Assessing the Readiness for Industry 4.0 and the Circular Economy

Edited by

Venkatachalam Anbumozhi
Krishnamurthy Ramanathan
Heinrich Wyes

Economic Research Institute for ASEAN and East Asia

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Foreword

Globalisation, technological advancement, and resource consumption have historically served humanity well by typically delivering both economic growth and social progress. However, as these drivers have accelerated, evolved, and become intertwined over time, a divergence between economic growth and environmental sustainability has occurred, placing the planet and social progress under strain. In this context, the emerging concepts of Industry 4.0 and the circular economy offer promising opportunities for correcting the course with the right governance, an enabling environment, and public–private partnerships.

The countries and companies of the Association of Southeast Asian Nations (ASEAN) and East Asia stand at an important moment in history. The global, digitally enabled Industry 4.0 is already the fastest period of innovation ever. It is underpinned by rapid advances in technologies, including artificial intelligence, robotics, the Internet of Things, nanotechnology, and biotechnology, to name a few. Previous industrial revolutions advanced economic development but came largely at the expense of environment. In the past 2 decades, ASEAN and East Asia have emerged as the world's largest consumers of natural resources and raw materials. Resource demands continue to expand in line with the region's increasing population, rapid urbanisation, and continued economic growth. Without appropriate planning, the consumed resources and materials may ultimately end up as waste and pollution. It is, therefore, imperative that countries in the region focus on and invest in the circular economy for the improvement of resource efficiency.

Using Industry 4.0 is crucial to make the transition from a linear to a circular economy and requires closer cooperation between the research, technological, and business communities. It also requires the creation of an enabling policy and an appropriate institutional, business, and financial environment to make this cooperation possible. The major entry points to advance the integration of the rapidly evolving technological and business fields are resource use and waste management – the beginning and the end of the circular economy model. Raw material extraction, processing, and production companies can use Industry 4.0 technologies more efficiently, while the same technologies can be used for more efficient resource management and to turn the raw materials into new raw materials, closing the material cycle.

An important role in building a life strategy for Industry 4.0 and the circular economy lies in the results of assessments of the readiness of national economies and companies to adapt and adopt the initiatives. Readiness is often defined as the ability to capitalise on future production opportunities, mitigate risks and challenges, and be resilient and agile in responding to uncertainties. There are different approaches to such an assessment of readiness that use different qualitative and quantitative key indicators, both for countries and individual companies.

The chapters in this volume show assessment frameworks of differing magnitude for embracing the two concepts in the context of the fast-growing emerging economies of ASEAN. To provide governments and businesses with action-oriented information on the readiness of Industry 4.0 and the circular economy, the contributing authors developed multi-level self-assessment frameworks. It is the first comprehensive, quantitative measure of readiness in ASEAN and East Asia. Subsequent validation in countries and industries has led to various improvements in the way the ERIA Self-assessment Tool for Industry 4.0 and the Circular Economy is constructed and used.

As policymakers and industry leaders continue to refine and expand their industrial development and environmental protection programmes, this book provides them with useful measures to assist in their decision-making. This book is being published as part of ERIA's efforts to disseminate knowledge products that can be used to promote industrial restructuring in ASEAN and East Asia. I am confident that this book will help countries to identify the policy challenges and opportunities associated with the Fourth Industrial Revolution and allow for greater integration of it into the thinking on sustainability.

H. Nishimura

Professor Hidetoshi Nishimura
President, Economic Research Institute for ASEAN and East Asia

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List of Contributors

Venkatachalam Anbumozhi, Senior Energy Economist, Economic Research Institute for ASEAN and East Asia.

Heinrich Wyes, Senior Advisor to the Executive Director, Central Asia Regional Environment Centre (CAREC), Almaty, Kazakhstan (based in Berlin, Germany).

Krishnamurthy Ramanathan, Faculty member, Western Sydney University, Sydney, Australia.

V.G.R. Chandran Govindaraju, Associate Professor, University of Malaya, Kuala Lumpur, Malaysia.

Jootae Kim, Professor, School of Business and Economics, Dankook University, Seoul, South Korea.

Ick Jin, Director, Economic Analysis Coordination Division, National Assembly Budget Office, Seoul, South Korea.

Premaratne Samaranayake, Senior Lecturer, Western Sydney University, Sydney, Australia.

Nuwong Chollacoop, Renewable Energy and Energy Efficiency Research Team Leader, National Energy Technology Center (ENTEC), National Metal and Materials Technology Center (MTEC), Bangkok, Thailand.

Arie Rahmadi, Head of Technology Services, Center for Fuel Technology Research and Engineering Design, Jakarta, Indonesia.

Michikazu Kojima, Research Fellow, Economic Research Institute for ASEAN and East Asia.

Dian Lutfiana, Research Associate, Economic Research Institute for ASEAN and East Asia.

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CHAPTER 1

Introduction: Principles, Terminology and Measurement Frameworks

Venkatachalam Anbumozhi

Both advanced and emerging economies of the Association of Southeast Asian Nations (ASEAN) and East Asia recognise that a new industrial revolution built on the principles of cyber-physical systems and automation is inevitable and will shape the future of economic growth. In addition to various national initiatives relating to enhancing industrial productivity, there has been heightened recognition of the importance of Industry 4.0 at the international level. The European Commissions' New Industrialization strategy aims to increase the share of gross value added to 20%, based on industry 4.0 initiatives. Various elements under the ASEAN Economic Community (AEC) Blueprint 2025, from global megatrends, intellectual property, consumer protection, and science and technology, to e-commerce as well as work under the other two pillars of the ASEAN Community and the cross-cutting work on connectivity all serve as building blocks towards an Industry 4.0-ready Community. While there is growing awareness of Industry 4.0 at the sectoral level, a more holistic approach is needed.

On the other hand, emerging ASEAN economies depend on an interrupted flow of natural resources and materials, including metals, minerals, energy carriers, timber, and water etc. Growing demand for manufacturing goods requires a massive increase in the use of these resources, but they are limited, and consumption cannot be unlimited. To maintain competitive and sustainable growth, economies need to produce and consume resources more efficiently, generating little or no waste. In the closed loop of circular economy systems, waste has value because treatment allows the recovery of materials that can be reused as inputs or for the remanufacturing of industrial goods. Various elements under the ASEAN Socio-cultural Community (ASCC) Blueprint 2025, such as the Reduce, Reuse and Recycle (3R) initiative, solid waste management, and smart cities, serve as building blocks for a circular ASEAN. In the circular economy paradigm supported by Industry 4.0, ASEAN production no longer contributes hugely to pollution, and its reduction helps to generate income because part of gross domestic product (GDP) is no longer needed to pay for long-term environmental damage.

1. Enabling Factors of Industry 4.0 and Circular Economy

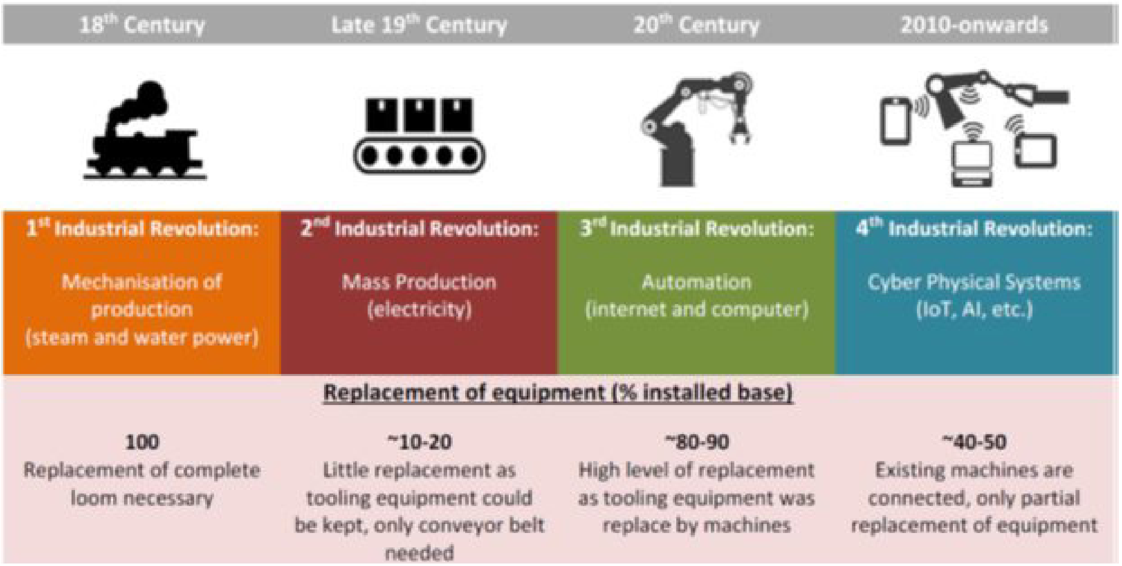
1.1.The concept of Industry 4.0

Technologies change over time and revolutionise production systems, which subsequently influences wider economic systems, social structures and, increasingly, political spheres. Industry 4.0 is preceded by three major industrial revolutions that took place since 1760. Each of these three earlier industrial revolutions had its own characteristics, but all were centred on introducing breakthrough technologies that altered society. Many of the technologies from the earlier industrial revolutions – such as electricity and the internet – remain in use today.

There are slight variations across existing studies in defining the timeline and key characteristics of each industrial revolution. Based on the commonalities between studies, however, the following characterisation and timeline can be drawn, as presented by Figure 1.1. The first industrial revolution in the late 18th century was characterised by the mechanisation of production, driven by steam and water power, while the second industrial revolution in the 19th century was marked by mass production, powered by electricity. The third industrial revolution in the 20th century was mostly about automation with a wider range of technological breakthroughs; computers and the internet appeared as its key features.

With economies of scale being focused in the first industrial revolution, the second and third industrial revolutions enhanced economies of scope and then moved to individual production, respectively (United Nations Industrial Development Organization, 2017). A comparison between the four industrial revolutions also suggests that despite its transformative changes, the fourth industrial revolution requires relatively less replacement of equipment through the upgrading of existing equipment, particularly in the aspects of sensors and connectivity (McKinsey, 2015).

Figure 1.1: Industry 4.0 Concepts



AI = artificial intelligence, IoT = Internet of Things.
Source: Author.

The term 'Industry 4.0' originates from the German government's project, 'Platform Industrie 4.0', to support small and medium enterprises in understanding and exploiting Industry 4.0 strategies and opportunities, particularly in the areas of standardisation and norms, security, legal frameworks, research, and workforce transformation (Box and Lopez-Gonzalez, 2017).

Despite several conceptualisations, there remains a lack of clarity in the definition of the Fourth Industrial Revolution. It is often described as digitisation or full-scale automation (Anbumozhi and Kimura, 2018); 'digitisation of the manufacturing sector' (Wyes, 2018); 'smart, connected manufacturing' (Deloitte 2016); or 'smart manufacturing or factory of the future', focusing on the transformation of the production or manufacturing base (Wilts, Lah, and Galinski, 2018). These various terms do not necessarily have a one-to-one correspondence and are often defined or used in different contexts in various studies. Many also refer to Industry 4.0 as a range of new technologies that combine the physical, digital, and biological worlds (World Economic Forum and Asian Development Bank, 2017). Other commonly used terms that refer to the similar phenomenon of Industry 4.0 include industrial internet, connected enterprise, SMART manufacturing, Manufacturing 4.0, Internet of Everything, and Internet of Things for Manufacturing (Kim and Hong, 2018; Ramanathan, 2018).

As a working definition, this book refers to the definition of Industry 4.0 by Anbumozhi and Kimura (2018), i.e. 'a range of new technologies that combine the physical, digital, and biological worlds'. It is, therefore, clear that for the purpose of assessing the readiness of a country or firm, it is important to look beyond the perspective of manufacturing and production to the broader transformation of sustainability and productivity that is brought about by these new technologies.

The scale, scope, and complexity of the impacts of Industry 4.0 are expected to be significantly different from its predecessors. Though they build upon existing technologies, new technologies brought by Industry 4.0 are evolving at an exponential speed, disrupting almost every industry across the globe, region, and in national economies, with fundamental impacts on entire systems of production, management, and governance (Schwab, 2016; Lah, 2016; Prabhakar, 2018). Industry 4.0 also leads to convergence between industries, such as information, communication, and entertainment, disciplines such as genomics, nanotechnology, robotics, and between biological, physical, and virtual worlds, such as cyber-physical systems.

1.2. The Concept of a Circular Economy

In essence, a circular economy represents a fundamental alternative to the linear take-make-consume-dispose economic model that currently predominates. This linear model is based on the assumption that natural resources are available, abundant, easy to source, and cheap to dispose of, but it is not sustainable, as the world is moving towards, and is in some cases exceeding, its planetary boundaries (Steffen et al., 2015).

The Ellen MacArthur Foundation defines a circular economy as one that is restorative and one that aims to maintain the utility of products, components, and materials and retain their value (Broekaert and Espinel, 2018). It thus minimises the need for new inputs of materials and energy while reducing environmental pressures linked to resource extraction, emissions, and waste. This goes beyond just waste, requiring that natural resources are managed efficiently and sustainably throughout their life cycles. A circular economy therefore provides opportunities to create well-being, growth, and jobs while reducing environmental pressures. The concept can, in principle, be applied to all kinds of natural resources, including biotic and abiotic materials, water, and land (Anbumozhi, 2016).

Eco-design, repair, reuse, refurbishment, remanufacture, product sharing, waste prevention, and waste recycling are all important in a circular economy. At the same time, material losses through landfill and incineration will be reduced, although these may continue to play a much-reduced role in safely removing hazardous substances from the biosphere and recovering energy from non-recyclable waste (Anbumozhi, 2016).

Table 1.1 lists the main characteristics of a circular economy and a number of technical, economic, and social enabling factors required to affect the transition to such an economy. The main characteristics differ for different types of system, for example for food that is consumed, metals that can be recycled, or water used in processing that can be recycled. Similar principles, however, apply, and some key characteristics and enabling factors can be defined. While the list of enabling factors is not exhaustive, it demonstrates the wide range of changes that will be needed to trigger or advance the transition. Central to achieving the necessary systemic changes, however, will be finding synergetic economic and social incentives, for example through financial mechanisms that encourage consumers and producers to hire rather than buy a product, while at the same time stimulating the eco-design of the product (Viswanathan and Anbumozhi, 2018).

Table 1.1: Characteristics and Enabling Factors of a Circular Economy

Key Characteristics of a Circular Economy	Enabling factors
Fewer inputs and greater use of natural resources	*Eco-design and innovation*
• Minimised and optimised exploitation of raw materials while delivering more value from fewer materials	• Products designed for longer life, enabling upgrading, reuse, refurbishment, and remanufacture
• Reduced import dependence on natural resources	• Product design based on the sustainable and minimal use of resources and enabling high-quality recycling of materials at the end of a product's life
• Efficient use of all natural resources	• Substitution of hazardous substances in products and processes, enabling cleaner material cycles
• Minimised overall energy and water use	*Repair, refurbishment, and remanufacture*
Increased share of renewable and recyclable resources and energy	• Repair, refurbishment, and remanufacture given priority, enabling the reuse of products and components
• Non-renewable resources replaced with renewable ones within sustainable levels of supply	*Recycling*
• Increased share of recyclable and recycled materials that can replace the use of virgin materials	• High-quality recycling of as much waste as possible, avoiding down-cycling (converting waste materials or products into new materials or products of lesser quality)
• Closure of material loops	• Use of recycled materials as secondary raw materials
• Sustainably sourced raw materials	• Well-functioning markets for secondary raw materials

Key Characteristics of a Circular Economy	Enabling factors
Reduced emissions	• Avoidance of mixing and contaminating materials
• Reduced emissions throughout the full material cycle through the use of less raw materials and more sustainable sourcing	• Avoidance of mixing and contaminating materials
• Less pollution through clean material cycles	• Cascading use of materials where high-quality recycling is not possible
Fewer material losses and residuals	*Business models*
• Build-up of waste minimised	• Focus on offering product-service systems rather than product ownership
• Incineration and landfill limited to a minimum	• Collaborative consumption
• Dissipative losses of valuable resources minimised	• Collaboration and transparency along the value chain
Keeping the value of products, components, and materials in the economy	• Industrial symbiosis (collaboration between companies whereby the wastes or by-products of one become a resource for another)
• Extended product lifetimes keeping the value of products in use	*Eco-innovation*
• Reuse of components	• Technological innovation
• Value of materials preserved in the economy through high-quality recycling	• Social innovation
	• Data, monitoring, and indicators

Source: Author.

Creating a circular economy requires fundamental changes throughout the value chain, from product design and technology to new business models, new ways of preserving natural resources (extending product lifetimes) and turning waste into a resource (recycling), new modes of consumer behaviour, new norms and practices, and education and finance (Hongo, 2016; Lah, 2016). Integration between policy levels and policy domains, as well as within and across value chains, is also essential (Anbumozhi et al., 2016). Action will be needed at all levels, from the regional level to the local level, and by all stakeholders, including governments and businesses (Ramanathan, 2016).

1.3. Empowering Industry 4.0 for the Circular Economy

Much positive hope has been built up around Industry 4.0 and circular economy notions over the last few years, creating awareness of the issue amongst policymakers and company executives and contributing significantly to the rejuvenation of industries in the ASEAN context (AT Kearney, 2016). In this aftermath, industry leaders in advanced economies remain optimistic overall and see the transition to Industry 4.0

and the circular economy as a unique opportunity to gain global competitiveness, consumer confidence, and environmental integrity.

In truth, momentum is already building in ASEAN and East Asia (Soulinthone, 2014; Permani, Sadicon, and Mahyassari, 2017). Almost two decades into the 21st century, ASEAN, along with China and India, has emerged as one of the world's largest consumers of minerals, ores, biomass, and fuels. Over the last 40 years, the use of materials has almost tripled from 26.7 billion tonnes in 1970 to 84.7 billion tonnes in 2017 (UNEP, 2017). Demands for resources and energy continue to expand in line with the region's industrialisation, rapid urbanisation, and accelerated economic growth. Without alternate models of growth and appropriate planning, the consumed materials and resources may ultimately end up as waste and pollution, imparting negative impacts on the economy.

As discussed before, in a circular economic system, resources are to be kept at the highest possible level of functionality at all times. This goes beyond just waste, requiring that natural resources be managed efficiently and sustainably throughout their life cycles. Eco-design, innovation, product sharing, waste prevention, and waste recycling are all important in a circular economy (Blunck, Werthmann, and Anbumozhi, 2018). At the same time, material losses through landfill and incineration will be reduced, although these may continue to play a much-reduced role in safely removing hazardous substances from the biosphere and recovering energy from non-recyclable waste. Several concepts and visualisations of a circular economy exist and can empower ASEAN to create economic and environmental co-benefits as the dependency on extraction and imports declines in parallel with a reduction in emissions (Tian, 2018). Thus, a circular economy generates new opportunities and needs for business. These can be grouped according to the following four archetypes, which each represent a specific business focus as the main entry point for developing a circular business model (OECD, 2003):

- Relationship with customer: providing a service instead of a product
- Product or process: circular product or process design
- Relationship with the value network: building circular value networks
- Sustainable identity: circularity as a unique selling proposition

In most cases, a company will combine elements of each archetype in its business approach. However, looking from an industrial perspective, the circular economy generates technological needs in the fields of manufacturing, processing, identification, and the recycling of materials and products. The main needs are the following:

- Advanced collection, sorting, and recycling technologies
- Efficient material-processing technologies
- Production technologies that support design for circularity
- Interactive platforms for enhanced connectivity

These needs are to be covered by robotics, analytics and artificial intelligence, sensors and connectivity, machine learning, and human-machine interfaces. All these technologies could typically be designated as Industry 4.0. Until now, the frameworks of Industry 4.0 and the circular economy have not been connected in theory, practice, policy initiatives, or research programmes (Anbumozhi and Kimura, 2018).

Nevertheless, the term Industry 4.0 is applied to a group of rapid transformations in the design, manufacture, operation, and service of manufacturing systems. The term originated in Germany, but developments in other Asian countries have resulted in other labels, such as smart factories, the industrial Internet of Things, smart industry, and advanced manufacturing. The European Parliament's briefing, 'Digitalisation for Productivity and Growth', mentions that Industry 4.0 builds upon six new technology developments (Table 1.2) (European Parliament, 2015). Similarly, Chandrasekar (2015) has identified 10 digital, engineering, and hybrid technologies that will enable the transformation of the current linear economy into a circular one.

On the other hand, PWC (2017) presented a framework for Industry 4.0 based on the following three elements:

- Digital business models and customer access
- Digitalisation of product and service offerings
- Digitalisation and integration of vertical and horizontal value chains

If these elements are compared, it is striking that similar concepts emerge. Both the circular economy and Industry 4.0 are based on the following:

- New product and process offerings
- Integration of value chains
- A change in the approach of customers

From this perspective, it becomes clear that Industry 4.0 and the circular economy at least share common levers of change. The circular economy is considered a driver for envisioning a sustainable industry, while Industry 4.0 provides the driver for circular innovation.

Table 1.2: Technological Developments for Industry 4.0 and the Circular Economy

Technological Developments for Industry 4.0	Ten Enabling Technologies for the Circular Economy
•Information and communication technology •Cyber-physical systems •Network communications: Internet of Things (IoT) •Simulation •Advanced data analytics •Robots, augmented reality, and intelligent tools for the support of human workers	•Mobile technology •Machine-to-machine communication •Cloud computing •Social media for business •Big data analytics •Modular desing technology •Advanced recycling technology •Life and material science technology •Trace and return systems •3D printing

Source: European Parliament (2015).

2. Monitoring the Economic and Environmental Benefits of Industry 4.0 and the Circular Economy

As the manufacturing system is undergoing a phenomenal shift with technological advancements and resource efficiency improvements, it is necessary to understand and adopt the opportunities available with Industry 4.0 and the circular economy. New opportunities will arise in different domains.

New opportunities from the interdisciplinary, cross-sector convergence of technologies: The convergence of multiple advanced technologies will create an innovation system along with new opportunities for further innovations. The Internet of Things (IoT) will interconnect almost everything, while cyber-physical systems – the technologies that marry the digital and physical worlds – will lead to smart production with intelligent systems independently communicating with each other with minimal human intervention (UNIDO, 2017).

New opportunities from data availability: The metaphor of 'data is the new currency', though not new, has been increasingly used to depict the vast opportunities from the age of IoT (Chandrasekaran, 2015). These data can lead to the restructuring of organisations and business models, placing efficiency and real-time capability at the heart of operations. The potential benefits are real. Companies that have applied IoT programmes have reported seeing 16% increases in revenue, with many identifying the ability to understand customers better as a key benefit (Thao and Nguen, 2018).

New opportunities from new business models: Disruptive technologies also give opportunities to unleash potential from new business models, including subscription-based models, broker platforms, intellectual property rights-based models, and monetising data models (McKinsey, 2015). Technologies also create a possibility to expand internationally and create new products and offerings (Deloitte, 2016). Businesses also benefit from technological advancements through improved labour productivity and efficiency, risk reduction, reduction in inventories (hence, lower capital costs), advanced quality control, improved understanding of customer demand, reduction in time to market, and improved and more affordable services and aftersales through, for example, remote maintenance (Cholifihani, 2018).

New opportunities from the changing manufacturing landscape in a circular way: The changing landscape of the global manufacturing industry driven by Industry 4.0 is expected to bring multiple impacts. For example, the use of 3D printing will allow for more active roles of customers in design and manufacturing processes and possibly the mass customisation of products and services (UNIDO, 2017). Benefits from the circular economy can also be derived from greater human-machine interaction, allowing workers to perform a given task for a longer period of time and faster (Li and Lin, 2016).

New opportunities for governments: Advanced technologies can also allow governments to improve efficiency in the delivery of public services with the greater involvement of citizens and enhanced responsiveness to their needs. Initiatives on e-governments have increasingly been part of and, in some countries, serve as the foundation for public sector transformation in responding to the Fourth Industrial Revolution (Jin, 2016; Ramanathan, 2018).

New opportunities for achieving sustainable development: According to the UN's Global Development Report – 2016 Edition, emerging technologies, such as in clusters of biotechnology, digital technology, nanotechnology, neurotechnology and green technology, are crucial for achieving the Sustainable Development Goals 2030 (UNIDO, 2017). Technologies range from self-driving cars, with the potential to increase traffic efficiency, productivity, and reduce traffic congestion and pollution, to decentralised solar systems providing remote communities access to electricity and technologies supporting a circular economy (Anbumozhi and Kojima, 2020).

Beyond the aforementioned opportunities, there are other enormous upsides to the technologies. To fully reap these benefits, however, addressing the enabling conditions is of utmost importance.

3. Challenges in Rolling Out Industry 4.0 and Circular Economy Concepts

New technologies from Industry 4.0 bring about not only new opportunities for the circular economy but also new challenges. At the broad policy level, to attain benefits from the Fourth Industrial Revolution, there are at least three pressing challenges that countries must address: (i) ensuring the benefits are distributed fairly; (ii) managing the negative externalities of the Fourth Industrial Revolution; and (iii) ensuring that the Fourth Industrial Revolution is human-led and human-centred (Schwab and Davis 2018; Anbumozhi and Kimura, 2018). Finally, there is a role for policy in addressing these challenges recognising that improving regulatory agility is a challenge. Discussions on each of these challenges in the context of ASEAN and East Asia are detailed elsewhere (Anbumozhi and Kimura, 2018), and a summary is presented below.

Uneven distribution of benefits: The first and one of the most critical challenges is to address the issue of the distribution of benefits. Benefits from the previous industrial revolutions were and continue to be unevenly distributed (Schwab and Davis, 2018). New technologies can further widen the gap through uneven access to knowledge and technologies and, hence, opportunities from the Fourth Industrial Revolution and Circular Economy (Viswanathan and Anbumozhi, 2018). Gaps exist between and within countries and regions with good electricity and internet infrastructure and those with less developed networks; and between countries with different levels of policy goals, attainments, and availability of skilled labour (Lah, 2016; Prabhakar, 2018). Many developing countries are also struggling to generate and/or attract high-skilled talents and workforce, which are key to further injecting innovation into the system. Within an economy, a key stakeholder group that is prone to the negative impact of Industry 4.0 is the workers. While new technologies can help labour performance, the risk of job replacement is evident. A significant number of jobs – or job tasks – are amenable to automation, while non-routine cognitive jobs (e.g. financial analysis or computer programming) and non-routine manual jobs (e.g. hairdressing) are less likely to be affected (UNEP, 2017). This concern also raises issues on social protection and the need to invest in human capital retraining or upskilling.

Negative externalities: While the economic benefits of previous industrial revolutions were widely acclaimed, there was too little effort to protect vulnerable populations, the natural environment, and future generations (Anbumozhi and Kimura, 2018; Kim and Hong, 2018). Industry 4.0 holds the potential not only to minimise negative externalities but also contribute to the resolution of persistent social and environmental issues (Mouri, 2016). At the same time, the circular economy is not without its own negative externality. Cybersecurity is a growing concern and was identified as one of the major risks in the WEF's Global Risks Report 2018. The financial impact of cybersecurity breaches has shown a steep increase with some of the largest costs in 2017 related to ransomware attacks; a notable recent example was the WannaCry attack, which affected 300,000 computers across 150 countries (WEF, 2017). Another possible negative externality is the issue of competition. Where data are the new currency, wealth, power, and resources are accumulated by, and increasingly concentrated in, a limited number of digital giants. Such issues can be even further exacerbated when these powers acquire smaller start-ups before they become potential competitions (UNIDO, 2017). Such accumulation is happening at a faster pace than how regulations can adapt to ensure fair competition, which brings us to the next challenge. In addition to the above broad challenges, each technology has its own characteristics, and, therefore, implications.

The lack of appropriate regulatory frameworks: This is imperative to capitalise on the opportunities or address the challenges brought about by Industry 4.0 and the circular economy. Opportunities can be better seized by ensuring that everyone has access to the technologies and knowledge required and will involve a portfolio of policies from investment and infrastructure to public–private partnerships (Anbumozhi et al., 2016). As for the challenges, these vary from addressing data security, including cyber security, protection, and privacy, and other measures to address ethical and other public concerns, intellectual property concerns relating to artificial intelligence (AI), and competition, to standards and interoperability (Deloitte, 2016).

4. Measuring the Readiness of Industry 4.0 and the Circular Economy

Growing recognition of the imminence of Industry 4.0 and the circular economy has led to the emergence of dedicated policy discourse on the topic, where discussions are centred around the changes that we are currently and will be facing, the new opportunities and challenges. However, questions and concerns have also emerged around how different agents can enhance their preparedness for Industry 4.0 for the circular economy. From the public sector perspective, the interest will be in the adequacy and agility of the policy tools and mechanisms that we have in hand to respond effectively to Industry 4.0. At the firm level, the interest will be in redefining operational strategies, benchmarking innovations, and building human capital (Sugimoto, 2016). The newness of the topic of Industry 4.0 and the circular economy means there are only a few in-depth studies that address the above policy and corporate strategy questions. While the relevant literature is growing, there is often disjointedness between the policy impacts and firm-level analytical work as studies on Industry 4.0 and the circular economy are often undertaken exclusively by institutions that are not part of the policy decision-making circle, whilst the development of policy and initiatives related to Industry 4.0 is not adequately backed and informed by rigorous analytical work. To this end, more strategic appraisal frameworks are needed in the advent of Industry 4.0 and the circular economy.

Countries and companies need to signal to investors and technology providers that they are ready for Industry 4.0 and the circular economy in an integrated way, which requires enabling policy measures and bold innovations at the institutional level. Empirical evidence suggests that enabling political, legal, institutional, and human resources is a key determinant of private sector activation in new frontier areas.

4.1. A Review of the Existing Readiness Assessment Frameworks for Industry 4.0 and the Circular Economy

There are at least seven recent and relevant frameworks that exist, as summarised in Table 1.3. Most frameworks aim at measuring or benchmarking a country's readiness for digital transformation; identifying key elements for improving countries' readiness; facilitating dialogue; and providing supporting evidence for monitoring and future agenda-setting.

Table 1.3: Comparison of Measurement Frameworks for Industry 4.0 Readiness

Framework	Key Dimensions
1. WEF Global Competitiveness Index (2019)	Institutions, infrastructure, macroeconomic environment, higher education, market efficiency, financial market development, technological readiness, business sophistication, market size
2. WIPO Global Innovation Index (2018)	Innovation input-institutions, human capital and research, infrastructure, market sophistication, innovation output
3.WEF Readiness for the Future of Production (2018)	Structure of production, complexity and scale, drivers of production, technology and innovation, human capital, global trade and investment, institutional framework, sustainable resources, demand environment
4. DII Global Industry 4.0 Readiness Index (2018)	Innovation aptitude, demand factors, driving forces, enterprise excellence, basic enablers, technological sophistication, Industry 4.0 enablers
5. KPMG Change Readiness Index (2017)	Enterprise capability, government capability, people, civil society capability
6. Dell Future-Ready Economies (2016)	Human capital, infrastructure, commerce
7. WEF Networked Readiness Index (2016)	Political and regulatory environment, business and innovation environment, infrastructure, affordability, individual usage, business usage, economic impacts, social impacts

DII = Danish Institute of Industry, WEF = World Economic Forum, WIPO = World Intellectual Property Organization.
Source: European Parliament (2015).

Comparison is made across these frameworks in terms of the data coverage and the feasibility and sustainability of the assessments in terms of access to datasets and the technical details of the methodology. The comparison exercise suggests that none of the existing reports covers all ASEAN countries. However, there is value in synthesising the assessment of these existing reports and indices to develop a hybrid ERIA readiness index for Industry 4.0, particularly at the country and company levels to benchmark positions relative to others in the world and to verify the outcomes of necessary interventions.

A comparison between the indices related to countries' readiness for Industry 4.0 is presented in Table 1.4. This exercise does not suggest comparability of the results given their different coverage, scales, scope, focuses, and objectives, but indicates emerging patterns in readiness, innovativeness, and competitiveness relative to each country in the region, and in comparison with their global counterparts.

Table 1.4: Indices for Measuring the Readiness of Industry 4.0

ASEAN Member States	Global Innovation Index			Global Competitiveness Index			Change Readiness Index			Global Industry 4.0 Readiness Index			Network Readiness Index		
	Rank out of 127 countries	Index score	Rank in ASEAN	Rank out of 137 countries	Index score	Rank in ASEAN	Rank out of 136 countries	Index score	Rank in ASEAN	Rank out of 120 countries	Index score	Rank in ASEAN	Rank out of 139 countries	Index score	Rank in ASEAN
Brunei Darussalam	71	32.89	5	46	4.52	5	-	-	-	-	-	-	-	-	-
Cambodia	101	27.05	8	94	3.93	8	85	0.48	7	115	1.5	7	109	3.4	8
Indonesia	87	30.10	7	36	4.68	4	39	0.57	3	41	3.1	4	73	4.0	4
Lao PDR	-	-	-	98	3.91	9	111	0.41	9	-	-	-	104	3.4	7
Malaysia	37	42.72	2	23	5.17	2	37	0.58	2	22	4.4	2	31	4.9	2
Myanmar	-	-	-	-	-	-	106	0.41	8	-	-	-	133	2.7	9
Philippines	73	32.48	6	56	4.35	7	45	0.55	4	44	3	5	77	4.0	5
Singapore	7	58.69	1	3	5.71	1	4	0.80	1	1	6.6	1	1	6.0	1

ASEAN Member States	Global Innovation Index			Global Competitiveness Index			Change Readiness Index			Global Industry 4.0 Readiness Index			Network Radiness Index		
	Rank out of 127 countries	Index score	Rank in ASEAN	Rank out of 137 countries	Index score	Rank in ASEAN	Rank out of 136 countries	Index score	Rank in ASEAN	Rank out of 120 countries	Index score	Rank in ASEAN	Rank out of 139 countries	Index score	Rank in ASEAN
Thailand	51	37.57	4	32	4.72	3	63	0.51	5	38	3.4	3	62	4.2	3
Viet Nam	47	38.34	3	55	4.36	6	81	0.49	6	91	2.1	6	79	3.9	6

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Source: Compiled by the author.

Comparison is also made regarding the circular economy policy frameworks in terms of sectoral coverage and the indicators of the assessment in Table 1.5. The comparison exercise suggests that wide areas of policies exist in ASEAN and East Asia countries. However, there is also value in synthesising the assessment of these policies and indices to develop a hybrid ERIA readiness index for the circular economy, particularly at the country and company levels to benchmark positions.

Table 1.5: Comparison of Frameworks for Assessments of Readiness for the Circular Economy

Framework	Key Dimensions and Indicators
1. Significant reduction in the quantity of municipal solid waste by encouraging both producers and consumers to reduce waste through resource recycling, greening lifestyles, and sustainable consumption	Specific policies and mechanisms that lead to a reduction of disposable plastic bags, packaging and other single-use consumer products, increased annual government expenditure on consumer awareness-raising, total waste disposed per capita, and total amount of municipal solid waste going to landfills
2. Significant increase in recycling rate of recyclables by introducing policies and measures and by setting up financial mechanisms and institutional frameworks involving relevant stakeholders	New policies and programmes introduced or existing policy/programmes are strengthened; increased number of state-of-the-art recycling facilities for key recyclables; employment in recycling industries

Framework	Key Dimensions and Indicators
3. Encourage businesses, including small and medium-sized enterprises (SMEs), to increase resource efficiency and eco-productivity, create decent works, and improve circular practices through applying standards, clean technologies, and cleaner production	Policy instruments that support resource efficiency and productivity are introduced or strengthened at the national and local levels; policy instruments are introduced aimed at improving labour conditions and standards in employment contracts; increased number of SMEs receiving expert advice, training, and other support from cleaner production centres and centres of excellence for resource efficiency
4. Promote circularity along the supply chain by encouraging industries and associated suppliers and vendors in socially responsible and inclusive development	Number of companies that have introduced circular supply chain management, number of companies that have introduced green accounting/voluntary environmental performance evaluation such as ISO 14000; vocational training activities/programmes on skills for circular jobs.
5. Promote industrial symbiosis, i.e. the recycling of waste from one industry as a resource for another, by providing relevant incentives and support	Increased number of eco-industrial parks and resource recycling zones; policy instruments introduced or strengthened to incentivise industrial symbiosis and the recycling percentage rate of industrial waste from selected sectors
6. Promote full-scale use of agricultural biomass waste and livestock waste through reuse and/or recycling measures to achieve a number of co-benefits, including carbon emission reduction, energy security, and sustainable livelihoods in rural areas	Greater amount of agricultural biomass waste and livestock waste recycled; number of new projects initiated that use agricultural biomass waste and livestock waste as material inputs
7. Improve resource efficiency and resource productivity through increased circular jobs nationwide in all economic sectors	Economy-wide material flow accounting indicators, such as tool material requirement, direct material input and domestic material consumption; energy efficiency schemes, product standards

Source: Compiled by the author.

A comparison between the indices related to the countries' readiness for the circular economy is presented in Table 1.6. This exercise does not suggest the comparability of results for sustainability given their different coverage, scales, scope, focuses, and objectives; but indicates emerging patterns in readiness, innovativeness, and competitiveness relative to each country in the region, and in comparison.

However, the comparison exercise of Industry 4.0 and the circular economy clearly shows the diversity in readiness amongst individual economies in the region. Levels of development appear to be strongly correlated with projected future readiness. Consideration should, therefore, also be given to capturing a country's conscious effort to put in place initiatives and investment in making their economy future-ready, which may not be reflected in their current economic performance alone (Tan and Wu, 2017).

Table 1.6: Selected Indicators for Measuring Sustainability

ASEAN Member States	Proportion of Population Practising Open Defecation (%)		Material Footprint per Capita (tonne)		Forest Area as a Proportion of Total Land Area (%)		Climate Risk Index Score (rank)
	2000	2015	2000	2017	2000	2015	2016
Brunei Darussalam	2.5	2.6	12.60	19.09	75.33	72.11	109.50 (120)
Cambodia	82.7	40.6	1.66	3.57	65.41	53.57	95.17 (111)
Indonesia	32.2	12.4	3.36	6.23	54.87	50.24	46.17 (37)
Lao PDR	62.0	22.1	1.26	7.37	71.60	81.29	109.50 (120)
Malaysia	1.6	0.3	19.19	22.61	65.72	67.55	65.50 (72)
Myanmar	11.2	4.7	0.53	1.50	53.39	44.47	57.17 (53)
Philippines	10.9	5.7	4.00	4.34	23.57	29.96	31.33 (16)
Singapore			51.14	73.04	23.06	23.06	109.50 (120)
Thailand	1.0	0.3	7.75	14.90	33.30	32.10	37.50 (20)
Viet Nam	17.7	3.9	3.42	10.01	37.82	47.64	15.33 (5)

Lao PDR = Lao People's Democratic Republic.
Source: Compiled by the author.

The suboptimal levels of several ASEAN countries regarding the readiness for Industry 4.0 and the circular economy, particularly given the opportunities and risks for the future, highlight the importance of identifying the key challenges facing the economies of the region. Furthermore, an integrated assessment warrants a methodology that can capture the firm-level and policy-level coverage while fitting with regional aspirations for collective actions in the areas of industrial research, innovation, and capacity building.

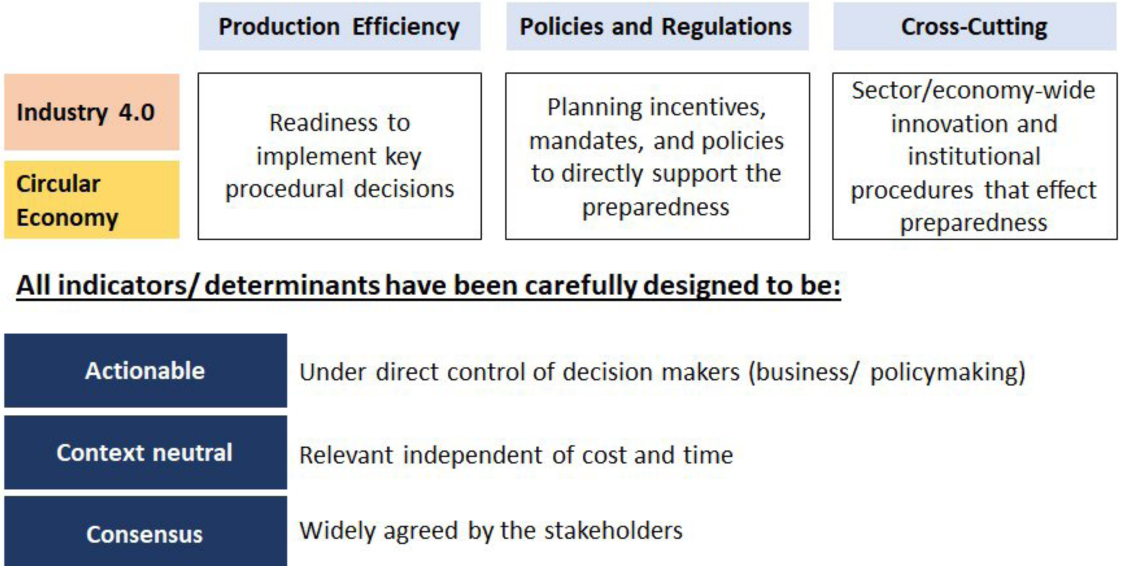
5.ERIA Industry 4.0 for Circular Economy Readiness Assessment Tool

The ERIA Industry 4.0 Readiness Assessment (I4R) for the Circular Economy is a suite of indicators that assesses the firm operational and enabling policy environment for the readiness of Industry 4.0 and the circular economy. I4R is relevant for a wide group of stakeholders. Crucially, it is aimed at policymakers and company managers responsible for identifying priority areas for change. However, seeking feedback from the private sector is an important aspect in the I4R framework development process as the policy and regulatory processes are designed to improve the readiness of firms to adopt new technologies and production processes and make innovations happen at the product level. It is designed as a self-assessment framework, as policymakers and company managers have to design the platform to secure investments and innovations but also in the larger interests of securing productivity and resource efficiency. Implementation of the I4R assessment tool for the circular economy will contribute to domestic and regional-level policy debates and discussions at the corporate level by providing a reference point on actions to facilitate the transformation and inform on the specific interventions needed. ERIA I4R will be a pioneering attempt to measure the readiness of countries and firms for adopting Industry 4.0 and the circular economy in an integrated way.

Underpinned by several levels of data collection at the country, sectoral, and firm levels, the ERIA I4R framework is expected to be updated regularly, thus benchmarking performance on the indicators over time while allowing countries and companies to measure incremental changes, which together will help countries and companies adopt and customise policies and operational measures while comparing themselves with their peers and good performers.

ERIA I4R assesses the readiness at three pillars of factors affecting production efficiency at the firm level; policy and regulations effecting changes at the country level; and the cross-cutting issues of institutions, innovations, and the application of information and communication technology at the sectoral level, thus better articulating the readiness competitively (Figure 1.2). While ERIA I4R builds on the hypothesis that the enabling environment is important for Industry 4.0 and the circular economy to be operationalised in a country or company, other market conditions affect the readiness level, which could rank from 0 to 4. A streamlined dataset, particularly in a panel format with focused criteria for each level, can allow robust identification of how the enabling environment affects innovations, technology integration, and investment flows, controlling for other factors.

Figure 1.2: Organisation of the ERIA Industry 4.0 for Circular Economy Assessment Framework



Source: Author.

The ERIA Industry 4.0 Readiness assessment framework for the circular economy originates from previous ERIA works on Industry 4.0 and the circular economy (Anbumozhi and Kimura, 2016) and global literature surveys on frameworks that evaluate the potential and opportunities, as well as risks and stakeholder consultations process and trial runs.

The assessment framework contributes to new knowledge given that none of the existing assessment frameworks on Industry 4.0 developed at the global level related to Industry 4.0 cover emerging the economies of ASEAN. It makes a specific attempt to customise the methodology to fit with the work under ASEAN at both the sectoral and functional levels.

