream and downstream), has put in place a collection, sorting, refurbishment, and remanufacturing mechanism to bring materials and used products upstream to the relevant nodes in the supply chain
Extent of collaborative consumption in action, wherein inter-firm network capabilities and location detection technologies are brought in the market place for resource sharing and recycling	The firm has no Industry 4.0 capabilities to track the location and condition of used devices and recyclable components and gather bills-of-material (BOM) information	The firm is in the process of developing basic digital capabilities to track the location and condition of used devices and recyclable components and gather BOM information for multi-level customer interaction	Through the use of advanced IT-based interventions, the firm can track the location and condition of some used devices and components, as well as BOM information, which are relevant only for its own use and multi-level customer profiling	Through the use of advanced IT-based cloud computing, the firm and some of its critical supply chain partners can track the location and condition of used devices and reusable components, as well as BOM information for their use and multi-level consumer market authentication	Through the use of advanced IT-based detection systems, the firm and its supply chain partners can track the location and condition of needed recyclable raw materials used devices and recyclable components, and also BOM information facilitates interfirm collaboration whereby the waste of one becomes a resource for another