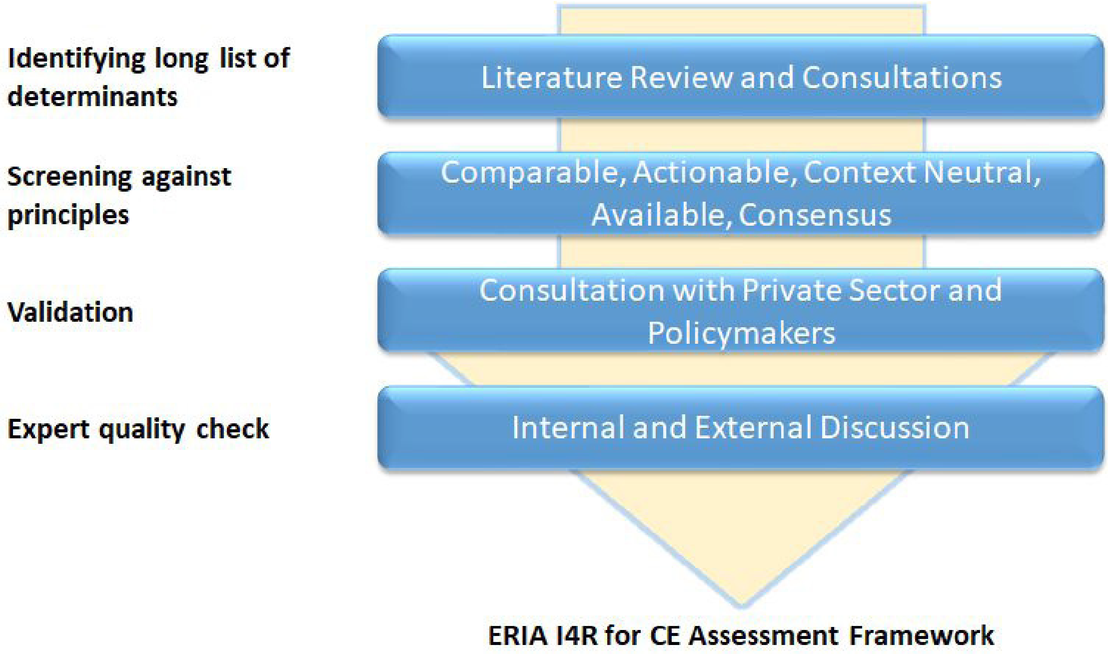
5.1. Development of the ERIA I4R Indicators

The readiness assessment covers the regulatory and institutional framework and reforms, reflecting the current economic base (i.e. education, science, technology and innovation, business and technology promotion, digital transformation, and trade and investment policies) and drivers of production at the firm level (strategy and organisation, plant and equipment, supply chain operation, quality management, resource consumption, product definition, informational technology systems, and human resources), based on which the focus areas are differentiated at four levels separately for Industry 4.0 readiness and circular economy readiness and then combined. The readiness assessment covers institutional and innovation efficiency as cross-cutting factors at the country and firm levels. The readiness level is again assessed on a 0–4 scale, with the assessment criteria to include political environment, economic environment, industrial structure, corporate leadership, business environment, and resources. The role of information and communications technology (ICT) in improving Industry 4.0 readiness for the circular economy is assessed with the factors of cloud manufacturing and use, IT and data security, operational data use, and virtualisation.

The rest of the chapters in the book present the readiness index at the firm, sectoral, and country levels. The in-depth case studies of the automobile, electronics, and textiles sectors in Indonesia and Thailand allow for validation of the methodology and lessons learned from the processes entailed in developing and implementing the suite of indicators across countries and firms that have varying statuses of data availability and information quality. Most importantly, it forms a solid base as a consultation document for the roll-out of Industry 4.0 and circular economy strategies. It also serves as a reference point for the measurement of readiness covering about 50 focus areas with a goal to further refinement.

ERIA I4R was developed in collaboration with the private sector. Figure 1.3 shows the four-step approach governed by a two-tier arrangement: a group of experts across the themes ensured the content, rigour, quality, and relevance of the indicators. In addition, an advisory group of the private sector and policymakers with knowledge of Industry 4.0 and the circular economy were consulted to ensure the indicators are pragmatic and would contribute to the ongoing policy development at the country and regional levels, and the operational agenda of firms selected for the case studies.

Figure 1.3: Methodology for ERIA Industry 4.0 Assessment for the Circular Economy



Source: Author.

A preliminary long list of indicators was initially identified based on a global literature review and on consultations with various stakeholders. A two-stage screening process was then employed to arrive at the first shortlist. In step 1, the four principles of objectivity, comparability, action, and context neutrality were applied to ensure that the indicators would be deployable in almost every country or firm. An attribute that stood out at this stage was one of reconciling various approaches that are considered good practices of circular economy at different points. Therefore, the ERIA I4R framework attempts to be time-neutral and avoids incorporating potential value judgements by the experts on the approach a country or firm is taking at a certain time to promote Industry 4.0 and circular economy outcomes. In step 2, three principles of universal data availability, cost effectiveness of data collection, and the presence of common consensus were then used.

This first shortlist and assessment framework went through multiple stakeholder consultations that informed the final suite of indicators. First, the experts provided advice and quality control in the two rounds of consultation. The private sector experts/advisors helped incorporate close country and sector knowledge on the production process and application potential of both Industry 4.0 and circular economy concepts. Second, the selection of indicators and associated methodological framework was discussed by a peer group of experts. The selection of the indicators also benefited from a private sector survey conducted by ERIA. Although all efforts were made to cover the key factors deciding the I4R, they are not intended as an exhaustive information set. Despite the collection of information and measurements at the policy and firm levels, it is not intended to be perfect set as the enabling conditions vary from factory to factory and country to country.

The assessment further highlights issues explaining variations in levels of readiness. By pilot testing in Indonesia and Thailand, uneven progress has been found in different areas of innovation and technology enablers, such as fixed broadband, 4G, research and development, patents, and cybersecurity. Meanwhile, gaps in human capital between and within factories persist and are considerably wide. On regulatory frameworks, improvements can be pursued through the putting in place and strengthening of the necessary regulations on key areas, such as e-commerce and further enhancement of e-government initiatives, while continuing improvement in the overall quality of the regulatory frameworks. Meanwhile, on supply chain connectivity and infrastructure, while areas for further improvement are country/sector-specific, there is a strong need to expand the region's financing architecture, which serves as a foundation for the further development of next-generation technologies. On the integration of Industry 4.0 and the circular economy, the assessment reinforces the importance of taking into consideration implications of technological advancements, as well as highlights the potential of technologies to serve as effective means to address productivity and resource efficiency issues

5.2. Limitations of the ERIA Industry 4.0 Assessment Framework for the Circular Economy

ERIA I4R is confined to the current set of indicators, and there are some limitations. While the exercises have developed the indicators over several rounds of revisions and consultations, this study has also been exposed to new information on Industry 4.0 and the circular economy, which has implications on the current availability, credibility, and validity of the indicators.

In ERIA I4R, indicators on procedural efficiency attempt to measure the effectiveness of policy and corporate strategy implementation. However, this still presents the limitation of the complete set of indicators in revealing the effectiveness of all policies and strategies. One example could be the exclusion of the effectiveness of institutions, as it is problematic to measure in a way that is comparable across countries and companies. Government and private sector staff numbers and budgets, for instance, are hard to pin down in absolute or relative terms and in ways that have significance in every country. Further, even where such information is measurable, channels of reporting may limit how easy it is to aggregate and make it available to the surveyor. Some measures on providing Industry 4.0 and the circular economy have narrow applicability, which, if properly used, can help promote better outcomes. However, there may not be agreement amongst the experts on deciding the level (0–4). Although, ERIA I4R attempts to measure the quality of the policies, strategies, innovation frameworks, and infrastructure connectivity by aggregating sub-indicators and presenting each indicator in a scalar way, the extent to which quality is captured is limited to the current set of sub-indicators. The quality of plans and strategies may vary by several other attributes. This evaluation also means that countries, companies, and technologies can stand idle as emerging good practices of Industry 4.0 and circular economy shift their goal posts, prompting them to work toward a favourable environment.

6. Structure of the Book

Given the above background and taking into consideration the existing work/ methodology, the self-assessment of readiness aims to: (i) measure country- and firm-level readiness for a circular economy and Industry 4.0 with selected indicators (ii) complement the assessment with a stock-take of the relevant initiatives at the national and regional levels in ASEAN and East Asia; and (iii) discuss the potential value‑added that can be derived from regional platforms to prepare countries and companies for Industry 4.0 and the circular economy.

Taking into account the approaches used in the existing studies, the assessment approach encompasses four stages: scoping and intelligence gathering; findings from the assessment; collation of initiatives in ASEAN; and case study analysis, as summarised in Table 1.7.

Table 1.7: Structure of the Chapters in the Book

Stage	Scoping and intelligence gathering	Key readiness assessment	Collation of initiatives at the ICT sector level	Case studies
Process	Literature review, review of existing assessments	Focus on multicriteria four-level assessment at the macro (policy), meso (cross-cutting) and micro (firm) levels	Link between national and regional activities and innovation	Assessment of readiness at the firm level in Indonesia and Thailand
Outputs	Chapters 1 and 2	Chapters 3, 4, 5, and 10	Chapter 6 and 9	Chapters 7 and 8

Source: Author.

The rest of the book is organised in eight chapters. Chapter 1 focuses on the first stage, i.e. scoping and intelligence gathering. Based on a literature search, the discussions above provide a better understanding of the characteristics of and technologies brought by Industry 4.0. Universal indicators and tools for measuring the economy-wide impacts of I4R are discussed in Chapter 2. Thematic elaborations on Industry 4.0 readiness with a circular economy focus are discussed in Chapter 3. Chapter 4 articulates the proposed readiness framework at the policy level with a reality check on ASEAN. Chapter 5 measures the cross-cutting factors influencing institutional innovation efficiency for I4R. Chapter 6 features ICT policy analysis conducted in the third stage, i.e. the collation of initiatives in ASEAN. Chapters 7 and 8 are country case studies of Indonesia and Thailand. Chapter 9 outlines national and regional initiatives in the face of Industry 4.0 and the circular economy. Chapter 10 briefly introduces ERIA's Industry 4.0 and Circular Economy Readiness Self-Assessment Tool, the technical details of which are available at http://i4r-eria.org/

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CHAPTER 2

Universal Indicators and Tools for Measuring the Economy-wide Impacts of Industry 4.0 Readiness

Heinrich Wyes

1. How is Industry 4.0 Related to the Overall Industry Climate in the World and ASEAN?

Globalisation, digitalisation, process technologies diffusion, network complexity, energy-saving, waste and inefficiencies reductions, the requests of customised products and the variability in customer demand have determined the need for a change in the manufacturing industry.

Since 2011, several initiatives addressing the theme of digitally connected industrial production have sprung up around the world, for example the Industrial Internet Consortium in the United States (US) and the Industrial Value Chain Initiative in Japan. The German government has promoted the Industry 4.0 initiative in cooperation with industrial and scientific organisations. The promotion of industrial change, the acquisition of a leadership position in the manufacturing sector in the world, increased productivity, and a lower resource footprint have been the main objectives for Germany (Bartodziej, 2017) as manufacturing companies are faced with increasingly competitive markets.

In 2012, the term 'Industry 4.0' was further refined. The following year, the understanding emerged that the entire value-added process – from product development and purchasing through to production, sales, and customer use – would be accompanied by a 'digital twin'. In this context, a digital twin refers to a digital replica of potential and actual physical production devices and industrial processes.

Soon realism set in in 2015, when it became clear that the Fourth Industrial Revolution would start incrementally by digitally capturing every facility and every process. Thus, 2016 became the year of the sensors that made an existing factory digital and Internet-enabled. The relevant data would be processed by industrial Internet platforms that would make the many data-based services possible. In 2018, the manufacturing industry moved away from physical production to software development for services. Artificial intelligence (AI) machines and systems became able to be combined in different ways and on demand. The factory become a stage where people, machines, and products are redone as required to be configured

Nowadays, the value creation process is based on the management of a large amount of data, known as 'big data', which can connect businesses and customers from all over the world (Xie et al., 2016). The chief economic potential of Industry 4.0 lies in its ability to accelerate both corporate decision-making and adaptation processes. This applies to processes for driving efficiency in engineering, manufacturing, services, and sales and marketing, as well as to changes to the business model. Industry 4.0 has become the new economic model for the industrial world (Peressotti, 2016).

A first global asset efficiency study to better understand the maturity of cyber-physical system deployments was prepared under the name of Industry 4.0: The State of the Nations (Infosys, 2015). This report allows comparisons amongst different types of industries and nations by looking at the leading organisations in five advanced manufacturing countries. It provides insights that decision makers in the Association of Southeast Asian Nations (ASEAN) region can use to help develop a roadmap for improving asset efficiency, amongst others that:

- Eighty-five percent of responding businesses saw the potential of Industry 4.0.
- Only 15% have dedicated strategies for Industry 4.0 in place.
- Eighty-nine percent of respondents are aware of the potential of information efficiency through the implementation of data standards.
- Only 11% have systematically implemented data security and standards.
- Eighty-one percent of respondents are aware of monitoring machine status for maintenance goals, but just 17% have put the principles into practice.
- Eighty-eight percent consider energy management to be important. Yet, only a small percentage implement practices into their processes.

Across the five countries surveyed in the report – China, France, Germany, the United Kingdom (UK), and the US – the level of maturity of Industry 4.0 varied significantly. While no country can claim to be the global early adopter in implementing Industry 4.0 in the context of asset efficiency, the percentage of companies in China that claim to be early adopters is significantly higher than anywhere else. It is expected that a number of factors are driving this; notably, the focused initiatives and investment from the Chinese government to develop more sustainable industry growth. Also, manufacturing is core for China, and the market is accustomed to rapidly implementing new technology, especially in green-field sites free of legacy infrastructures.

Germany (21%), the UK (26%), and the US (32%) have similar maturity footprints, both in terms of 2015 status and 2020 ambition. This could be because of their historical leadership in manufacturing. In France (14%), the Industry 4.0 implementation is comparatively less mature. The economic downturn and recent unsuccessful digitisation programs could be contributing factors.

A comparison of the average maturity rate in 2015 and the expected rate in 2020 reflects this progress of Industry 4.0 adoption. The study also revealed that the rate of progress expected in each country over the next five years is expected to be broadly the same. However, in France, average maturity rates are expected to be lower in 2020 than Chinese companies are, on average, claiming in 2015.

Further to the Industry 4.0: The State of the Nations report, the Global Manufacturing Competitiveness Index (Deloitte, 2017) outlines the competitiveness and attractiveness of a country and provides an overview about how the manufacturing sector contributes to the growth process in each country. For the manufacturing sector the competitiveness drivers are identified in three elements:

- Training activities, to have a high-qualified resource for realising high productivity levels;
- Digital innovation, to ensure high levels of competitiveness; and
- The definition of rules and regulations, to protect the technology transfer and intellectual property, as well as to establish incentives and subsidies in support of high-tech investments.

From the rankings in Table 2.1, it is possible to see how Germany and the United States achieved a score improvement through the implementation of Industry 4.0 policies.

Table 2.1: Global Manufacturing Competitiveness Index for the First 10 Countries

2011			2013			2016		
Rank	Country	Index Score	Rank	Country	Index Score	Rank	Country	Index Score
1	China	100.00%	1	China	100.00%	1	China	100.00%
2	India	81.50%	2	Germany	79.80%	2	United States	99.50%
3	Republic of Korea	67.90%	3	United States	78.40%	3	Germany	93.90%
4	United States	58.40%	4	India	76.50%	4	Japan	80.40%
5	Brazil	54.10%	5	Republic of Korea	75.90%	5	Republic of Korea	76.70%
6	Japan	51.10%	6	Taiwan	75.70%	6	United Kingdom	75.80%
7	Mexico	48.40%	7	Canada	72.40%	7	Taiwan	72.90%
8	Germany	48.00%	8	Brazil	71.30%	8	Mexico	69.50%
9	Singapore	46.90%	9	Singapore	66.40%	9	Canada	68.70%
10	Poland	44.90%	10	Japan	66.00%	10	Singapore	68.40%

Source: Deloitte (2017), with author's modification.

Leading enterprises in the development and application of Industry 4.0 created a consortium in 2016 in order to come up with a Global Industry 4.0 Maturity Index. The evolving global Industry 4.0 Maturity Index (Acatech, 2017) provides a tool to establish companies' current Industry 4.0 maturity stage and to identify measures to achieve a higher maturity stage in order to maximise the economic benefits of Industry 4.0 and digitalisation and prepare them for the step-by-step transformation.

2. What Indicators and Tools of Industry 4.0 for the Circular Economy Are Related to Societal and Sustainability Objectives?

Beyond addressing the developments associated with the Fourth Industrial Revolution from just a technological perspective, companies and societies also need to transform their organisation and culture. The key question is whether intelligent machines are replacing people and what societal changes are to be expected?

An ageing population, a gigantic modernisation and rationalisation wave, and a sharp increase in inequality in income and wealth are expected in Europe in the next 10–15 years. The distortions in the labour market erode the middle class and generate social and economic instability. Against this backdrop, companies need to streamline technology and at the same time target the top people. In addition, it is necessary to adapt to the changing patterns of consumption of large sections of the population. The digitisation wave over-compensates for shortages of skilled workers. For decades, companies have been able to access an almost inexhaustible potential workforce. First, the baby boomers flooded the labour market, then more and more working women and well-educated migrants joined. But the era of abundance is ending. Over the next 10–15 years, ageing populations throughout the developed world will trigger an unprecedented shortage of workers. In Europe, the total number of people employed will be shrinking. China is even under more pressure as a result of the one-child policy.

To compensate for the labour shortage, companies will increasingly invest in digital technologies that are now available across all industries. The suppliers of digital technologies can look forward to a huge boom. Rationalisation using AI, networking, and robots will increase labour productivity in the 2020s compared to 2015 on average by 30%. Productivity improvements of 50% are possible in the production, energy, and logistics sectors, as well as in the transport, trade, and hospitality sectors, and up to 20% in education and health care (Sinn, 2018). Autonomous cars, speech recognition software, and self-learning machines will also perform various service tasks in simple administrative jobs as well as in highly qualified professions, such as legal or financial advice.

As the demand for goods and services grows significantly slower than production potential, more and more jobs are lost over time. In Europe during the next 10 years, up to a quarter of the currently existing jobs will disappear. Despite declining populations, unemployment will therefore increase again.

Job losses or declining salaries in extinct occupations are no longer a prospect for only low-qualified, low-income earners in the decade of digitisation. Even educated populations with medium-to-good incomes will suffer from rapid structural change. Only the approximately 20% qualified specialists, who are excellently prepared for the digitised world, will have a bright future. All companies are vying for highly coveted digital experts.

Demography and technology in the 2020s will disturb the fragile balance between rich and poor in Europe. More and more people are being decoupled from economic dynamism. The already strong disparity in income, and thus also regarding pensions and assets, continues to increase. The prosperous middle class, the foundation of democratic societies, is shrinking. There is a threat of division into a few profiteers of the technology boom and a growing group of those suspended who no longer participate in economic and social progress.

Governments in many countries will react to these societal upheavals with countermeasures. Domestic interventions, such as stricter regulations on markets, increased cartel laws, and tax increases, as well as increased transfer services, are important. Moreover, as the number of pensioners and the unemployed increases, serious financing problems can arise in social systems.

The coming decade will be characterised by paradoxes. Shortages of skilled workers exist alongside mass unemployment; digital companies are achieving unprecedented stock market values while established firms are disappearing from the market; and some areas are booming due to new technologies while other sectors are becoming obsolete. Politics is becoming increasingly unpredictable in the face of growing inequality and social tensions for businesses. Social change is causing massive changes in consumer behaviour.

Over the years, the erosion of the middle class has also become more and more a brake on growth. If investment is reduced because most businesses are digitised and modernised, stagnation or even recession looms worldwide.

The European economic drivers should focus on a prolonged period of high economic and political risks and prepare their companies for this extreme volatility with greater flexibility and resilience. Whoever decides quickly is closely connected with their customers and can rely on a dedicated workforce, and not only recovers from external shocks faster but also gains momentum back.

A study by Oxford University researchers came to the alarming conclusion that almost every second job was easily replaced by learning machines (Walsh, 2017). This fear is not new, as US economist Jeremy Rifkin wrote in his 1995 book, The End of Work: 'Intelligent machines replace human beings in countless tasks, they drive millions of workers and employees into the queues of the unemployed, or – worse still – under the poverty line' (Rifkin, 1995). It is expected that Industry 4.0 favours the further division of labour into comparatively few high-paying, high-skilled jobs and a variety of lower-paid jobs.

Researchers at the ZEW–Leibniz Centre for European Economic Research (ZEW) in Mannheim have explored the question of why the 'end of work' persists despite the triumph of computers and industrial robots. On behalf of the German Federal Ministry of Research, they examined where German companies have been using networked production technologies since 2011, and how this has had an impact on the overall number of jobs. According to their study, the ZEW team 'wants to contribute significantly to the understanding of the actual change in the division of labour between man and machine' (ZEW, 2018).

The authors rely on data collected where this change takes place: in the factories. The results of the study are remarkable. Between 2011 and 2016, many companies increased the use of technologies that fall into the areas of Industry 3.0 and Industry 4.0. Industry 3.0 is understood to mean robots and computers, while Industry 4.0 largely comprises self-controlling machines, so-called 'smart factories'. The net employment effects of technology investment were as follows: the modernisation of production replaced within five years replaced 5% of employees.

While machines have displaced many people in the past because they can perform certain activities better and cheaper, the job balance of digitisation is positive. At the same time, the investments set in motion further processes, which in turn had a positive effect on the number of employees:

- The use of high technology has made many companies more competitive. They therefore produce larger quantities at cheaper prices, and for this reason have sometimes hired more people in other positions.
- Due to a 'multiplier effect'; the more productive companies generate new income in the form of wages, profits, and capital income. The higher incomes of the employees and shareholders of the companies created jobs in other parts of the economy.

These positive effects of technological change have even overcompensated for the 5% loss of employment due to the increased use of machinery, according to the ZEW (2018), which highlighted that digitisation from 2011 to 2016 led to job creation by 1%.

This development is likely to continue in the future. Based on the information provided by the companies surveyed, the ZEW estimates that the further spread of Industry 3.0 and Industry 4.0 technologies in companies will lead to an increase in employment by 1.5%–1.8% in 2021.

A similar effect had previously been associated with the use of information technology (IT) in businesses, which has cost many clerks and secretaries their jobs. Overall, however, while computerisation has increased according to calculations by the ZEW for the period from 1995 to 2011, employment increased by almost 0.2% per year.

Depending on the industry, however, the effects differ significantly. Particularly strong employment growth is evident in the electronics industry, vehicle construction, and other manufacturing industries. These sectors benefit from the fact that they themselves produce computer-aided technologies, which are becoming increasingly widespread. In particular, many jobs were lost in the construction and the health sectors. In the construction industry more and more building modules are prefabricated industrially. In turn, changes in medicine rarely lead to cost reductions, and the use of modern technology usually does not increase demand either.

The study also shows that technological change is nevertheless causing changes in the labour market. The jobs that are newly created usually place much higher demands on the workforce. From 2011 to 2016, the increased use of Industry 3.0 and Industry 4.0 systems has led, above all, to the loss of jobs that are heavily influenced by recurring routine activities. An example of this is the replacement of human labour in the assembly of heavy machinery by industrial robots. The newly created jobs, however, show a more complex requirement profile. The robots replace skilled workers but must be programmed and monitored by engineers. Digitisation will therefore change the structure of employment. Highly rewarded analytical and interactive professions are gaining importance. The downside of development is that investments in new technology have already promoted inequality in the past five years. Salaries in high-wage occupations have grown much stronger than in medium- and low-paid areas.

3. How Did European Countries Score?

3.1. The World's Two Industrial Fractures

The global industrial footprint has changed dramatically over the past 20 years. In 1991, the world's manufacturing value added stood at €3,451 billion. Over 60% of that could be attributed to six major industrial nations: the US, Japan, Germany, Italy, the UK, and France. At that time, emerging countries only produced 21% of the manufacturing value added. This gap is even more striking when looking at the evolution of industrial jobs in different countries. The number of manufacturing jobs in China and Brazil increased by 39% and 23%, respectively, whereas in Germany this figure decreased by 8%, in France by 20%, and in the UK by 29% (Roland Berger, 2014). This can be contributed to three main factors:

- The major productivity gains achieved in mature economies over the last few decades.
- The loss of market share to newly emerging competitors.
- Outsourcing of activities, such as logistics, facility management, maintenance, and different types of professional services to the service industry. This outsourcing often resulted in the relocation of the activity.

With this outsourcing trend now ending, increased productivity and international competition are the main drivers of the decrease in industrial employment. But while some traditional industrialised countries have adapted to this new situation, others have not.

The first fracture appeared with the rise of emerging countries. This incursion was led by Brazil, Russia, India, and China (the BRIC countries), but European countries, such as Poland, Romania, and the Czech Republic, soon followed. During the last three decades, the traditional industrialised countries saw their average manufacturing value added increase by 17%, while in the emerging industrial countries it increased by 179%. The emerging countries now represent 40% of the total manufacturing value added worldwide.

A second fracture appeared amongst the traditional industrialised countries. A few have retained high industrial value added despite the significant decline in jobs; Germany, Italy, and Switzerland have kept their industrialisation rate (manufacturing value added as a percentage of total value added) around 20% over the past 10 years. Others, however, saw both industrial employment and value added fall. This is the case for France, whose rate of industrialisation decreased from 15% in 2001 to 11% in 2011. Spain and the UK followed the same trend.

These two fractures cut right across Europe, making the continent's industry extremely diverse. And regarding the future strategy for industrial value creation, Europe seems to be drifting apart as opposed to moving in one direction.

Traditional industrialised countries, such as Germany, Sweden, and Austria, capture important value in key sectors. However, Europe also has several industrialised countries on its eastern side, such as Poland, Romania, and the Czech Republic, where industry's role in the economy has always been strong (over 20% of the national value added). Their main advantage used to lie in low-cost manufacturing, and the value added per job is still lower than in traditional industrialised countries. But recently established plants in these territories are brand new, highly automated, and will enable the rapid development of high-value-added activities. Meanwhile, France, the UK, Spain, and Belgium are facing considerable declines in industrial employment and value added.

In summary, Europe is now at a crossroads. Countries clearly need some industry. But Europe has to determine what the new pattern of industrialisation amongst its member states should be.

Industry is a core element of the European value chain. An industrial imbalance creates a rift in trade policies. Ultimately the growing gap between European countries in terms of industrial performance has an impact on European international trade relationships. On one side of the gap are countries with a strong industrial sector, which are dependent on exports and keen on open borders, and on the other side are countries with a weak industrial sector that are more inclined to put up barriers to protect themselves.

Innovation, automation, and sophisticated processes are at the root of industrial success strategies and have proven to be critical in maintaining a leading position. A successful approach to reindustrialisation should consider the changing environment and align processes, production, and products to the new situation. Europe's industrial future has to be envisioned and designed to cross borders.

The Fourth Industrial Revolution is already on its way. This trend is also affecting the way goods are manufactured and services are offered, and Industry 4.0 will be an answer to the challenges lying ahead of Europe. If the European economy can achieve a strong position within Industry 4.0, divestment will no longer be a threat. Industry 4.0 requires investments. But Industry 4.0 also substantially increases capital productivity through potential benefits such as mass customisation, networks, and the means to meet them with new production technologies, new materials, and new ways of storing, processing, and sharing data.

Digitised products and services generate approximately €110 billion of additional revenue per year for European industry. Companies that have already digitised their product portfolio have grown above average in the past three years. Companies even expect sales to rise by more than 20%. In total, this amounts to an average incremental sales increase of 2.5% per annum. Compared to all industrial companies in the five core industry sectors, this is equivalent to an annual sales potential of more than €30 billion for Germany and reaches up to €110 billion of additional revenue for European industry in total.

Germany's economy is one of the most competitive in the world. Its gross domestic product (GDP) grew by 1.9% in 2016, faster than any other G7 economy, and its employment rate has risen by 10 percentage points over about a decade. This puts Germany in a strong position to face potentially disruptive trends, including an ageing population, rising global competition, and especially digitisation and automation through Industry 4.0. In order to preserve Germany's strong competitive position, business leaders and policymakers will need to do more to harness the potential of new technologies and make the most of Germany's competitive advantages. Quick adoption of automation technology could add up to 2.4 extra percentage points to Germany's annual per capita GDP growth to 2030.

German industry is generally in a good position to capture these opportunities as it has already taken many of the steps needed for digitisation and has the resources to move further quickly. Individual companies are becoming industry leaders in the Internet of Things (IoT). To reap these benefits, however, Germany will need to accelerate its embrace of emerging digital technologies, and policymakers also need to take steps to prepare the workforce for the upcoming transition. Though many of these trends and changes are still evolving, German business and policy leaders can begin with a programme of action items each to ensure competitiveness for a digital future:

- Digitise the public sector: Set a clear and ambitious digitisation target for all levels of government and work aggressively towards it.
- Catch up in lagging sectors: Help the less-digitised German sectors – like construction, real estate, and the fragmented tail in banking – to catch up with the most digitised firms.
- Attract foreign talent, and nurture and retain talent in Germany: Further encourage and facilitate the migration of highly skilled tech leaders to Germany, and work with businesses to motivate more of the best workers to stay.
- Strengthen training and education programmes to help young people – including women and the children of asylum seekers – prepare for the future of work.
- Provide digital infrastructure and ecosystems: Build high-performance broadband networks, drive the European Union (EU) digital single market, and otherwise create an environment where digitised businesses can thrive.

- Plan for future labour markets: Modify labour institutions to better support independent workers and others already navigating the future of work, including those who may be left behind in the transition.
- Set a clear and bold digital agenda from the top: Make digital transformation a priority to improve its chances of success.
- Digitise across value chains: Ensure marketing and distribution, supply chains, and products themselves – amongst other elements – take advantage of digitisation and AI.
- Seek and scale opportunities outside traditional boundaries: Identify new and adjacent markets opened up by the digital age and test them for growth.
- Reinvest savings from digital into new opportunities: New tech tools will change businesses' cost structures, which can create the headroom for additional investments in the tools of the future.
- Embrace flat and agile working structures: The stereotypical 'German engineering' culture will need to adapt to the more flexible working models favoured in the digital age.

This European example indicates that because of Europe's primary resource dependency, Europe increasingly faces the limitations of a linear economy, which is the lost value of materials and products, scarcity of resources, volatile prices, waste generation, environmental degradation, and climate change (Tukker, 2015). It comes as no surprise that the European Commission and Parliament developed a policy package to create a 'resource efficient Europe' (European Commission, 2011). The European Environmental Research and Innovation Policy aims to support the transition to a circular economy in Europe, define and drive the implementation of a transformative agenda to green the economy, and achieve sustainable development. The policy debate so far has focused on waste management, which is the second half of the cycle, and only limited efforts have been done to address the first half, which is eco-design (Bagheri and Kao, 2015).

Employment in the eco-innovation sector continued to increase during the recession, from 3.0–4.2 million jobs (2002–2011), with 20% growth in the recession years (2007–2011). The EU holds a third of the global market, which is worth a €1 trillion. In Europe, it is estimated that resource productivity could grow by up to 3% annually.

This would generate a primary-resource benefit of as much as €0.6 trillion per year by 2030 to Europe's economies. In addition, it would generate €1.2 trillion in non-resource and externality benefits, bringing the total annual benefits to around €1.8 trillion compared with today. This would translate into a GDP increase of as much as 7 percentage points relative to the current development scenario, with an additional positive impact on employment.

Europe's economy remains very resource-dependent. Views differ on how to address this against an economic backdrop of low and jobless growth as well as the struggle to reinvigorate competitiveness and absorb massive technological change. Proponents of the circular economy argue that it offers Europe a major opportunity to increase resource productivity, decrease resource dependence and waste, and increase employment and growth. They maintain that a circular system would improve competitiveness and unleash innovation, and they see abundant circular opportunities that are inherently profitable but remain uncaptured. Others argue that European companies are already capturing most of the economically attractive opportunities to recycle, remanufacture, and reuse. They maintain that reaching higher levels of circularity would involve an economic cost that Europe cannot afford when companies are already struggling with high resource prices. They further point out the high economic and political costs of the transition.

The EU created the so-called Industry 4.0 Readiness Index for the EU's key industrial countries. to analyse EU member states' readiness for the Fourth Industrial Revolution. In creating the new index, the EU followed the methodology the World Economic Forum uses to generate new indices based on the calculation of secondary indices, choosing indicators that are closely related to the innovative performance and development of the countries. The results divide the European economies into four major groups.

The frontrunners are characterised by a large industrial base and very modern, forward-looking business conditions and technologies (Sweden, Austria, and Germany). The traditionalists are found mainly in Eastern Europe. They still thrive on their sound industrial base, but few of them have thus far launched initiatives to take industry into the next era. The third group, the hesitators – a mixture of southern and eastern European countries – lack a reliable industrial base. Many of them suffer from severe fiscal problems and are therefore not able to make their economies future-proof. The industrial base of the potentialists has been weakening over the past few years. Here we find countries such as France and the UK – in the corporate sector, we find indications of a modern and innovative mindset.

Europe's industry has lost ground in the past two decades. Industry 4.0 provides an opportunity for Europe to reindustrialise and increase its industry share from 15% to 20% of the region's value added. Industry has always played a major central role in the economy of the EU, accounting for 15% of value added (compared to 12% in the US). It serves as a key driver of research, innovation, productivity, job creation and exports. Industry generates 80% of the EU's innovations and 75% of its exports. Including its effect on services, industry could be considered the social and economic engine of Europe. Yet European industry has lost many manufacturing jobs over the last decade and is facing tougher competition from emerging markets.

European industry is fundamentally diverse. While the German industrial sector is gaining market share and seeing productivity grow rapidly, other EU states are on the road to deindustrialisation. French and British industry in particular have seen their market share shrink drastically. Industry 4.0 provides a compelling case for strengthening and developing industry in Europe.

How much will Europe need to invest? Industry 4.0 is an opportunity to change the economic rules of the industry, especially to overcome the deindustrialisation trends faced by some European countries. In the current industry setup, there are ways to maintain Europe's competitive edge compared to low labour-cost countries: selecting high-added-value products or activities, having modern and automated production units with critical size, and implementing manufacturing excellence practices.

From an economic point of view, if industry wants to offer incentives to investors it has to go about it in a different way due to its risk profile. Investors expect a return on capital employed (ROCE) of 15% as an average for European industry. There are countries achieving this with activities that require low capital intensity and low-value-added products. The countries with low labour costs are leveraging a labour-intensive workforce and more manual processes. Those are rare in Europe.

Nevertheless, this box contains France, Spain, and the UK. Due to underinvestment over the years, their industrial assets have progressively lost their value. At the same time, labour costs are high. Therefore, profitability is declining, and competitiveness is decreasing.

Europe has countries with state-of-the-art production processes. They are more competitive due to automation and scale effects and can afford higher margins to pay off their capital needs. Germany has a high ROCE of even greater than 15%, which allows the country's industries to invest its employed capital in future industry technologies. In contrast, France currently earns much lower margins from its industry, preventing it from investing and thus eroding the capital employed.

Industry 4.0 requires investments. But Industry 4.0 also substantially increases capital productivity, as mentioned above, with the potential benefits of mass customisation and networked manufacturing, etc. which optimise the way capital is leveraged.

If the European economy can achieve a strong position within Industry 4.0, divestment will no longer be a threat, and Europe's economy will become more competitive,.

The EU Commission set the goal of boosting manufacturing's share of GDP in Europe from 15% to 20% by 2020. This objective is challenging because advanced manufacturing economies, such as Germany, Poland, and Austria, will not be able to boost their shares much more. Even in China, manufacturing only accounts for 30% of the economy – and this figure is declining. Against this backdrop, reaching the 20% goal in Europe would mean that countries such as the UK and France, which for decades have been shutting down their industries and are now at around the 10% mark, would have to re-establish manufacturing on a huge scale in less than a few years. This target is certainly not achievable considering today's situation (Industry 3.0). Instead, it can only be achieved by taking part in the Fourth Industrial Revolution. Reaching 20% means that Europe must create €500 billion in value added and 6 million jobs (provided current GDP growth and inflation remain the same). This would not mean that a product currently manufactured in China will be manufactured by a European worker: it will be manufactured by a European robot or machine, which is programmed by a European engineer.

Currently, the industrial investment level in Europe is €30 billion lower than the level of depreciation, meaning that assets are slowly losing value. Therefore, to achieve the goal by 2030, European firms must keep investing about €90 billion per year to generate the necessary additional value added. This would add up to €1,350 billion over the next 15 years. This amount is not so large at the European level and is far below numerous investment activities of European politics, such as the bailout programmes for indebted member states or subsidies for the agricultural sector.

Europe's ability to switch over to Industry 4.0 will be a major competitive advantage for an economy over its global competitors. Europe as a whole is in better shape to embrace the new industrial world than many people think. Besides having a solid industrial base, many countries are in a good position (equipment, knowledge, expertise, networks) for converting to Industry 4.0. European companies have a chance to develop a competitive edge here.

4. What Are the European Lessons from the Industry 4.0 Readiness Rollout for ASEAN and East Asia?

The ASEAN region has a unique opportunity to leapfrog to the forefront of the fast-moving global digital economy. Many of the fundamentals are already in place in the region. It has:

- A robust economy, generating US$2.5 trillion GDP and growing at 6% per year;
- a literate population of more than 600 million people, with 40% under 30 years of age;
- smartphone penetration of around 35% that is growing rapidly;
- a well-developed ICT cluster with a track record of innovation and investment in new technology; and
- a renewed sense of optimism and urgency for economic integration with the implementation of the ASEAN Economic Community, which pledges to promote the free movement of goods, services, investment, skilled labour, and the free flow of capital.

The ASEAN digital economy currently generates approximately US$150 billion in revenue per year (Kearney, 2016). Connectivity and online services are the biggest components, each accounting for 35%–40% of overall revenues. The user interface (including devices, systems, and software) constitutes the third-largest segment, accounting for close to 20% of revenues. However, these elements are growing at very different speeds. For example, connectivity revenues are expected to grow just 3%–5% per year, whereas online services are likely to grow at more than a 15% compound annual growth rate over the next five years.

The industrial Internet is already a key subject in the industry, and this trend will become increasingly more important in the future (Wan et al., 2016). However, companies in the ASEAN region should take on numerous challenges for the successful and timely implementation of digital concepts. In this respect, the expected high investment levels and the often-unclear cost benefits for new Industry 4.0 applications remain limiting factors. Many companies have not yet developed specific plans for the implementation of Industry 4.0 solutions and have also not made any larger investments. This is because the solutions are new for many companies and require significant internal adjustments. The quantification of potential is also complex and diverse. There is an urgent need for more transparency and the exchange of experiences across industry sectors (Buhr, 2017).

Added value proposition: As organisations shift in Europe towards Industry 4.0-driven products and services, it is increasingly important to develop a sales strategy that can deliver state-of-the-art solutions that utilise some of the aforementioned considerations: know the client, start the sales process earlier, expand the scope of relationships both within and outside of the customers' organisations, explore new service offerings, develop a strong understanding of the data and the possibilities, and start with smaller pilot programmes to demonstrate value. Doing so requires a shift in thinking and a willingness also to change the sales mindset. Manufacturers in the ASEAN region may not get this relationship just right in the early days, but they can use the experience to invest and learn, incorporating new types of skills for the staff, new ways of selling for the teams, and potentially new business partnerships with the clients. The results, when successful, can mean new business opportunities and revenue streams as well as a longer-term focus on shifting customer concerns, collaboration, and creating value.

Employee qualification is an important topic across all industry sectors. The digital change will alter the requirements for employees across all steps of the value chain – from development on through to production and sales. Processes and business models will become more agile and data-based and require completely new employee skills and qualifications. The need for software developers and data analysts in industry will once again significantly increase, which requires appropriate training and education programmes.

So far, ASEAN (as a single community) lags its global peers in the digital economy, yet it has the potential to enter the top-five digital economies in the world by 2025. Moreover, the implementation of a radical digital agenda could add US$1 trillion to the region's GDP over the next 10 years. A decade from now, ASEAN's manufacturing sector is likely to have embraced Industry 4.0 technologies.

5. What Are the Perceived Key Barriers to the Implementation of Integrated Industry 4.0 and Circular Economy Concept in ASEAN Countires and Companies?

Key lessons from national Industry 4.0 policy initiatives in Europe are a result of framing the respective policies. The first policy dimension is financing, as the majority of the national Industry 4.0 initiatives are primarily financed through public means. However, private sector co-financing has played a part. Secondly, national Industry 4.0 initiatives tend to focus on technology and infrastructure, with skills development as a secondary goal. In terms of governance and implementation, most of the national Industry 4.0 policies examined essentially adopted a top-down approach to designing, initiating, and implementing the initiatives. What this means is that while other stakeholders have been consulted and played a part in relevant national initiatives to follow Industry 4.0 policies, governments are in the driver seat. In general, the participation of diverse actors is a defining strength of the national Industry 4.0 policies.

Collaboration with industry actors/stakeholders is most frequently cited as a driving force by the implementing authorities. In some cases, industry proactively encouraged the creation of the initiatives, giving the initiatives additional impetus.

The involvement of regional authorities which are engaged in adopting Industry 4.0 strategies at the regional level – often in the framework of smart specialisation strategies – have regularly allowed for greater policy alignment between the national and regional levels. Last but not least, the initiative of public authorities in pushing forward the Industry 4.0 policies is also amongst the key drivers. The public impetus can be particularly useful when industries are too segregated or fragmented to reach consensus amongst industry actors. The example of Industrie 4.0 in Germany shows how a large Industry 4.0 platform can reduce industry segregation and improve networking.

Yet, there are several major roadblocks standing between ASEAN and an advanced digital economy and society. To bring about a full digital revolution, the following barriers will need to be addressed:

- Weak business case for building broadband
- Regulations inhibiting innovation in mobile financial services and e-commerce
- Low consumer awareness and trust, which hinder the uptake of digital services
- No single digital market
- Limited supply of local content, primarily due to a weak local digital ecosystem

Gaps in the policy enablers required to support devices, networks, and applications mean that many ASEAN Member States are lagging the potential of innovative sectors associated with the digital economy, such as mobile financial services, e-commerce, and cloud services.

Still, the ASEAN region has the potential to leapfrog other countries and rank as an elite global digital economy. A true digital revolution will transform ASEAN by 2025. Singapore, Malaysia, and Thailand would be in the top 20 of the global digital rankings, while all other ASEAN countries would be ranked in the top 40 worldwide. Achieving this ambition would go hand in hand with delivering a substantial increase in GDP across the 10-nation bloc. Transforming ASEAN into a global digital economy powerhouse could potentially generate an additional US$1 trillion in GDP over the next 10 years. Realising this goal will require a joint effort and a shared vision across ASEAN.

The uplift to GDP will be driven by three major factors: an increase in broadband penetration; higher worker productivity; and new digital industries, such as e-commerce and mobile financial services.

Digitisation is not limited to ICT industries. It is also disrupting traditional industries. It involves three key elements: (1) digitising product and service offerings (for example, remote health monitoring), (2) digitising customer engagement (for example, digital channels for sales and digital self-serve channels), and (3) digitising internal operations to increase productivity (for example, digitising the sales force). As labour costs rise in the manufacturing and engineering sectors, digitisation will help ASEAN move up the economic value chain. Technology sensors and devices are being integrated into equipment and machinery through the IoT, while advances in computational ability are enabling the analysis of huge information (big data) related to production, logistics, and sales. In the future, factories will be far more flexible than today in terms of producing individual products and achieving higher efficiency. Manufacturing will be faster, lower-cost, and higher-quality.

Over the next decade, Industry 4.0 will emerge in Southeast Asia, aided by support from far-sighted business and political leaders. Industry 4.0 consists of the intelligent networking of product development and production, logistics, customers, and beyond. We will begin to see intelligent machines and smart factories that will bring about the Fourth Industrial Revolution. The resulting revolution in ASEAN's manufacturing sector will increase the region's productivity and competitiveness, while lowering unemployment rates and creating higher-wage jobs.

Discrete manufacturing industries, from the automotive to the electrical and electronics sectors, will all benefit from the operational efficiencies reaped from new technologies. In Singapore and Malaysia, high-value product manufacturing, such as printed electronics and miniaturisation, could undergo a high degree of automation and optimisation. These sectors will be amongst the first to integrate Industry 4.0 into their production platforms.

A true single digital market requires member states to align their digital visions and strategies to create a single, borderless digital market and harmonised digital regulations. ASEAN is quite far from realising this ideal.

Only three countries – Singapore, Malaysia, and the Philippines – have a mature and comprehensive digital strategy. Indonesia has an ICT master plan focused primarily on connectivity until 2016, with a subsequent focus on creating a digital Indonesia. Thailand and Viet Nam's digital strategies were works in progress as of September 2015, with only high-level information available at the time of writing. Cambodia and Brunei Darussalam's digital strategies are quite nascent, with Brunei focusing mostly on digital government.

The harmonisation of regulations needs to begin from the top down. This does not mean creating the same laws in different countries. But there is a need for a common standard that applies to digital services in ASEAN, like the EU's privacy directive or the streamlined sales tax system in the US for cross-state e-commerce transactions. Today, different ASEAN countries are taking very different approaches to infrastructure, spectrum sharing, and spectrum trading, while the maturity of cybersecurity and data protection policies varies significantly from country to country.

There are five steps policymakers can take to eliminate the roadblocks described in the previous section. These are the following:

- Pursue universal mobile broadband access
- Accelerate innovation in mobile financial services, e-commerce, and connected cities
- Enhance trust and security in ASEAN's digital economy
- Strengthen the local digital economy
- Foster digital innovation within ASEAN

Agility is a strategic characteristic that is becoming increasingly important for successful companies. In this context, agility denotes the ability to implement changes in the company in real time, including fundamental systemic changes to the company's business model, for example.

Consequently, the significance of Industry 4.0 lies in the key role of information processing in enabling rapid organisational adaptation processes. The faster an organisation can adapt to an event that causes a change in its circumstances, the greater the benefits of the adaptation. In this context, the umbrella term 'event' may relate to a range of different business decisions. Events may be short-term in nature, for instance a production line breakdown, or medium- to long-term, for example a change in product requirements and the associated modifications to the product design itself, to the manufacturing process and to related processes in purchasing, quality, and service.

Leaders of high-tech industrial enterprises understand that their most important assets are the machinery and assembly tools on their factory floors. These companies have often spent decades developing their manufacturing plants to produce an ever-increasing array of goods and products that they sell around the world. They have also spent decades improving their industrial processes – including just-in-time inventory – to be as efficient as possible. But given the technology developments that have taken place over the past five years, even the industrial enterprises that are the leaders in lean processes are in danger of being left behind in the 21st century. This is because the mere deep knowledge of industrial practices is not enough to succeed in today's ultra-competitive and technology-enabled marketplace.

By tapping into the principles of Industry 4.0 and adopting emerging technologies, today's set-intensive organisations can hone their ability to stay ahead in a new world where machinery and tools are being amplified by digitisation. This cyber-physical world offers the bold riches of enhanced global competitiveness and entry into radically new marketplaces.

The next 5 years will be vital for ASEAN countries for the adoption of Industry 4.0. The largest improvements that an ASEAN roadmap should focus on are in the following areas:

- Data standards and interoperability between modern and legacy shop floor systems in a multi-vendor environment as a precursor for seamless interaction, which enables multiple aspects of efficiency up the value chain.

- Effective root-cause analysis and corrective actions that build a logical approach in solving problems at their source, rather than just fixing the apparent. This is therefore considered as key for any continuous improvement programme.

- Dynamic asset classification based on asset type, relation to other equipment, hierarchy, complexity, and criticality is an important aspect to build the right model that enhances operational and maintenance efficiencies.
- Real-time production planning and scheduling can optimise all aspects of operations accurately by minimising resources consumed and maximising efficiency.
- Knowledge capture and management enable improved operations and the maintenance of complex machines, as people and their knowledge are intangible assets in industrial manufacturing.
- Manufacturing companies of today will need to adopt advanced technologies to improve in these areas if they plan to achieve higher maturity levels in their journey of Industry 4.0.

Experience with the implementation of lean management principles since the 1990s has taught that it is not enough simply to ring the changes – successful implementation also requires an in-depth understanding of the organisation and a widespread willingness to change amongst its members. Just as lean production is about far more than simply preventing waste, Industry 4.0 is not merely a matter of connecting machines and products via the Internet, the use of new technologies, or the acquisition of knowledge.

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CHAPTER 3

Industry 4.0 Readiness with a Circular Economy Focus: An Integrated Assessment Framework

Krishnamurthy Ramanathan

1. The Importance of Firm-level Industry 4.0 Readiness from a Circular Economy Perspective

Industry 4.0 is talked about extensively as the 'Fourth Industrial Revolution' that will have a major impact on manufacturing value-chains at both local and global levels, not just in industrially advanced high-cost nations but also in less industrialised low-cost nations (Schwab, 2016). While many descriptions and definitions of Industry 4.0 exist, a simple way of looking at it at an overall level is as a 'collective term for technologies and concepts of value-chain organization' (Hermann, Pentek, and Otto, 2015).

According to the Rüßmann et al. (2015) of the Boston Consulting Group, this transformation is being driven by several foundational technological advances that enable sensors, machines, workpieces, and information technology (IT) systems to be linked along a value chain beyond a single enterprise. Deloitte (2015) refers to these foundational technological advances as 'acceleration through exponential technologies'. While the broad Industry 4.0 literature (Albert, 2015; D'Aveni, 2015; Deloitte, 2015; Hermann, Pentek, and Otto, 2015; Iansiti and Lakhani, 2014; Mohr and Khan, 2015; Whitmore, Agarwal, and Xu, 2015) classifies these exponential technologies in many ways, they include the industrial Internet of things (IoT), big data and analytics, simulation, advanced robotics, artificial intelligence (AI), additive manufacturing (3D printing), cloud-based software platforms, and augmented reality.

Deloitte (2015), in their study of challenges and solutions for the digital transformation and use of exponential technologies, pointed out that Industry 4.0 has four main characteristics, namely: vertical networking of smart production systems through the use of cyber-physical production systems (CPPS); horizontal integration of real-time optimised global value-creation networks; cross-disciplinary through-engineering across the entire value chain and across the full life-cycle of both products and customers; and the acceleration of individualised solutions, flexibility, and cost savings in industrial processes through the use of exponential technologies. Hermann, Pentek, and Otto (2015) pointed out that an Industry 4.0 scenario needs to take into consideration six design principles – interoperability, virtualisation, decentralisation, real-time capability, service orientation, and modularity.

However, Ubisense, a global firm specialising in location intelligence solutions found out, through its 2014 Smart Manufacturing Technologies Survey of 252 manufacturing engineers and product designers, that 40% of manufacturers have no visibility into the real-time status of their manufacturing processes; more than 80% rely on human observation to support process-improvement initiatives; nearly 85% of quality issues can be attributed to worker errors; nearly 10% of manufacturing personnel spent considerable time daily looking for equipment and products; and that over 10% of cycle time per product is non-value-added time (Ubisense, 2015). This suggests that even in industrially advanced settings, there are many barriers to Industry 4.0 that need to be overcome by firms in the manufacturing sector.

Schumacher, Erol, and Sihn (2016), based on the findings of strategic orientation workshops with various companies, pointed out that transitioning to Industry 4.0 presents many difficulties to firms and that the following are the major issues:

- Inability to determine their state of development with regard to an Industry 4.0 vision, thereby making it difficult for them to identify specific steps that need to be taken in terms of actions, projects, and programmes; and
- Inability to link their specific domain and business strategy.

Schumacher, Erol, and Sign (2016) thus argued that to overcome uncertainty and dissatisfaction in manufacturing firms in adopting Industry 4.0, methods and tools have to be developed to provide them with the needed guidance to plan the transition and align business strategies and operations.

The first objective of this chapter is therefore to develop a conceptual framework that will enable a firm in the manufacturing sector to assess its Industry 4.0 readiness (I4R). In recent years, several attempts have been made to develop I4R frameworks, and these have been popularly referred to as 'maturity models' or 'readiness models'. This study will, therefore, adopt an eclectic approach to develop the I4R assessment framework by evaluating the concepts and ideas proposed by existing models and incorporating them into a holistic framework.

Secondly, this chapter will also focus on developing a framework that will enable a firm in the manufacturing sector to assess its I4R from a circular economy (CE) perspective. The positive impact that Industry 4.0 can have from a CE perspective is that it can, if well designed and used effectively, help to minimise the leakage of both biological and technical materials, especially the loss of materials, energy, and labour (Nguyen, Stuchtey, and Zils, 2014). However, this second objective is based on the premise that rather than seeing less leakage of biological and technical materials as a by-product of Industry 4.0 adoption, it would be more advantageous if firms explicitly build in CE considerations into their Industry 4.0 actions, projects, and programmes.

To achieve these two objectives this chapter will adopt the following steps:

- Develop a framework for assessing the status of I4R in a manufacturing firm;
- Develop a framework for assessing the extent of the CE focus in I4R;
- Propose a classification to determine the extent to which a manufacturing firm's Industry 4.0 status has a CE focus. This will be referred to as a 'Circular Economy-focused Industry 4.0 Readiness Rating' (CEF I4R Rating); and
- Delineate some managerial implications, from a CE perspective, for manufacturing firms that are transitioning to an Industry 4.0 setting.

The rest of this chapter is presented in four sections. The next, which is the second, presents the framework for assessing the status of I4R in a manufacturing firm. The third section proposes an approach to evaluate the extent of the CE focus in I4R. The next examines how management in a manufacturing firm can combine the findings to evaluate where they stand in terms of the CE focus of their I4 operations ecosystem. The last section delineates some managerial implications and presents some concluding remarks.

2. Assessing the Status of Industry 4.0 Readiness at the Firm Level

One of the earliest studies on I4R is due to RolandBerger (2014). This study examined Industry 4.0 readiness in Europe and highlighted the challenges faced not just at the firm level but within the business eco-system and the national economic setting. Based on this analysis, the report suggested that different European nations could be classified as 'frontrunners', 'potentialists', 'traditionalists', and 'hesitators' with respect to transitioning to Industry 4.0. Clearly, the initiatives to be taken by the nations in each category to advance to Industry 4.0 would be different. Frontrunner nations, such as Germany and Sweden, would set the pace, while hesitator nations would have much to do to make the transition. However, this report is not a firm-level study and it also does not present the methodology used to make the national-level assessments.

The IMPULS–Industrie 4.0 Readiness study by Lichtblau et al. (2015) proposed six dimensions, namely: 'strategy and organisation', 'smart factory', 'smart operations', smart products', 'data-driven services', and 'employees.' Each of these core dimensions contained several sub-dimensions to enable a comprehensive evaluation of I4R with respect to each of these dimensions. Table 3.1 shows these details. Six rating levels are used in conjunction with these determinants to assess the state of I4R. These levels are: level 0, outsider; level 1, beginner; level 2, intermediate; level 3, experienced; level 4, expert; and level 5, top performer. While insightful to experienced practitioners, this approach is not easy for a firm to use as a self-assessment tool.

The WMG–University of Warwick I4R (2017) assessment tool, also has six dimensions, namely: 'strategy and organisation', 'manufacturing and operations', 'supply chain', 'products and services', 'business model' and 'legal considerations.' Table 3.1 shows these dimensions and the associated sub-dimensions. Four rating levels are used in conjunction with these determinants to assess the state of I4R. These levels are: level 1, beginner; level 2, intermediate; level 3, experienced; and level 4, expert. The advantage of the WMG I4R tool is that it can be used as a self-assessment tool by firms.

While the 'manufacturing and operations' dimension is comprehensive and insightful from a manufacturing technology perspective, other aspects, such as quality and energy consumption, are not explicitly included. Also, the people dimension has not been adequately addressed.

The Yáňez (2018) Maturity Index Framework has eight dimensions, namely: 'operational processes', 'industrial assets', 'energy', 'people', 'internal logistics and supply chain', 'quality', 'supply-demand synchronisation', and 'time to market'. These dimensions and their sub-dimensions are shown in Table 3.1. This framework, while very useful for assessing I4R from the manufacturing and operations perspective, does not explicitly address equally important dimensions, such as 'strategy and organisation', and 'information technology systems.'

The Akdil, Ustungdag, and Cevikcan (2018) Maturity and Readiness Model for Industry 4.0, proposes 10 core dimensions. These are: 'smart products and services', 'smart business processes: production, logistics, and procurement', 'smart business processes: R&D and product development', 'smart business processes: after-sales service', 'smart business processes: human resources', 'smart business processes: pricing/promotion', 'smart business processes: sales and distribution channels', 'smart business processes: information technology', 'smart business processes: smart finance', and 'strategy and organisation'. Table 3.1 shows these dimensions, the sub-dimensions, and principles to be used to assess I4R. The authors use four stages, namely 'absence,' 'existence,' 'survival', and 'maturity', to determine the maturity level. While insightful to experienced practitioners, this approach is not easy for a firm to use as a self-assessment tool.

Table 3.1: Summary of Core Dimensions and Sub-dimensions of Selected Industry 4.0 Readiness Assessment Frameworks

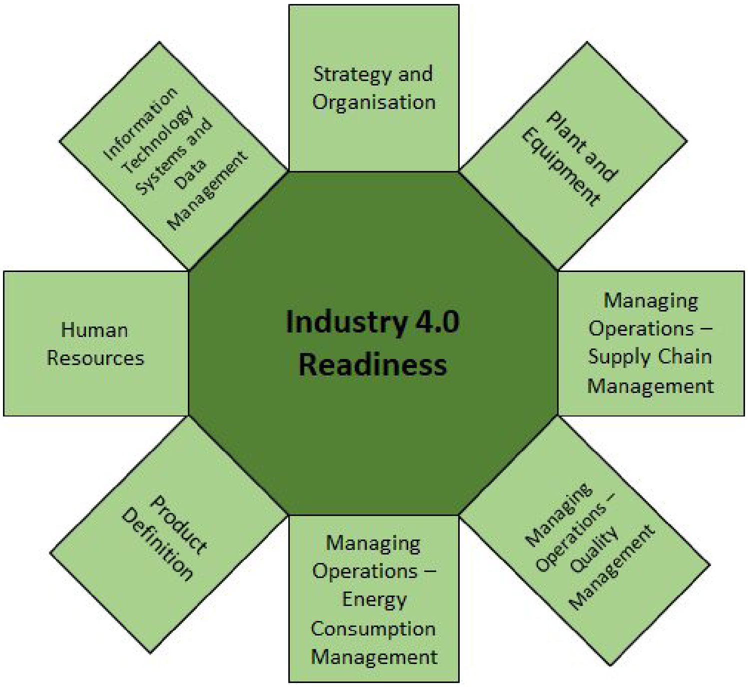
IMPULS–Industrie 4.0 Readiness Framework (2015)	WMG–University of Warwick Industry 4.0 Readiness Assessment Tool (2017)	Yanez Maturity Index Framework (2018)	Akdil, Ustungdag, and Cevikcan Maturity and Readiness Model for Industry 4.0 (2018)
Strategy and Organisation • Strategy • Investments • Innovation management Smart Factory • Digital modelling • Equipment infrastructure • Data usage • Information technology (IT) Systems Smart Operations • Cloud usage • IT security • Autonomous processes • Information sharing Smart Products • Data analytics in the usage phase • Add-on functionalities Data-driven Services • Share of data used • Share of revenues • Data-driven services Employees • Staff acquisition • Employee skill set	Strategy and Organisation • Degree of strategy implementation • Measurement • Investments • People capabilities • Collaboration • Leadership • Finance Manufacturing and Operations • Automation • Machine and operations system integration • Equipment readiness for I4 • Autonomously guided workpieces • Self-optimising processes • Digital modelling • Operations data collection • Operations data usage • Cloud solution usage • IT and data security Supply Chain • Inventory control using real-time data management • Supply chain integration • Supply chain visibility • Supply chain flexibility • Lead times	Operational Processes • Sensoring, monitoring, and control • Intelligent processes • Virtualisation Industrial Assets • Flexible manufacturing and modular systems • Access and remote control • Predictive maintenance Energy • Monitoring and control • Smart consumer • Efficient energy systems People • Digital training • Interfaces • Human-cyber-physical Systems Internal Logistics and Supply Chain • Warehouse management • Internal logistics • Manufacturing supply Quality • Unitary quality control • Digital quality management • Full traceability in value chain	Smart Products and Services • Real-time data management • Interoperability • Decentralised • Service oriented Smart Business Processes: Production, Logistics, and Procurement • Real-time data management • Virtualisation • Decentralised • Agility • Integrated business process Smart Business Processes: R&D and Product Development • Real-time data management • Virtualisation • Agility Smart Business Processes: After-sales Service • Real-time data management • Virtualisation • Agility • Service oriented Smart Business Processes: Human Resources • Real-time data management • Agility

Table 3.1: (Continuted) Summary of Core Dimensions and Sub-dimensions of Selected Industry 4.0 Readiness Assessment Frameworks

IMPULS–Industrie 4.0 Readiness Framework (2015)	WMG–University of Warwick Industry 4.0 Readiness Assessment Tool (2017)	Yanez Maturity Index Framework (2018)	Akdil, Ustungdag, and Cevikcan Maturity and Readiness Model for Industry 4.0 (2018)
	Products and Services • Product customisation • Digital features of products • Data-driven services • Level of product data usage • Share of revenue Business Model • 'As a service' business model • Data-driven decisions • Real-time tracking • Real-time and automated scheduling • Integrated marketing channels • IT-supported business Legal Considerations • Contracting models • Risk • Data protection • Intellectual property	Supply-Demand Synchronisation • Product tailored to customer based on data • Customer logistics • Logistic routes Time to Market • Innovation process • Product life cycle	Smart Business Processes: Pricing/Promotion • Real-time data management • Decentralised • Service oriented • Integrated business process Smart Business Processes: Sales and Distribution Channels • Real-time data management • Agility • Service Oriented Smart Business Processes: Information Technology • Real-time data management • Interoperability • Virtualisation Smart Business Processes: Smart Finance • Real-time data management • Decentralised Strategy and Organisation • Business models • Strategic partnerships • Technology investments • Organisational structure and leadership

Based on the four frameworks described in Table 3.1 and an evaluation of other publications related to specific aspects of Industry 4.0, an eclectic framework consisting of eight key determinants is proposed for assessing I4R at the firm level. These eight determinants are listed below and are shown schematically in Figure 3.1.

Figure 3.1: Schematic Representation of the Determinants of Industry 4.0 Readiness



Source: Author.

The eight determinants of the proposed I4R framework are:

- Strategy and organisation
- Plant and equipment
- Information technology systems and data management
- Human resources
- Product definition
- Managing operations – energy consumption management

- Managing operations – quality management
- Managing operations – supply chain management

Each of these determinants consists of several elements, which, collectively, will determine the Industry 4.0 readiness level with respect to each determinant. These elements are shown in Appendix 1, titled 'A Framework for Assessing the Status of Industry 4.0 Readiness in Manufacturing'. The elements for each of these determinants were synthesised from the four models described in Table 3.1. Furthermore, the elements for the determinants were also obtained from sources that dealt specifically with individual determinants of relevance to I4R. These are summarised in Table 3.2 below.

Table 3.2: Sources Used in Developing the Elements of the Proposed Framework for Assessing I4R

Determinant	Sources
Strategy and organisation	Akdil, Ustundag, and Cevikcan (2018), Lichtblau et al. (2016), WMG–University of Warwick (2017), Yáňez (2018)
Plant and equipment	Akdil, Ustundag, and Cevikcan (2018), Kolberg and Zühlke (2015), Lichtblau et al. (2016), Stock and Seliger (2016), Wagner, Herrmann, and Thiede (2017), WMG–University of Warwick (2017), Yáňez (2018)
Information technology systems and data management	Akdil, Ustundag, and Cevikcan (2018), Li, Xu, and Zhao (2015), Li, Tryfonas, and Li (2014), Lichtblau et al. (2016), Luo et al. (2016), Weber et al. (2017), WMG–University of Warwick (2017), Yáňez (2018)
Human resources	Akdil, Ustundag, and Cevikcan (2018), Baena et al. (2016), Hecklau et al. (2016), Lichtblau et al. (2016), WMG–University of Warwick (2017), Yáňez (2018)
Product definition	Akdil, Ustundag, and Cevikcan (2018), Lichtblau et al. (2016), WMG–University of Warwick (2017), Yáňez (2018)
Managing operations: energy consumption management	Yáňez (2018)
Managing operations: quality management	Yáňez (2018)
Managing operations: supply chain management	Akdil, Ustundag, and Cevikcan (2018), Barreto, Amaral, and Pereira (2017), Hofmann and Rüsch (2017), Lichtblau et al. (2016), Luo et al. (2016), Szoda (2017), Tjhajono et al. (2017), WMG–University of Warwick (2017), Yáňez (2018)

3. Assessing the Extent of the Circular Economy Focus in Industry 4.0 Readiness

Industry 4.0 holds considerable promise for sustainable industrial value creation. While it is still regarded as a manufacturing paradigm that is still new, the emerging literature based on recent developments in the field suggests that it is possible to postulate likely positive impacts that Industry 4.0 can have from a circular economy perspective even without explicitly incorporating CE considerations into Industry 4.0 actions, projects, and programmes.

The term 'lean manufacturing' was formally coined by Womack and Jones (1996) to emphasise the importance of reducing what the Japanese automotive industry referred to as the 'seven deadly wastes'. A reduction of these wastes will have a beneficial impact from a CE perspective, even without a firm explicitly incorporating CE aspects into their strategic and operational planning (Wagner, Herrmann, and Thiede, 2017). The seven deadly wastes are: transport, inventory, motion, waiting, over-processing, overproduction, and defects. These are popularly referred to by the mnemonic TIMWOOD. Table 3.3 shows how Industry 4.0 can contribute towards a CE through the reduction of TIMWOOD, which in turn can lead to the reduction in the use of material and energy resources.

Table 3.3: Industry 4.0 and TIMWOOD Reduction for a Circular Economy

Seven deadly wastes	How Industry 4.0 can eliminate and/or minimize the seven deadly wastes
Transport (T)	• Processes located close to each other enable timely direct material movement • Streamlined production pathway reduces needless transport • Long and complex warehousing and material-handling systems avoided
Inventory (I)	• Enables working with smaller batch sizes due to reduced set-up times • Facilitates easier implementation of pull systems
Motion (M)	• Optimised workstation layouts lead to the smooth transfer of parts and materials leading to less worker effort • Redesigned layouts and workplaces and smaller batch sizes enable less movement of materials internally

Seven deadly wastes	How Industry 4.0 can eliminate and/or minimize the seven deadly wastes
Waiting (W)	• All operations run on schedule leading to less/no idling of subsequent workstations • Deliveries from suppliers and other departments arrive on time • Machines are well maintained with, therefore, less downtime • Well-trained workers and better-maintained machines lead to improved worker-machine coordination • Reduced or no waiting time since there is less/no rework of a product
Overproduction (O)	• Smaller batch size production possible through more reliable processes • Stable production schedules, balanced lines, and no bottlenecks become possible • Closer cooperation with customers leads to production based on actual demand
Over-processing (O)	• Standard operating procedures, well-trained workers, clear specifications, and explicit quality standards lead to optimal processing
Defects (D)	• Trained workers improved and standardised processes, closer coordination with suppliers, and reduced operator errors minimise defects and rework

Note: TIMWOOD refers to the seven deadly sins as listed in the table.
Source: Womack and Jones (1996).

At the heart of manufacturing in Industry 4.0 is the 'smart factory', where there is vertical integration of smart production systems, horizontal integration of value-chain systems, and 'end-to-end' or through-engineering across the entire value chain (Stock and Seliger, 2016; Mohr and Khan, 2015). The cyber-physical production system (CPPS) in a 'smart factory' uses sensor systems to identify and localise value creation entities, such as other machines, products being made, and people. Based on the monitored 'smart data', the actuators in the equipment respond in real-time to changes. The exchange of smart data between the value creation entities and the value chain is executed through the cloud. Table 3.4 shows how these value-creating factors can contribute towards a CE.

Table 3.4: Contribution by Value-creating Factors in Industry 4.0 Towards a Circular Economy

Value-creation factors	Contribution towards waste reduction and circular economy
Equipment	• Automated machine tools and robots work collaboratively with other value-creation factors. These smart machines are likely to be organised into modular working stations, which are error-proofed and have 'plug and produce' capability. • Existing manufacturing equipment can be retrofitted with sensors, actuators, and control logics as a cost-efficient way of upgrading to reduce the heterogeneity of equipment within the factory. • In addition to economic and environmental dimensions of sustainability, this could enable small and medium-sized enterprises to move towards Industry 4.0.

Value-creation factors	Contribution towards waste reduction and circular economy
People	• Overall decrease in the number of workers, but with a high percentage of knowledge workers who will increasingly have to monitor the CPPS, engage in decentralised decision-making, and participate in through-engineering activities. • As knowledge workers and, with responsibility for decentralised decision-making, these workers will have to be extensively trained to effectively use smart data and support tools based on AI. • Equipped with smart watches, 'smart operators' will receive, monitor, and take action in real-time to prevent failures and machine downtime.
Organisation	• Decentralised decision-making with local information being used by workers and machines in conjunction with AI helps the CPPS to find the optimum balance between the highest possible capacity utilisation at each work station and the continuous flow of goods. • If the organisation is suitably structured to foster decentralised decision-making and collaboration along the supply chain with a focus on resource conservation, then the implementation of smart grids, smart logistics, customer relationships, and other integrative approaches can promote holistic resource efficiency.
Process	• The use of exponential technologies, such as additive printing and internally cooled tools for metal-cutting, can lead to the design of resource-conserving and sustainable manufacturing processes.
Product	• Smart products' can be designed based on 'cradle-to-cradle' principles with mass customisation becoming possible. Through the adoption of exponential technologies, integrated after-sales functionality and access for improved performance can be built in, leading to a lower total cost of ownership. • Through the application of identification systems for the recovery of products for remanufacturing and the real-time tracking of the performance of products at the customer end, the total costs of production and ownership can be reduced while promoting the sustainable use of resources.

AI = artificial intelligence, CPPS = cyber-physical production systems.
Source: Adapted from Stock and Seliger (2016); Kolberg and Zühlke (2015); and Mohr and Khan (2015).

However, rather than regarding Industry 4.0 technologies as contributing to a CE through waste reduction, it has been recently proposed that it would be beneficial if a roadmap could be developed to explicitly incorporate CE principles into Industry 4.0 approaches (De Sousa Jabbour et al., 2018). In this context, De Sousa Jabbour et al. (2018) suggested that it would be useful to examine how the six business actions proposed by the Ellen MacArthur Foundation, and referred to as the ReSOLVE framework, can be used to implement the principles of CE in Industry 4.0 approaches. These six principles ReSOLVE) are briefly summarised below (De Sousa Jabbour et al., 2018).

- Regenerate: Emphasises shifting to the use of renewable energy and materials. Biological cycles become important from the perspective of enabling the circulation of energy and materials, and in converting organic waste into sources of energy and raw material for other chains.
- Share: Goods and assets are shared between individuals and in such a 'shared economy' setting, products are designed to last longer with maintenance enabling the re-use and extension of product life.
- Optimise: This technology-centred strategy requires organisations to use exponential technologies to reduce waste in production systems across supply chains. This aspect has been summarised above in Tables 3.3 and 3.4.
- Loop: This emphasises the use of biological and technical cycles to recapture the value of organic waste. For instance, anaerobic digestion can recapture the value of some organic wastes through a biological cycle. Technical cycles based on good reverse logistics can recover and restore the value of used products and packaging through repair, reuse, remanufacture, and recycling approaches.
- Virtualise: This emphasises service-focused strategies, which replace physical with virtual and dematerialised products.
- Exchange: This involves adopting a technological substitution approach through innovation where old and non-renewable goods are replaced by more advanced and renewable ones. The advantage of this is that replacement by cheaper and renewable substitutes can mitigate the supply risks of scarce materials, such as rare earth elements.

If these types of principles can be incorporated explicitly into the actioning of the eight determinants in the proposed Industry 4.0 Framework (Appendix 1), then firms would have a Circular Economy-focused Industry 4.0 setting that can enhance profitability through sustainability.

Appendix 2 shows the 'Framework for Assessing the Extent of the Circular Economy Focus in Industry 4.0 Readiness.' The eight determinants are the same as in the I4R framework to ensure compatibility between the two frameworks. Each of these determinants consists of several elements which, collectively, will determine the extent of the CE focus with respect to each determinant. The CE-based elements for each of these determinants were synthesised from De Jesus et al (2018), De Sousa Jabbour et al. (2018), Jovanoviċ, Filipoviċ, and Bakiċet (2017), Lieder and Rashid (2016), Malinauskaite et al. (2017), and SITRA (2016). Furthermore, CE-relevant aspects from Lichtblau et al. (2015), Nguyen, Stuchtey, and Zils (2014), PricewaterhouseCoopers (2014), WMG–University of Warwick (2017), and Yáñez (2018) were included in developing the elements.

4. Assessing the 'I4R' and the 'CE Focus in I4R' in a Manufacturing Firm Using the Proposed Frameworks

The proposed frameworks may be used by an investigator to assess I4R and CE focus in a manufacturing firm. The frameworks may be also used as a self-assessment tool by firms. The procedures for carrying out these assessments are described in Appendix 3 and Appendix 4. These two procedures involve following the steps summarised below. The steps described below are those that could be adopted by an investigator.

Step 1: Obtaining background information on the firm

Having obtained approval to carry out the study in a large manufacturing firm (e.g. a firm in automobile manufacturing, machine tool manufacturing, textile and garment manufacturing, etc.), it will first be necessary to have a general discussion with management on the competitiveness status of the firm, future strategic plans, the challenges faced, and risk mitigation strategies that the firm has put into place to meet these challenges. This information will be useful in placing the findings in context.

Step 2: Assessing 'Industry 4.0 Readiness'

This step aims at rating the elements under each determinant using Appendix 1. This will involve meeting the appropriate managers in charge of these areas and asking them to choose the level at which the firm is with respect to the elements of each of the eight determinants. The managers must be asked to provide evidence to support their rating. This must be recorded by the investigator. To illustrate this, Appendix 3 shows an example of a hypothetical rating (shaded in blue) of the levels of the four elements of Determinant 2 (plant and equipment).

If possible, it will be useful to ask a few managers to independently choose the level with respect to each element so that the bias of an individual manager is not reflected in the rating. Ideally, there should be congruence.

If there are differences in the ratings, then the analyst should probe further to identify the reasons for the different ratings and then eventually arrive at a consensus.

Step 3: Assessing the 'CE Focus in Industry 4.0 Readiness'

This step aims at rating the elements under each determinant using Appendix 2. As in Step 2, this will involve meeting the appropriate managers in charge of these areas and asking them to choose the level of CE focus at which the firm is with respect to the elements of each of the eight determinants. The managers must be asked to provide some examples to support their rating. This must be recorded by the investigator. To illustrate this, Appendix 4 shows a hypothetical rating (shaded in green) of the levels of the four elements of Determinant 2 (plant and equipment).

Step 4: Presentation of the findings

The results of both assessments can be summarised using Table A3.2 in Appendix 3 and Table A4.2 in Appendix 4. Table A3.2 can be used to develop a summary of the case study firm's Industry 4.0 Readiness and Table A4.2 can be used to develop a summary of the case study firm's 'Circular Economy Focus in Industry 4.0 Readiness'. The maximum values attainable for each determinant are shown in both tables. The actual values obtained and the maximum values can be depicted using a radar diagram. It is suggested that separate radar diagrams be drawn for 'Industry 4.0 Readiness' and for the 'Circular Economy Focus in Industry 4.0 Readiness'.

Step 5: Interpretation of the findings of Table A3.2 (summary of I4R)

This will be the most difficult part. However, it is suggested that the findings be discussed with the management of the firm to obtain their views on the options available to the firm to accelerate their transition to Industry 4.0.

Since there are 33 elements in assessing I4R, the maximum score achievable will be 132 (i.e. 33 x 4). The status of I4R may be classified as follows.

0–33	Hesitators
34–66	Potentialists

67–99	Experienced
100–133	Experts or frontrunners

Step 6: Interpretation of the findings of Table A4.2 (summary of CE Focus in I4R)

This, too, will require discussion with the management of the firm to obtain their views on what they plan to do to explicitly bring in a CE focus into their Industry 4.0 programme. A firm that can effectively build in a CE focus is likely to achieve greater effectiveness in its Industry 4.0 programme.

Since there are 14 elements in assessing the extent of CE focus in I4R, the maximum score achievable will be 56 (i.e. 14 x 4). The status of CE focus in I4R may be classified as follows.

0–14	Business as usual
15–28	CE beginners
29–42	CE fast adopters
43–56	CE leaders

Step 7: Developing a CE-adjusted I4R index

A hypothetical example is used to illustrate how an overall score for a CE-focused I4R index may be calculated as follows.

Suppose Firm A achieves the following scores:

Industry 4.0 Readiness Score	= 102 (out of a maximum of 132)		
Extent of Circular Economy Focus in Industry 4.0 Readiness	= 38 (out of a maximum of 56)		
Industry 4.0 Readiness Index	= 102/156	=	0.77
Circular Economy Focus in Industry 4.0 Readiness Index	= 38/56	=	0.68
Circular Economy Focused Industry 4.0 Readiness Rating (CEF I4R Rating)	= 0.77 x 0.68	=	0.52

5. Using the Proposed Frameworks as a Self-assessment Tool to Transition to a Circular Economy-focused Industry 4.0 Setting

Based on the two assessment frameworks and the proposed analysis, Figure 3.2 provides a schematic representation of possible combinations that an analyst may come across with respect to a firm's I4R and the extent of the CE focus in its I4R. The proposed matrix in Figure 3.2 shows several possible combinations, some which are likely to not be valid. For instance, it is unlikely that an I4 hesitator will be a CE leader. Similarly, it is unlikely that a I4 frontrunner will adopt a business-as-usual approach with respect to CE. Some unfeasible combinations are shown in the CE-I4R matrix. Once an investigator completes the analysis or a firm carries out a self-assessment, this matrix can be used to position the firm in the CE-I4R matrix.

Figure 3.2: Circular Economy-focused Industry 4.0 Readiness Matrix

		Status of CE Focus in I4R			
		Business as Usual (0–14)	CE Beginners (15–28)	CE Fast Adopters (29–42)	CE Leaders (43–56)
Industry 4.0 Readiness Status	Expert/ Frontrunner (100-133)	Unlikely			I4 and CE Champion
	Experienced (67-99)	Unlikely			
	Potentialists (34–66)	Unlikely			
	Hesitators (0-33)	I4 and CE Novice	Unlikely	Unlikely	Unlikely

CE = circular economy, I4 = Industry 4.0, I4R = Industry 4.0 readiness.
Source: Author.

Once the CE-I4R assessment is carried out, the next stage will be complex, where the firm will have to develop a blueprint for action to be taken to move towards the top-right-hand corner of the matrix to become an 'I4 and CE champion'. Extensive cross-functional discussions within the firm will be needed, and external guidance may have to be sought to bring in new ideas and fresh thinking to supplement internal expertise.

A recent study carried out PwC Strategy & Germany (Geissbauer et al., 2018) points out that for a firm to become a 'digital champion' in the context of Industry 4.0, it is necessary to cleverly design and develop effective business ecosystems (customer solutions ecosystems, operations ecosystems, technology ecosystems, and people ecosystems) that are supported by a visionary digital culture reflecting the vision of the leadership, the company's way of working, and skill development of people. Geissbauer et al. (2018), also suggested a six-step approach that can be taken to facilitate the planning to become a digital champion. This six-step approach has been adapted to develop a procedure that can be used by a firm to plan its move upwards in the CE-I4R matrix.

Step 1: Use the two assessment frameworks to reach a consensus on immediate feasible actions that can be taken

- The discussion here should focus on the determinants that should receive priority and which of the elements within these determinants can be upgraded quickly to move forward so that customer value and competitiveness can be enhanced.
- If the two assessments have been carried out with care, then the results can provide transparency that can enable discussions to be held without bias or apportioning blame.

Step 2: Use the outcomes of the discussion in Step 1 to define a vision for the short term and the longer term

- Senior management can use the outcomes of the discussions in Step 1 to define a vision for the short and longer terms.
- The vision can be debated using customer value propositions and stakeholder aspirations as a basis for prioritising actions to be taken to achieve the vision.

- This step should logically conclude with agreement on the actions, projects, and programmes to be undertaken to achieve the vision.

Step 3: Identify the partnerships needed both at the upstream and downstream end of the supply chain to implement the actions, projects, and programmes

- Implementation of the projects and programmes will require the cooperation of suppliers (including lower-tier suppliers as well), distributors, retailers, and end consumers. The degree of cooperation needed with these entities will vary.
- This will require improving channels of communication along the supply chain and the identification of solutions that may have to be implemented along the supply chain.
- Arriving at the solutions will involve looking at interfaces, interdependencies, and information flows, etc. throughout the supply chain so that seamless integration can be achieved.
- These initiatives will then become an integral part of the actions, projects, and programmes that have been identified in Step 2.

Step 4: Appoint a steering committee to review the implementation of the actions, projects, and programmes and ensure that the CE-I4R transition proceeds as envisaged

- A steering committee comprising of senior managers who have the authority to make investment decisions should be appointed to review the progress and monitor key milestones.
- Discriminatory funding may have to be allocated to high-priority projects based on actual need.
- The steering committee may use 'stage-gate' models to review progress and take corrective actions.

Step 5: Build internal capabilities as well as supply chain capabilities to enable effective implementation

- Capabilities will need to be built in each determinant to move from a lower level to a higher one. These will be part of the projects and programmes identified.

- This will require working with internal as well as external human assets.
- Capability building may be implemented using agile project management techniques that utilise scrum and sprint approaches so that key skills and related resources can be shared amongst the projects quickly.

Step 6: Strive for perfection through radical improvements (kaikaku) supported by continuous improvement (kaizen)

- While the upgrading efforts would normally be expected to adopt a kaikaku (radical) approach, the projects, once implemented, will need continuous improvement (kaizen) so that the full value of the CE-I4R can be realised.
- Such kaizen efforts can also generate information needed for newer projects that may be needed to keep progressing.

In recent years the interest in assessing I4R at the firm level has intensified. Several studies have been carried out, mainly by leading consulting firms, to assess the I4R firm. However, these studies have not attempted to link I4R with CE. This chapter, while adopting an eclectic approach to develop an I4R assessment framework, has attempted to overcome this shortcoming by also developing a companion assessment framework that can assess the CE focus in I4R. Together these two frameworks can enable a firm to carry out a self-assessment of its I4R and its CE focus in I4R. Detailed procedures for carrying out the relevant analysis have been provided and managerial interventions needed for a firm to become a 'CE and Industry 4.0 champion' have been suggested.

The frameworks, after discussion and improvement, can be circulated by ERIA to help firms carry out CE-focused I4R self-assessments. It may also be useful to extend the two firm-level assessment frameworks to the level of a supply chain so that the focal firm in a supply chain can initiate action to help the smaller entities in the supply chain to upgrade their I4R with a CE focus.

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Appendix 1: A Framework for Assessing the Status of Industry 4.0 Readiness in Manufacturing

This framework has been developed based on a synthesis of recent literature. The details of all the references and how they were used to arrive at the criteria were presented at the ERIA Meeting in May 2018.

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 information technology (IT) has facilitated this	Departments realise the value of cross-functional collaboration to improve performance and use IT-based interventions, such as enterprise resource planning (ERP) systems	Cross-functional collaboration is the norm and the use of IT-based interventions has enabled the extensive sharing of information

Determinant 1: Strategy and Organisation					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
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 indicators (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 exist that assess 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
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 and the 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 information technology (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 amongstst departments through the use of information technology (IT)	In-company information sharing through the use of IT and 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 implemented across the business and have been extended to cover data and information sharing with all relevant external partners
Operations data collection for internal process improvement	No formal data collection system; data is collected manually by departments for their own usage as needed	Required data is collected digitally by some departments and data available is current	Data is 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

Determinant 3: Information Technology Systems and Data Management					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Operations data usage	Collected data is not integrated with the company's performance measurement system and is used mainly for reporting	Collected data is made available for integration with the company's performance measurement system and is used selectively for remedial action (e.g. quality improvement)	Data is 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 the 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 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	Some information sharing amongst departments through the use of information technology (IT)	In-company information sharing through the use of IT and 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
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 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, product life management (PLM), CIMM, and digital twins), and business analytics (descriptive, diagnostic, predictive, and prescriptive) are now available within the enterprise	Cloud-based solutions have been implemented successfully across most or all areas of the business
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 the exchange of hard copy information	Horizontal integration of information systems along the horizontal value chain (sales, outbound logistics, manufacturing, inbound logistics, and procurement)	Data is 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

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 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 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 – Energy Consumption Management					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Monitoring energy consumption	Consumption information provided by the energy provider	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 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)
Managing energy consumption	Conventional power management	Regular energy audits carried out for developing improvement initiatives	Advanced energy saving systems have been installed	Energy consumption aspects are built into product and process design to proactively reduce energy usage	Product value arises from the protected intellectual property used and extensive digital features
Energy systems	Energy consumption on demand	Control of energy demand	Power self-generation	Energy storage systems have been installed and the energy demand curve is well balanced	The enterprise has minimal demand on the external energy provider and, through its own self-generation, has a positive net balance

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	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 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)
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	Use of advanced control systems (e.g. artificial vision) along with machine learning systems and automatic adjustment of machine parameters to achieve zero defects.	Product value arises from the protected intellectual property used and extensive digital features

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	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 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)
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 is 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 and 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

Determinant 8: Managing Operations – Supply Chain Management					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
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 (2PL) service providers for defined deliveries	Use of third-party logistics (3PL) service providers to manage transportation within the supply chain	Use of fourth-party (4PL) service providers to integrate logistics within the supply chain and reduce lead times	Use of 4PL service providers and autonomous transportation

Appendix 2: Assessing the Extent of the Circular Economy Focus in Industry 4.0 Readiness

Determinant 1: Strategy and Organisation					
Circular Economy (CE) Focus Criteria	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 focus	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 arms-length and is 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 and reuse	Comprehensive ESI from concept development, design, and specification stages, and to create an ecosystem that will support circular product designs

Circular Economy (CE) Focus Criteria	Determinant 1: Strategy and Organisation — 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 and ensure that the principle of 'multiple cycles of disassembly and reuse' is adhered to	None have been developed and top management does not subscribe to the need for such a model	There is interest but work on the development of such models 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 adapting CE practices	Comprehensive models have been developed and implemented successfully with all partners based on trust, information exchange, and shared understanding of the value of adapting CE practices
Extent of emphasis of eco-innovation principles in innovation that includes increased functionality, modular parts, enabling reuse of parts, refurbishment, use of non-toxic and pure components (to enable return to the biosphere) and de-materialisation (e.g. use of the internet and reduced packaging)	No consideration of eco-innovation principles; the focus is mainly on cost reduction and improved performance, even if this means sacrificing eco-innovation principles	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 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					
Circular Economy (CE) Focus Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Capability of plant and equipment and facilities layout to adopt the principle of 'remanufacturing', consisting of disassembly, cleaning, inspection and sorting, reconditioning, and reassembly	Adoption of the remanufacturing principle will not be possible with the current facilities layout and production processes	Some sections of the production process can be converted to adopt remanufacturing, but the organisation has not initiated the move	The sections of the production process that can be converted to adopt remanufacturing are being suitably redesigned and renovated	Remanufacturing is adopted in several sections of the production process	The entire manufacturing facility is capable of adopting remanufacturing
Capability of plant and equipment and facilities layout to adopt resource conservative manufacturing (ResCoM, viz; conservation of energy, water, material, and value added through waste prevention and environmental protection)	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					
Circular Economy (CE) Focus Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent of design of the information technology system and data management to quickly generate information needed for incorporating CE principles explicitly into the firm's operations (e.g. reverse logistics information needed for collection, sorting, remanufacturing, and refurbishment; tracking the location and condition of used devices and components, as well as storing bill-of-materials information; energy consumption and usage, etc.)	No consideration has been given to the generation of such information	The data needed may be available in a raw form, but the IT system software 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					
Circular Economy (CE) Focus Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent to which CE value networks have been built amongst stakeholders	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 ways of working to support the firm's initiatives in adopting CE-based approaches	Employees of the firm, and all suppliers, distributors, and retailers are aware of the CE imperative and have adopted new ways of working to adopt CE-based approaches through the entire supply chain; initiatives are underway to convince and inform customers about maintenance and repair services, environmental impacts, materials that have been put in place to foster a circular economy	Employees of the firm, and all suppliers, distributors, and retailers are aware of the CE imperative and have adopted new ways of working to adopt CE-based approaches through the entire supply chain; consumers reinforce the CE-based approaches by demanding sustainable products, commodities, and services

Determinant 5: Product Definition					
Circular Economy (CE) Focus Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extent of 'regenerative design' considerations with distinction being made between 'technical nutrients' (materials that can be refurbished, reused, or recycled) and 'biological nutrients' (materials that can safely enter the biosphere)	No explicit consideration; design is based on cost and what is available; 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 'critical material design' considerations, such as less material usage, miniaturisation, modularisation, less production processing, long-lasting products, ease of component reuse, and ease of remanufacturing	No explicit consideration; design is based on cost and what is available; any critical material design aspects that appear are incidental	Critical material design aspects are focused on just a few considerations and aspects mainly on technical nutrients; biological nutrients focus is restricted to those needed because of regulatory requirements	Critical material 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 critical material 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 critical material design considerations with the complete participation of all suppliers who incorporate these considerations into the parts and components that they supply

Determinant 6: Managing Operations – Energy Consumption Management					
Circular Economy (CE) Focus Criteria	Readiness 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 footprint	None used	Thermochemical conversion approaches such as combustion (hot gases) and refuse-derived fuel (RFD) are used in an ad-hoc way	Thermochemical conversion approaches, such as combustion (hot gases) and refuse derived fuel (RFD), are used on 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 wastes generated by the firm	Comprehensively used across the supply chain based on a sophisticated understanding of the nature of wastes generated by the supply chain

Determinant 7: Managing Operations – Quality Management					
Circular Economy (CE) Focus Criteria	Readiness 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	Defects are regarded as inevitable, and the emphasis is on reducing the extent	There is interest in moving towards a ZD target, and plans are being made	Formal ZD programmes have been initiated within the firm and some are being piloted	Formal ZD programmes have been initiated comprehensively within the firm with continuous monitoring and improvement	Formal ZD programmes have been initiated comprehensively within the firm and with all key partners in the supply chain

Determinant 8: Managing Operations – Supply Chain Management					
Circular Economy (CE) Focus Criteria	Readiness 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 entities 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 reverse-network-management capabilities	The firm has no capabilities to track the location and condition of used devices and components or gather bills-of-material (BOM) information	The firm is in the process of developing basic capabilities to track the location and condition of used devices and components, and gather BOM information	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	Through advanced IT-based interventions, the firm and its critical supply chain partners can track the location and condition of used devices and components, as well as BOM information for their use	Through the use of advanced IT-based interventions, the firm and its supply chain partners can track the location and condition of used devices and components and also BOM information

Appendix 3: Procedure for Assessing the Industry 4.0 Readiness of a Manufacturing Firm

The eight determinants for assessing Industry 4.0 readiness (I4R) are as follows:

1. Strategy and organisation
2. Plant and equipment
3. Information technology systems and data management
4. Human resources
5. Product definition
6. Managing operations – energy consumption management
7. Managing operations – quality management
8. Managing operations – supply chain management

Each of these determinants consist of several elements which, collectively, will determine the Industry 4.0 readiness level with respect to each determinant. These elements are shown in Appendix 1, titled ‘A Framework for Assessing the Status of Industry 4.0 Readiness in Manufacturing’.

The framework may be used to carry out an assessment of the I4R of any firm in the manufacturing sector. However, it is suggested that a study be carried out in a firm that is currently considered to be relatively advanced in manufacturing.

The following steps may be adopted in carrying out the case study.

Step 1: Obtaining background information of the case study firm

Having obtained approval to carry out the study in a large manufacturing firm (e.g. a firm in automobile manufacturing), it will first be necessary to have a general discussion with management on the competitiveness status of the firm, their plans for the future, the challenges faced, and risk mitigation strategies that the firm has put in place to meet these challenges. This information will be useful in placing the findings in context.

Step 2: Rating the 'Industry 4.0 readiness' of the elements of the eight determinants

This step aims at rating the elements under each determinant using Appendix 1. This will involve meeting the appropriate managers responsible for these determinants and asking them to choose the level at which the firm is with respect to the elements of each of the eight determinants.

If possible, it will be useful to ask a few managers to independently choose the level with respect to each element so that the bias of an individual manager is not reflected in the rating. Ideally, there should be congruence. If there are differences in the ratings, then the analyst should probe further to identify the reasons for the different ratings and then eventually arrive at a consensus.

The managers must be asked to provide evidence to support their rating. This must be recorded by the investigator. A hypothetical rating (shaded in blue) of the levels of the four elements of Determinant 2 is shown below in Table A3.1.

Table A3.1: A Hypothetical I4R Rating of Determinant 2 – Plant and Equipment

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 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

Determinant 2: Plant and Equipment					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Machine and system infrastructure	Machines and systems cannot be controlled through information technology (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 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

The following scores may be assigned for the different levels.

Level 0:	0	Level 1:	1
Level 2:	2	Level 3:	3
Level 4:	4		

For the illustrative example above, the scores for each of the elements would be as follows.

Plant and equipment readiness for Industry 4.0	2
Machine and system infrastructure	2
Autonomously guided workpieces	0
Maintenance of plant and equipment	1

The score for this determinant is therefore 5 out of a maximum possible score of 12.

The values may then be entered for the elements of this determinant in Table A3.2, the Industry 4.0 Readiness Assessment Summary.

Step 3: Interpretation of the findings of Table A2.2

This will be the most difficult part. However, it is suggested that the findings be discussed with the management of the firm to obtain their views on what the available options are to accelerate their transition to Industry 4.0.

Since there are 33 elements, the maximum score achievable will be 132 (i.e. 33 x 4). The status of I4R may be classified as follows.

0–33	Hesitators
34–66	Potentialists
67–99	Experienced
100–133	Experts or frontrunners

Table A3.2: Industry 4.0 Readiness Assessment Summary

Determinants of Industry 4.0 Readiness	Assigned Score	Maximum Score Attainable
Determinant 1: Strategy and Organisation		
Extent of Industry 4.0 emphasis in strategy formulation and implementation		4
Inter-firm collaboration		4
Critical allocation of funds for Industry 4.0 investment		4
Measuring the impact of Industry 4.0 implementation		4
Leadership		4
Innovation orientation		4
Sub total		**24**
Determinant 2: Plant and Equipment		
Plant and equipment readiness for Industry 4.0		4
Machine and system infrastructure		4
Autonomously guided workpieces		4
Maintenance of plant and equipment		4
Sub total		**16**
Determinant 3: Information Technology Systems and Data Management		
Seamless system-integrated information sharing		4
Cloud usage		4
Information technology (IT) and data security		4
Operations data collection for internal process improvement		4
Operations data usage		4
Virtualisation		4
Sub total		**24**
Determinant 4: Human Resources		
IT capabilities		4
Industry 4.0 digital training		4
Human-machine interface		4
Skills for people–system collaboration		4
Sub total		**16**

Determinants of Industry 4.0 Readiness	Assigned Score	Maximum Score Attainable
Determinant 5: Product Definition		
Product customisation		4
Digital features of the product		4
Management of the product life cycle		4
Sub total		**12**
Determinant 6: Managing Operations – Energy Consumption Management		
Monitoring energy consumption		4
Managing energy consumption		4
Energy systems		4
Sub total		**12**
Determinant 7: Managing Operations – Quality Management		
Quality assurance		4
Quality traceability in the supply chain		4
Sub total		**8**
Determinant 8: Supply Chain Management		
Customer demand management and supply chain integration		4
Supply chain visibility and integration		4
Inventory management		4
Warehouse management		4
Transportation		4
Sub total		**20**

Appendix 4: Procedure for Assessing the Industry 4.0 Readiness of a Manufacturing Firm

The eight determinants for assessing Industry 4.0 readiness (I4R) are as follows:

1. Strategy and organisation
2. Plant and equipment
3. Information technology systems and data management
4. Human resources
5. Product definition
6. Managing operations – energy consumption management
7. Managing operations – quality management
8. Managing operations – supply chain management

Each of these determinants consists of several elements, which, collectively, will determine the I4R level with respect to each determinant. These elements are shown in Appendix 1, titled 'A Framework for Assessing the Status of Industry 4.0 Readiness in Manufacturing'.

Appendix 3 shows how the extent of the circular economy (CE) focus can be assessed for each of these determinants. This assessment should be carried out at the same firm where the I4R assessment was carried out to enable assessment of the CE focus in that firm's I4R. The following steps may be used to carry out the CE focus assessment.

Step 1: Assessing the 'CE Focus in Industry 4.0 Readiness'

This step aims at rating the elements under each determinant using Appendix 3. As in the case of the I4R assessment, this too will involve meeting the appropriate managers in charge of these areas and asking them to choose the level of CE focus at which the firm is with respect to the elements of each of the eight determinants. The managers must be asked to provide some examples to support their rating. This must be recorded by the investigator. A hypothetical rating (shaded in green) of the levels of the four elements of Determinant 2 is shown in Table A4.1 below.

The following scores may be assigned for the different levels.

Level 0:	0
Level 1:	1
Level 2:	2
Level 3:	3
Level 4:	4

Table A4.1: A Hypothetical Circular Economy Focus Rating of Determinant 2 – Plant and Equipment

Determinant 2: Plant and Equipment					
Circular Economy (CE) Focus Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Capability of plant and equipment and facilities layout to adopt the principle of 'remanufacturing', consisting of disassembly, cleaning, inspection and sorting, reconditioning, and reassembly	Adoption of the remanufacturing principle will not be possible with the current facilities layout and production processes	Some sections of the production process can be converted to adopt remanufacturing, but the organisation has not initiated the move	The sections of the production process that can be converted to adopt remanufacturing are being suitably redesigned and renovated	Remanufacturing is adopted in several sections of the production process	The entire manufacturing facility is capable of adopting remanufacturing
Capability of plant and equipment and facilities layout to adopt resource--conservative manufacturing (ResCoM, viz; conservation of energy, water, material, and value added through waste prevention and environmental protection	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

For the illustrative example above, the scores for each of the elements would be as follows.

Capability of plant and equipment and facilities layout to adopt the principle of 'remanufacturing'	2
Capability of plant and equipment and facilities layout to adopt resource-conservative manufacturing (ResCoM)	2

The score for this determinant is therefore 4 out of a maximum possible score of 8. The values may then be entered for the elements of this determinant in Table A4.2, Circular Economy Focus in Industry 4.0 Readiness Summary.

Table A4.2: Circular Economy Focus in Industry 4.0 Readiness Summary

Determinants of Industry 4.0 Readiness	Assigned Score	Maximum Score Attainable
Area 1: Strategy and Organisation		
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		4
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		4
Extent to which the firm has developed profit sharing models and incentives to encourage partners to work with the firm to adopt circular economy (CE) principles		4
Extent of emphasis of eco-innovation principles in innovation		4
Sub total		**16**
Area 2: Plant and Equipment		
Capability of plant and equipment and facilities layout to adopt the principle of 'remanufacturing'		4
Capability of plant and equipment and facilities layout to adopt resource conservative-manufacturing (ResCoM)		4
Sub total		**8**

Determinants of Industry 4.0 Readiness	Assigned Score	Maximum Score Attainable
Area 3: Information Technology Systems and Data Management		
Extent of design of the information technology system and data management to quickly generate information needed for incorporating CE principles explicitly into the firm's operations		4
Sub total		**4**
Area 4: Human Resources		
Extent to which CE value networks have been built amongst stakeholders		4
Sub total		**4**
Area 5: Product Definition		
Extent of 'regenerative design' considerations, with distinction being made between 'technical nutrients' and 'biological nutrients'		4
Extent of 'critical material design' considerations		4
Sub total		**8**
Area 6: Managing Operations – Energy Consumption Management		
Extent to which 'waste-to-energy' (WtE) approaches, such as thermochemical conversion, physicochemical conversion, and biochemical conversion, are used as a secondary resource to reduce the carbon footprint		4
Sub total		**4**
Area 7: Managing Operations – Quality Management		
Extent to which a 'zero-defect (ZD)' approach is being used to eliminate waste		4
Sub total		**4**
Area 8: Supply Chain Management		
Level of sophistication of the reverse logistics system from a CE perspective		4
Extent of reverse-network-management capabilities		4
Sub total		**8**

CHAPTER 4

Measuring and Benchmarking the Policy Factors Influencing Industry 4.0 Readiness and the Circular Economy: A Reality Check for ASEAN

V.G.R. Chandran Govindaraju

1. Introduction

Currently, two emerging issues surround the debate of policymakers who are attempting to progress significantly to embrace those issues in order to catch up with the rest of the world. The first is the attempt to catch up with a new wave of industrial revolution, Industry 4.0 (I4), and the second is to move towards a sustainable economy, mainly transforming the economy into a circular economy. The Association of Southeast Asian Nations (ASEAN) is no exemption in moving forward to embrace I4 and the circular economy. ASEAN's commitment to the Sustainable Development Goals (SDGs) via its 2025 vision, especially in promoting green growth and the circular economy and addressing climate change as well as advancing sustainable consumption and production, requires clever policy alternatives in making the circular model work. The technological and innovation emphasis of I4 would promise an alternative avenue for the ASEAN Member States to move closer to promoting the circular economy, if planned properly. It also provides an opportunity for economic diversification, and if the policy design of the I4 simultaneously addresses the circular economy issues, one would expect that the technological link could support ASEAN to move closer to a circular economy. For this to happen, first, coordination at the policy level is required. It is also clear that policymakers lack understanding of the policy initiatives needed to kick-start the process. For instance, Vu and Anh (2017) claim that policymakers in Viet Nam had played a critical role in initiating the discourse about I4 but had not engaged in any actual policy responses. In contrast, in the case of Singapore, policy initiatives by the government have positioned Singapore as one of the 25 countries that are well prepared to benefit from I4 (WEF, 2018).

In the planning and catching-up phase of I4, developing countries can redefine development and growth by reducing the use of raw materials and negative externalities using the specific technologies of I4. The attempt to embrace I4 within the manufacturing sector, as well as other sectors, would also provide an additional impulse for a nation to achieve circular economy goals since technological advancements would make firms and organisations more efficient in the use of materials and resources – a feature that is crucial for the circular economy. As such, in designing policies for I4, policymakers could also take advantage if those policies are also aligned to achieve the intended goals of a circular economy. The current attempts of the ASEAN Member States are more inclined to prepare the nations to embrace I4. For instance, Malaysia is in the midst of preparing its roadmap for I4. And, as such, these attempts should be proliferated to benefit the attempts to foster a circular economy. The renewed interest in I4 and the circular economy can go hand in hand if, and when, policies are coordinated.

This chapter aims to provide insights on the issues of measuring and benchmarking policy readiness for I4 as well as the circular economy at the macro level. The chapter further explores the policy complementarities related to I4 and the circular economy. In doing so, the chapter develops policy assessment toolkits as well as a policy matrix interlinking I4 and the circular economy. This matrix serves as a guide for policymakers to align both the initiatives and to help the transformation process.

2. The Concepts: Industry 4.0 and the Circular Economy

2.1. Industry 4.0

I4[1] is seen as an integration of complex technology, machinery, and other devices with interacted sensors and software to improve business outcomes. It entails putting in place proper planning, controlling, and predictive mechanisms during the production stages. Indeed, I4 is regarded as a novel organisation of a value chain according to a respective product life cycle (Henning, 2013) as well as comprising the concept of technology collectiveness (Hermann, Pentek, and Otto, 2016). The emphasis is on the key production technologies and mechanisms, such as cyber-physical system (CPS) production, radio frequency identification (RFID), enterprise resource planning (ERP), Internet of Things (IoT), cloud-based manufacturing, and social product development (Georgakopoulos et al., 2016; Lin et al., 2016).

Cyber-physical (CP) technological systems, for instance, are able to connect machines and related devices in production systems via integrated cyber space and physical processes. CP technological systems are complemented with sensors and actuators, mainly for data accumulation and distribution in real time to promote an efficient business organisation (Yu et al., 2015). It enables managers to make decisions based on real data information, especially for the prioritisation of production orders, the optimisation of tasks, and reporting of maintenance needs (Lee, Bagheri, and Kao, 2015). Similarly, other technology, such as the cloud manufacturing system, is a virtual open space that enables manufacturing resources and capabilities to be shared through the internet. Indeed, it improves supplier and customer transaction processes via e-commerce features. Under these circumstances, the suppliers are able to provide customised products and timely services as requested by their respective customers (Yu et al., 2015).

Apart from that, additive manufacturing is another driver in I4 which enables production through digital design with the assistance of 3D printers. In other words, additive manufacturing does not require any special or sophisticated tools, especially in producing parts of products (Holmström et al., 2016), apart from the 3D printers.

[1]The I4 concept was established for the German economy in 2011 (Vogel-Heuser and Hess, 2016). It is also commonly known as the Fourth Industrial Revolution (I4R).

Ultimately, additive manufacturing not only enables interaction amongst designers, engineers, and users but also minimises the production lead time by producing customised products according to clients' needs. I4 is also closely linked to the smart factory concept since it involves the IoT, which facilitates and integrates the entire production plant operation from production to delivery service. Indeed, the full digitalisation of equipment and machinery in the production plant and warehouse (Henning, 2013) gives rise to the concept of lean automation, whereby robotic and automation technologies are employed to achieve lean manufacturing.

As a whole, achieving higher efficiency and productivity growth with the application of a complex technological system is the ultimate goal of I4. For this reason, the core elements of I4 relate to the digitisation, optimisation, and customisation of production, automation and adaptation, and human-machine interaction, as well as data exchange and communication (Roblek, Meško, and Krapež, 2016).

2.2 Circular Economy

The circular economy refers to an economy that is able to achieve resource efficiency by utilising and minimising resource usage and minimising waste and emissions by improving production systems, including product and service design. Along the way, it requires production sectors to engage in the processes of long-lasting design, reuse, remanufacturing, and recycling, as well as repair and maintenance. In other words, the circular economy operates within the realm of: (1) minimising resource use, 2) optimising resource yield, and (3) fostering an effective system by minimising negative externalities.

Scholarly reviews of the literature suggest that CE aims to utilise natural resources efficiently (Kirchherr et al., 2017; McDowall et al., 2017) as well as close the loops in the industrial ecosystem to minimise waste. According to MacArthur, Zumwinkel, and Stuchtey (2015), CE comprises two main cycles, namely, technical and biological. From the technical perspective, the focus is on the product lifespan, which includes reusing, repairing, refurbishing, and remanufacturing (Zhao and Zhu, 2015) as well as recycling the production waste to make new production resources (Bocken et al., 2017; Murray, Skene, and Haynes, 2017).

However, a biological cycle comprises the minimisation of natural resource extraction by means of the utilisation of renewable energy and the reuse of energy or organic waste via anaerobic digestion processes. That said, a consensus emerges in that the three ultimate goals of CE are the preservation of natural resources by leading sustainable consumption between renewable and non-renewable resources, the boosting of the resource lifespan via technical and biological cycles, and the minimising of the harmful effects of production systems on the environment (MacArthur, Zumwinkel, and Stuchtey, 2015).

More importantly, in driving the CE, the creation of new business models is critical (McDowall et al., 2017). In fact, technologies such as 3D printing, production customisation, and digitalisation are required for CE to yield greater benefits in terms of energy and material efficiency, as well as provide greater economic, environmental, and social benefits. With these in mind, several countries, such as China, Japan, and European countries are already making progress in establishing and enforcing the protocols to lead CE values (Geng et al., 2013; Ghisellini, Cialani, and Ulgiati, 2016; Mathews and Tan, 2016; Winans, Kendall, and Deng, 2017).

2.3 Industry 4.0 Readiness and Policy Planning Transition for the Circular Economy

As explained, the main thrust or the core values of the circular economy would be achieving the efficient use of resources, utilising resources, and avoiding external externalities. As such, I4 could help achieve sustainable business operations, leading to a circular economy by integrating a value chain via data collection and information sharing (de Man and Strandhagen, 2017; Stock and Seliger, 2016). Therefore, sustainable management in the business decision-making process is closely associated with the core values of the circular economy and I4 mechanisms. Thus, many features of I4 can help nations to move forward with their circular economy goals.

I4 is seen as a driver to lead the circular economy by minimalising utilisation and reusing limited natural resources to promote sustainable production eco-systems through design and production processes (Preston, 2012). Eventually, the circular economy will resolve the environment-related problems, mainly pollution via sustainable production practices in the respective industrial system. In essence, resources and energy could be managed efficiently in the CE through I4, which embraces a sustainable production system. As such, a sustainable production system is mandatory in ensuring zero waste and promoting renewable energy despite progressing to environmental sustainability (Griffiths and Cayzer, 2016). It is important to realise that the use and application of 3D printers, IoT, cyber-physical space, and additive manufacturing in I4 can stimulate efficiency and sufficiency in terms of resource utilisation. Ultimately, this will lead to recovery, recycling, and the reduction of waste, particularly in material consumption and CO2 emissions in the environment.

In terms of economic viability, I4 minimises the cost, risk, and waste established in the circular economy to ensure the overall production system is viable economically. For example, efficiency in logistic operations processes could be achieved through I4 drivers, especially the IoT, with the assistance of several tracking devices, such as RFID tags and barcodes, mainly to prevent the products from getting lost and being exposed to any wastage. On the other hand, I4 could help achieve the circular economy via the 'loop' business model. This business model represents the circularity of energy and materials in the circular economy as a whole. In fact, numerous I4 support drivers, namely CPS, IoT, cloud manufacturing systems, and additive manufacturing systems, could lead to the circular economy through the adaption of design, production, and logistics decisions. For instance, a product design equipped with sensors or chips may alert users by providing relevant information regarding product components and their lifespan. As such, product information may facilitate users to proceed with product disassembly or recycling activities at the end of the product lifespan. Comparatively, a sustainable production agenda is possible with the adoption of an additive manufacturing approach. Indeed, the additive manufacturing mechanism minimises the waste from production and eventually enables the recycling of waste on a small scale with the availability of a 3D printer (Despeisse et al., 2017). As a consequence, organisations are able to reuse, remanufacture, or recycle the components of products and packaging (Vanderroost et al., 2017) that eventually will enable the use of circular economy principles.

As discussed, policy planning for I4 and circularity integration within the planning would create value in terms of resource management. As such, emphasis on resources should entail the I4 landscapes by promoting value optimisation in an overall production system to enhance the sustainability of resources with minimal wastage.

3. Policy Thrust: Critical Policy Drivers for Industry 4.0 Readiness and the Circular Economy

Policy and national institutions matter in driving both I4 and the circular economy. This section discusses how policymakers could assess I4 and circular economy policy readiness. In this section, a toolkit, which is a self-assessment exercise, is suggested to policymakers to assess their policy readiness. The self-assessment offers a more detailed assessment tool for policymakers to engage different stakeholders to specifically assess their policy-related readiness. In doing so, policymakers should first assess the policy readiness for I4 and the circular economy respectively, and then identify policies that complement and catalyse the drivers that promote and accelerate the move towards I4 and the circular economy jointly. The policy dimensions are mainly developed based on literature research with expert group consultation.[2] The assessment is a macro-level policy assessment that focuses on policies and drivers that directly relate to the dimensions of I4 and the circular economy.[3] Expert opinions and the respective agencies are involved in the policymaking to do the self-assessment. To be more objective, specific measurable indicators (quantitative data) could be assigned and used as evidence to see whether a country has achieved the intended scores within the policy dimensions.

3.1. Policy Readiness for Industry 4.0 and the Circular Economy

In this section, we briefly explain the policy dimensions that can be vital in driving I4 and circular economy.[4] In driving I4, emphasis on a few interrelated policy dimensions is important. The full details of the assessment toolkit are available in Appendix 1 and 2. Policymakers should consider all the dimensions as a holistic framework as each dimension is interrelated. First, the institutional and regulatory framework and reforms are critical as these policies as well as institutional capability drive economic

[2] The idea was inspired by an SME policy index exercise by ERIA and the Organisation for Economic Co-operation and Development as well as the toolkit for delivering the circular economy by Ellen MacArthur Foundation. The report is available at https://www.ellenmacarthurfoundation.org/programmes/government/toolkit-for-policymakers

[3] This is a more simplified version of the policy self-assessment tool, and policymakers could improve it to suit their national context or even expand the dimensions. The self-assessment may still have a few shortcomings in terms of fully representing I4 and the circular economy.

[4] The detailed self-assessment is presented in Appendix 1 and 2.

development. This should be followed by other related policies that enable a full transformation of the economy to prepare itself to drive I4 and circularity.

The focus of this policy assessment framework is to have policies in place to stimulate market activities as well as to fix the market and regulatory failures.

Table 4.1 illustrates the policy thrust and its focus in I4. In policy planning with regards to the regulatory and institutional framework and reforms, we focus on the regulatory preparedness and institutional ability to coordinate activities to achieve I4. In the first thrust, eight policy focus areas are proposed, whereby three relate to policy reviews and the other five on institutional capabilities. In most developing countries, policy consistency is an issue and, more importantly, a lack of institutional capacity in coordination and consultation effectively limits the implementation of policies and regulations. The idea is to have a more uniformed framework to drive I4 initiatives. The framework should incorporate the inter-governmental coordination needed. Likewise, all ASEAN Member States have some form of industrial policy,[5] and this policy requires further reform and revisions to take into account the new wave of disruptive technologies and sectors. For instance, in the case of Malaysia, the Industrial Master Plan 3 (2006–2020) and other sectorial policies (e.g. national automotive policy), and in Indonesia, the Master Plan of National Industry Development 2015–2035, could be points of reference. Similarly, most of the ASEAN Member States have also established and announced their respective I4 plans, for instance Malaysia with the National Policy on Industry 4.0, Singapore with its smart industry initiatives and Thailand 4.0 plan. ASEAN, as a bloc has also initiated various plans, to name a few, the ASEAN Economic Community Blueprint, ASEAN Master Plan on ICT 2020; ASEAN Work Programme on Electric Commerce (2017–2025) and ASEAN Plan of Action on Science, Technology, and Innovation (2016–2025). These plans require further coordination to further fully drive the I4 initiatives.

The other building blocks of the policy thrust are education and human capital policies that cut across education, human resources, and industry or economic ministries within ASEAN. It is vital that these three ministries work closely with one another.

[5] Many of the industrial plans also form part of the National Development Plans.

Table 4.1: Policy Thrust and Focus for Industry 4.0

Policy Thrust	Policy Focus
Regulatory and institutional framework and reforms	i. Regulatory and policy a. A comprehensive I4 policy framework b. Review and amendment of legislation and regulations for I4 (for example, regulations related to intellectual property and information and communications) c. Facilitation of data integrity, standards, and sharing security to facilitate the seamless integration of I4 ii. Institutional a. Intra-governmental coordination in I4 policy formulation b. Awareness programmes/initiatives across all stakeholders c. Platform to assess and develop I4 capabilities d. Mechanism for consultations for I4 development e. National strategic/action plan on transfer of technology (ToT), digital trade zones, internet economy, e-commerce, and other related strategies for I4
Enabling Policies Related to Infrastructure Readiness to Support Industry 4.0	
Building education and human capital to respond to I4	i. Review of education policy ii. I4 education promotion (schools) iii. I4 education promotion (higher learning/training institutions) iv. Business–academia collaboration in engineering and technology-related programmes
STI policy	i. Strategic approach to STI policy for I4 ii. STI strategic and technology focus iii. R&D programmes iv. Technology and innovation (incentives and grant systems)
Business technology promotion	i. Promotion for automation and digitalisation ii. ICT technology adoption and promotion
Digital transformation	i. Access to smart technologies and standards ii. Support for creative industries; digitalisation, adoption of ToT, artificial Intelligence iii. Data security; cyber security initiatives
Trade and investment policies	i. Investment promotion in strategic sectors of I4 ii. Export promotion initiatives in strategic sectors of I4 iii. International cooperation and collaboration

I4 = Industry 4.0, ICT = information and communications technology, R&D = research and development, STI = science, technology, and innovation.
Source: Author.

The attempt is to ensure that education and human resource policies are ready to prepare the workforce with skills that the newly emerging industries demand.

The types of education as well as training programmes that a nation would like to introduce depend on the current and future technological trajectories of the individual nation itself. Likewise, science, technology, and innovation (STI) policy, business development, digital transformation, and policies related to investment and trade have been equally important to drive I4. Within the policy thrust, a few important dimensions are proposed. For instance, investment promotion strategies are essential given that many of the ASEAN Member States have budget constraints and foreign direct investment plays an important role – not only for investment per se but also for technology access and availability that are mostly embedded in products and services. A fully detailed scale is established in Appendix 1 with regards to assessing different aspects of the policy dimensions. The scale (0–4) can then be averaged for each policy thrust to assess the strengths and weaknesses of the policy framework.

Similarly, the policy thrust for the circular economy is illustrated in Table 4.2. Five policy thrust areas are proposed with a number of dimensions within each thrust. The intention is to capture the institutional and regulatory readiness as well as the driving factors, such as education and awareness, public–private collaboration, business support systems, and infrastructure system readiness to embrace the circular economy. The institutional and policy thrusts incorporate various policies related to circularity, namely, waste management, energy, and standards, including strategies related to resource productivity and the adoption of remanufacturing principles. The policy thrust for the circular economy, therefore, assesses the policies, initiatives, and programmes at the institutional level. The detailed self-assessment framework is presented in Appendix 2.

Table 4.2: Policy Thrust and Focus for Circular Economy

Policy Thrust	Policy Focus
Institutional and regulatory framework	i. A comprehensive circular economy policy framework (reduce, recycle, reuse, remanufacture, refurbish) ii. Intra-governmental coordination in circular economy policy formulation iii. Awareness programmes/initiatives across all stakeholders (consumers, suppliers, financers, and others) iv. Waste management regulations, such as extended producer responsibility v. Resource efficiency strategies vi. Adoption of remanufacturing and sharing (eco-innovation principles) vii. Increased share of renewable energy and greenhouse gas emissions policy and regulations viii. Standards regulations
Education, information, and awareness	i. Public communication and information campaigns/ programmes ii. Promotion of circular economy thinking in schools and universities
Collaboration and partnership platforms	i. Public-private partnerships with businesses ii. Voluntary industry participation and collaboration platforms and information sharing iii. Technology development, eco-design and R&D programs in the fields of circular economy (material sciences and bio systems, etc.)
Business support systems for the circular economy	i. Financial incentives, such as shifting tax bases and internalisation of environmental costs for the circular economy ii. Non-financial support (technical support, advisory, training and demonstration of best practices to businesses)
Public procurement, infrastructure, and technology	i. Public procurement for the circular economy ii. Public investment in infrastructure for the circular economy iii. Promoting I4 related technologies for the circular economy

Source: Author.

4. Assessment of Policy Readiness for ASEAN – Quantitative Measurement

Likewise, to gauge the current state of readiness, this chapter also assesses ASEAN's readiness based on selected input and output indicators that are currently available.[6] This serves as the ex-post assessment exercise of the policy commitment.[7] In this approach, we attempt to match the datasets (selected input and output indicators) with their possible policy thrusts in order to gauge the policy readiness and commitments. Likewise, the input and output indicators should be able to provide insights into the strengths and weaknesses of a nation in specific dimensions, and, in return, policymakers can take note and ensure the nation catches up in these dimensions.[8] Given that the indicators use different scales of measurement, we use the standard normalisation methodology without weightage. For instance, the normalisation scores for the institutional framework are as follows:

$$Institutional\ Framework = \frac{Actual\ Country\ Score - Sample\ Minimum\ Score}{Sample\ Maximum - Sample\ Minimum} x\ 100$$

A score value of 100 indicates that the country (within the sample) is at the frontier, while a score of 0 indicates that the country is lagging far behind. In other words, a score of 0 indicates that the country has the lowest scores within the sample. We use three frontier countries as the benchmark for this exercise, namely Japan, Germany, and the United States (US).[9] Within ASEAN, Singapore can be used as the benchmark.[10]

[6] This is not possible if countries have a weak reporting system. The quantitative assessment does not consider all the policy thrusts discussed earlier, and it is used for illustration purposes only. The challenges in the ex post assessment are greater especially when moving away from aggregate indicators to specific policy measures, given that there is no proper monitoring at the policy level.
[7] Please note that this would not be a perfect match for each of the respective dimensions as policy focus and self-assessment by policymakers based on Appendix 1 are needed. Nevertheless, this assessment would provide some indications on the positions of the member countries and their readiness.
[8] One should apply caution in interpreting the figures due to their limitations.
[9] Selection was amongst the top countries that are well prepared for I4 based on the World Economic Forum (2018) report, Readiness for the Future of Production.
[10] Based on the World Economic Forum (2018), Singapore has been in the lead amongst ASEAN Member States.

Table 4.3 shows the scores for the selected policy thrust ex post assessment of the I4 policy readiness. In terms of the institutional environment, the Philippines, Indonesia, Thailand, Viet Nam, and Cambodia require much effort predominantly in improving their regulatory efficiency as well as future regulatory orientations. Singapore, Malaysia, Indonesia, and Thailand have already put into place initiatives and framework on I4, whereas the Philippines and Viet Nam's I4 is still in the planning stages. The government should be effective in providing the needed regulatory framework to ensure a speedy transformation towards I4. Regulations that relate to cyber security, intellectual property, privacy, data sharing and management, and personal data use are some examples which the government could focus on in the future. On average, human capital preparedness is still low in many of the ASEAN Member States. Malaysia, specifically, lacks the knowledge-intensive employment which may reflect that the sector constitutes a lower share of GDP. Likewise, STI has also been a main concern in ASEAN. While some of the input-related indicators of STI have improved, the ability to innovate as well as the availability of venture capital markets are still poor.

Manufacturing technology is another area of concern. Even the more mature economies like Malaysia and Singapore are beneath the frontier countries. Data at the technological level shows that the current state of industrial robotic operations within ASEAN is low. Thailand has progressed more significantly compared to countries like Malaysia and Indonesia. The operational stocks of industrial robotics in Thailand, Malaysia, and Indonesia in 2015 were 14,902, 3,931, and 3,208, respectively.[11] In the automotive sector, Thailand is moving forward towards robotics operations due to foreign direct investment – e.g. Isuzu has been investing in robotics plants. Thailand has been seen as one of the potential markets (IFR, 2017) and the Japanese automotive manufacturing output in Thailand accounts for 25% of robotics operations (Bangkok Post, 2018). Nevertheless, in ASEAN as a whole, the density of robotics installations is still low in many of the member states, except Singapore, and in 2016, Singapore topped the list of the top-five most automated countries in the world – others included the Republic of Korea, Germany, and Japan. The current global average is 74 industrial robots per 10,000 employees in the manufacturing industry.

[11] Based on Industrial Robots Statistics; International Federation of Robotics.

Table 4.3: Policy Readiness, ASEAN and Frontier Countries

Indicators	Cambodia	Indonesia	Malaysia	Philippines	Singapore	Thailand	Viet Nam	Lao PDR	Brunei	Japan	Germany	US
Institutional Framework (Average)	0.3	19.6	73.1	14.5	100.0	24.2	21.2			57.4	54.2	83.6
Regulatory efficiency	0.6	0.0	78.4	29.0	100.0	34.1	28.0			72.0	44.2	85.1
Future orientation of government	0.0	39.3	67.9	0.0	100.0	14.3	14.3			42.9	64.3	82.1
Human Capital (Average)	4.8	38.6	67.4	32.1	97.6	23.6	6.1	14.2	32.4	46.4	76.0	88.6
Knowledge-intensive employment	0.0	1.4	38.8	34.2	100.0	9.3	1.8		68.7	33.3	77.6	63.0
Digital skills amongst the population	0.0	52.0	76.0	40.0	92.0	36.0	20.0			40.0	72.0	100.0
Country capacity to attract and retain talent	12.5	50.0	66.7	0.0	95.8	20.8	4.2			8.3	70.8	100.0
Availability of research and training services	0.0	43.5	82.6	47.8	100.0	17.4	4.3	13.0	13.0	69.6	82.6	91.3
Reliance on professional management	11.5	46.2	73.1	38.5	100.0	34.6	0.0	15.4	15.4	80.8	76.9	88.5
STI (Average)	2.8	19.9	38.0	6.6	66.5	13.0	8.0			59.1	58.7	93.6
R&D expenditure (% of GDP)	0.0	0.0	34.3	0.0	60.0	11.4	2.9			100.0	51.4	74.3
Venture capital deal volume per size of economy	9.6	15.4	9.1	2.5	61.3	0.0	3.7			1.7	29.4	100.0
Availability of scientists and engineers	0.0	52.0	84.0	24.0	80.0	36.0	24.0			84.0	80.0	100.0
Ability to innovate	1.5	12.3	24.6	0.0	64.6	4.6	1.5			50.8	73.8	100.0
Manufacturing Technology (Average)	5.2	32.9	60.1	27.6	78.2	40.9	8.6	3.0	12.5	91.5	85.9	90.4
Economic complexity	0.0	13.3	50.0	36.7	73.3	46.7	13.3			100.0	90.0	76.7
Availability of latest technologies	15.4	34.6	61.5	26.9	84.6	38.5	3.8	0.0	26.9	92.3	84.6	100.0
Firm-level technology absorption	5.3	47.4	68.4	31.6	78.9	42.1	5.3	0.0	10.5	73.7	84.2	100.0
Production process sophistication	0.0	36.4	60.6	15.2	75.8	36.4	12.1	9.1	0.0	100.0	84.8	84.8
Digital Transformation (Average)	8.2	28.1	68.4	25.9	90.5	44.6	24.0		33.9	82.3	89.1	93.7
ICT and business model creation	9.4	38.6	83.1	21.7	100.0	55.1	5.1		0.0	65.7	91.3	100.0
ICT and organisational models creation	31.7	42.9	69.4	15.4	79.1	33.4	14.6		0.0	48.6	85.1	100.0
ICT access	0.0	14.5	58.1	14.9	93.3	27.7	12.4		69.4	97.3	100.0	86.2
ICT use	0.0	11.3	64.6	20.4	87.5	49.6	19.5		66.9	100.0	93.2	91.4
E-participation	0.0	33.3	66.7	57.4	92.6	57.4	68.5		33.3	100.0	76.0	90.7

Table 4.3: (Continued) Policy Readiness, ASEAN and Frontier Countries

Indicators	Cambodia	Indonesia	Malaysia	Philippines	Singapore	Thailand	Viet Nam	Lao PDR	Brunei	Japan	Germany	US
Trade and Investment (Average)	12.4	24.0	41.5	19.5	80.6	26.2	20.5			45.6	59.0	69.1
Trade % GDP	34.1	3.2	34.5	12.7	100.0	32.7	54.0			2.6	19.4	0.0
Degree of tariff reduction performance	0.0	44.4	44.4	55.6	100.0	22.2	11.1			77.8	88.9	77.8
Logistics performance	0.0	7.7	38.5	0.0	92.3	30.8	7.7			84.6	100.0	84.6
Greenfield investments	0.0	31.1	18.1	6.9	10.8	6.5	29.7			7.7	14.3	100.0
FDI and technology transfer	27.8	33.3	72.2	22.2	100.0	38.9	0.0			55.6	72.2	83.3

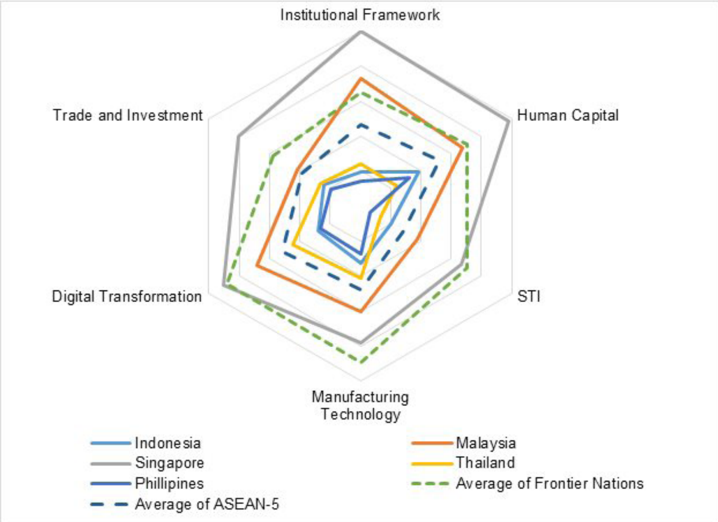
FDI = foreign direct investment, GDP = gross domestic product, ICT = information and communications technology, Lao PDR = Lao People's Democratic Republic, R&D = research and development.
Source: Author's computed normalised scores based on various sources (WEF (2018); Global Innovation Index, 2018; and The Global Competitiveness Report 2017-2018).

Amongst ASEAN countries, the score of digital transformation requires further improvements, specifically when it comes to business participation in using information and communications technology (ICT). ASEAN, as a whole, has been improving significantly in providing the needed infrastructure and improving societal participation. Nevertheless, the challenge would then be to transform this advantage so that businesses could move into using information technology and further engage in intelligent production and service delivery. A recent study (Business Times, 2018) shows that the technology adoption rate is still low and the challenge at the firm level is attributed to lack of talent, budget constraints, and information technology infrastructure constraints.

Countries that have lower manufacturing shares would be at a disadvantage in catching up with the new wave of industrialisation. In addition, countries experiencing premature deindustrialisation, for instance Malaysia (Chandran and Devadason, 2017; Rasiah, 2011), could also be at a disadvantage if policy is not adequately developed and supported. As such, trade and investment policies play a role as a main driver of I4. For instance, many of the achievements of the ASEAN Member States are due to production fragmentation and the ability of the economies to plug into the global production network. Similarly, the capital-intensive wave of transformation requires ASEAN Member States to connect with global production as a channel to learn and transfer technology. In this regard, trade and investment offer an important channel. As for ASEAN as a whole, the assessment indicates that reforms have taken place in areas of digital transformation, trade and investment, human capital, and institutional framework but in an unbalanced form across members. Interestingly, the assessment shows that almost all ASEAN Member States (except Singapore, to some extent) are lagging behind with regards to the STI and manufacturing technology pillars.

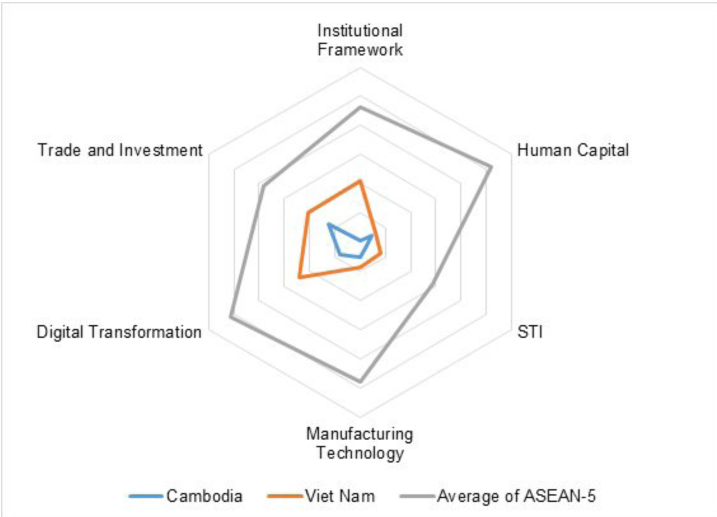
Figures 4.1 and 4.2 show the visual average score of the six pillars. We separately plot the main policy dimensions based on the development stage, separating Cambodia and Viet Nam and considering Singapore, Malaysia, and Thailand as the first tier with leading or strong readiness for future, and the Philippines and Indonesia as the second tier with high potential and a strong economic case but facing risks in the future. Singapore and Malaysia are above the average of ASEAN in all pillars, while the other ASEAN Member States (Thailand, Indonesia, and the Philippines) require further reforms to improve their readiness for I4.

Figure 4.1: ASEAN-5 Policy Readiness in Critical Pillars



STI = science, technology, and innovation.
Note: 'Average of frontier nation refers' to the average of Japan, Germany, and the United States. 'Average of ASEAN-5' refers to the average scores of Singapore, Malaysia, Indonesia, Thailand, and the Philippines. Alternatively, the median values were used instead of the average of ASEAN-5, and Thailand performed relatively better in digital transformation, manufacturing technology, trade, and investment.
Source: Author's computed normalised scores based on various sources (WEF (2018); Global Innovation Index, 2018; and The Global Competitiveness Report 2017-2018.

Figure 4.2: Viet Nam and Cambodia's Policy Readiness in Critical Pillars



STI = science, technology, and innovation.
Note: 'Average of frontier nation refers' to the average of Japan, Germany, and the United States. 'Average of ASEAN-5' refers to the average scores of Singapore, Malaysia, Indonesia, Thailand, and the Philippines. Alternatively, the median values were used instead of the average of ASEAN-5, and Thailand performed relatively better in digital transformation, manufacturing technology, trade, and investment.
Source: Author's computed normalised scores based on various sources (WEF (2018); Global Innovation Index, 2018; and The Global Competitiveness Report 2017-2018.

Viet Nam and Cambodia's readiness is lagging far due to their limited current economic base, but they are well-positioned for the future if one compares them with the ASEAN average scores. While Viet Nam has developed its policy potential in institutional framework, trade and investment, and digital transformation, it is severely lacking in areas such as manufacturing technology, STI, and human capital. Cambodia, as can be seen, is making progress in the trade and investment dimensions – a move that most underdevelopment economies use to catch up with positive trajectory interims of dimensions of readiness with the development stage.

As for the circular economy assessment, two available indicators are considered – sustainability (based on Readiness for the Future of Production (WEF, 2018)) and ecological sustainability (based on the Global Innovation Index). Sustainability measures a wide range of indicators, while ecological sustainability focuses on three aspects. Table 4.4 indicates that all ASEAN Member States are required to make more effort to improve their sustainability.

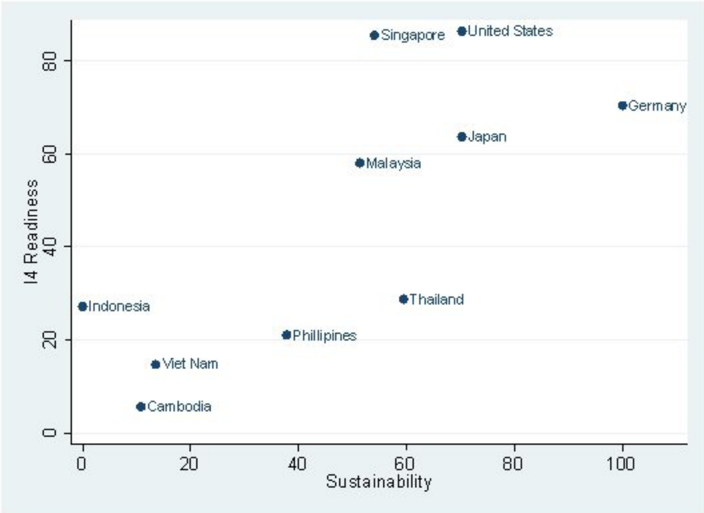
Table 4.4: Circular Economy Policy Readiness

Country	Sustainability Scores	Ecological Sustainability Scores
Cambodia	10.8	0.0
Indonesia	0.0	33.2
Malaysia	51.4	45.8
Philippines	37.8	61.3
Singapore	54.1	100.0
Thailand	59.5	26.6
Viet Nam	13.5	14.8
Japan	70.3	93.0
Germany	100.0	87.1
United States	70.3	45.0

Note: The data were normalised based on values obtained from Readiness for the Future of Production (WEF, 2018) and the Global Innovation Index. Sustainability is measured based on six indicators (alternative and nuclear energy use, CO_2 intensity, CH_4 intensity, N_2O intensity, baseline water stress, and wastewater treatment), while ecological sustainability is measured based on three indicators, energy use, the environmental performance index (based on Yale and Columbia Universities), and environmental standards certification (IS0 14001).
Source: WEF (2018) and Global Innovation Index

Policymakers should also focus on specific weaknesses by examining in detail the indicators at a more disaggregated level. Singapore's low score in the dimension of sustainability as opposed to ecological sustainability is due to the low scores for baseline water stress. As for Indonesia, the relatively low score in the sustainability dimension is due to the lack of use of alternate energy sources. Cambodia scores low in ecological sustainability due to the fact that it has a low environmental management certification (ISO 14000) and is low in the overall environmental performance index.[12]

Figure 4.3: Matching Industry 4.0 Readiness and Circularity



Source: Author.

By plotting both I4 and the circular economy, the overall average scores show how the countries fare and progress in both the areas as well as where they are relative to the benchmarked countries (see Figure 4.3). Malaysia and Singapore seem to be catching up with the more advanced nations, while other ASEAN Member States are lagging behind. Malaysia's readiness for I4 seems to be better than Thailand if one measures it in a more holistic way – lacking in I4 readiness. Countries near to the blue line indicate a more balanced development in both policy dimensions. Cambodia, Viet Nam, Indonesia, and the Philippines need to significantly catch up.

[12] The index covers 24 indicators.

5. How Can Countries Improve Their Industry 4.0 Readiness Policies for the Circular Economy?

Renewed thinking in policymaking and planning is vital. In other words, a basic philosophical change in policy thinking would be able to benefit both I4 and the circular economy. Policymakers should be able to plan and analyse policy interconnectivity so that efforts can be streamlined and better coordinated. For instance, agencies promoting and creating awareness about I4 and the circular economy can work together to create awareness and provide skill training by incorporating both the agendas of I4 and circular economy simultaneously. This will later entail agencies working together to formulate these programmes. In this way, agencies would also be efficient as they reduce budgets and repeat efforts or even multiply overlapping activities, which would otherwise be carried out by the implementing agencies separately. The matrix approach should be adopted so that policy overlaps can be identified, indicating which policy instruments can be streamlined to achieve the intended results for both. In interlinking I4 with the circular economy, policymakers should address the following: (1) which I4 technologies would support the transition to the circular economy; (2) how the business models could be transformed; (3) what policy and finance are needed; (4) what human capital, training, and education for I4 would also benefit the transition to the circular economy.

In this chapter, we establish a guide by proposing a policy complementarities matrix. Table 4.5[13] directly shows the proposed policy complementarities matrix based on the dimensions discussed earlier. The policy complementarities matrix illustrates how policymakers could align their policy thrusts in order to synchronise their I4 policy planning for the circular economy.

To bring a few examples, complementary forms of investment promotion in strategic sectors of I4 can co-exist with the policy planning for resource productivity strategies, waste management, the adoption of remanufacturing, and energy and greenhouse gas emissions of the circular economy policy dimensions (see Table 4.5).

[13] We only illustrate a few examples. The table is not mutually comprehensive and the details can be further expanded.

Table 4.5: Policy Complementarities Matrix – Industry 4.0 and the Circular Economy

INDUSTRY 4.0 POLICY FRAMEWORK		CIRCULAR ECONOMY POLICY FRAMEWORK																	
		Institutions and Regulatory								Education, Information & Awareness		Collaboration and Partnership Platforms			Business Support Systems for Circular Economy		Public Procurement, Infrastructure, and Technology		
		A comprehensive Circular Economy Policy Framework	Intra-governmental coordination in Circular Economy Policy Formulation	Awareness programme/ initiatives across all stakeholders	Waste Management Regulations	Resource Productivity Strategies	Adoption of Remanufacturing and Sharing (Eco-Innovation Principles)	Energy and greenhouse gas emissions policy and regulations	Standard Regulations	Public Communication and information campaigns/ programs	Promotion of Circular Economy Thinking	Public-private partnerships with businesses	Voluntary industry collaboration platforms and information sharing	Technology and R&D Programs	Financial Incentives for Circular Economy	Non-Financial Supports (Technical support, advisory, training, etc.)	Public Procurement for Circular Economy	Public Investment in Infrastructure for Circular Economy	Promoting I4.0-related technologies for Circular Economy
Regulatory and Institution	A Comprehensive I4.0 Policy Framework																		
	Review and amendment of legislations and regulation for I4.0																		
	Facilitation for data integrity, standards, sharing security to facilitate seamless integration of I4.0																		
	Intra-governmental coordination in I4.0 policy formulation																		
	Awareness programme/ initiatives across all stakeholders																		
	Platform to assess and develop I.40 capabilities																		
	Mechanism of the consultations for the I4.0 deveopment																		
	National Strategic/ Action Plan on IoT, Digital Trade Zone, Internet Economy, E-commerce, and others related strategies for I4.0																		
STI Policy	STI Policy for I4.0																		
	STI Strategic and Technology Focus																		
	Technology and R&D Programs				X	X	X	X					X						
	Technology and Innovation (Incentives/ Grants)																		
SEM Development	Promotion for automation and digitalization																		
	ICT Technology adoption and promotion																		

Table 4.5: (Continued) Policy Complementarities Matrix – Industry 4.0 and the Circular Economy

INDUSTRY 4.0 POLICY FRAMEWORK		CIRCULAR ECONOMY POLICY FRAMEWORK																	
		Institutions and Regulatory								Education, Information & Awareness		Collaboration and Partnership Platforms			Business Support Systems for Circular Economy		Public Procurement, Infrastructure, and Technology		
		A comprehensive Circular Economy Policy Framework	Intra-governmental coordination in Circular Economy Policy Formulation	Awareness programme/ initiatives across all stakeholders	Waste Management Regulations	Resource Productivity Strategies	Adoption of Remanufacturing and Sharing (Eco-Innovation Principles)	Energy and greenhouse gas emissions policy and regulations	Standard Regulations	Public Communication and information campaigns/ programs	Promotion of Circular Economy Thinking	Public-private partnerships with businesses	Voluntary industry collaboration platforms and information sharing	Technology and R&D Programs	Financial Incentives for Circular Economy	Non-Financial Supports (Technical support, advisory, training, etc.)	Public Procurement for Circular Economy	Public Investment in Infrastructure for Circular Economy	Promoting I4.0-related technologies for Circular Economy
Digital Transformation	Access to Smart Technologies and Standards																		
	Support for creative industries - digitalization, adoption of ToT, AI, and others																		
	Data security - cyber security initiatives																		
Trade and Investment	Investment promotion in strategic sectors of I4.0				X	X	X	X				X	X	X	X			X	X
	Export Promotion Initiatives in Strategic Sectors of I4.0																		
	International cooperation and collaboration																		

AI = artificial intelligence, I4 = Industry 4.0, IoT = Internet of Things, ITC = information and communications technology, R&D = research and development, STI = science, technology, and innovation, ToT = transfer of technology.
Note: X = complementarities.
Source: Author.

In addition, such investments – those bringing more positive externalities – can be given more priority by the investment-promoting agencies or afforded more incentives and other benefits, such as tax holidays. The dual-purpose nature of the investment would allow a nation to achieve both its goals more effectively. Indeed, the investors could be further encouraged to show how the investment that promotes I4 would also help the circular economy building blocks. Similarly, for the STI policy thrust of I4, R&D programmes can co-exist with the motive of improving the bio system (see Table 4.5). In a similar vein, policymakers should identify the interlink in which the policy thrusts can co-exist during the policy planning process.

The identification of policy complementarities can also occur at the meso and micro levels. For instance, at the meso level, policymakers could think about institutional arrangements or even specific programme designs that would complement I4 and the circular economy. Similarly, at the micro level, the focus could be in the form of instruments and mechanisms used in achieving the policy objectives – for instance, incentives, skills and talents, and funding, as well as technologies. Next, to illustrate, we show how mapping at the technology level would allow one to achieve the complementarities.

Scholars argue that a horizontal policy design (a broader policy that does not target specific sectors, picking the winners) is preferable due to government failures since identifying and removing all distortions simultaneously is not possible because of imperfect knowledge, transaction costs, and implementation constraints. However, taking the same view as Chang (2011),[14] we argue that policymakers should at least understand some of the key technologies that would unleash the nation to move towards I4 and circularity. Therefore, similar to the discussion at the policy level, policymakers should also look at avenues on how the complementary can be assessed at the technology level so that coordination and efforts ensure mutual benefits. Technological prioritisation is key in this aspect. In some countries, technology foresights provide the needed information to do this, while others have developed specific sectoral road maps. Both of these would aid policymakers in understanding the technology complementarities. Indeed, given the lack of technological capability amongst the ASEAN Member States, technology prioritisation would help

[14] Targeting is unavoidable and it is also easier to monitor and minimise leakages. We should also recognise the cost of targeting.

policymakers to place investment and trade policies and target technologies that would be instrumental in catching up for I4 and the circular economy. For example, once these technologies are identified, technology-specific barriers to trade can be further removed. For instance, Chandran and Devadason (2017), identify that while tariff rates are low in green technology trade (e.g. solar), the tariff rates related to the components of green technology trade are still high, limiting the creation of local industries. In this example, tariff rates should not just be reduced for the final product (say, solar panels) but also in the component segments (storage battery, cables, etc.) that form the system.

Thus, policy assessment, at least in a broader sense, should have some details on technological priorities. This specificity will also allow policymakers to identify the relevant industries and encourage investments. This will give instrumental inputs to driving STI, trade, investment, education, and human capital policies that focus on promoting their respective activities. Table 4.6 shows several critical technologies of I4 that enable circularity. The policy documents (for example, sectoral roadmaps or technological foresights) should not only give clear indications on the next wave of emerging technologies for I4 but also the interlinkages and relevancy of those technologies for the circular economy are needed. For instance, ICT solutions for the factory floor have a range of effects on circularity, especially in minimising resource use, minimising waste, and promoting sustainability (see Table 4.6). The other enabling technologies have their profound effects, respectively.

Table 4.6: Enabling Technologies for I4 and Circularity

Enabling Technologies	Energy Efficiency	Material Efficiency	Less Waste	Fewer Emissions	More Safety	Higher Flexibility	Sustainable Product	Customisable Product
Technologies for 'self assembly'	**	**	*			***	**	***
Innovative micro/nano-manufacturing processes	***	***	**		**	***	***	***
Additive manufacturing	*	***	***		*	***	**	***
Flexible sheet-to-sheet (S2S) and roll-to-roll (R2R)	**	**	***	**	**	***	**	**

Enabling Technologies	Energy Efficiency	Material Efficiency	Less Waste	Fewer Emissions	More Safety	Higher Flexibility	Sustainable Product	Customisable Product
Innovative physical, chemical, and physicochemical processes	***	***	**			***	***	***
Integration of non-conventional technologies and conventional technologies	***	***	**			***	***	***
Methods for handling of parts, metrology, and inspection	***	***	**			***	***	***
Photonics-based materials processing technologies	***	***	***	**	**	***	***	***
Collecting, dismantling, sorting, and recycling processes	***	***	***	***	***	***	***	***
Shaping technology for difficult-to-shape materials	***	***	***	***	**	***	**	***
ICT solutions for factory floor and physical world inclusion	***	***	***	***	***	***	***	***
ICT solutions for modelling, simulation, and management tools	***	***	***	***	***	***	***	***
Control technologies, robots, and automation	***	***	***	***	***	***	***	***

ICT = information and communications technology.
Note: * shows the level of significance from lowest to highest.
Source: Georgoulias (2017).

6. How Can the Region Move Forward?

The new wave of industrial revolution offers numerous benefits for ASEAN, including moving forward towards sustainability by embracing the circular economy. In this section, we provide a few suggestions for ASEAN to move forward.

6.1 Policy Complementarities and Coherency

ASEAN, as a region, will be in a position to leverage the opportunities offered by the Fourth Industrial Revolution. Nevertheless, national policies matter in allowing the seizing of these opportunities. Research shows that complementarity is a necessary condition to sustain growth, and the effect is higher in developing countries (De Macedo and Martins, 2008).

Given that resources are scarce, e.g. finance and also public budgets, the policy design approach should be complementary in nature. What matters is to ensure that national policies are seen as mutually reinforcing to promote jointly the various aims of the nation. Two issues should be looked into. First is a look at how policies could tackle the multiple objectives of the nation – in our case, achieving I4 and circularity.

In policy planning and design, policymakers seldom explore the policy complementarities given that the policy resides in various ministries and agencies. In most cases, a policy also lacks details and forms a very general direction for one to follow. The main constraint, which is binding, is that it allows for multiple interpretations by the implementing agencies. Second is on how to ensure policy coherence that reduces any policy conflict and does not have a contradictory effect. For instance, many countries promote talent mobility via education policy, but most often, mobility efforts are hindered due to immigration procedures and policy. Efforts to attract skilled migrants, for instance scientists and researchers, are critical, and human resources management at the national level would require the interplay between immigration, STI, human resources, sectorial policy complementary, and coherency. The above should go further than just the national level. Regional policy complementary and coherency, if possible, would jointly ensure fast growth potential for ASEAN. Nevertheless, undertaking policy complementarity initiatives requires government and institutional capacity. As such, cooperation is required to build government and institutional capacity and knowledge in public policymaking tools.

6.2 Investment and Trade

Trade and investment are the most critical elements for ASEAN to catch up in the new forms of revolution. The new technologies that the I4 bring in are disruptive and revolutionary in nature, bringing with them speed and intelligence that greatly change the way things are done. ASEAN, as a whole, is lagging behind in technology. Therefore, ensuring more investments and identifying trade channels that promote technological upgrading is critical. Importantly, efforts that mitigate the deficiencies in the market, such as uncertainty, information asymmetry, and technology information, as well as market information, could help ASEAN achieve its next wave of industrial revolution. This in return will allow for more investments in future technologies or even promote local industries. For instance, providing and facilitating market information is seen to be more important than technological information since the market creates demand that eventually allows firms to invest in specific activities and technologies.

6.3 Information and Data Sharing Platforms

Information and data form the foundation for the transition to I4. Data sharing, at the national level and across borders helps the transition process towards adopting I4 amongst ASEAN Member States. Information and data sharing can cover a wide range of issues, from policies to regulatory requirements. Indeed, this platform does not only help policymakers but also businesses to have more transparency on the requirements of the regulators, markets, and others. ASEAN also needs to work collaboratively on crafting and formulating rules and regulation that facilitate data sharing as well as the challenges that come with it – e.g. security and privacy. This is crucial in the age of information technology as well as to promote technology adoption and use amongst society and businesses. The idea is to have a strong regulatory environment regionally so that businesses and society members at large will be able to embrace the new technologies. For instance, ASEAN has yet to develop proper cybersecurity regulatory and measures, which may impede the adoption.

6.4 Building Human Capital and a Skilled Labour Mobility Network

Regionally, ASEAN needs to build its human capital and allow a better flow of skilled labour within ASEAN and globally. This entails setting ASEAN as the platform to negotiate mutual skill recognition and setting an information platform on labour demand and supply. The current provision under mutual recognition agreements only covers eight occupational fields. A restrictive labour policy and requirements such as demonstrating skills transfer to locals also make it difficult for companies to hire skilled workers. Standards of qualification are also an area of concern and promoting intra-industry labour mobility is essential as new types of jobs will replace old jobs. Efforts and initiatives on reskilling and training and education are required to create the talent pool for I4. New work arrangements are likely to emerge with the creation of 'virtual jobs', where networks matter more than the boundaries of nations. Digitalisation and internet technology will not require the physical movement of labour; instead contracts can be established for workers to work remotely from their own countries thereby facilitating labour law and contract enforcement. Moreover, universities, professional bodies, and industry should work closely in developing programmes and curricula with specific capabilities for I4 and the circular economy.

Industry could provide skill demand for the emerging technology and jobs. The current ASEAN science and technology fellowship programme is one good initiative, and extending the outreach to allow greater exchange would benefit ASEAN Member States, especially if it places fellows, researchers, and scientists in the industrial sectors.

6.5 Technology and Innovation Capability

ASEAN needs to promote technology and innovation capability in technologies related to I4. It needs strong commitment and collaboration in technology and innovation initiatives to build its foundation on I4-enabling technologies. Few of the ASEAN Member States are well-positioned in the electronics and ICT industries or knowledge-intensive services, while others are still lagging behind. These industries are cross-cutting industries that would catalyse other industries, and they are fundamental to the development of the core I4 technologies. Similarly, establishing technological infrastructure is critical to promoting technology adoption. Given that technology is advancing faster than predicted, collaborative research activities and technology transfer would act as an additional channel to promote the technology and innovation capabilities needed for I4. This necessitates strengthening STI, trade, and investment policy jointly.

7. Conclusion

This chapter proposes, develops, and assesses the policy readiness of ASEAN for I4 and the circular economy. The proposal is a guiding principle mostly in guiding the overall policy process and providing lessons for policymakers to start thinking about policy design for I4 and the circular economy. It is important to recognise some of the caveats that apply to the proposal. Since the future is uncertain and predicting it is difficult, this guiding principle needs continuous updating by policymakers, which includes accounting for any country-specific context. Nevertheless, at least for now, it provides some impetus to start the discussion on policy planning and a catalyst on regional dialogues to shape the development of future forms of industrialisation strategies.

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Appendix 1: Assessment Framework for Industry 4.0 Policy Readiness

Regulatory and Institutional Framework and Reforms					
Levels	Level 0	Level 1	Level 2	Level 3	Level 4
A comprehensive Industry 4.0 (I4) policy framework	No policy framework exists.	Policy framework is in a drafting stage.	No uniform definition of I4 is available and various ministries/ agencies have developed policy frameworks	Uniform definition of I4 is in place, but it is not streamlined (different application) in government programmes and policies within countries.	There is a uniform application of I4 definition in government programmes and policies within countries.
Review and amendment of legislation and regulations for I4 (e.g. regulations related to intellectual property and information and communications)	There are no systematic reviews of redundant or ineffective legislation and regulations.	There is a review, and a list of an inventory of all relevant legislation and regulations has been made.	There were ad-hoc activities carried out on amendments of redundant or ineffective legislation and regulations. The government plans to carry out this exercise.	Implementation of the plan is underway, covering key legislation and regulations related to enterprise policy.	The implementation is well advanced and most or all of the legislation and regulations have been revised.
Facilitation for data integrity, standards, and sharing security to facilitate seamless integration of I4	No measure is in place to systematically tackle the facilitation.	Plan is in preparation to tackle the facilitation.	Plan to tackle the facilitation has been adopted after inter-ministerial and stakeholder consultation. Action plan defined.	There is evidence that some elements of this plan have been implemented.	Solid evidence of implementation of the facilitation plan with indication of key targets achieved.
Intra-governmental coordination in I4 policy formulation	No institution is responsible for policy formulation.	Several institutions are responsible for policy formulation and they have overlapping portfolios and limited coordination.	Legislation for the establishment of a single institution/unit/ division is under consideration.	Approval for the establishment of a single institution in charge of leading and coordinating policy formulation.	The institution/unit/ division is established with staff and budget in place. System of consultation with the implementing agency or agencies is in place.
Awareness programme/ initiatives across all stakeholders (digitalisation, Internet of Things (IoT), automation etc.)	No awareness programme is initiated.	Uncoordinated programmes initiated by various ministries/ agencies/ Institutions.	Coordinated programmes initiated by an implementing major ministry/ agency/ institution.	The programmes are operated with limited geographical coverage and for limited sectors.	The programmes are fully functional nationwide, and a significant number of firms have participated.

Regulatory and Institutional Framework and Reforms					
Levels	Level 0	Level 1	Level 2	Level 3	Level 4
Platform to assess and develop I4 capabilities	No initiative is placed to undertake a comprehensive assessment on the status of the industry capability for I4.	An assessment strategy for capabilities is under elaboration. Review of expired strategies is under way.	Multiyear assessment strategy for current period is approved by the government.	The multiyear I4 assessment strategy has been implemented with moderate success.	Solid evidence of assessment of the I4 development strategy with indication of the key targets achieved and assignments completed.
Mechanism of consultations for I4 development	No existing consultative mechanism.	Consultative mechanism is local- based.	Consultative mechanism is undertaken in various sectors in an ad-hoc manner.	National and local consultations are done on a per issue basis.	National, local, and sectoral consultations are done on a regular basis using a committee structure (e.g. agriculture, industry, small and medium-sized enterprises, and taxation committees) where positions or white papers are produced.
National strategic/action plan on transfer of technology (ToT), digital trade zones, internet economy, e-commerce, and other related strategies for I4	There is no government action plan on I4.	A government strategic plan on identifying I4 is under preparation.	The plan covers a range of support services and has been implemented with moderate success.	Solid implementation record of achievements of the action plan.	Implementation is well advanced and monitoring systems in place to measure the impact of the plan.
Education					
Review of education policy	No initiative is undertaken to revise and revamp the education policy with emphasis on science, technology, engineering, and mathematics (STEM); the integration of computational thinking; and information technology (IT) in the national curriculum.	STEM and IT are recognised as a developing feature within education and training policy for future policy review.	There is a review and the list of an inventory of all relevant elements related to STEM and IT.	The review is completed and awaiting allocation and other resources for implementation.	The implementation is well advanced and most or all of the education policy has been revised with adequate budget and monitoring.

Regulatory and Institutional Framework and Reforms					
Levels	Level 0	Level 1	Level 2	Level 3	Level 4
Promotion of education supporting I4 (schools)	No materials or expertise to promote science and technology (S&T) or technology key competencies (e.g. robotics, ICT).	Technology-competent teaching materials and teacher training programmes are under development in areas of technology related to I4.	Materials are under pilot. Some evidence of arrangements that allow the promoting of key technology competencies of I4.	Secondary schools are equipped with teaching materials and staff with knowledge and skills for teaching technology and science (monitored through education ministry records).	Secondary schools with teaching materials and staff with knowledge and skills for teaching technology-related subjects cover up to 50% of enrolments.
Promotion of education supporting I4 (higher education/ training institutions)	No vocational schools or universities offer subjects on I4 (e.g. digital manufacturing and design, artificial intelligence, robotics, etc.).	Higher education curriculum includes the promotion of subjects and courses related to I4.	Wide variety of higher education/ training institutions offer courses or subjects related to I4.	Some major universities offer a specific degree in I4-related areas at least.	National higher education networks function to regularly review higher education curricula to ensure evaluation, accreditation, and dissemination of education and skills related to I4.
Business-academia collaboration in engineering and technology-related programmes	No business-academia collaboration with respect to programme development.	Few programmes with business-academia collaboration.	Apprenticeship or internship with industry required of students as part of curriculum.	Universities adopt practicum for students taking engineering and technology-related programmes, involving counselling with industry.	Universities and private sectors jointly support programmes, curricula, research, customised training services, coaching, awards, and scholarships.
Science, Technology, and Innovation					
Strategic approach to science, technology, and innovation (STI) policy for I4	No strategic plan or STI policy incorporating I4.	STI policy is under preparation incorporating I4.	STI strategy elements included in some enterprise policies, industrial policies, human capital development policies, or education and research policies, but no consistent approach and no indication of implementation action.	STI policy developed and integrated into a number of strategic documents. Information on implementation plans, budget, and time lines included in each of the documents. Strategic approaches are not coordinated.	STI strategic approaches are coordinated. Innovation programmes/ strategy are under implementation and adequately funded. Major components of the plan are active with explicit programmes for I4.

Regulatory and Institutional Framework and Reforms					
Levels	Level 0	Level 1	Level 2	Level 3	Level 4
STI strategic and technology focus	No strategic I4 sector identified.	Strategic sector focus roadmaps are being planned.	Strategic sector focus roadmaps have been developed.	Strategic sector focus roadmaps have been developed with action plans and estimated budget. They are at the implementation stage.	Strategic sector focus roadmaps have been implemented with adequate budget and institutional arrangement.
Research and development (R&D) for I4	No formal framework to support technology development in universities, R&D labs, and incubators for I4.	Government has declared plans to support technology development in universities, R&D labs, and incubators for I4.	Government has established a legal and/or policy framework to support technology development in universities, R&D labs, and incubators for I4.	Active implementation of framework for linking industry with standards, and technology development in universities, R&D labs, and incubators for I4.	Strong connectivity and coordination exist between technology development activities in universities, R&D labs, and incubators and industry for I4.
Technology and innovation (incentives and grant systems)	There are no public funds supporting R&D activities related to I4.	There is a policy framework for public R&D support for I4.	There are pilot public funds supporting R&D activities specifically for I4 sectors with limited allocation.	Fully operating funds supporting R&D activities for I4 sectors. There is a proper appraisal system of eligible projects.	There is a record of accomplishment of effective allocation of funding to develop I4 sectors.
Business Technology Promotion					
Promotion of automation and digitalisation	Business technology promotion initiatives not available.	Business technology promotion initiatives have been revised to incorporate the promotion of automation and digitalisation.	Business technology promotion initiatives already have strong features of automation and digitalisation promotion.	Business technology promotion initiatives have been implemented with initiatives for automation and digitalisation efforts amongst SMEs with adequate budget.	Business technology promotion initiatives have been fully implemented to encourage automation and digitalisation efforts with adequate monitoring and impact assessment.
ICT technology adoption (broadband, smart technologies)	No initiatives or programmes and plans to encourage ICT adoption in SMEs.	ICT technology adoption in SMEs is between 20%–30%.	ICT technology adoption in SMEs is between 30%–40%.	ICT technology adoption in SMEs is between 40%–50%.	ICT technology adoption in SMEs already accounts for more than 50%.

Regulatory and Institutional Framework and Reforms					
Levels	Level 0	Level 1	Level 2	Level 3	Level 4
Digital Transformation					
Access to smart technologies and standards and broadband	No technology infrastructure policy or plans (e.g. broadband, smart technologies) for supporting businesses.	Government has started plans to establish the provision of technology infrastructure.	An action plan to lay technology infrastructure and the legal framework has been established.	The laying of technology connections is underway either nationwide or in special economic zones/clusters.	Technology connections are available nationwide or in special economic zones/clusters with the enactment of appropriate cyber laws.
Support for creative industries – digitisation, ToT, AI, and others	No creative industry plan or initiative.	Some form of government support is available for the development of creative industries.	Government has dedicated support programmes for the development of a creative industry.	Level 2 + government has dedicated agencies monitoring the progress of creative industries.	Level 3 + government has dedicated plans to interlink the creative industry to real sectors (e.g. manufacturing and others).
Data security/ cyber security initiatives	No legislation or policy on cyber security put in place.	Legislation and policy on cyber security under preparation.	Cyber security legislation and policy have been revised and approved.	Cyber security strategy and systems (creation, protection, utilisation) were established with a budget and implementing agency.	Level 3 + international cooperation has been established with regional coordination on cyber security.
Trade and Investment Policies					
Investment promotion in strategic sectors of I4	No effort established in investment policy to promote I4-related industries.	Investment promotion strategies include broad I4 sectors and products.	Level 2 + investment policy includes some targeted sectors of I4 with various opportunities for incentives.	Level 3 + specific domestic investment promotion strategies are targeted.	Level 3 + investment promotion strategy takes a holistic approach to promote the entire value chain (ecosystem) of the I4 sectors.
Trade Promotion Initiatives in Strategic Sectors of I4	Trade promotion strategies have yet to be developed.	Important I4-related sectors have been identified and market access strategies have been developed.	Level 1 + there is a dedicated agency/division/ unit to help businesses to get market information.	Level 2 + there is an effort to minimise barriers to trade (including for imports) in I4 sectors.	Level 3 + policies and strategies are available for export promotion, exporters' development, trade and market information, and trade advisory services.
International cooperation and collaboration (bilateral and regional trade agreements, technology transfers, know-how, etc.) in I4 sectors.	No international cooperation or collaboration established.	Informal arrangement (non-binding) is available for cooperation and collaboration.	Level 1 + already established a few formal arrangements with a few partner countries.	International cooperation and collaboration have been committed with adequate allocation.	Level 3 + dedicated agencies/units/ divisions are available to monitor and assess the progress in international cooperation/ collaboration.

Appendix 2: Assessment Framework for Circular Economy Policy Readiness

Levels	Level 0	Level 1	Level 2	Level 3	Level 4
Regulatory and Institutional Framework for Circular Economy					
A comprehensive circular economy policy framework (reduce, recycle, reuse, remanufacture, refurbish)	No policy framework exists	Policy framework is in a drafting stage.	No uniform definition of the circular economy is available and various ministries/ agencies have developed a policy framework.	Uniform definition of the circular economy is in place, but it is not streamlined (different application) in government programmes and policies within countries.	There is a uniform application of the circular economy definition in government programmes and policies within countries.
Intra-governmental coordination in circular economy policy formulation	There are no systematic reviews of redundant or ineffective legislation and regulations.	There is a review, and a list of inventory of all relevant legislation and regulations has been made.	There has been ad-hoc activity carried out on the amendment of redundant or ineffective legislation and regulations. The government is planning to carry out this exercise.	Implementation of the plan is under way, covering key legislation and regulations related to circular economy policy.	The implementation is well advanced and most or all of the legislation and regulations have been revised.
Awareness programmes/ initiatives across all stakeholders	No measure in place to facilitate awareness about the circular economy.	Plan in preparation to tackle awareness facilitation.	Plan to tackle the facilitation has been adopted after inter-ministerial and stakeholder consultation. Action plan defined.	There is evidence that some elements of this plan have been implemented.	Solid evidence of implementation of the facilitation plan with indication of key targets achieved.
Waste management regulations	There is no waste management regulation/policy.	A government strategic plan on identifying waste management is under preparation.	The plan covers a range of support services and has been implemented with moderate success.	Solid implementation record of the achievements of the regulation via action plans.	Implementation well advanced, and monitoring systems in place to measure the impact of the waste management plans.
Resource productivity strategies	No strategy is established for resource productivity (minimise energy use, waste, pollution)	Several strategies are formulated and they have overlapping portfolios and limited coordination.	Strategies established with a single institution/ unit/division are under consideration.	Approval for establishment of a single institution in charge of leading and coordinating the strategies.	The institution/unit/ division is established with staff and budget in place.

Levels	Level 0	Level 1	Level 2	Level 3	Level 4
Adoption of remanufacturing and sharing (eco-innovation principles)	No remanufacturing or sharing programme is initiated.	Uncoordinated programmes initiated by various ministries/ agencies/ institutions.	Coordinated programmes initiated by the implementing major ministry/ agency/ institution.	The programmes are operated with limited geographical coverage and for limited sectors.	The programmes are fully functional nationwide and a significant number of firms have participated.
Energy and greenhouse gas emissions policy and regulations	No initiative has been done to undertake a review of the policies.	Policy review and assessment are under elaboration. Review of expired strategy under way.	Multiyear policy review and assessment strategy for current period is approved by the government	The multiyear policy assessment has been implemented with moderate success.	Solid evidence of assessment of policies with indication of key targets achieved and assignments completed.
Standard regulations (reuse, recycle, use of chemicals, remanufacturing, refurbishing, etc.)	No product and standard regulation established.	Initiatives to develop some of these standards are underway.	Level 1 + a clear plan has been identified to categorise these standards.	Level 2 + implementing institutions are available with budget.	Products and standard regulations are enforced with a dedicated institution monitoring the standards.
Education, Information, and Awareness					
Public communication and information campaigns/ programmes	No initiative undertaken to develop programmes and campaigns.	There is initiative but work on the development is still at a preliminary stage.	Programmes and campaigns have been developed and pilot tested with some critical partners but are not ready for full implementation.	Programmes have been developed and implemented successfully with some critical partners based on trust, information exchange, and shared understanding of the value of adopting circular economy practices.	Comprehensive programmes have been developed and implemented successfully with all partners based on trust, information exchange, and shared understanding of the value of adopting circular economy practices.
Promotion of circular economy thinking in schools and universities	No materials or expertise to promote circular thinking in schools and universities.	Materials are currently in the development stage.	Materials are under pilot. Some evidence of arrangements that allow the promoting of circular economy thinking.	Secondary schools and universities are equipped with teaching materials and staff with knowledge and skills in circular economy teaching.	Level 3 + circular economy thinking, knowledge, and teaching incorporated in more than 50% of schools and universities.
Collaboration and Partnership Platforms					
Public-private partnerships with businesses	No strategic plan for public-private partnership.	Partnership channels are being identified.	Partnership elements are included in some of the policy documents.	Level 2 + information on implementation plans, budget, and time lines included in each of the documents.	Partnerships have been established with moderate success at the national, regional, and city levels.

Levels	Level 0	Level 1	Level 2	Level 3	Level 4
Voluntary industry participation and collaboration platforms and information sharing	No platform exists.	Government is currently planning such a platform.	Government and industry have actively engaged in such platforms.	Level 2 + the engagement has resulted in a few success stories.	Level 3 + engagement has driven most of the industries to incorporate circular thinking in their operations.
Technology development and R&D programmes in the fields of circular economy (e.g. material sciences and bio systems)	No formal framework to support technology development in universities, R&D labs, and incubators for the circular economy.	Plans are available in policy documents to support technology development in universities, R&D labs, and incubators related to the circular economy.	Dedicated funding is available in the fields of the circular economy.	SMEs, universities, and R&D labs have actively participated in funding and undertaken research in fields of the circular economy.	Level 3 + strong connectivity and coordination exist between technology development activities in universities, R&D labs and incubators, and SMEs for the circular economy.
Business Support Systems for the Circular Economy					
Financial incentives for the circular economy	No financial incentive available.	Government is identifying financial incentives.	Financial incentives are available in various ministries/ departments.	Various financial incentives are available in more coordinated and organised ways.	Various financial incentives are available and implemented successfully.
Non-financial support (e.g. technical support, advisory, training, and demonstration of best practices to businesses)	No support system available.	Government is identifying the support system.	Support systems are available in various ministries/ departments.	Multiple support systems are available in more coordinated and organised ways.	Multiple support systems are available and implemented successfully, including with partners from abroad.
Public Procurement, Infrastructure, and Technology					
Public procurement for the circular economy	No public procurement policy.	Government has started plans to establish public procurement policy.	An action plan to lay public procurement and the legal framework has been established.	The public procurement has been implemented with moderate success.	Level3 + public procurement is successfully implemented with huge success.
Public investment in infrastructure for the circular economy	No investment plan for the circular economy.	Some form of government investment is available for circular economy infrastructure development.	Government has dedicated investment plans for the development of circular economy infrastructure.	Level 2 + government has dedicated agencies monitoring the progress of investment.	Level 3 + government has successfully rolled out infrastructure for the circular economy.
Promoting I4-related technologies for the circular economy	No technology identification established.	Technologies related to the circular economy have been identified.	Level 1 + strategy plans are available to promote these technologies.	Level 2 + budget and implementing agency are in place.	Level 3+ international cooperation has been established to transfer technologies.

CHAPTER 5

Measuring Cross-Cutting Factors Influencing Institutional and Innovation Efficiency for Industry 4.0 and the Circular Economy

Jootae Kim and Ick Jin

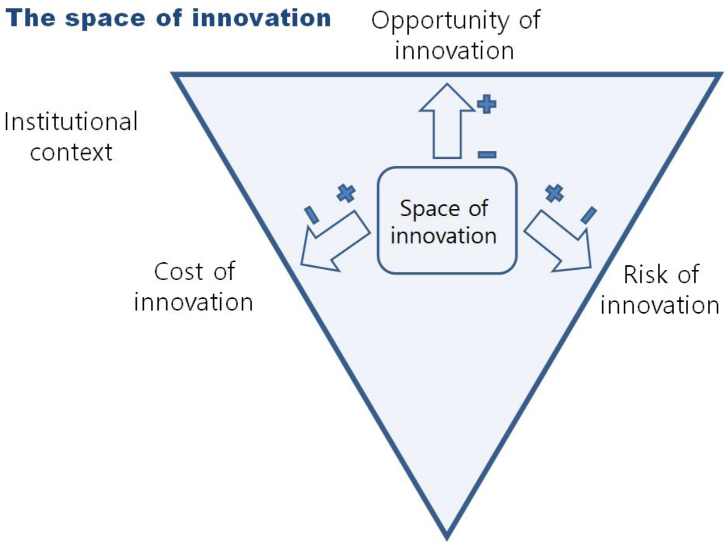
1. Introduction

The objective of this chapter is to develop a series of measurement frameworks to show how ready a country is for Industry 4.0 (I4) and the circular economy (CE). I4 reflects the degree of digital transformation of a country, and the CE is a path leading to sustainable development. Sustainability is a very critical topic for the current human society. The circular economy is an umbrella term used for industrial processes and business models that do not generate waste but instead reuse natural resources repeatedly. At its core, the circular business is about economics and competitiveness (Anbumozhi and Kimura, 2018). At the firm level, higher resource efficiency is sought through the '3Rs': reduce consumption of resources, reuse resources, and recycle the by-products. New, digitally-enabled technologies include advances in production equipment, such as 3D printing and advanced robotics; smart finished products, such as connected cars and home appliance systems using the Internet of Things (IoT); advanced analytics, such as big data analytics and analytics across the global value chain; and human–machine interfaces, such as picking technology using augmented reality and artificial intelligence, etc. These digital technologies can contribute towards the circular economy. Most aspects of human life will be changed from the adoption of digital technologies, and resource circularity is also an area where these technologies can contribute.

1.1. Institutional Efficiency

Some countries are prepared for the introduction of I4 and the CE, but other countries lack good environments to enable these innovations. There are many cross-cutting factors that influence the readiness for I4 and the CE of a country. Some cross-cutting factors are proxies to measure institutional efficiency and innovation efficiency in a country. In a country with high institutional efficiency, the introduction of I4 and the CE may be easier. Many cross-cutting factors can be considered to measure institutional efficiency. I4 is achieved from continuous innovative efforts and exponential growth. The overall institutional environments of a country can influence the performance of automation and connections through information and communications technology (ICT) technologies (North, 1991). Some factors in a country may be helpful for innovation, but other factors may be obstacles against innovation (Peng, 2002). Institutional efficiency in a country can be evaluated. Figure 5.1 explains the relationship between institutions and innovation. The performance of innovative efforts is determined in the context of an institutional environment. Innovations can create technologies that can transform the circularity of economic activities. But, institutions are needed to create business practices, market design, regulation, and policy instruments, as well as finance to make innovation happen. Institutional efficiency for designing I4 and the CE necessitates consumer engagement, supply-side management, and demand responses. Generally, institution environments are made up of formal institutions, such as laws and regulations, and informal institutions, such as culture. As shown in Figure 5.1, these institutions can function as the opportunity, cost, or risk for the success of innovative efforts. As an example, the Uber service is widespread in many countries, but in some countries, it is prohibited or delayed by the government because of pressure from the stakeholder groups of taxi drivers. In this case, the interests of taxi drivers and the law are the cost or risk for the introduction of Uber. Car-sharing services, such as Uber, use digital technologies and contribute to resource saving and carbon emission reduction.

Figure 5.1: Innovation and Institutions

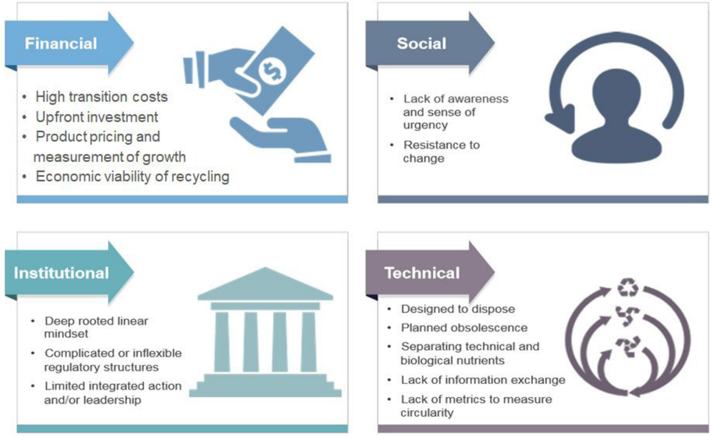


Source: Zhu, Wittmann, and Peng (2012).

1.2. Common Obstacles

To find the diverse institutional factors to determine the readiness for I4 and CE, we must consider what obstacles usually exist against the introduction of I4 and the CE. Figure 5.2 and Figure 5.3 show the major obstacles to successfully introducing I4 and the CE.

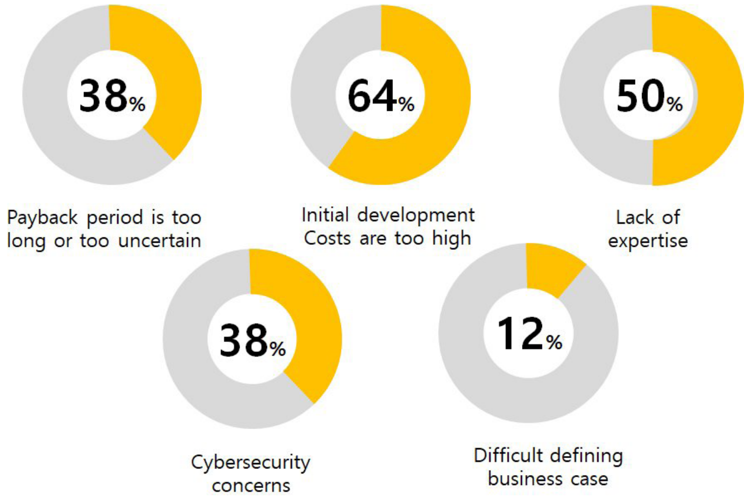
Figure 5.2: Obstacles to the Circular Economy



Source: World Economic Forum (2018).

There exist four categories of challenges against pursuing the circular economy. The first obstacle is the financial hurdle. To achieve any innovation in our society, financial investment is the key requirement. The CE is a new approach in human society, and, therefore, it requires an economic paradigm shift for changes in human behaviour and attitudes. Lack of awareness or social resistance should be considered as possible responses from ordinary people. An existing linear mindset or regulatory structure can limit the adoption of new concepts. Another basic problem is the need for innovative technologies. A large volume of investments is required to obtain advanced technologies.

Figure 5.3: Obstacles to Industry 4.0



Source: Churchill (2018).

The obstacles to a successful I4 in Figure 5.3 are summarised as financial, technology, and security concerns.

1.3. Institutional Efficiency in the ASEAN Region

The main objective of this book is to analyse the readiness for I4 and the CE in Association of Southeast Asian Nations (ASEAN) countries. The ASEAN region is one of the fastest-growing regions in the world, with a population of over 625 million and a combined nominal gross domestic product (GDP) of over US$2.6 trillion in 2015. Of the 10 ASEAN nations, Singapore and Brunei Darussalam are classified by the

World Bank as high-income (non-Organisation for Economic Co-operation and Development (OECD) countries); Malaysia and Thailand as upper-middle-income countries; Indonesia, the Lao People's Democratic Republic (Lao PDR), Myanmar, the Philippines, and Viet Nam as lower-middle-income countries; and Cambodia as a low-income country. This suggests that there is heterogeneity amongstst the ASEAN Member States from an economic development perspective (Ramanathan, 2018). The institutional efficiency of ASEAN countries seems to be lower than that of other advanced economies such as Japan or the European Union (EU). Unstable political systems, inconsistency of government policies, less-developed economies, different cultural environments, and low-level industry/technology advancement represent the institutional limitations of ASEAN countries in limiting the successful implementation of I4 and the CE (Kim, 2018a). The Global Competitiveness Report (2015–2016) (World Economic Forum, 2016) provides considerable information on the status of critical indicators of what it refers to as the 'pillars of development' of nations. Basic requirements are measured by the items of institutions, infrastructure, macroeconomic environments, and health and primary education. The overall ratings from this measurement are above 5.0 for Japan, Germany, the Republic of Korea (henceforth, Korea), and China, with the highest being 7, but for ASEAN countries except Malaysia and Singapore, the overall ratings are below 5 (Ramanathan, 2018). China has been experiencing very rapid economic development during the last 3 decades. The Chinese government is trying to upgrade the institutional environment to increase the speed of economic development. It is said that the formal institutions, such as laws and regulations, can be modified relatively quickly, but it takes a long time to change the informal institutions, such as culture. Most countries try to change their laws to adapt to new environments. Even if laws or formal processes are changed by the government quickly, it takes time to spread the changes to the real lives of ordinary people. Many ASEAN Member States may perform institutional transition, but for the real transition, the recognition and preparation of the ordinary people must be made. Table 5.1 evaluates various institutional aspects of China in relation to innovation efficiency. China has been working significantly for its institutional transition, and the institutional efficiency of China is understood to be slightly better than that of ASEAN. The summary of the institutional obstacles in China in Table 5.1 can give some implications for the understanding of ASEAN institutions and, furthermore, for the improvement of them.

Table 5.1: Institutional Barriers to Innovation in China

	Cost of Innovation	Risk of Innovation	Opportunity for Innovation
Competition Fairness			
No priority for government procurement	+		-
Difficult to start a business	+		-
Poor enforcement of the Unfair			
Competition Law	+	+	-
Regional protectionism	+		-
Access to Financing			
Difficult to get bank credit	+		-
High barrier for capital market	+		-
Lack of venture capital, especially angle capital		+	-
Hard to access to public sources of funding	+		
Tax Burden			
Current value-added tax (VAT) system	+		-
Pro-innovation tax system	-	-	+
R&D tax credit policy	-	-	+
Laws and Regulations			
Extra entry barriers	+		-
Unclear assess to intangible collateral	+	+	-
Weakness of property rights			-
Lack of regulations and/or concrete regulations at operational level	+	+	-
Ambiguity of property rights and			
creditors' rights in the event of bankruptcy	+	+	-
Inconsistent policies		+	
Lack of regulations to protect non-technological innovation	+	+	-

	Cost of Innovation	Risk of Innovation	Opportunity for Innovation
Public Supporting Systems			
Lack of infrastructure	+		-
Lack of linkages with public research institutes	+	+	-
Deficiencies in the availability of external services	+	+	-
Lack of information on markets	+	+	-
Lack of information on technology	+	+	-
Short of training and education	+		-
Lack of intermediary to provide services for SMEs	+	+	-

R&D = research and development, SME = small and medium-sized enterprise.
Source: Zhu, Wittmann, and Peng (2012).

2. How Do Cross-cutting Factors Relate to the Overall Industry 4.0 Readiness Measurement and the Enabling Environment?

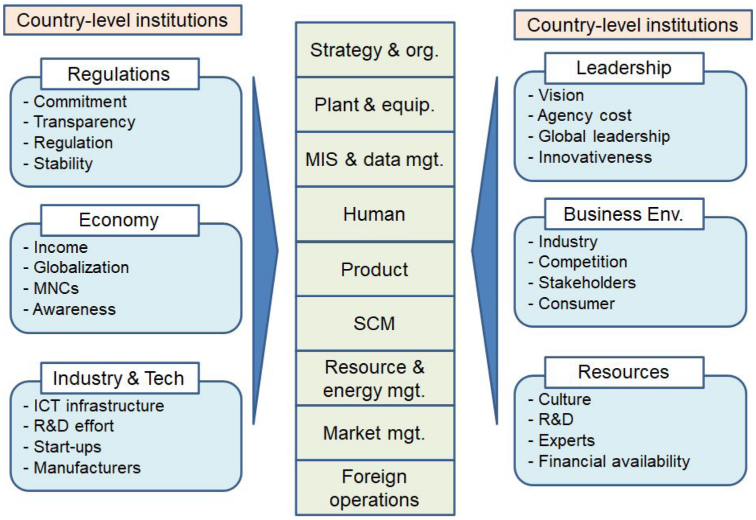
To exploit the full potential of I4 and the CE, cyber-physical systems need to be communicated internally within modular structured factories and offices, along with cooperation across participants in the value chain. In a corporation, I4 and the CE are realised through the internal processes in factories and offices. The adoption of digital technologies in the manufacturing process and office environment can bring about not only cost reductions but also resource savings and recycling effects. I4 and the CE can also occur in transportation and storage. For raw material sellers and distribution channels existing within the value chain, I4 and the CE need to be realised. This is one of the reasons why we try to measure the institutional readiness for I4 and the CE. A model is presented to measure such institutional readiness for I4 and the CE for ASEAN Member States.

The institutional readiness model is based on six dimensions for I4 and the CE. The six dimensions correspond to universally applicable dimensions to be taken into account: the first 3 dimensions at country (macro) level (regulations, economy, and industry and technology), and other the dimensions at the corporate (micro) level (leadership, business environment, and resources). Each of these six dimensions is further delineated into four factors to be operationalised with the appropriate indicators.

They form the basis for measuring the institutional readiness for I4 and the CE of ASEAN Member States.

Figure 5.4 provides an overview of the institutional readiness model: six boxes show the six basic dimensions. The bullets in each box show the items associated with each of the six dimensions. A total of 24 items are evaluated using the appropriate qualitative and quantitative indicators. The green pillar at the centre represents the relevant factors at the corporate level discussed in the previous chapter.

Figure 5.4: Cross-cutting Factors for the Readiness for Industry 4.0 and the Circular Economy



MIS = management information system, MNC = multinational corporation, R&D = research and development, SCM = supply chain management.
Source: Authors.

The vision of I4 and the CE and the path to this vision will be different for each country. Not every country has a short-term ambition to implement the full target vision of I4. Countries define their own interim and final goals based on their own background and status quo. For this reason, 24 factors of I4 and the CE are used to develop a five-level score for measuring the readiness. Each of the five readiness levels (0–4) includes minimum requirements that must be met to complete the level.

The five levels of the institutional readiness model can be described as follows. Level 0 describes the situation where countries have done nothing or very little to plan or implement I4 and CE activities with respect to the relevant item. A country at this level does not meet any of the requirements for I4. Level 0 is also automatically assigned to those companies that indicated I4 and the CE were either unknown or irrelevant for them. In contrast, Level 4 describes the situation where countries have successfully implemented all I4 and CE activities in terms of the item. In other words, Level 4 of the model means a state of full implementation of the target vision when entire value chains are integrated in real-time and can interact.

2.1. Country-level Factors

1) Regulation

a. Political leadership (or presidential commitment)
For the institutional readiness of I4, the political leadership (or presidential commitment) is an important item in the regulation dimension. The strong vision and commitment of a leader are necessary. At Level 0, the political leadership does not show any interest in I4. At Level 1, the political leadership comments on I4 and the CE sometimes, but does not have a critical agenda on it. At Level 2, the political leadership stresses the importance of I4 but does not offer various programmes for it. At Level 3, the political leadership presents various plans for I4, but those plans are not feasible to be implemented. At Level 4, the political leadership formulates quite realistic and feasible plans for I4.

b. Transparency (and democracy)
For the institutional readiness of I4, the transparency of the political system (and democracy) is another important item in the regulation dimension. At Level 0, a country faces severe corruption and unfair competition. At Level 1, a country is trying to reduce corruption, but some adaption to corruption is inevitable for businesses in reality. At Level 2, a country recognises that some informal factors affect competition. At Level 3, corruption is sometimes found but it is not a serious problem any longer. At Level 4, competition is transparent by and large and the level of corruption related with business operations is very low.

c. Business regulations

In many developing countries, it is said that too many regulations exist and lessen the effect of the innovative efforts of the private sector. Governments should try to reduce unnecessary regulations to make innovative efforts easier. At Level 0, business regulations are a serious hurdle to private firms and many experts advise that a regulation reform is necessary. At Level 1, businesspeople make many complaints about the business regulations. At Level 2, businesspeople sometimes raise concerns about regulatory inefficiency. At Level 3, businesspeople hardly feel the regulations as an obstacle to business. At Level 4, overall laws and regulations are regarded to be efficient for business.

d. Security (and stability)

Security and political stability are another requirement to make private firms more productive and effective. At Level 0, the security for businesses is very unstable and stable business operations are impossible. At Level 1, there exists a possibility of war, coup d'état, strike or demonstration. At Level 2, some factors cause an unstable society or some people worry that society will become unstable. At Level 3, security threats can exist, but they are not significant for business operations. At Level 4, there exists no security problem any longer.

2) Economy

a. Economic development

Economic development is one of the most prominent items in the economy dimension for the institutional readiness for I4. GDP per capita is the most apparent and established indicator. At Level 0, GDP per capita is less than US$1,000. At Level 1, GDP per capita lies between US$1,000 and US$5,000. At Level 2, GDP per capita is greater than US$5,000 but less than US$10,000. At Level 3, GDP per capita falls into the range of US$10,000 and US$30,000. At Level 3, GDP per capita exceeds US$30,000.

b. Globalisation (and openness)

Globalisation (and openness) is one of the necessary items in the economy dimension for the institutional readiness for I4 and the CE. At Level 0, the interest in global standards is minimal. At Level 1, attempts to accept global standards begin to be taken, but those efforts are not effective yet.

At Level 2, institutional transition is active through trying to keep global standards. At Level 3, most global standards are relatively common. At Level 4, a country is regarded to be a global leader.

c. Performance of multi-national corporations

The performance of multi-national corporations (MNCs) is another measurement item for the institutional readiness for I4. Having excellent multinational corporations represents the global capability of the economy. Most competitive MNCs are from advanced economies. At Level 0, there are few domestic MNCs, and only a few foreign MNCs exist in a country. At Level 1, there are still few domestic MNCs, but many foreign MNCs invest in the domestic market. At Level 2, a country starts to produce successful MNCs and those MNCs begin to open foreign factories and subsidiaries. At Level 3, some MNCs are globally competitive and most MNCs have many sub-activities operate overseas. At Level 4, a country has many globally leading MNCs.

d. Overall consumer awareness

Overall consumer awareness is also a fundamental factor in introducing I4 and the CE successfully. The need of consumers for I4 and the CE should exist to make firms invest in these areas. I4 and the CE represent a range of new technologies that aim to combine various types of consumers on the physical, digital, and biological domains. From time to time, the resistance from some consumers on a particular domain can be a serious obstacle against any innovative attempts in markets. At Level 0, most consumers do not have any knowledge about I4 and the CE. At Level 1, consumers only in leading positions understand I4 and the CE. At Level 2, most consumers are aware of I4 and the CE, but they are not significantly interested in them. At Level 3, many consumers recognise the importance of I4 and the CE, but they are hardly willing to buy the related products or services. At Level 4, most consumers want to buy products or services related with I4 or CE.

3) Industry and Technology

a. ICT infrastructure

ICT infrastructure is the most critical factor necessary for the success of digital transformation. In our study, the smartphone penetration rate (SPR) is used as a practical indicator. At Level 0, the existing ICT infrastructure only partially satisfies future integration and communications requirements. SPR is less than 50% for this level. At Level 1, the ICT infrastructure does not satisfy all the requirements for future expansion. This level goes along with SPR between 50% and 70%. At Level 2, the ICT infrastructure is upgradable to accommodate future expansion. SPR is greater than 70% and less than 80% for this level. At Level 3, further expansion is possible since the ICT infrastructure already satisfies future integration requirements. SPR falls into the range of 80% and 90% in this case. At Level 4, the ICT infrastructure satisfies all the requirements for integration and system-integrated communications. Now, SPR exceeds 90%.

b. R&D effort

For the institutional readiness of I4, the R&D effort of a country is one of the most frequently monitored items in the industry and technology dimension. The ratio of the amount of R&D to GDP (RDGR) is a typical indicator. At Level 0, a country is involved in I4 and the CE through R&D investments in a single area. The RDGR is under the global top 70 for this level. At Level 1, R&D investments relevant to I4 and the CE are being made in a few areas. This level goes along with RDGR between the global top 70 and global top 50. At Level 2, a country is making I4-related R&D investments in multiple areas. The RDGR is greater than the global top 50 and less than the global top 30 for this level. At Level 3, R&D investments are being made in nearly all relevant areas. The RDGR falls into the range of the global top 30 and global top 10 in this case. At Level 4, I4 and CE strategy and monitoring is supported by R&D investments throughout the country. Finally, the RDGR is in the global top 10.

c. Support for start-ups and entrepreneurs

Currently, business innovation, job creation, and economic development can be achieved from the support for start-ups and entrepreneurs. The ICT industry has been led by famous start-ups such as HP, Apple, Google, and Amazon. At Level 0, a country shows no stress on or interest in start-ups. At Level 1, it is recognised that start-ups are necessary for the economy but the policy for nurturing start-ups is not very strong. At Level 2, a country stresses the importance of start-ups, but there are few successful start-ups. At Level 3, start-ups are active in many areas and nurturing programmes supported by the government are found. At Level 4, many start-ups are globally successful and play critical roles in their national economy.

d. Strength of the manufacturing industry
For the institutional readiness of I4, we cannot miss the strength of the manufacturing industry as one of the most fundamental items in the industry and technology dimension. At Level 0, a country has no ability to develop its own manufacturing industries, and most industries depend on foreign firms. At Level 1, many foreign MNCs invest in the domestic markets, and the capability of domestic firms is weak. At Level 2, most domestic manufacturing firms are dominant in local markets, but they are not competitive in global markets. At Level 3, domestic manufacturing firms are trying to produce and sell in foreign markets, but their global capability is still insufficient. At Level 4, several local manufacturing industries are competitive in global markets.

2.2. Corporate-level factors

1) Leadership

a. Managerial entrenchment (agency problems)
In the current business research, the management entrenchment is recognised to influence the ineffectiveness of firm management. Some business research asserts that the agency problems of management tend to reduce the R&D activities of a firm. At Level 0, governance reform is strongly required by stakeholders. At Level 1, it is agreed that governance reform is necessary and protests to the management are seen. At Level 2, managerial entrenchment is regarded as a critical problem for decreasing corporate competitiveness. At Level 3, agency problem and entrenchment exist but they are not considered to be serious problems. At Level 4, the agency problems of management are negligible.

b. Global leadership
Corporate managers should have global talent and vision. At Level 0, the leadership has little experience in foreign environments. At Level 1, most of the past careers of leadership were made in domestic environments. At Level 2, the leadership is familiar with foreign markets, but it lacks much in global competence, including business languages such as English. At Level 3, the leadership can lead a foreign subsidiary with the help of local people, although it has some limitations as a global leader.

At Level 4, it is believed that the leadership has global talent and vision and can work with any foreign employees.

c. CEO innovativeness

CEO innovativeness is one of the most frequently addressed items in the leadership dimension for the institutional readiness for I4. At Level 0, CEOs dislike risk-taking situations and they avoid any projects with high uncertainty. At Level 1, CEOs tend to be risk-averse and they pursue only a stable management style. At Level 2, CEOs accommodate risk-taking behaviour from employees. At Level 3, CEOs have some experience of innovative performance during their past careers. At Level 4, CEOs have led the introduction of new products or business models.

d. Corporate vision

The corporate vision is an indispensable item in the leadership dimension for the institutional readiness of I4. At Level 0, a corporate vision is not presented, or it is seen as neither clear not realistic. At Level 1, many employees have strong concerns or complain about the corporate vision. At Level 2, the current corporate vision looks so ambiguous that it is not understood or supported by employees. At Level 3, a clear corporate vision is offered but it needs to persuade employees. At Level 4, a clear and feasible vision is offered, and most employees are motivated by the vision.

2) Business environment

a. Industry condition

The industry condition, as a business environment factor, can influence a firm's institutional readiness for I4. At Level 0, an industry is in the declining stage and its exit should be considered. At Level 1, few technological innovations are observed and the industry is mature. At Level 2, marginal innovations are happening frequently. At Level 3, technology change is regarded as a critical driver and start-ups and M&A are active for the development of new technologies. At Level 4, innovations in products and business models are prevalent.

b. Competition and rivalry

For the institutional readiness of I4, the competition structure and rivalry are significant items in the business environment dimension. At Level 0, the business environment is dominated by a monopoly of an inefficient firm. At Level 1, the business environment is dominated by a monopoly of an efficient firm. At Level 2, there are many players in the market but the competition is not fierce. At Level 3, several firms compete and they are sensitive to others' strategies and performances. At Level 4, competitive pressure is strong, the competition amongst many firms is fair, and competition occurs globally.

c. Stakeholder pressure

For the institutional readiness of I4, stakeholder pressure is one of the underlying items in the business environment dimension. At Level 0, there is no interest from stakeholders in I4 and the CE. At Level 1, I4 and the CE are stressed in society, but individual firms are not pressed to adopt them. At Level 2, pressure on I4 and the CE is strong, but the corporate response is superficial in a sense that it only takes place for advertising effect. At Level 3, the pressures from stakeholders on I4 and the CE are strong and management is trying to follow them. At Level 4, the pressure from diverse stakeholders for I4 and the CE is strong and the relevant responses are made as well as monitored.

d. Consumer expectation

For the institutional readiness of I4, the consumer expectation is one of the most important items in the business environment dimension. At Level 0, consumers have little knowledge of I4 and the CE and their needs in society are small. At Level 1, consumers have heard about I4 and the CE but they do not understand them in detail. At Level 2, consumers understand the importance of I4 and the CE but they are not interested in the effective responses of firms. At Level 3, consumers understand that I4 and the CE should be reflected in the corporate management process. At Level 4, consumers are eager to purchase products satisfying the requirements of I4 and the CE.

3) Resources

a. Corporate culture and creativity

Corporate culture and creativity are one of the fundamental requirements as a corporate resource for facilitating the introduction of I4. At Level 0, the technology level is very low and independent management without foreign firms' help is hard. At Level 1, companies can survive only in the domestic or regional market, and the traditional management system is dominant. At Level 2, the transition from a traditional culture to a creative one is discussed amongst companies. At Level 3, some companies are changing to a creative culture, they are successful in catching up with the leading products and technology, and they compete well with global leaders. At Level 4, many companies introduce innovations in products, production, or other management processes and then they become leaders in the global market.

b. R&D input

The R&D input is one of the most recognised items in the resources dimension to improve institutional readiness for I4. The ratio of the R&D amount to sales (RDSR) is a typical indicator. At Level 0, companies are involved in I4 and the CE through R&D investments in a single area. The RDSR is under 5% for this level. At Level 1, R&D investments relevant to I4 and the CE are being made by companies in a few areas. This level goes along with an RDSR between 5% and 10%. At Level 2, companies are making I4-related R&D investments in multiple areas. The RDSR is greater than 10% and less than 15% for this level. At Level 3, R&D investments are being made by companies in nearly all relevant areas. The RDSR falls into the range of 15% to 20% in this case. At Level 4, I4 and CE strategy and monitoring is supported by R&D investments by most companies. Finally, the RDSR is over 20%.

c. Ability of experts

The ability of experts is one of the most indispensable items in the resources dimension to improve the institutional readiness for I4. At Level 0, there are no experts in I4 and the CE. At Level 1, the ability of experts lags behind compared with that of experts in the leading firms. At Level 2, experts understand the top-level technologies, but they can only introduce and imitate them. At Level 3, the ability of experts is at the global top level, but they have not produced many innovations in the global market.

At Level 4, experts in I4 and the CE are at the top level compared with any experts in the world and they lead innovations in the world market.

d. Financial availability

Financial availability is one of the most critical items in the resources dimension to improve the institutional readiness for I4. At Level 0, companies are in significant difficulty for financial availability. At Level 1, companies have a high level of debt and they cannot invest in long-term innovation, such as for I4 and the CE. At Level 2, companies hold only a limited amount of funds to be invested in innovative projects. At Level 3, many companies are recognised as sound ones in terms of their financial availability. At Level 4, the financial availability of companies is not a concern at all for the development of I4 and the CE.

3. Case Application: The Republic of Korea

To evaluate the content and structure of our institutional readiness model, a case study for Korea is conducted. Korea is positioned between developed nations and developing nations. ASEAN Member States, as developing economies, can benchmark Korea rather than Japan or the United States. Korea has achieved economic success during the short time of 50 years. The history and current situation of the Korean economy can provide valuable lessons for ASEAN Member States. Korea will ramp up its investment in R&D for promising technologies that will accelerate the advent of I4 and the CE. Such technologies include autonomous cars, IoT-fitted electronics, semiconductors and displays, bio-health, and renewable energy. The Korean government will increase its R&D spending on those industries to 50% of the country's total R&D spending by 2022 from the current 30%.[1] To successfully implement this formidable strategy, however, Korea also faces many challenges to overcome on six dimensions for I4 and the CE: regulations, economy, industry and technology, leadership, business environment, and resources. The evaluation results from two Korean experts[2] are presented for testing the practical usability of our assessment tool.

[1] According to statistics announced by the Ministry of Trade, Industry and Energy (MTIE) in March 2018, the Korean government has allocated about W900 billion (US$844 million) to the five sectors out of this year's total R&D spending of W3.16 trillion.

[2] The two Korean experts are researchers in economics and have a speciality in sustainability, such as the environment, climate change, and recycling. The first expert is a professor in business in a Korean university, and the other is a chief economist in a Korean national research institute.

3.1. Scores in Country-level Factors

1) Regulation dimension

Expert A rates the presidential commitment of Korea as Level 4, evaluating that the political leadership formulates quite realistic and feasible plans for I4. Expert B is more pessimistic on this item of Korean political leadership, and rates it as Level 2, where the political leadership stresses the importance of I4 and the CE but does not offer various programmes for it. Next, both experts evaluate the transparency of Korea as Level 2, which implies that the country recognises that some informal factors affect competition. Then, both experts evaluate the business regulations of Korea as Level 2 because both think that businesspeople in Korea frequently raise concerns about regulatory inefficiency. Finally, expert A shows a strong concern for the security of Korea by rating it as Level 0, which means that the security for business in Korea is so unstable that stable business operations are impossible. In contrast, expert B provides a more favourable rating for the security concern item by evaluating it as Level 2, where some factors cause Korea to be unstable or some people worry about it. Applying equal weights over the four items, the weighted average score is 1.5 from expert A and 1.75 from expert B.

Table 5.2: Scores for the Regulation Dimension for the Republic of Korea

Item	Weight (%)	Expert A	Expert B
Political leadership	25	4	2
Transparency	25	2	2
Business regulations	25	1	1
Security concern	25	0	2
Weighted average	100	1.5	1.75

Source: Authors.

2) Economy

Since the GDP per capita of Korea was US$29,745 at the end of the year 2017, both experts rate the economic development of Korea as Level 3, which falls into the range of $10,000 and $30,000. Next, expert A evaluates the globalisation of Korea as Level 3 based on the thought that most global standards are relatively common in Korea. Expert B gives a lower rating of Level 2, where institutional transition is active through trying to keep with global standards. Then, expert A regards the MNC performance of Korea as Level 3, i.e. the status shows that some MNCs are globally competitive and most MNCs have many sub-activities and operate overseas. Expert B is less favourable by rating this item as Level 2, where a country starts to produce successful MNCs, and those MNCs begin to open foreign factories and subsidiaries. Lastly, expert A also gives a generous rating as Level 3 for the consumer awareness of Korea, believing that many consumers recognise the importance of I4 and the CE, but they are hardly willing to buy the related products or services. In contrast, expert B gives a relatively low rating for the item as Level 1, implying that consumers only in a leading position understand about I4 and the CE. With equal weights on each of four items, the weighted average score of 3.0 from expert A is higher than 2.0 from expert B as shown in the table 5.3.

Table 5.3: Scores for the Economy Dimension for the Republic of Korea

Item	Weight (%)	Expert A	Expert B
Economic development	25	3	3
Globalisation	25	3	2
MNC performance	25	3	2
Consumer awareness	25	3	1
Weighted average	100	3.0	2.0

MNC = multinational corporation.
Source: Authors.

3) Industry and technology

For the item of ICT infrastructure, expert A gives the highest score of Level 4, suggesting that the ICT infrastructure satisfies all the requirements for integration and system-integrated communications and that the SPR exceeds 90%. Expert B gives Level 3 to the item, meaning that further expansion is possible since the ICT infrastructure already satisfies the future integration requirements because the SPR falls into the range of 80%–90%. The difference in this rating seems to result from the discrepancy in statistics referenced by the experts. Next, both experts evaluate the R&D effort of Korea as the highest rate of Level 4, reflecting the statistics to show that Korea has an RDGR of about 4.24% and is ranked second in the world. However, both experts give a low rating of Level 2 for start-up support, which indicates that Korea stresses the importance of start-ups but there are few successful start-ups. Finally, both experts also highly score the strength of Korean manufacturers as Level 2, based on the observation that several local manufacturing industries are competitive in global markets. These scores are summarised in Table 5.4.

Table 5.4: Scores for the Industry and Technology Dimension for the Republic of Korea

Item	Weight (%)	Expert A	Expert B
ICT infrastructure	25	4	3
R&D effort	25	4	4
Support for start-ups	25	2	2
Strength of manufacturers	25	4	4
Weighted average	100	3.5	3.25

ICT = information and communication technology, R&D = research and development.
Source: Authors.

3.2. Scores in Corporate-level Factors

1) Leadership

First, expert A assigns the lowest grade of Level 1 to the managerial entrenchment item for Korea. The rating shows that governance reform is necessary and protests against management are seen. Expert B has the opinion that managerial entrenchment is regarded as a critical problem for decreasing corporate competitiveness, and, thus, the rate is a bit more positive as Level 2. Next, expert A's grade for the global leadership of Korea is Level 3, meaning that the leadership can lead foreign subsidiaries with the help of local people, although it has some limitations as a global leader. The grade from expert B is lower at Level 2, which implies that the leadership is familiar to foreign markets but lacks much in global competence, including business languages such as English. Next, both experts' grades on CEO innovativeness in Korea are low at Level 1. Both experts seem to agree that Korean CEOs tend to be risk-averse and they pursue only a stable management style. Lastly, both experts also have the same view of Level 2 for the corporate vision in Korea. There seems to be a consensus between two experts about the view that current Korean corporate visions look so ambiguous that they are not understood or supported by employees. Overall, the weighted average scores from both experts are equal to 1.75. These scores are summarised in Table 5.5.

Table 5.5: Scores for the Leadership Dimension for the Republic of Korea

Item	Weight (%)	Expert A	Expert B
Managerial entrenchment	25	1	2
Global leadership	25	3	2
CEO innovativeness	25	1	1
Corporate vision	25	2	2
Weighted average	100	1.75	1.75

CEO = chief executive officer.
Source: Authors.

2) Business environment

There is agreement between the two experts on the grade for the industry condition in Korea. The consensus is Level 2, which represents the intermediate situation of Korea where marginal innovations are happening frequently. Next, the grade of Level 3 on the competition item is also the same between the two experts. Both experts think that several firms compete in Korea and they are sensitive to each other's' strategies and performances. Then, the item of stakeholder pressure in Korea receives the same grade of Level 2 from the two experts. Both experts seem to agree that the pressure on I4 and the CE is strong in Korea, but the corporate response is superficial because they are only used for advertising effects. Finally, expert A gives a grade of Level 3 to the consumer expectation item for Korea. Expert A seems to believe that consumers understand that I4 and the CE should be reflected in the corporate management process. In comparison, expert B has a lower expectation on the item of consumer expectation. The grade from expert B is Level 1, which describes the situation where consumers have heard about I4 and CE but they do not understand them in detail. As a result, the weighted average score from expert A is 2.5 and that from expert B is lower at 2.0. These scores are summarised in Table 5.6.

Table 5.6: Scores for the Business Environment Dimension for the Republic of Korea

Item	Weight (%)	Expert A	Expert B
Industry condition	25	2	2
Competition	25	3	3
Stakeholder pressure	25	2	2
Consumer expectation	25	3	1
Weighted average	100	2.5	2.0

Source: Authors.

3) Resources

First, the item of corporate culture in Korea is graded at Level 2 by both experts. The result shows that Korea stays at the stage where the transition from a traditional culture to a creative one is discussed amongst companies. Next, both experts give a relatively high grade of Level 3 for the R&D input item. Such evaluations seem to be based on the observation that R&D investments are being made by companies in nearly all relevant areas, and the RDSR falls into the range of 15%–20% for Korea. Then, both experts give a rating of Level 2 for the ability of experts in Korea. The result represents the common evaluation that Korean experts understand the top-level technologies but they can only introduce and imitate them. Lastly, expert A's view of Level 3 on financial availability in Korea is Level 3, which is different from that of Level 2 from expert B. Expert A seems to think that many Korean companies are recognised as sound ones in terms of their financial availability, whereas expert B seems to think that Korean companies hold only a limited amount of funds to be invested in innovative projects.

Table 5.7: Scores for the Resources Dimension for the Republic of Korea

Item	Weight (%)	Expert A	Expert B
Corporate culture	25	2	2
R&D input	25	3	3
Ability of experts	25	2	2
Financial availability	25	3	2
Weighted average	100	2.5	2.25

R&D = research and development.
Source: Authors.

According to the evaluation example for Korea presented above, Korea is likely to be a 'learner' at both the macro level and the micro level. Note that the final score from expert A is close to the edge of 'leader' in this explanatory grouping scheme. It implies that Korea would progress towards 'leader' with a little improvement in some of the 24 items for institutional readiness for I4 and the CE.

Table 5.8: Grouping Example for the Republic of Korea

Dimension	Weight (%)	Expert A	Expert B
Regulation	16.7	1.50	1.75
Economy	16.7	3.00	2.00
Industry and technology	16.7	3.50	3.25
Leadership	16.7	1.75	1.75
Business environment	16.7	2.50	2.00
Resources	16.7	2.50	2.25
Weighted average	100	2.57	2.18
Financial availability	25	3	2
Weighted average	100	2.5	2.25

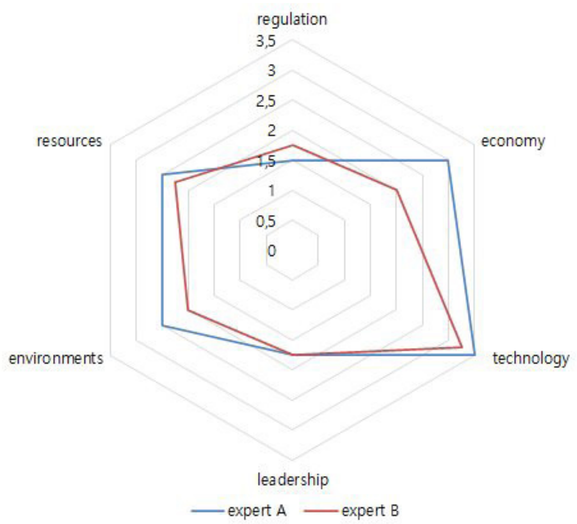
R&D = research and development.
Source: Authors.

The overall evaluation results of the two Korean experts are shown as a graph in Figure 5.5, and the findings from the analysis are summarised as follows.

- First, the scores for the regulation environment and corporate leadership are relatively low. In the regulation environment, we measured presidential commitment, political transparency, business regulations, and national security. Even if democracy in Korea has improved significantly compared with the 1970s and 1980s, some obstacles still exist to deter the innovative capabilities of private companies. Corruption between government officials and large corporations should be eliminated. Fewer regulations on business operations and open environments for start-ups are prepared in Korea.
- Second, the score for industry technology was higher than for other scores. This factor was measured by ICT infrastructure, R&D effort, support for start-ups, and the competitiveness of manufacturers. Except for the support for start-ups, the other elements are good in Korea. The other 3 factors are seen to be the strengths of Korean industries. Especially in relation to information technologies, Korea has achieved excellent performance.

- Third, the scores on the national economy, corporate environment, and firm resources are modest. The overall status of Korea is seen to be as a learner, which is between 2 and 3. These 3 dimensions are of a similar status. The national economy, corporate environment, and corporate resources are not at the top levels. However, they have been improved significantly and are expected to reach the top levels in the near future.

Figure 5.5: Scores for the Republic of Korea



Source: Authors.

3.4. Considerations for Implementation

As described by Schumacher, Erol, and Sihn (2016), measuring the readiness based on our institutional model may follow a procedure that can be integrated into an easy-to-handle and software-supported tool. First of all, the readiness evaluation on the prescribed 24 items may be conducted by using a standardised questionnaire consisting of one closed-ended question per item. Each question may be designed to require an answer with a Likert scale reaching from Level 0 to Level 4. It is important to provide respondents with sufficient information on the concepts of I4 and the CE because respondents can only properly answer the questionnaire when they understand the concepts well. External consulting would help increase the accuracy of the institutional readiness model. Responses to the questionnaire can then be put as inputs into the software tool to calculate the readiness level.

In the next step, the readiness level of the dimension can be calculated from the weighted average of the readiness level over the four items within each dimension. The weighting factor may reflect the average importance rating from experts for each item. Since all items do not seem to have the same contribution to readiness for I4 and the CE, it would be better for expert ratings to be systematically incorporated into the development procedure. The practical importance of each item can also be graded on a Likert scale, and then the evaluation results through our institutional model are likely to be considered meaningful if the overall average of the ratings for the items is sufficiently high. Such an approach would help us find out an item's readiness contribution as well as validate the readiness item's practical meaningfulness.

Then, the level of detail and mode of representation may be adjusted to the practical needs of stakeholders. It would be desirable to transform the institutional model into an easy-to-use assessment tool that can be used by countries to self-assess their readiness for I4 and the CE. For that purpose, it is worthwhile integrating the questionnaire into a webpage, receiving responses from as many experts as possible, processing those responses in an automated manner, calculating the results systematically, and summarising the final outcomes in a compact report. The first page could contain the readiness dashboard depicting all readiness levels in six dimensions at a glance. The concise dashboard could be followed by definitions of the readiness levels, determinations for each item, and the overall characteristics.

In the end, countries can be categorised based on their readiness levels to help stakeholders better understand the evaluation results. Such a grouping also makes it easier to identify specific action items with regards to the progress toward I4 and the CE. If countries have a low score smaller than 1.33, then they may be labelled as 'beginners'. This group represents countries that have done either nothing or very little to deal with I4 and the CE. When countries are in the middle with a score between 1.33 and 2.67, then they may be labelled as 'learners' as those countries that have already taken some steps in implementing I4 and the CE. Likewise, if countries have a score higher than 2.67, then they can be labelled as 'leaders'. This benchmark group include countries that are already well on their way to implementing I4 and the CE.

4. How Can the Republic of Korea Improve?

From the case study on Korea above, the following issues can be discussed to analyse the country's situation and make some remedies to improve its institutional efficiency and innovation efficiency. Table 5.9 evaluates Korea's situation by looking at what the country has done and strategies for future improvements.

Table 5.9: The Republic of Korea's Situation

Past Performance	Future Strategies
• Economic growth - Government leadership - Corporate entrepreneurship - People's capacity building • ICT infrastructure and industry technologies - Electronics, auto, steel - Internet infrastructure, R&D investment	• Transparent leadership - Decrease in political corruption - Responsibility of 'chaebol' owners • Proactiveness of sustainability - Reduction in greenhouse gas emissions - Resource circularity - Environmental protection

ICT = information and communications technology, R&D = research and development.
Source: Authors.

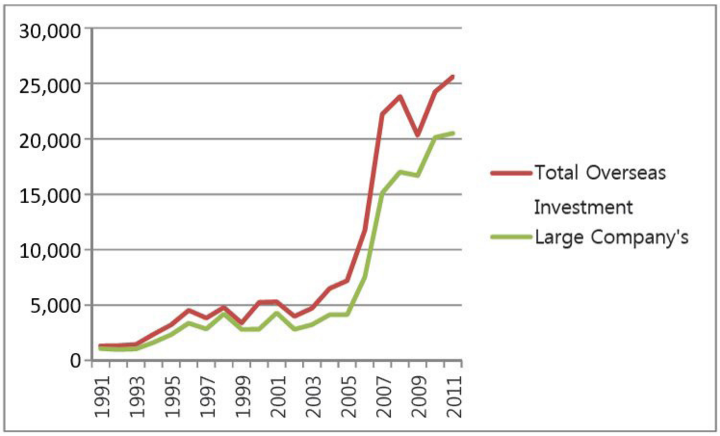
4.1. Competitiveness of Private Firms

Innovative performance for I4 or the CE is mostly made by private firms. The leading firms in Korea are competitive in global markets, and these firms can lead the transformation to a digital and sustainable economy. Most of the private firms in Korea are called 'chaebol', which is a large business group in Korea. Samsung, Hyundai, and LG are the top Korean chaebols. These chaebols played a major role in developing the rapid Korean economy from the 1970s and after the 1990s, they have obtained competitive power even in global markets. To be a rich economy, Korea must have several firms that have excellent competitiveness in global markets. Most of the competitive multinational corporations are from developed countries such as the US, EU, or Japan.

The success of the Korean economy during the last five decades originates from the competitive evolution of Korean chaebols. As shown in the case analysis of Korea above, the scores in the economic environment are relatively high. This can be explained by the successful economic development of Korea from the combination of the leadership of the government, the entrepreneurship of firms, and the sincerity of ordinary people (Cho and Kim, 2007). The economic achievement of Korea was enormous and large Korean chaebols have evolved into competitive global players. As a result, the openness and globalisation of the Korean economy are quite good. The performance in industry and technology development has been remarkable. The level of R&D is high, even compared with other advanced economies (Kim, 2017). The electronics and auto industries are very competitive globally, and the ICT infrastructure in Korea is highly developed.

The most successful Korean chaebols are Samsung, Hyundai, and LG. Samsung Electronics, which is the largest firm in Korea, is leading the global market for televisions, semiconductors, and smartphones. Hyundai Motor Company is one of the top five automakers in the world. LG Electronics is also a global leader in home electronics. POSCO, a steel manufacturer, is one of the largest steel companies in the world. These Korean companies grew as imitators of Japanese companies in the 1970s and 1980s, but now they have stronger competitive powers than their Japanese counterparts. Under the last President Park, the Korean government and firms tried to transform themselves from imitators to creators. It is expected that many innovative performances in global markets can be created by these Korean large companies. As shown in Figure 5.6, most of the overseas investment and exports in Korea are performed by the large corporations.

Figure 5.6: Overseas Investment of Korean Companies (US$'0,000)



Source: Moon (2017).

4.2. Leadership Crisis

Efficient and transparent leadership is required for both governments and corporations. Recently, corporate governance is one of the important areas in management research (Moon, 2017). The stewardship of top leaders can determine the competitiveness of nations or corporations. In Korea, the lack of successful leadership is recognised by both the government and firms. Since the 1990s, Korea has achieved political democracy and has had six presidents from either the republican or the democratic parties. The current president, Moon, is the sixth leader, and the last five presidents were not free from corruption scandals. In particular, former President Park was impeached due to her corruption scandal in 2017. It is usually said in Korea that the economy is at a high level, but the country's politics are at a low level. In chaebols, the agency problems of the controlling shareholders are discussed as governance issues (Cho and Kim, 2007; Moon, 2017). Usually, agency problems in US firms are recognised between CEOs and shareholders, but in Korean firms the agency problems come from selfish decision-making by the controlling shareholders with the sacrifice of the minority shareholders' interests.

After completing rapid economic growth during the last 40 years, Korea is facing the issue of the fair and transparent distribution of wealth. Political and economic leaders are pressed to achieve both continuous economic growth and the fair distribution of the fruits from economic development. The current President Moon, who is from the Democratic Party, tries to lead the economy by distributing wealth more fairly and widely and increasing the income of the ordinary people. He believes that the increased income of the ordinary people will increase consumption in the market and result in the increased production of companies. Currently, the international politics surrounding Korea are very complex. High uncertainty exists from the threat of North Korea's nuclear weapons and its recent moves to talk with Korea and the US on the rapid economic development of China and the trade war between the US and China. Except for Japan, Korea is the only Asian country that has achieved both economic prosperity and political democracy. Successful leadership in government and private corporations is required to upgrade Korea to a new advanced economy with GDP per capita higher than US$30,000.

4.3. ICT Infrastructure and Resource Circularity

The overall ICT infrastructure and the performance in resource circularity in Korea are quite good. ITU News reported about the achievement of Korea in the ICT sector as follows (ITU News, 2018):

> 'Korea has a well-earned reputation as a global information and communication technology (ICT) leader, and it's not hard to see why. Home to world-leading electronics and ICT companies such as Samsung, LG, SK, and KT – Korea's economic growth is digitally delivered. The Republic of Korea has some of the world's fastest Internet speeds. It's in the race to be first with 5G. And it leads the world in Internet penetration rates, with nearly every household online. These are some of the reasons why the Republic of Korea has ranked in the top three of ITU's Global Information and Communication Technology (ICT) Development Index (IDI) in each of the past 5 years. In addition, the country reigns supreme in the Bloomberg Index of 'Most Innovative Economies'.

It is also indicated that Korea's ICT infrastructure remains the best in the world. As a result of a comprehensive assessment conducted by the International Telecommunication Union (ITU) on the ICT infrastructure level, including the ICT access, use, and skills of 167 countries around the world, Korea reclaimed the first place in 2015, after heading the list in both 2012 and 2013 and stepping down by one place in 2014 (Table 5.10).

Table 5.10: The Republic of Korea's Rankings in the ICT Development Index, 2013–2015

	2013	2014	2015
	Rank	Rank	Rank
ICT Development Index (Overall)	1	2	1
ICT Access	11	8	9
· Fixed-telephone subscriptions per 100 inhabitants	1	3	4
· Mobile-cellular telephone subscriptions per 100 inhabitants	70	79	71

	2013	2014	2015
	Rank	Rank	Rank
· International Internet bandwidth (bit/s) per Internet user	63	82	71
· Percentage of households with a computer	21	28	37
· Percentage of households with Internet access	1	1	1
ICT Use	2	3	4
· Internet users per 100 inhabitants	15	17	15
· Fixed broadband Internet subscriptions per 100 inhabitants	5	6	6
· Wireless broadband subscriptions per 100 inhabitants	5	9	13
ICT Skills	1	2	2
· Gross enrolment: Secondary	48	51	54
· Gross enrolment: Tertiary	1	2	2
· Adult literacy rate	15	20	22

ICT = information and communications technology.
Note: The total number of countries surveyed was 157 in 2013, 166 in 2014, and 167 in 2015.
Source: ITU (2017).

Korea shows excellent performance in resource circularity, too. As shown in Table 5.11, Germany, Korea, Slovenia, and Austria are the world leaders in recycling, according to the World Economic Forum (2018). In all of these countries, less than half of the total waste output is sent to landfills. In comparison, the US recycles only 35% of its waste.

Table 5.11: Recycling Rates in the World

Country	Recycling Rate (%)
Germany	67
Republic of Korea	59
Austria	58
Slovenia	58
Belgium	55
Australia	41
United Kingdom	43
Italy	41

Country	Recycling Rate (%)
France	38
United States	34
Canada	24
Japan	20
Israel	19
Mexico	5

Source: World Economic Forum (2018).

4.4. Recognition of the Circular Economy

Today, sustainable management is required for most corporations. In addition to profit maximisation, corporations should perform ethical management, environmental protection, reduce GHG emissions, and resource circularity. The circular economy is part of a sustainable economy. The efforts to realise the circular economy can be a cost burden on corporations, at least on a short-term basis. Achieving a circular economy is a duty pressed on private companies and consumers. The role of governments is critical to make corporations and consumers respond positively and proactively toward the issue of circularity.

In Korea, the government has developed some regulations and processes to realise the circular economy and, as result, its performance in resource recycling is outstanding, as shown in Table 5.11. Large firms have made significant efforts to support the government's policies for the circular economy. For example, POSCO, a large Korean steel company, has been doing quite well in this area. POSCO is trying to achieve low-carbon management (Kim, 2018). In the annual report of POSCO, low-carbon management consists of four areas: green steel, green business, green life, and green partnership. In green steel, POSCO reduces GHG emissions by recycling the by-products from the steel manufacturing process. The proactiveness of Korea towards the circular economy is led by the government and large corporations. The commitment of SMEs and the increased recognition of ordinary people should be added, too.

- Green steel: This addresses how POSCO makes attempts to reduce carbon emissions in the steel production process. An example of these activities is improving energy efficiency.

- Green business: The necessity for climate change responses and carbon emissions reduction may be a burden on a firm's costs, but new business opportunities can be made through strategic reactions.

- Green life: As a GHG emission reduction project, POSCO's carbon-neutral programme was launched in 2009 with support from diverse societal groups, such as students, civic organisations, and housewives. If participants propose new ideas to offset carbon emissions, they can apply for programme sponsorship that chooses the most doable suggestion.

- Green partnership: Since 2003, POSCO has been participating in the Dow Jones Sustainability Indexes and the Carbon Disclosure Project and has disclosed activities related with climate change and CO2 emissions. By doing so, POSCO received positive evaluations from external institutions.

5. What Are the Lessons for ASEAN?

This chapter intends to measure the institutional efficiency and innovation efficiency related with the successful introduction of I4 and the CE. Various cross-cutting factors are developed that influence institutional efficiency and innovation efficiency. To create better environments for pursuing I4 and the CE, the cross-cutting factors are developed in two dimensions: country-level factors and corporate-level factors. The country-level factors are political commitment and transparency, economic development and globalisation, and technology development in major industries. The corporate-level factors are the innovative leadership of the top management, major stakeholders as the business environment, and corporate culture and resources. While all of these factors should be seriously considered in ASEAN, the following four issues are addressed to give policy implications for ASEAN Member States.

5.1. Strong Leadership of Governments

Successful leadership by political leaders is critical. The strong commitment of leaders is necessary to pursue digital transformation and achieve a sustainable society nationwide. In Korea, the past government from 2008–2013 showed a strong commitment to green growth policy and created the national green growth committee to lead these policies in the country. The strong interest of the president pressed many firms to reduce their carbon emission amounts through their manufacturing and management processes. The recent economic recovery of Japan or the US seems to be the result of the various policies of Prime Minister Abe or President Trump. The political leaders of ASEAN should study how they can perform innovations in their countries by introducing I4 and the CE.

Generally, the degree of democracy and transparency in ASEAN countries seems to be low. Singapore, the richest ASEAN Member State, is also limited in its political democracy. Democracy can guarantee the freedom of economic activities. For example, in Korea, the large firms have become competitive in global markets, but their close link with Korean politicians is still one of the serious problems to be solved in the future.

- A committee working for I4 and the CE that reports to the president directly can be set up.
- Governments intervene to measure how well firms realise I4 and the CE and provide the rewards to some firms based on the evaluation results.

5.2. Competitiveness of Domestic Firms

Porter (1990) asserted that the wealth of a nation is created when it has several competitive industries. To have competitive industries, good corporations are critically required to create successful industries. In many developing countries, there are few competitive domestic firms. The most famous firms in the world were born in North America, the EU, or Japan. Korea which is an example of economic success from a poor country 60 years ago, has borne several top-level corporations, such as Samsung, Hyundai, and LG. China, which has enjoyed very rapid economic evolution, has produced good companies such as Alibaba, Huawei, and Xiaomi. The economies of most ASEAN Member States are dependent upon foreign corporations for their domestic production and exports. For example, in Viet Nam, Samsung Electronics, a Korean multinational, exports about 25% of the total Vietnamese export amount. In Dalat of Viet Nam, where the weather is very adequate for flower production, only Dutch and Japanese firms export the flowers of the region.

- Governments require multinationals in their markets to raise or be linked with domestic SMEs.
- Attractive incentives are given to domestic firms showing high growth potential.

5.3. Infrastructure Investment for Digital Transformation

For digital transformation, investment in ICT infrastructure is important. The investments should be made by both governments and private organisations. Efficient mechanisms for public–private partnerships for improvement in ICT infrastructure need to be created in ASEAN Member States. International cooperation can be helpful, too. As shown in ITU (2017), the degree of overall ICT development in ASEAN area is comparably low in the world.

Efforts to improve ICT development have been made in ASEAN Member States, and some positive results have been obtained (ASEAN, 2015). For example, the ASEAN ICT Masterplan (AIM) 2015 launched various investments in the following areas:

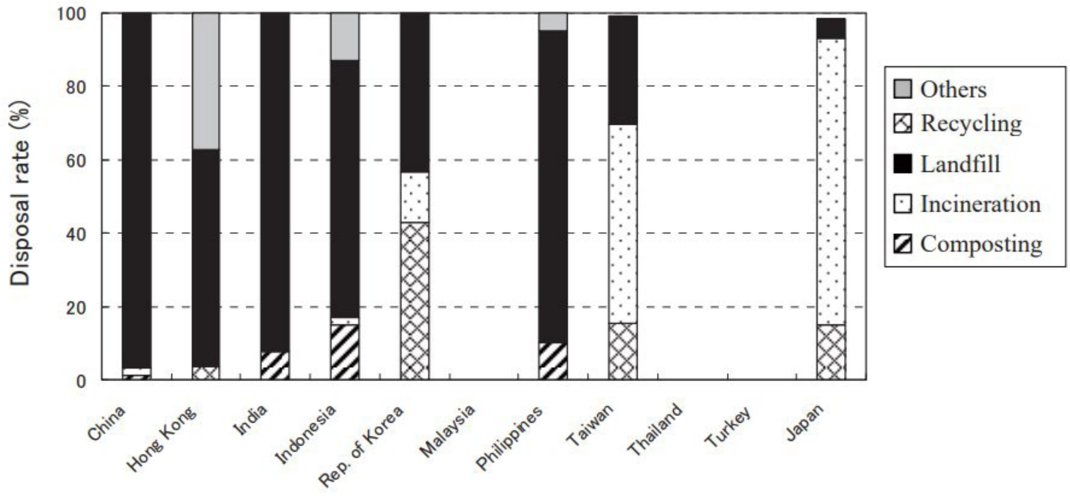
- Economic transformation
- People engagement and empowerment
- Innovation
- Infrastructure development
- Human capital development
- Bridging the digital divide

- Firms investing in ICT infrastructure development are provided with tax reductions.
- Firms are evaluated on their degree of digital transformation, and some incentives can be given based on their performance.

5.4. Proactiveness for the Circular Economy

Achieving the circular economy brings about cost burdens for governments and corporations, at least in the short term. Therefore, a proactive attitude towards sustainability is important. Generally, rich countries tend to lead sustainability policies. In responding to the threat from climate change and reducing carbon emission amounts, the EU is the most advanced region. In contrast, the US seems to be reluctant to deal with the climate change issue and has exited from the Paris Agreement. Figure 5.7 shows the structure of waste disposal in Asian countries. It is evident that the richer the country, the higher the recycling ratio. In developing nations, economic development may take priority over sustainability policies. They may not own the sufficient resources to be invested in sustainability areas. Leaders in developing nations should be able to attain economic goals through satisfying the sustainability needs.

Figure 5.7: Comparison of Waste Disposal Amongst Countries



Source: Terazono et al. (2005).

- Corporate cases on how investment in resource circularity can lead to better firm performance are developed and distributed nationwide.
- Education programmes about the circular economy and its link with the national economy and firm competitiveness are prepared for both corporate managers and ordinary citizens.

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Appendix 1: A Framework for Assessing Industry 4.0 Readiness for the Circular Economy

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Country-level Factor 1: Politics and Regulations					
Presidential commitment	No interest.	Comment sometimes, not a critical agenda.	Stress the importance, but not offer various programmes.	Present various plans, but they are not feasible.	Present various plans and programmes. They are quite realistic and feasible.
Democracy and transparency	Corruption and unfair competition is severe.	Trying to reduce corruption. In reality, proper adaption to corruption is necessary for business.	Recognised that some informal factors affect competition.	Not a serious problem and only sometimes found.	Competition is transparent. Corruption related with business operations is very low.
Business regulation	Many experts advise that regulation reform is necessary. Serious hurdle to private firms.	Many complaints are made from business people.	Sometimes hear criticisms of regulatory inefficiency.	Hardly feel regulation is an obstacle to business.	Laws and regulations are regarded to be efficient for business.
Security and stability	Very unstable. Stable business operations are impossible.	Possibility of war, coup d'état, strikes, or demonstrations.	Some factors cause an unstable society. Some people worry about an unstable society happening.	Security threats can exist but they are not significant.	No security problems are felt.
Country-level Factor 2 : Economic Environment					
Economic development	Gross domestic product (GDP) per capita < US$1,000	US$1,000 < GDP per capita < US$5,000	US$5,000 < GDP per capita < US$10,000	US$10,000 < GDP per capita < US$30,000	GDP per capita > US$30,000
Globalisation and openness	Interest in global standards is minimal.	Attempts to accept global	Institutional transition is active. Trying to keep global standards.	Most global standards are relatively common.	Regarded to be a globally leading country.
Performance of Multi-national corporations (MNCs)	Few domestic MNCs and only a few foreign MNCs exist.	Few domestic MNCs. Many foreign MNCs invest in the domestic market	Start to produce successful MNCs. They begin to open foreign factories and subsidiaries.	Some MNCs are globally competitive. Most MNCs have many sub-activities that operate overseas.	Have many globally leading MNCs.

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Consumer awareness	Most people do not have knowledge about Industry 4.0 (I4) and the circular economy (CE).	People only in the leading class understand about I4 and the CE.	Most people have heard about I4 and the CE but are not interested significantly	Many people recognise the importance of I4 and the CE, but hardly buy the related products or services.	Most consumers want to buy products or services related with I4 or the CE
Country-level Factor 3: Industry and Technology					
ICT infrastructure (smartphone penetration rate)	Smartphone penetration rate (SPR) < 50%	50% < SPR	70% < SPR	80% < SPR	90% < SPR
R&D effort (R&D amount/GDP)	Under global top 70	Global top 70	Global top 50	Global top 30	Global top 10
Support for start-ups and entrepreneurs	No stress on or interest in start-ups.	It is heard that start-ups are necessary for the economy, but the policies are not very strong.	Government stresses the importance of start-ups, but there are not many successful start-ups.	Start-ups are active in many areas. Support programmes from the government are found.	Many start-ups were globally successful. Start-ups function in a critical role in the economy.
Strength of manufacturing industry	There is no ability to develop own manufacturing industries. Most industries depend on foreign firms.	Many foreign MNCs invested in the domestic markets. Domestic firms also exist, but the capability is weak.	Most manufacturing firms are dominant in the domestic markets, but not competitive in world markets.	Domestic manufacturing firms are trying to produce and sell in foreign markets. The global capability is still insufficient.	Several manufacturing industries are competitive in the world market.
Corporate-level Factor 1: Leadership					
Managerial entrenchment (agency problems)	Governance reform is strongly required by stakeholders.	Agreed that governance reform is necessary. Protests against the management are seen.	Regarded as a critical problem to decrease corporate competitiveness.	Agency problems or entrenchment exist but are not considered to be serious problems.	Agency problems of management are negligible.
Global leadership	Little experience in foreign environments.	Most of past career was made in domestic environments.	Familiar to foreign market, but lacks om global competence, including English.	Have some limitations as a global leader. Can lead foreign subsidiary with the help of local people.	Managers have global talent and vison. Can work with any foreign employees.
CEO innovativeness	Dislike risk-taking situations. Avoid any projects with high uncertainty.	Tend to be risk-averse. Pursue stable management style.	Requires risk-taking behaviour from employees.	Has experience of innovative performance during their past career.	CEO has led the introduction of new products or business models.

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Corporate-level Factor 1: Leadership					
Corporate vision	Vision is not presented or is neither clear nor realistic.	Many employees have strong concerns or complain about t hevision.	Current vision looks somewhat ambiguous. Is not understood or supported by employees.	Clear vision is offered, but needs to persuade employees.	Clear and feasible vision is offered. Have most employees motivated by the vision.
Corporate-level Factor 2: Business Environment					
Industry condition	Industry is in declining stage. Exiting from the industry should be considered.	Few technological innovations. Industry is mature.	Marginal innovations are happening.	Technology change is critical. Start-ups and M&A are active for the development of new technologies.	Innovations in products and business models are frequent.
Competition and rivalry	Monopoly by an inefficient firm.	Monopoly by an efficient firm.	There are many players in the market, but competitive is not fierce.	Several firms compete. They are sensitive to others' strategies and performances.	Competitive pressure is strong. Competition amongst many firms is fair. Competition occurs globally.
Stakeholder pressure	No interest from stakeholders.	I4 and the CE are stressed in society. Individual firms are not pressed to adopt them.	Pressure is strong, but the corporate response is superficial. Only for advertising effect.	Pressures from stakeholders are strong. Management is trying to follow.	Strong pressure from diverse stakeholders for I4 and the CE. Right response is made and also monitored.
Consumer expectation	Little knowledge about I4 and CE, or the necessity of them in society is small.	Heard about I4 and the CE, but do not understand them in detail.	Understand the importance of I4 and the CE. Not interested in the effective responses of firms.	Understood that I4 and the CE should be reflected in corporate management process.	Eager to purchase products satisfying I4 and the CE.

Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Corporate-level Factor 3: Resources					
Corporate culture and creativity	Technology level is very low. Independent management without the help of foreign firms is hard.	Survive only in domestic or regional market. Traditional management system is dominant.	Transition from traditional culture to creative culture is discussed.	Is successful in catching up with the products and technology of leading firms and compete well against global leaders. Is changing to creative culture.	Introduced innovations in products, production, or other management processes. A leader in the global market.
R&D input	R&D/sales < 5%	R&D/sales > 5%	R&D/sales >10%	R&D/sales >15%	R&D/sales > 20%
Experts	There are no experts in I4 or the CE.	The ability of experts lags behind that of the experts in the leading firms.	Experts understand the top-level technologies, but they can only introduce and imitate them.	The ability of the experts is in the top level in the world, but they have not produced many innovations in the world market.	Experts in I4 and the CE are at the top level compared with any experts in the world. They lead innovations in the world market.
Financial availability	Is in significant difficulty in financial availability.	Has high level of debt and cannot invest in long-term innovation, such as I4 and the CE.	Only limited amount of funds can be invested in innovative projects.	Recognised as a sound firm in its financial availability.	Financial availability is not concern a at all for the development of I4 and the CE.

CHAPTER 6

Assessing the Critical Role of Information and Communications Technology in Improving Industry 4.0 Readiness for the Circular Economy

Premaratne Samaranayake

1. Introduction

TIn recent times, Industry 4.0 (I4), referred to as 'the fourth industrial revolution characterised by a paradigm shift from centrally controlled to decentralised production processes' (Hermann, Pentek, and Otto, 2016, p.3929), has attracted significant attention across the globe, including from emerging economies, from the government level to practitioners and researchers (Hermann, Pentek, and Otto, 2016; Ramanathan, 2016; Liao et al., 2017). An investigation into various aspects of I4 includes studies on the characterisation of I4 through a systematic literature review (Liao et al., 2017); implementation and/or transition to I4 with a range of foci, mainly at the firm level (Hermann, Pentek, and Otto, 2015; Weyer et al., 2015; Ramanathan, 2016; and Samaranayake, Ramanathan, and Laosirihongthong, 2017); comprehensive reviews of current practices and future directions (Wang, Törngren, and Onori, 2015; Qin, Liu, and Grosvenor, 2016; Hofmann and Rusch, 2017; Lu, 2017; Liao et al., 2017; Pagoropoulos, Pigosso, and McAloone, 2017; Moeuf et al., 2018); and, more recently, on Industry 4.0 readiness (I4R) at the firm level, focusing on the circular economy (CE) (Ramanathan, 2016; Stock and Seliger, 2016; Waibel et al., 2017; Trentesaux et al., 2016).

Many studies on the implementation and/or transition to I4 have reported on different perspectives of practices and outcomes, including the drivers, barriers, initiatives, and success factors (Wang Törngren, and Onori, 2015; Liao et al., 2017) as well as implications for the industry (Hofmann and Rusch, 2017). It is evident from these studies that the main focus has been on technology, in particular the characterisation of the key components of I4, current industry practices, and future directions (Hofmann and Rusch, 2017; Liao et al., 2017). With increasing interest in I4 and the focus on CE in manufacturing broadly in recent times by both developing and emerging economies, many research initiatives have investigated how the principles of CE can be deployed by I4 (de Sousa Jabbour et al., 2018) and how I4 can enable CE at the firm level (Ramanathan, 2018). This brings us to the point of departure from the literature on the current level of I4R for CE at the firm level, with an indication of limited studies focusing on the sector and industry-specific levels.

While implementation/transition to I4 at the firm level has been studied and reported, with an emphasis on CE principles, the importance of understanding the current level of maturity in the industry context is emphasised (Bibby and Dehe, 2018). The need for assessing I4R for CE from information and communications technology (ICT) perspectives at the firm and sector levels is also emphasised due to the increasing level of industry-specific supply chain practices focusing on circular economies and the close relationships between I4 technology components and ICT systems. Thus, this chapter extends the current knowledge of I4 practices at the firm level by exploring I4R for CE focusing on the firm and industry/sector levels, emphasising the critical role of ICT systems as one of the determinants of assessing I4R (Ramanathan 2018).

Therefore, the key objectives of this study are:

(i) Provide guidelines for assessing the critical role of ICT systems in improving I4R, focusing on both firm- and sector-level applications of ICT systems.
(ii) Identify and emphasise the measurable parameters of I4R for CE from the perspective of the critical role of ICT.

(iii) Describe trends for shaping the future manufacturing landscape and provide some guidelines on how Association of Southeast Asian Nations (ASEAN) policymakers and businesses can prepare for the change, using the analysis associated with objectives (i) and (ii) above.

Guidelines for assessing the critical role of ICT systems in improving I4R for CE, from ICT systems perspective at the firm and industry/sector levels to the measures and parameters of the assessment framework, are explored from a theoretical background concerning the key concepts of I4, CE, and industry sectors, as well as the characterisation of ICT systems, with a particular focus on firm- and industry-specific ICT systems and their relation to measuring I4R for CE.

This chapter proposes a framework for the assessment of I4R for CE from the ICT systems perspective. The framework is based on the key principles of I4 and CE, an overview of industry sectors from the perspective of I4, and the key requirements for I4R, focusing on CE across firms and industry/sector levels. This is followed by trends for shaping the manufacturing landscape, implications for policy/decision makers, and examining how businesses can prepare for the potential change. In addition, this chapter presents parameters and measures as part of the framework for assessing the critical role of ICT in improving I4R for CE at the firm and industry/sector levels and reports on how the assessment framework can be developed and guided by the principles of both themes (I4 and CE). It is expected that the complex dynamics of I4 and CE will lead to the need for careful investigation on how both work together at the firm, industry/sector, and national levels.

2. Research Background

2.1. Industry 4.0 and the Circular Economy

There has been a substantial amount of academic research and industry-driven exploratory/investigatory work reported in the literature on I4 from various perspectives since its inception in 2011 (Hermann, Pentek, and Otto, 2016). These studies cover a range of topics, including a comprehensive literature review on current practices and potential future directions (Lu, 2017; Liao et al., 2017), the current status and latest developments of various systems of I4 (Wang et al., 2015), and implementation perspectives from frameworks and I4 industry-specific applications (Qin, Liu, and Grosvenor, 2016; Stojkić, Veža, and Bošnjak, 2016; Dada and Thiesse, 2008). In addition, studies have investigated other aspects, including technologies and key components (Kang et al., 2016; Zhong et al., 2017; Hofmann and Rusch, 2017); characteristics, including interoperability (Lu, 2017) and integration (Kagermann, Wahlster, and Helbig, 2013; Chen, 2017); the application of technologies with increased performance (Trentesaux, Borangiu, and Thomaset, 2016); communication with customers in real time (Shrouf et al., 2014); and the relationships with sustainability and CE (de Sousa Jabbour et al., 2018; Fisher et al., 2018).

Many research studies have identified the key components and technologies of I4, including cyber-physical systems (CPS), cloud computing, Internet of Things (IoT), additive manufacturing, and Internet of Services (IoS) (Hermann, Pentek, and Otto, 2016; Hofmann and Rusch, 2013; de Sousa Jabbour et al., 2018). These key components and technologies have been studied from a range of perspectives, including the CPS of integrated computer and ICT systems as the basis for developing cyber-physical production systems (CPPS) leading to I4 (Monostori et al., 2016) and the advancement of CPS in manufacturing, reflecting on the increasing openness, autonomy, distributed control, adaptability, and degree of integration through a number of examples (Wang et al., 2015). Furthermore, IoT as a key component has been used in various ways for the advancement of manufacturing in recent times, in particular I4 and smart factories as part of the IoT and IoS (Kang et al., 2016) and smart production systems integrating the virtual and physical worlds on IoT platforms (Waibel et al., 2017).

Amongst the latest developments and future directions of I4 reported in recent times, I4 for CE has attracted increased attention from both academics and industry practitioners. This is from a range of research investigations on various aspects, including sustainable development (McDowall et al., 2017), regulations to implement CE principles to encourage organisations to pursue CE principles (Winans, Kendall, and Deng, 2017), and very recently on a roadmap for sustainable operations, supported by I4 (de Sousa Jabbour et al., 2018).

Recently, de Sousa Jabbour et al. (2018), using a roadmap to enhance the application of CE principles in organisations by means of I4 approaches, presented a matrix of relationships between CE, I4, and sustainable operations management and highlight the connections between the individual steps of CE principles (MacArthur, Zumwinkel, and Stuchtey, 2015) using components of I4 across the product life cycle.

Studies on concepts and principles of CE are emphasising sustainability in different forms, including sustainable production and consumption (Fahimnia et al., 2017), the sustainable use of natural resources (McDowall et al., 2017), maximising the circularity of resources and energy within production systems (Ghisellini, Cialani, and Ulgiati, 2016), the extension of a product's lifespan through a hierarchy of circularity strategies (Zhao and Zhu, 2017), and transforming waste into resources for other production systems (Bocken et al., 2017; Murray, Skene, and Haynes, 2017).

When considering CE principles for the purpose of I4, MacArthur (2015) outlined three principles to govern the CE cycles and proposes six business actions, labelled the 'ReSOLVE' framework, to guide organisations through implementing the principles of CE (de Sousa Jabbour et al., 2018). The principles and the framework for implementing the CE principles proposed by MacArthur, Zumwinkel and Stuchtey (2015) are adopted in this research as the basis for identifying the critical role of ICT systems in implementing I4 for CE. One of the limitations of current I4R assessment frameworks is that assessment is focused mainly at the firm level and not on the sector/industry levels. In order to develop a framework for assessing I4R for CE at the firm and industry/sector levels from the perspective of ICT, we next consider and briefly outline the theoretical background regarding industries/sectors and the associated ICT systems.

2.2. Industries/Sectors and ICT Systems at the Firm and Industry/Sector Levels

All three sectors (primary, secondary, and tertiary) consist of various industries and are an integral part of any economy, producing goods and services for local and global consumption. Some industries can be considered as a combination of more than two sectors, with possible crossovers depending on the nature of production and the products and services involved. Each sector is supported by a range of processes

and systems. In this case, key processes associated with any industry sector can be categorised into two distinct areas: IT-based processes and manufacturing processes. ICT-based and manufacturing processes are interrelated and connected through the respective systems and communication technologies. From the system perspective, IT-based and manufacturing processes are facilitated through ICT systems, such as enterprise resource planning (ERP) systems (also called enterprise systems) and manufacturing systems, respectively. From the operational perspective, enterprise systems within broader ICT systems play a significant role in any industry, given ICT systems are critical resources for any organisation.
It can be noted from the classification of the industry sector from the ICT systems perspective, in particular enterprise systems (SAP AG, 2018), that organisations can have very unique requirements of ICT systems, depending on various factors, including the nature of the products and services they produce and the type of sector and associated industry that they belong to. Furthermore, it is evident from the industry classification by ICT systems that enterprise systems have evolved into providing not just ICT systems supporting ICT-based processes at the firm level, but also ICT systems with industry-specific solutions for a range of industries (SAP AG, 2018).

Since ICT systems for functional applications at the firm and industry/sector levels play a significant role in providing integrated ICT-based processes and operational data and information within the organisation and organisations in the supply chain, assessing the critical role of ICT in improving I4R for CE is guided by measures and parameters associated with assessment criteria within ICT systems and the data management determinants of the proposed framework (Ramanathan, 2018).

In the context of the ICT systems perspective, enterprise systems provide process and data integration at the firm level (e.g. application modules of enterprise systems, system access through a firm-level intranet, and electronic data interchange) and at the industry/sector level (e.g. industry-specific enterprise solutions, supported by other applications, such as supplier relationship management (SRM), customer relationship management (CRM) and strategic enterprise management (SEM) for information-sharing with suppliers, customers, and stakeholders (Shehab et al., 2004).

While various systems at the firm level facilitate connections amongst organisations in the supply chain, it is also necessary to assess the critical role of ICT systems for improving I4R for CE at the industry/sector level. In this case, parameters and measures for the assessment of the critical role of ICT in improving I4R for CE are considered at both the firm and industry/sector levels, emphasising how the measures at both levels are defined and evaluated, and how the level of readiness at the firm level can influence readiness at the sector/industry level.

3. Methodology

The methodology for assessing the critical role of ICT systems in improving I4R for CE consists of three stages: (i) identifying the critical role of ICT systems in improving I4 for CE; (ii) developing a framework for assessing the critical role of ICT systems based on the broader framework (Ramanathan, 2018) by incorporating both firm and sector/industry level parameters and measures; and (iii) illustrating the proposed framework by incorporating a measurement tool for assessing the critical role of ICT in improving I4R for CE at the firm and industry/sector levels, taking measures and parameters at the firm and industry/sector levels into consideration.

In order to identify the critical role of ICT in I4R for CE, the relationships amongst I4, CE, and ICT systems are discussed using a comprehensive literature review of contemporary studies. Identification of the critical role of ICT will enable answering the question: What is the role of ICT in I4R and CE? In addition, this research involves the evaluation of current I4 practices in the CE as a way of answering the question: What trends will shape the future manufacturing landscape? This involves identification of the technologies of I4, their adoption in the CE, and the relationships between I4 and CE from the perspective of ICT systems. Furthermore, guidelines for policy/decision makers for the potential change are presented based on the critical role of ICT systems and the framework for assessment at the firm and sector/industry levels, highlighting the required and necessary steps for the transition to I4 through assessment of the current status and plans for the implementation.

4. Critical Role of ICT Systems in Industry 4.0 Readiness for the Circular Economy

Since the main focus of this research is to assess the critical role of ICT systems, ICT systems are outlined and discussed from the applications perspective on their relationships and the overall ICT systems portfolio of any organisation, in particular organisations as part of the supply chain (representation of industries), prior to identifying the critical role of ICT systems in improving the I4R. ICT systems cover a range of applications at the firm and industry/sector levels, including basic office/desktop applications (e.g. email and workflow), enterprise systems for ICT-based process and data integration, communication networks/systems (e.g. mobile networks and wireless networks) and internet technologies. All these systems can be part of an integrated system environment and are supported by various forms of technology infrastructure available at the firm and industry/sector levels (Wollschaeger, Sauter, and Jasperneite, 2017). In this context, the proposed framework for assessment is guided by examples of ICT systems, such as enterprise systems (integration of data, process, and applications across the organisation) and the associated communication technologies for the integration of systems across organisations. For example, Table 6.1 shows some examples of ICT systems (e.g. enterprise systems) that can be used as the basis for assessing I4R for CE.

Table 6.1: Examples of ICT Systems at the Firm and Industry/Sector Levels, Categorised by Key Criteria for Assessing Industry 4.0 Readiness

	Information Sharing	Cloud Storage, IT and Data Security	Operations Data	Virtualisation
Firm Level	Enterprise system with functional modules (Shehab et al., 2004)	Cloud storage of enterprise system data, cloud-based applications for data and IT security	Transaction data in enterprise systems (e.g. purchase orders and sales orders) (SAP AG, 2018)	Server virtualisation using
Sector/Industry Level	Enterprise systems with functional and other modules (e.g. advanced planner and optimiser, CRM, SRM, SEM), industry-specific enterprise system solutions (SAP AG, 2018)	Cloud storage of supply chain data, cloud-based applications for data warehousing, big data and analytics	Transaction data in SRM, CRM, and SEM systems (e.g. consignment orders, vendor-managed inventory status, available to promise data)	Network virtualisation using Internet of Things (IoT)

CRM = customer relationship management, IT = information technology, SEM = strategic enterprise management, SRM = supplier relationship management.
Note: Criteria sourced from Ramanathan (2018).
Source: Author.

A recent review of I4 technologies has categorised various research studies into key research categories, including (i) concepts and perspectives of I4, (ii) CPS-based I4, (iii) interoperability of I4, (iv) key technologies of I4, and (v) applications of I4 (Lu, 2017). It is evident from this review that there are a significant number of research studies on the key technologies and applications of I4 (47 out of 88). Similarly, many other studies have identified key I4 technologies, including four core technologies identified by Kang et al. (2016). Those core technologies include CPS, IoT, cloud manufacturing, and additive manufacturing and are described using the key concepts of I4 and resources associated with each technology (de Sousa Jabbour et al., 2018; Lu, 2017). It is noted from the description of these technologies in different applications that these core technologies are supported by highly developed automation and digitisation processes using communication and information technologies where IoT, CPS, ICT, and enterprise integration are closely related (Lu, 2017; Roblek, Meško, and Krapežet, 2016; Haddara and Elragal, 2015). Since these relationships are common and have been identified in various studies, the critical role of ICT systems in the CE is explored from the perspective of relationships amongst technologies, followed by other studies in key areas including literature reviews (review frameworks) and characteristics.

4.1. Relationships between I4 Key Technologies and ICT Systems

Technologies identified as core for I4 are closely related to a range of processes and resources (Kang et al., 2016). Similarly, processes, supported by data for execution using various resources, are the core of enterprise systems (Shehab et al., 2004). Since enterprise systems are an integral part of ICT systems and play a significant role in both the processes and resources, which also are an integral part of I4 technologies, there is a strong connection with ICT for the effective implementation of I4 technologies. For example, CPS, such as controllers and sensor systems, can be directly linked to production processes through enterprise systems for the automation and monitoring of manufacturing in real time (Monostori et al., 2016). In this case, the critical role that enterprise systems play includes the connection between production processes within enterprise systems as the basis for real-time monitoring of the process using sensors for quality control (e.g. detecting defects through temperature measurement).

Apart from the connection between ICT systems and I4 technologies through processes and resources, some resources are clearly part of ICT systems, such as the internet as a resource of cloud computing (Kang et al., 2016). Information generated from real-time data through some of the resources of I4 technologies is directly supported by ICT systems, such as enterprise systems (Stojkic et al., 2016). Furthermore, the relationships are identified at various levels and means, including ICT systems' connection for implementing I4 technologies (Hermann, Pentek, and Otto, 2016) and the integration of ICT systems with I4 technologies at various levels and across different applications and frameworks for assessing I4R at firm levels (Lu, 2017). The direct relationships between key I4 components and ICT systems are evident from a range of research activities, including critical reviews of I4 components indicating the physical networks of interconnected components, the cyber-networks of intelligent controllers and communication links (Hofmann and Rusch, 2017), and I4's close relation with IoT, CPS, ICT, enterprise architecture (EA), and enterprise integration (EI) (Lu, 2017).

It is also evident from research studies on smart systems prior to the concept of I4 that intelligent manufacturing using smart, safe, and sustainable systems emphasises the importance of the interoperability of smart systems with existing ICT systems, including enterprise systems for ensuring the viability of smart solutions in manufacturing (Alsafi and Vyatkin, 2010). This suggests that ICT systems such as enterprise systems are fundamental for the effective and efficient application of safe, smart, and sustainable systems.

The level of integration/facilitation can be used as the basis for supporting close connections amongst those components/technologies. This is evident from various studies, including on (i) the integration of systems through communication using ICT systems and the storage of large amounts of data using ICT systems (de Sousa Jabbour et al., 2018), (ii) ICT facilitating the integration of emerging technologies in I4 technologies (Zhong et l., 2017), (iii) facilitating smart manufacturing that is supported through the introduction of various ICT technologies and convergence with the existing manufacturing technologies (Kang et al., 2016), (iv) the integration of 10 major technologies for integrated and intelligent manufacturing, in particular three levels of integration (vertical, horizontal, and end-to-end) supported by the respective ICT systems (e.g. enterprise systems for vertical integration at the organisation level) for the effective and efficient use of resources across the supply chain (Chen, 2017), and (v) the need for three levels of integration supported by ICT systems for the realisation of I4 (Kagermann, Wahlster, and Helbig, 2013).

Recently, Lu (2017) identified the main characteristics of I4, which include integrated, adapted, optimised, and interoperable manufacturing processes. Integrated and interoperable manufacturing processes are directly linked with materials-planning and the production (the execution of plans) processes of enterprise systems, supported by ICT systems, such as service-oriented architecture for application distribution, networking for three-tier architecture, and database technology for data integrity and real-time data maintenance (Monostori et al., 2016).
Recently, Zhong et al. (2017) highlighted the significance of ICT in smart and intelligent manufacturing, and outline current applications of ICT that focus on the integration of the technologies of I4, such as IoT and CPS. Some examples of ICT systems associated with I4 technology are presented in Table 6.2.

Table 6.2: Relationships between I4 Principles, Technology, and ICT Systems

Principles of Industry 4.0 (I4)	Description	Examples – I4 Technology, Process(es) and Data	Related ICT Systems	ICT Activity/Process
Integration (Wang et al., 2015), integrated manufacturing (Chen, 2017)	Integration of physical things and devices (materials and machines), with the ability to process a large range of data, information, and knowledge in real time (Chen, 2017)	Prioritisation of production orders through the integration of CPS, physical processes, and objects in production lines (Ahmadov and Helo, 2018; Lee et al., 2015)	Sensors and actuators (Yu et al., 2015). Vertical integration using technologies such as the manufacturing execution system and computer-aided process planning (Chen, 2017)	Gathering and distributing real-time data using sensors and actuators (Yu et al., 2015) Real-time data update using three levels of integration in manufacturing: vertical integration, horizontal integration, and end-to-end integration (Kagermann et al., 2013)
Interoperability	Synthesises software components, application solutions, and business processes (Berre et al., 2007)	Data interoperability: seamless exchange of electronic product, process, and project data is enabled through the interoperable data systems used by collaborating divisions or companies and across design, construction, maintenance, and business systems (Kang et al., 2017)	Data systems of business systems (Kang et al., 2017)	Real-time manufacturing information-capturing through sensor-embedded manufacturing resources and IoT architecture based on real-time manufacturing information integration services (Zhang et al., 2015)

Principles of Industry 4.0 (I4)	Description	Examples – I4 Technology, Process(es) and Data	Related ICT Systems	ICT Activity/Process
Intelligence (Qin et al., 2016; Chen, 2017)	Intelligent manufacturing using intelligent systems, through the power of computing intelligence to enhance the decision-making process in manufacturing (Chen, 2017)	Mobile CPS has emerged with advances in cloud computing and wireless sensing technologies (Chen, 2017)	Current applications of ICT focus on integration with other technologies, such as cloud computing and the IoT, so that the existing information systems can be combined with cutting-edge technologies (Zhong et al., 2017)	Information systems connected with cutting-edge technologies.

CPS = cyber-physical systems, ICT = information and communication technology, IoT = Internet of Things.
Source: Author.

Various literature review-based studies on I4 concepts and technologies and the relationships between I4 components and ICT systems are highlighted using both the outcomes of the literature reviews and the frameworks being used for the literature reviews. In the case of outcome-based studies, from a systematic literature review of digitisation and automation in the context of I4 in the construction industry, Oesterreich and Teuteberg (2016) conceptualised the impact of I4 technologies on the construction value chain. The conceptual model clearly shows both horizontal and vertical integration of key I4 components, including digitisation and virtualisation through various ICT components and vertical integrated organisational processes, supported by ICT systems, such as enterprise systems. From a systematic literature review on the past, present, and future of I4, Liao et al. (2017) identified three necessary integration points for the realisation of I4, for which each integration point is clearly related to the integration of various I4 components with ICT systems.

Recently, Moeuf et al. (2018) used an analytical framework of key I4 technologies as the basis for a scientific literature review of I4. The proposed analytical framework confirms ICT systems to be a key component/technology of I4.

For example, big data and analytics, simulation, virtual reality, and cybersecurity are directly related to ICT systems as vehicles for implementation. In addition, Qin et al. (2016), emphasising integration as a part of the intelligence level of the manufacturing framework for I4, identified three levels of automation, including process automation attributed to an automated labour force and optimised production efficiency using ICT systems.

Similarly, the framework of interoperability of I4 proposed by Lu (2017) indicates relationships between I4 components (CPS and CPPS, and associated smart concepts/objects) and ICT systems. In this case, the interoperability of I4 is referred to as the ability of two systems to understand each other and use the functionality of one another, and represents the capability of two systems exchanging data and sharing information and knowledge (Berre et al., 2007; Lu, 2017).

Most of the studies on relationships from applications of I4 perspectives have emphasised the information flow using ICT systems. Recently, Hofmann and Rusch (2017), using a logistics-oriented I4 application model, indicated that there exist several ICT-based service options beyond the simple logistics services.

Overall, the relationships amongst the I4 components/technologies and ICT systems outlined above suggest that I4 components/technologies are closely connected with ICT systems. In order to conceptualise these relationships, examples are sought through applications. In this context, Table 6.3 shows a spectrum of technologies, with a brief description of each technology and examples of resources and relevant ICT applications as a link between I4 technology and ICT systems. The information provided in Table 6.3 extends an overview of the core technologies reported earlier (Kang et al., 2016).

4.2. Relationships between Industry 4.0, Circular Economy, and ICT Systems

Recently, de Sousa Jabbour et al. (2018) have proposed a pioneering roadmap to enhance the application of CE principles in organisations by means of I4 approaches. Since CE concepts are defined by a range of process steps (MacArthur, Zumwinkel, and Stuchtey, 2015) focusing broadly on resources and materials from different perspectives (e.g. converting waste material into sources of energy, sharing goods and assets amongst individuals, and using digital manufacturing technologies and various reverse logistics related processes) that are directly connected with a range of I4 technologies, the effective utilisation of those resources can be guaranteed by the best practices of those processes, which are usually run by industry-specific enterprise systems.

Table 6.3: Relationships between I4 Technologies and ICT Systems through Applications and Associated Resources

Technology	Description by Contemporary Research	Examples of Resources	Application of Technology Associated with the Resource(s)	ICT System Associated with the Application
Cyber-physical systems	Enables automation, monitoring, and control of processes and objects in real time (Wang et al., 2015). Provides integration and coordination through embedded devices that are networked to sense, monitor, and actuate physical elements in the real world (Monostori et al., 2016).	Controllers and sensor systems (Wang et al., 2015; Yu et al., 2015). Sensors and actuators especially designed for manufacturing execution systems for energy monitoring (Monostori et al., 2016). Sensor-based communication-enabled autonomous systems and wireless sensor networks (Zhong et al., 2017	3D model-driven remote assembly as a cyber-physical system – an off-site operator can manipulate a physical robot instantly via virtual robot control in a cyber-workspace	Web-based virtual environment, connected through the internet
Cloud manufacturing	Virtual portals which create a shared network of manufacturing resources and capabilities offered as services (Yu et al., 2015)	The internet and communication networks	Suppliers and customers interacting in order to sell and buy services, through the design, simulation, manufacture, and assembly of products (Yu et al., 2015)	Communication technology for connecting through the internet
Internet of Things	A computational system which collects and exchanges data acquired from electronic devices (Kang et al., 2016)	Radio-frequency identification (RFID) technology tags, sensors, barcodes, smart phones (Da Xu et al., 2014)	A number of applications as reported in Da Xu et al. (2014)	Communication technology, such as mobile/wi-fi networks. Database technology of ICT systems for managing real-time data (e.g. enterprise system databases)
Additive manufacturing	Represents agile, connected prototyping of parts of products on a large scale, enabling customisation (Holmstrom et al., 2016)	3D printers	Applications as reported in Guo and Leu (2013)	Communication technology for connection, ICT systems for product prototyping and customisation

Source: Author.

The close relationship between I4, CE, and ICT is further evident from a scientific literature analysis indicating I4 technologies have the potential to leverage the adoption of CE concepts by organisations and society becoming more present in our daily lives (Nobre and Tavares, 2017).

It can be noted from the relationships between CE, Industry 4.0 and sustainable operations, presented using a matrix for measuring the overall experience, that the CE concepts identified by the ReSOLVE framework (MacAuthur, Zumwinkel, and Stuchtey, 2015) are directly related to I4 technologies and reverse logistics. Since the ReSOLVE framework is directly associated with key process steps, which are associated with I4 technologies, these connections are required to be maintained dynamically for real-time data/information flows and the effective performance of CE practices. These connections between processes and technologies can be dynamically maintained through ICT systems. For example, goods (materials) and assets (resources) as part of the sharing aspect of CE concepts can be effective when the information associated with these goods and assets is maintained and shared across the organisation. Enterprise systems within broader ICT systems provide best practices for maintaining data with data integrity, real-time data updates, and sharing across an organisation using data, process, and technical integration.

Similar to the relationship between CE, I4, and ICT outlined above, the processes associated with each step are explored and the relationships identified. Thus, all the relationships identified are presented in Table 6.4.

It can be noted from the above discussion on the key technologies, characteristics, and relationships that ICT plays a significant role in I4R for CE from the perspective of implementation at the firm level. It is also evident from a number of studies on the applications of I4 from both the theoretical and practical perspectives that there is a need for the evaluation of I4R at both the firm and industry levels. Thus, the evaluation of I4R for CE at the firm and industry levels is discussed next, with a framework/tool that can be used to measure readiness at the organisation level, as part of extending it to the industry-specific level.

Table 6.4: Relationships between CE Principles, I4 Components/Technologies and ICT Systems

ReSOLVE Process Step (de Sousa Jabbour et al., 2018)	Industry 4.0 Component Associated with the Process Step	Examples	ICT Systems
Regenerate	Internet of Things (IoT) de Sousa Jabbour et al., 2018)	Conversion of organic waste into sources of energy and raw materials for other chains (de Sousa Jabbour et al., 2018)	Sensors and apps connected through communication networks
Share	IoT and cloud computing (de Sousa Jabbour et al., 2017)	Collecting information on consumers' behaviour for organisations to improve both product and service design for better utilisation or replacement of equipment, and increase customers' satisfaction (Rymaszewska, Helo, and Gunasekaran, 2017)	Websites and apps for connecting people and organisations
Optimise	Cyber-physical systems and IoT (de Sousa Jabbour et al. 2018; Nobre and Tavares, 2017)	Environmental compliance by using RFID tags and IoT, leading to the optimisation of resource usage (de Sousa Jabbour et al. 2018). Case of Philips lighting – with the use of technology, lighting needs can be controlled and monitored online and in real time (Nobre and Tavares, 2017)	RFID tags and sensors connected through communication technologies
Loop	Cyber-physical systems, IoT, and cloud computing (de Sousa Jabbour et al., 2018; Nobre and Tavares, 2017)	Circular model for production and consumption of sports shoes, which allowed the implementation of a re-distributed manufacturing system (Siemieniuch and Sinclair, 2015)	Powered by digital technologies, consumers using a mobile phone app and virtual reality (Siemieniuch et al., 2015)
Virtualise	Cloud computing, IoT, and additive manufacturing technologies (de Sousa Jabbour et al., 2018)	Use virtual reality software to help to resolve issues remotely, thus reducing vehicle travel (Heyes et al., 2018)	Virtualisation software, communication technologies, and web applications (Jain and Paul, 2013)
Exchange	Additive manufacturing (3D printing) (Siemieniuch and Sinclair, 2015; Despeisse et al., 2017)	Advanced renewable and sustainable production, in which the process uses as little material as possible (Siemieniuch and Sinclair, 2015; Despeisse et al., 2017). Use of 3D printing for repair and remanufacturing, production of 3D filament, including the commercialisation of filament that contains recycled materials (Despeisse et al., 2017).	Communication technology for additive manufacturing and IT systems for product design and manufacturing process execution

Source: Author.

5. Framework for Assessing the Critical Role of ICT in Improving I4R for CE

The assessment framework involves two stages: (i) the conceptual framework for assessing the critical role of ICT, based on the framework developed by Ramanathan (2018), by extending the determinants of ICT and data management to the industry/sector level, and (ii) Illustration of the assessment framework for assessing I4R using an industry example (case scenario), identifying measures at the core firm and other organisations in the selected industry.

5.1. Development of the framework for assessing I4R at the firm and industry/sector levels

The proposed framework is based on the conceptual framework for assessing the status of I4R in the manufacturing sector (Ramanathan, 2018). It is assumed that the proposed framework can easily be extended to other sectors by incorporating necessary elements for each determinant.

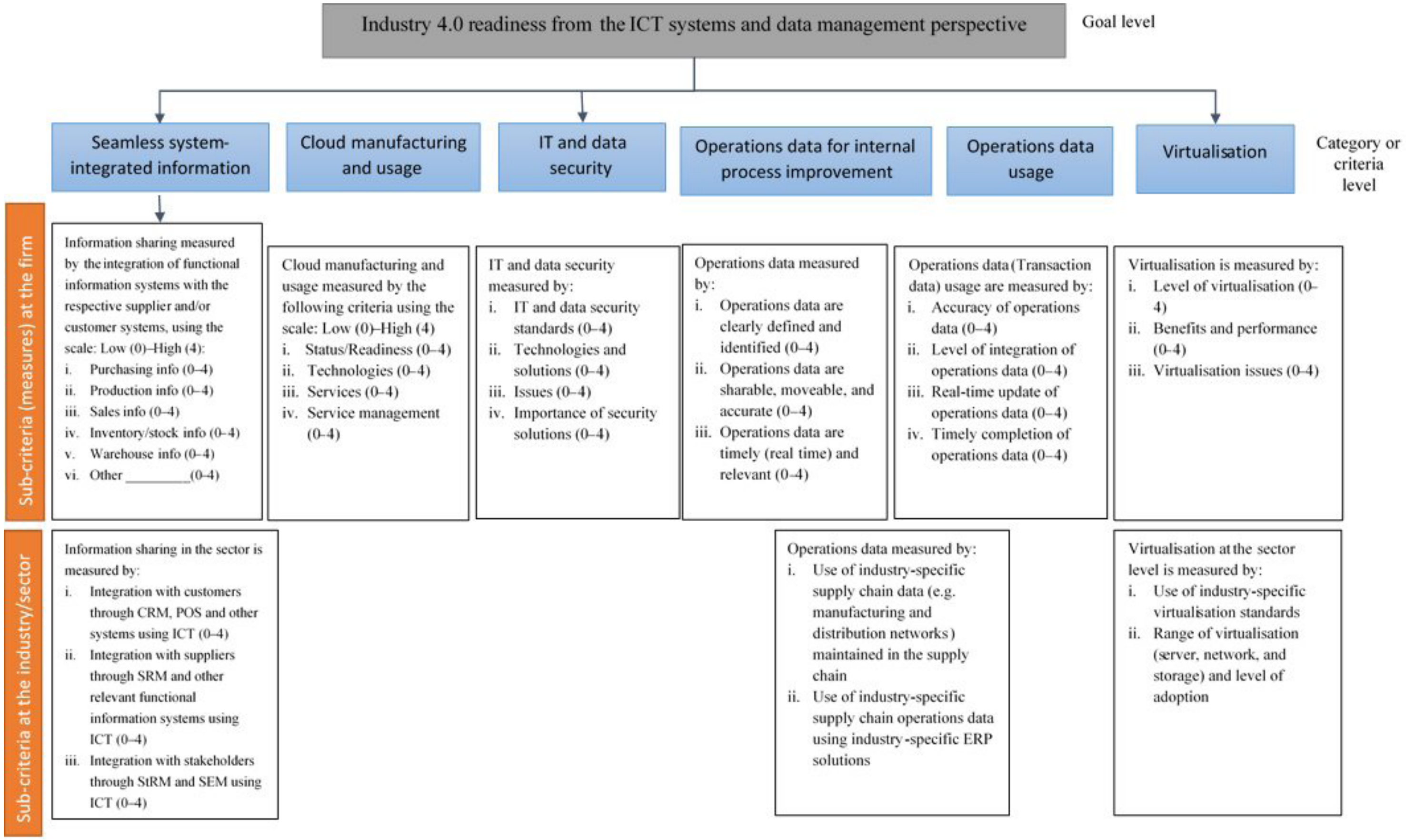
The assessment framework proposed by Ramanathan (2018) consists of two stages: (i) six elements/criteria for rating the level of readiness, mainly focusing on I4, and (ii) one element/criterion, with a CE focus. Based on this framework, in particular the assessment of readiness from the perspectives of ICT systems and data management (determinant 3 of the framework), a hierarchical structure for evaluating I4R at both the firm and industry/sector levels is developed, incorporating details of each criterion at the firm level and sub-criteria (individual measures) at the industry/sector level as shown in Figure 6.1. Each criterion used in this structure is represented by a set of measures at the firm level. However, measures at the industry/sector level are consolidated into three main criteria, since criteria 4 and 5 of determinant 3 (Ramanathan, 2018) related to operational data can be represented by one criterion. In addition, criteria 2 and 3 (cloud usage and IT and data security) measured at the firm level sufficiently represent the industry/sector level perspective. Thus, measures at the industry/sector level are mainly centred around three criteria on information sharing, operational data, and virtualisation. Therefore, the proposed framework is based mainly around three key areas of evaluation at the industry/sector level, in addition to all criteria at the firm level using enterprise systems as a central part of ICT systems at the firm and industry/sector levels. In addition, the hierarchical structure is based on key characteristics of the manufacturing sector, with reference to discrete industries such as the high-tech and automotive industries. Discrete industries within the manufacturing sector can be considered as the centre of I4 initiatives, given the nature of the manufacturing involved and their importance in any global economy, including both developed and emerging economies, such as Thailand and Indonesia.

5.2. Illustration of the framework for assessing I4R using an example from the manufacturing industry/sector

In order to illustrate the proposed framework for assessing I4R for CE, an example of a high-tech industry of the manufacturing sector is considered. For the purpose of illustration, six criteria for assessing I4R from the perspective of ICT systems and data management (determinant 3 of the framework developed by Ramanathan (2018)) are consolidated into four categories: IT-based process integration and cloud usage (cloud-based solutions) for information sharing; IT and data security; operations data collection and usage; and virtualisation. These four categories are closely related to four key elements of ICT systems: (i) IT-based processes, (ii) IT and data security, (iii) operations data including basic data and organisational data (in an enterprise resource planning system, operations data are represented by transactions data and transactions documents), and (iii) virtualisation. It is evident from a broad spectrum of ICT systems that ICT and data security can be directly related to both data and applications, in particular through applications such as cloud-based solutions.

Before presenting the assessment framework using an example of a selected industry case scenario, two key categories (out of four) for the assessment of I4R are outlined, emphasising the relationship between those categories and the level of integration within enterprise systems, since both ICT-based processes and data are integral parts of enterprise systems. The other two categories (ICT and data security, and virtualisation) are discussed later as part of the next stage of this research project.

Figure 6.1: Hierarchical Structure of the Industry 4.0 Readiness Assessment from ICT Perspectives at the Firm and Industry/Sector Levels



ERP = enterprise resource planning , ICT = information and communication technology, IT = information technology

Source: Author.

Level of ICT-based process integration at the firm level, identified by the following parameters:

i. Standard ICT-based processes (no integration of processes to process integration through enterprise systems)

ii. Cross-organisational ICT-based processes (best practices of enterprise systems, from the intention of adding other applications to link with suppliers (SRM), customers (CRM), stakeholders (SEM), to a fully functional enterprise system with all peripheral systems)

iii. Industry-specific business practices (best practices of enterprise systems, combined with industry-specific solutions)

Level of data integration at the firm and sector levels, identified by the following parameters:

i. Data integrity (integrated data; data have the same meaning across multiple functions of the enterprise; unique data set/definitions with no duplicates)

ii. Real-time data at the firm level is available to share with partners in the supply chain – limited to 100% real time

iii. Information sharing through partnership(s) – very limited to full sharing

It can be noted from practices of ICT systems at the firm and industry/sector levels that a range of systems is available to manage ICT, data security, and virtualisation. ICT systems associated with these aspects will be considered at the next stage of the research.

Based on the discussion of sectors and associated industries, and the conceptual framework presented (Figure 6.1), it is clear that a framework for assessing I4R at the industry/sector level needs to collectively assess a range of industries. This can be very challenging when each industry constitutes a range of organisations across the supply chain. In order to make the assessment framework practical and easy to adopt, assessment can be carried out at a level that represents the industry. In this case, each industry can be represented by the supply chain of entities. Thus, the supply chain is considered as the central unit of analysis for assessing I4R at the industry/sector level. In this case, parameters and measures for assessing readiness need to be defined at the firm level, across a range of organisations associated with the supply chain under consideration, specific to the sector.

For example, the high-tech industry in the manufacturing sector will have different supply chain entities and associated parameters/measures to assess I4R at the industry/sector level. Once a reasonable representation of industries within the sector (e.g. manufacturing) is assessed for I4R, they can be used with the appropriate priorities (e.g. weights assigned to each organisation of the selected industry) to determine the overall readiness at the industry/sector level. In order to carry out the assessment of I4R from an ICT perspective for CE for a selected industry/sector, a measurement tool incorporating firm and industry/sector level measures for assessing I4R from the ICT systems perspectives and sustainable practices from CE principles and perspectives is proposed and is shown in Table 6.5. As shown in Table 6.5, measurement is divided into two levels: the firm and industry/sector levels. Each level comprises measurement criteria (only the main criteria) used for assessing I4R from the ICT perspective (Appendix A). In order to make an assessment of I4R from the ICT perspective for a CE, individual organisations selected from each industry/sector as representative organisations of the selected industry need to assess their readiness at the firm and industry/sector levels using the comprehensive assessment criteria outlined in Appendix A. For example, if the selected industry is the high-tech industry, organisations representing the industry could include the manufacturers of high-tech products (central entities of the supply chain of the selected industry), first-tier suppliers, key distributors/wholesalers, and selected retailers. Once each organisation is assessed on their readiness at the firm and industry/sector levels, using Appendix A, Table 6.5 can be completed by assigning the respective I4R assessment from the ICT perspective obtained from the overall assessment (Appendix A) and the additional assessment of I4R from the ICT perspective at the industry/sector level (Appendix B) that corresponds to sustainable practices and CE principles. In this case, each sustainable practice and CE principle can be selected and assigned a percentage (0%–100%) respectively.

Table 6.5: Measures for Assessing Industry 4.0 Readiness from the ICT Systems Perspective for a Circular Economy at the Industry/Sector Level (e.g. High-Tech Industry)

Level of Assessment	Core ICT Systems and Data Management Measures (Appendix A)	Overall Assessment Using Sub-criteria (Appendix A)	Sustainable Practices	Yes (Tick)	Circular Economy Principles	Percentage (0%–100%)
Firm level	i. Seamless system-integrated information using four sub-criteria (0–16) ii. Cloud manufacturing and usage, using four sub-criteria (0–16) iii. IT and data security, using four sub-criteria (0–16) iv. Operations data collection for interal process improvement and operations data usage, using four sub-criteria (0–16) v. Virtualisation, using three sub-criteria (0–12)	____ ____ ____ ____ ____	Sustainable design Sustainable procurement Sustainable manufacturing Sustainable distribution Reverse logistics	☐ ☐ ☐ ☐ ☐	Use of renewable energy Utilisation of digital manufacturing technologies Sharing of resources Virtual systems Renewable materials	____ ____ ____ ____ ____
Industry/ Sector level	i. Seamless system-integrated information sharing across the industry/sector, using three criteria (0–12) ii. Operations data for supply chain improvement across the industry/sector, using two criteria (0–8) iii. Virtualisation across the industry/sector level, using two criteria (0–8)	____ ____ ____	Sustainable design Sustainable manufacturing Sustainable procurement Sustainable distribution Reverse	☐ ☐ ☐ ☐ ☐	Use of renewable energy Utilisation of digital manufacturing technologies Sharing of resources Virtual systems Renewable materials	____ ____ ____ ____ ____
Total score/ rating	Firm level (min: 0, max: 76) Industry/sector level (min: 0, max: 28)	____ ____	Firm level (0%–100%) Industry/sector level (0%–100%)	____ ____	Firm level (0%–100%) Industry/sector level (0%–100%)	____ ____

Source: Author.

In order to illustrate the overall assessment using the framework proposed and outlined above, one industry (i.e. the high-tech industry) is selected with a set of related organisations in the supply chain. It is assumed that the selected industry is represented by six organisations, including the manufacturer of high-tech products, two first-tier suppliers, one wholesaler (main), one logistics service provider, and one retailer (main). Each organisation is assessed at the firm and industry levels for I4R from the ICT systems perspective for a CE using the respective assessment tools (Appendix A and Table 6.5). The summary of the assessment is shown in Table 6.6.

Table 6.6: An Illustrative Example of the High-Tech Industry for I4R for CE from the ICT Systems Perspective

Organisation	I4R from the ICT Perspective at the Firm Level (min: 0, max: 76)	I4R from the ICT Perspective at the Industry/ Sector Level (min:0, max: 28)	Sustainable Practices at the Firm Level (1%–100%)	Sustainable Practices at the Industry/ Sector Level (1%–100%)	Circular Economy Principles at the Firm Level (1%–100%)	Circular Economy Principles at the Industry/ Sector Level (1%–100%)
Manufacturer	70 (92%)	22 (79%)	70%	65%	80%	60%
First-tier supplier 1	72 (95%)	22 (79%)	72%	65%	75%	65%
First-tier supplier 2	68 (89%)	18 (64%)	68%	62%	70%	65%
Wholesaler (main)	66 (87%)	18 (64%)	68%	60%	65%	60%
TPL provider (main)	68 (89%)	20 (71%)	72%	65%	75%	65%
Retailer (main)	65 (86%)	18 (64%)	66%	65%	70%	65%
Overall assessment	409 (90%)	118 (70%)	69%	64%	72.5%	63%

ICT = information and communications technology, TPL = third-party logistics.
Source: Author.

It can be noted from Table 6.6 that there seem to be varying levels of I4R from the ICT system perspective for a CE for the selected industry (high-tech industry) across a range of organisations. Making an overall assessment of I4R for CE requires choosing an appropriate method of assigning appropriate weights for each organisation of the selected industry/sector. If each organisation is assumed with equal weight, the overall assessment of I4R from the ICT perspective at the firm level is shown to be 90%. However, assuming an equal weight for each organisation needs to be justified in the context of assessment. It is suggested that appropriate methods, such as an analytical hierarchical process (AHP) and grey relational analysis (GRA), be used as appropriate and relevant methods for prioritising different entities/organisations of the supply chain of the selected industry for arriving at the overall I4R of the selected industry/sector. The details of these methods are beyond the scope of this chapter and will not be discussed herein. It is expected that the proposed framework for assessing the critical role of ICT in improving I4R be developed as a software tool (online tool) in the future.

6. Trends for Shaping the Future Manufacturing Landscape

Manufacturing is diverse and considered to be a significant part of any economy. Evolving from the traditional manufacturing of the first revolution to the current I4 manufacturing, modern manufacturing is diverse and involves a range of technologies, including CPS, IoT, cloud manufacturing, and additive manufacturing (Hofmann and Rusch, 2017). All of these technologies are closely connected with ICT systems of different forms, and, as a result, manufacturing is no longer limited to traditional processes and resources confined to manufacturing plants (centralised) but is rather distributed in various locations (decentralised), depending on the type of industry and ever-increasing customer expectations, and monitored/controlled by integrated and intelligent manufacturing systems (Chen, 2017). This evolution of manufacturing is driven by various factors and exacerbated by competitive pressures (Kang et al., 2016; Chen, 2017). For example, it is noted from recent studies that I4 technologies are being applied in various industries and there have been cases of shifting of manufacturing from traditional plant to re-distributed manufacturing systems (Nobre and Tavares, 2017).

The future manufacturing landscape can be looked at from a range of perspectives, including the advanced technologies involved, the latest developments from industry perspectives, the level of practices in the world, and factors influencing the future change in manufacturing.

6.1. Future manufacturing landscape from advanced manufacturing technology, application, and industry perspectives

I4, driven by the promise of increased flexibility in manufacturing along with mass customisation, was introduced as the fourth industrial revolution by Germany in 2011. The fundamental change from the previous manufacturing landscape was mainly the adoption of advanced technologies supported by ICT systems for integrated and intelligent manufacturing. Various studies have reported a range of technology-specific assessments of the current practices of I4, highlighting key technology components (Hofmann and Rusch, 2017) and the adoption of those technologies, supported by key characteristics of I4, such as interoperability, integration, intelligence, and capabilities beyond traditional manufacturing (Lu, 2017). The future manufacturing landscape from technologies can be seen as further refinement of all those characteristics and applications in a range of industries. For example, the future of I4 can be the adoption of advanced technologies using integrated and intelligence manufacturing supported by the full interoperability of products, processes, and data using high-speed internet. This means that manufacturing is not only flexible and mass customised, but products are smart and interoperable. In this context, manufacturing using CPS, IoT, and cloud computing can be supported by smart infrastructure for integrated and intelligent manufacturing.

Apart from the shifting manufacturing resources supported by ICT systems and smart infrastructure for mass customisation, another trend in manufacturing is smart factories, comprised of smart logistics, smart grids, smart buildings, and smart products (Kang et al., 2016). For example, smart products can collect and use information from sensor and semantic technologies for continuous process improvement (Mrugalska and Wyrwicka, 2017). In this context, Mrugalska and Wyrwicka (2017) emphasised a future for I4 that allows creating a smart network of machines, products, individuals, and ICT systems in the entire value chain to have an intelligent factory. In addition, the manufacturing execution systems of the future are expected to change from traditional centralised systems to decentralised systems as part of I4's broader vision of an ecosystem of smart factories with intelligent and autonomous shop-floor entities (Almada-Lobo, 2015). Overall, future manufacturing is evolving around smart manufacturing with smart infrastructure and I4's vision of ecosystems of smart factories and smart products as well as decentralised manufacturing systems.

6.2. Future manufacturing landscape from national and international perspectives

As is evident from the broader manufacturing landscape that has evolved from the I4 concept, the concepts have evolved into various forms of advanced manufacturing with different labels. National Network for Manufacturing Innovation and 'Manufacturing USA' by the United States; 'Made in China 2025', introduced in China in 2015; and Japan's Industrial Value Chain Initiative are a few of the initiatives seen in the developed world in recent times (Chen, 2017). All of these initiatives have taken different routes, while I4 has been at the centre of many initiatives in the developing world, aiming for flexible and mass customisation in their manufacturing. Recently, a comprehensive study by Zhong et al. (2017) has reported on current international efforts and identified future directions in each country. In addition to future directions from the global context, Kang et al. (2016) identified global trends in smart manufacturing technology through analysis of the policies and technology roadmaps of Germany, the United States, and the Republic of Korea. They emphasised the need for addressing many issues for the realisation of smart manufacturing, in terms of research, development, and commercialisation. However, there are very limited or no studies that investigate I4 in many other countries, in particular the boom of I4 adoption and/or attempts by developing countries. Amongst many developing countries taking the initiative for I4 adoption, Southeast Asian countries seem to be showing an increased interest in adopting some sort of I4 application across various industries.

7. Guidelines for Policymakers and Decision Makers for Potential Change

From the ICT system perspective, with due consideration of the relationships between I4 technologies and ICT systems, it is important for firm- and industry-level policymakers to consider the evaluation of I4R as a priority and make policies that consider not just the manufacturing landscape but also the ICT landscape of an organisation and industry best practices. It is evident from various research studies (Ramanathan, 2017; Bibby and Dehe, 2018) that firms must begin with understanding their current level of maturity in their specific context if they are to develop their I4 status. In this context, a number of frameworks have been suggested and reported in the literature, including (i) one of the early studies by Blanchet et al., (2014) that classified different European nations into four categories: frontrunners, potentialists, traditionalists, and hesitators; (ii) an assessment of readiness using six levels ranging from outsider (level 0) to top performer (level 5) (Lichtblau, 2015), (iii) the eight dimensions of Yáňez's (2018) maturity framework; and (iv) an assessment tool with six dimensions and four ratings by WMG–University of Warwick (2017). All these assessment frameworks and/or tools indicate the importance of assessing I4R from a range of perspectives. Based on the comprehensive analysis of all these frameworks, Ramanathan (2018) proposed an evaluation of the frameworks using 8 determinants and comprehensive criteria for each determinant (totalling 33 elements) that can be assessed using five levels (0–4). The I4 assessment proposed by Ramanathan (2018) provides an organisation with a final score (with a maximum score of 132 = 33*4) and indicates the status of I4 readiness using four classifications: hesitators (0–33), potentialists (34–66), experienced (67–99), and experts (100–132).

Once the level of maturity in the context of the firm and broader industry level is clear, the organisations need to prioritise improvement opportunities and management development plans (Becker, Knackstedt, and Pöppelbußet, 2009), commence work on developing a blueprint for I4 transition with a clear set of guidelines and steps (Ramanathan, 2018) and seek top-level management support as one of the critical success factors for the successful adoption of I4 (Ramanathan, 2018).

Apart from the need for assessing I4R and prioritising improvement opportunities arising from the level of maturity, organisations need to aware of the critical issues and success factors for I4 adoption. Since the core of I4 is the adoption of advanced/smart technology and organisations already using a range of technologies requiring some changes, one of the most critical issues identified is interoperability (Kang et al., 2016). Other issues that are identified from a range of applications and case studies reported to date include the level of complexity associated with integration and resistance to change from the workforce (Lu, 2017). As is evident from various studies on technology transfer and/or the implementation of new ICT systems, such as enterprise systems, critical success factors also need to be considered as guidelines for moving to I4 transition. In this context, top management support from inception to completion of any I4 transition is critical for a successful outcome. Thus, organisations need to make sure that the critical success factors are identified and sustained during the entire project of I4 transition.

8. Discussion

The investigation into various aspects of the fourth manufacturing revolution, referred to as Industry 4.0 (I4) has been an important subject for many scholars and industry practitioners in recent times. The potential benefits of I4 and the cost of implementation or transition to I4 are well documented, highlighting the need for large capital investment and organisations to be ready for changes expected in the implementation/transition process (Ramanathan, 2016). Since the concept is at an early stage, at least for many emerging economies, studies on I4R have increased in recent times. In this context, I4R for CE is identified as a key driver for many emerging economies as the basis for moving towards I4 with renewed emphasis on sustainable practices.

Although I4 is well established in many developed economies, focusing on circular economies, investigation into I4R for CE is still at an early stage, but limited to the firm level rather than the sector/industry level. This gap is currently being addressed through developing a framework on I4R for CE, through a level of readiness with a set of criteria over a number of determinants (Ramanathan, 2018). One of the determinants considered in the framework is ICT systems and data management, which were explored in this research study.

Recognising the need for readiness at the industry/sector level and the importance of ICT systems for I4R, this chapter outlined an approach to extending the current framework for measuring readiness to cover industry/sector level measures and parameters. Since there are a number of factors that shape this research, including themes of I4 and CE, as well as assessing readiness at the industry/sector level from the perspective of ICT systems, sectors and associated industries are selected from enterprise systems (one of the main IT systems) that closely relate to the respective industry-specific enterprise solutions. These sectors and associated industries are used as the basis for developing the framework using the criteria defined for assessing ICT systems and data management (Ramanathan, 2018).

The framework for assessing readiness, with detailed analysis from the ICT systems perspective, is proposed by incorporating measures and parameters at both the firm and industry/sector levels. The measures and parameters at the firm and industry/sector levels, categorised into five main criteria from the framework by Ramanathan (2018), are guided by ICT systems, such as enterprise systems, given their relevance for the criteria chosen for assessing the ICT systems and data management perspectives. Although measures at the firm level are clear and easy to evaluate using the level of enterprise system applications at the firm level, measures at the industry/sector level are dependent on the applications of advanced ICT systems, such as industry-specific enterprise solutions and advanced enterprise system modules such as SRM, CRM, and SEM.

The framework is illustrated using the example of a manufacturing case scenario (high-tech manufacturing), with relevant parameters and measures at the firm and sector levels. It is expected that a case scenario from the manufacturing sector will be selected for testing and validating the proposed framework for assessing the critical role of ICT in improving I4R for CE from the ICT systems perspective in the near future. Once the case organisation is selected, plans for data collection will be finalised, followed by the required data collection, case scenario analysis, and reporting of the results and findings.

It is evident from the trends in the future manufacturing landscape that manufacturing is rapidly moving from traditional, centralised plant-based manufacturing to a re-distributed, decentralised system of manufacturing. In addition, manufacturing is moving towards adopting the concepts of CE, supported by smart infrastructure and logistics amongst many other contemporary practices. In order for ASEAN policymakers and businesses to prepare for this change in the manufacturing landscape in the future, directions and guidelines are proposed, highlighting the need for assessing I4R for CE, prioritising the improvement opportunities, and recognising the importance of the critical role ICT plays at the firm and industry levels.

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Appendix A: Framework for Assessing Industry 4.0 Readiness from the ICT Systems Perspective at the Firm Level

This framework is based on one of the criteria developed for assessing the status of Industry 4.0 readiness (I4R) in manufacturing (Ramanathan, 2018) and succinct literature on broader information and communications technology (ICT) systems and associated technologies. This framework is directly related to the hierarchical structure of I4R from the ICT perspective at the firm and industry/sector levels (Figure 6.1) and, therefore, can only be used in conjunction with specific parameters of the manufacturing organisation of the selected industry. This is ideally carried out using piloting of the framework using case studies.

Sub-criteria for Assessing Seamless System-integrated Information	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Criterion 1: Seamless System-integrated Information					
Purchasing information system (PIS) within an enterprise resource planning (ERP) system across the enterprise, integrated with Industry 4.0 technologies using ICT	There is no PIS. Relevant purchasing data and information are stored and processed manually using simple applications, which are not integrated with other applications/ systems.	PIS is of interest at the purchasing department level but is not explicitly incorporated into an enterprise-level procurement strategy, such as centralised purchasing.	PIS is recognised as important and is being introduced as a standalone system (e.g. not part of an ERP system) and is incorporated into the strategy formulation process.	PIS of the ERP system has been developed and/ or bought and implementation is in progress in stages. However, PIS is not directly integrated with relevant suppliers' systems using ICT and relevant technologies.	PIS of the ERP system has been implemented and is being continuously reviewed and updated. PIS is directly integrated with relevant suppliers' systems using ICT and associated technologies, including RFID and sensors.
Production information system (PrIS) within an ERP system across the enterprise, integrated with Industry 4.0 technologies using ICT	There is no PrIS. Production-relevant data and information are stored and processed manually using simple applications, which are not integrated with other applications/ systems.	PrIS is of interest at the production department level but is not explicitly incorporated into an enterprise-level production planning strategy, such as sales and operations planning.	PrIS is recognised as important and is being introduced as a standalone system (e.g. not part of an ERP system) and is incorporated into the strategy formulation process.	PrIS of the ERP system has been developed and/ or bought and implementation is in progress in stages. However, PrIS is not directly integrated with suppliers and customers using ICT, including RFID and sensors.	PrIS of the ERP system has been implemented and is being continuously reviewed and updated. PrIS is directly integrated with suppliers and customers using ICT and associated technologies, including RFID and sensors.

Sub-criteria for Assessing Seamless System-integrated Information	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Sales information system (SIS) within an ERP system across the enterprise, integrated with Industry 4.0 technologies using ICT	There is no SIS. Sales-relevant data and information are stored and processed manually using simple applications, which are not integrated with other applications/ systems.	SIS is of interest at the sales department level but is not explicitly incorporated into an enterprise-level sales and distribution strategy.	SIS is recognised as important and is being introduced as a standalone system (e.g. not part of an ERP system) and is incorporated into the strategy formulation process.	SIS of the ERP system has been developed and/ or bought and implementation is in progress in stages. However, SIS is not directly integrated with customers using ICT and relevant technologies.	SIS of the ERP system has been implemented and is being continuously reviewed and updated. SIS is integrated with customers using ICT and associated technologies.
Inventory/warehouse information system (IWIS), within an ERP system across the enterprise, integrated with Industry 4.0 technologies, using ICT	There is no IWIS. Inventory and warehouse-relevant data and information are stored and processed manually using simple applications, which are not integrated with other applications/ systems.	IWIS is of interest at the relevant functional level but is not explicitly incorporated into an enterprise-level inventory/ warehouse management strategy.	SIS is recognised as important and is being introduced as a standalone system (e.g. not part of an ERP system) and is incorporated into the strategy formulation process.	IWIS of ERP system has been developed and/ or bought and implementation is in progress in stages. However, IWIS is not directly integrated with internal/external customers using ICT and relevant technologies.	IWIS of ERP system has been implemented and is being continuously reviewed and updated. IWIS is integrated with customers using ICT and associated technologies (e.g. RFID and automated guided vehicles).
Criterion 2: Cloud Manufacturing and Usage (Ramanathan, 2018)					
Manufacturing infrastructure – current status and readiness	Not suitable for a cloud manufacturing environment and/ or no interest in integration of distributed manufacturing resources or applications.	There is some interest in cloud manufacturing infrastructure but will need substantial overhaul for cloud manufacturing infrastructure readiness.	Current infrastructure is ready for cloud manufacturing and Some of the plant, equipment, and systems can be upgraded for cloud manufacturing.	Current infrastructure is ready for cloud manufacturing and most of the plant, equipment, and systems meet cloud manufacturing requirements and standards.	Current infrastructure is ready and all the plants, equipment, and systems meet cloud manufacturing requirements and standards.
Key enabling cloud manufacturing technologies	Current machines and systems cannot be integrated with cloud manufacturing technologies through the internet.	Some machines/ equipment and systems can be integrated with cloud manufacturing technologies through ICT systems, but there is no ERP system for functional applications and no machine-to-machine (M2M) connectivity.	Most machines/ equipment and systems can be integrated with cloud manufacturing technologies and some machines can be controlled through ICT systems and have M2M connectivity.	All machinery/ equipment can be controlled through ICT systems and most machines/ equipment have M2M connectivity.	All machinery/ equipment can be completely controlled through ICT systems and have full M2M capability.

Sub-criteria for Assessing Seamless System-integrated Information	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Cloud manufacturing services (e.g. virtualising manufacturing resources and capabilities, manufacturing as a service and multi-tenancy, intelligent on-demand manufacturing, flexibility and scalability)	No cloud manufacturing service in use and no consideration of manufacturing cloud.	No cloud manufacturing service in use, but business cases for their adoption are being prepared for consideration.	Cloud manufacturing architecture and some of the cloud manufacturing services are being planned/ piloted.	Some cloud manufacturing services are in use.	Cloud manufacturing services are widely adopted with continuous improvements being made in their use.
Cloud manufacturing service management	No effective management and coordination of cloud services in a centralised way to ensure the service performance, quality, security and successful operation of manufacturing clouds.	Management and coordination of cloud services only for a limited scope (e.g. only in some functional areas) and provided in a decentralised way.	Management and coordination of cloud services for a majority of functional areas of the enterprise, but provided in a decentralised way.	Management and coordination of cloud services for all of functional areas of the enterprise, but provided in a decentralised way.	Fully effective management and coordination of cloud services in a centralised way to ensure the service performance, quality, security, and successful operation of manufacturing clouds.
Criterion 3: IT and Data Security					
IT and data security standards	Not recognised as an important aspect for the organisation.	IT and data security standards are recognised as important and security standards are being considered for adoption.	IT and data security standards (Chen and Zhao, 2012) have been adhered in multiple areas of the organisation.	IT and data security standards have been achieved across the entire organisation and are constantly monitored and upgraded with the latest updates on improvement.	IT and data security standards have been achieved across the entire organisation and have been extended to cover applications of direct customers and suppliers.

Sub-criteria for Assessing Seamless System-integrated Information	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Criterion 3: IT and Data Security					
IT and data security technologies and solutions	Not a concern for the organisation.	IT and data security technologies and solutions are recognised as important and are being considered for adoption.	IT and data security solutions have been implemented in multiple areas of the business.	IT and data security solutions have been comprehensively implemented across the business and are constantly monitored for bridging gaps that arise with time.	IT and data 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.
IT and data security issues	Not a concern at this stage and/or not recognised/ identified as an issue.	IT and data security as an important issue is recognised and preliminary steps have been taken for addressing the issue.	IT and data security is continuously addressed across multiple areas of the business.	Security issues have been addressed across the enterprise.	Security issues have been addressed across the enterprise and extended to include any security concerns from customers and suppliers.
Importance of IT and data security	Very low	Low	Neutral	High	Very high
Criterion 4: Operations Data Collection for Internal Process Improvement and Operations Data Usage					
Enterprise-level organisational and master data	No unique data definitions for enterprise-wide data and no single database for maintaining master data.	Unique data across the enterprise but no single database for enterprise-wide data	Unique data definitions and single database for most enterprise-wide data	Unique data definitions, single database for enterprise-wide data using an enterprise resource planning (ERP) system, but limited functional applications are being used.	Unique data definitions, single database for enterprise-wide data using an ERP system with full ERP system functionality.

Sub-criteria for Assessing Seamless System-integrated Information	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Criterion 4: Operations Data Collection for Internal Process Improvement and Operations Data Usage					
Enterprise-wide transactional (operations) data	No formal data collection system. Data are collected manually by departments for their own usage as needed.	Required data is collected digitally (e.g. financial/ accounting data by 'mind your own business' systems) by some departments and data available are current.	Data is collected digitally by most departments using the relevant functional applications of the ERP system.	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, using ERP integrated with other systems, such as SCM, CRM, and strategic enterprise management system (SEM).
Enterprise-wide information and reporting	No formal enterprise-wide information and reporting.	Information is collected and processed by some departments.	Information is collected and processed by all departments but with limited reporting.	Information is collected and processed by all departments, and makes standard and flexible analyses using ERP system and user defined structures.	Information is collected and processed by all departments from a variety of sources (e.g. internal ERP system, business warehouse, external data, other systems such as SCM and CRM) for business intelligence and data analytics.
Enterprise-wide operations data usage, quality and, accuracy	Operations data are collected manually but not evaluated for accuracy and quality.	Operations data are collected manually. Some considerations are given for evaluating the quality and accuracy.	Operations data are collected across the enterprise using standalone systems but with limited evaluation on quality and accuracy.	Comprehensive operations data across the enterprise, collected using an enterprise-wide ERP system and are evaluated for accuracy and quality.	Comprehensive operations data across the enterprise are collected using an enterprise-wide ERP system and are of high quality, timely, and accurate. Operations data are used for decision making.

Sub-criteria for Assessing Seamless System-integrated Information	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Criterion 5: Virtualisation					
Virtualisation at system, storage, and network levels	There is awareness but no plans to develop the capacity.	Some virtualisation of resources (e.g. hardware, storage, network) are being planned	Some virtualisation of resources (e.g. hardware, storage, network) have been implemented.	Comprehensive use of virtualisation across the entire organisation but limited to traditional resources, not associated with Industry 4.0 resources.	Complete virtualisation of hardware, operations systems, applications, storage, and networks through cyber-physical production systems.
Virtualisation benefits and performance (e.g. flexibility, availability, scalability, hardware utilisation, security, cost and load balancing)	Aware of benefits but no plans to develop the capacity.	Some plans to develop capacity and expected to have some benefits in the future.	Some benefits as a result of some virtualisation.	Significant benefits and advantages are currently being achieved.	Full benefits are achieved as a result of virtualisation.
Virtualisation issues	Not a concern at this stage or issues are not being identified/ addressed.	Issues are identified and preliminary steps have been taken for addressing the issues.	Issues are continuously identified and addressed across multiple areas of the business.	All issues have been addressed across the enterprise.	All issues have been addressed across the enterprise and extended to include any security concerns from customers and suppliers.

Appendix B: Framework for Assessing Industry 4.0 Readiness from the ICT Systems Perspective at the Industry/Sector Level

This framework is directly related to the framework for assessing Industry 4.0 readiness (I4R) from the information and communications technology (ICT) perspective at the firm level (Appendix A) and therefore should only be used in conjunction with the assessment of I4R from the ICT systems perspective at the firm level of selected organisations (e.g. manufacturers, first and second tier suppliers, third-party logistics service providers, and wholesalers/distributors and retailers) of the selected industry/sector, taking into consideration the specific parameters of the manufacturing organisation of the selected industry. While individual case studies can provide I4R from the ICT perspective at the firm level, I4R from the ICT perspective at the industry/sector level requires case studies associated with the key organisations of the selected industry/sector. For example, I4R from the ICT perspective for the automotive industry requires assessment of the core manufacturing organisation, upstream suppliers (e.g. engine suppliers and body/frame suppliers) and downstream customers (wholesalers, exporters, and dealers). .

Sub-criteria for Assessing Seamless System-integrated Information Sharing	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Criterion 1: Seamless System-integrated Information Sharing across the Industry/Sector					
Information sharing through system integration with customers, using customer relationship management (CRM) and information systems (e.g. point of sales (POS), maintenance monitoring, stock/ inventory)	Not suitable for information sharing with customers and/ or no interest in a CRM system and integration with customers' systems for information sharing.	There is some interest in information sharing with customers, interest in an CRM system, and integration with customers' systems for information sharing, but not explicitly incorporated into corporate strategy.	Information sharing with customers, deploying a CRM system and integration with customers' system/s are being introduced.	Information sharing with customers has been introduced and implementation of a CRM system and integration with customers' systems are in progress in stages.	Information sharing with all/relevant customers is in full operation, using a CRM system and integration with customers' systems. Information sharing capabilities are continuously monitored, reviewed, and updated.

Sub-criteria for Assessing Seamless System-integrated Information Sharing	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Information sharing through system integration with suppliers, using a supplier relationship management (SRM) system and relevant information systems (stock/inventory overview, production information)	Not suitable for information sharing with suppliers and/ or no interest in an SRM system and integration with suppliers' systems for information sharing.	There is some interest in information sharing with suppliers, interest in an SRM system and integration with suppliers' systems for information sharing, but not explicitly incorporated into corporate strategy.	Information sharing with suppliers, deploying an SRM system, and integration with customers' system/s are being introduced.	Information sharing with suppliers has been introduced. Implementation of an SRM system and integration with customers' systems are in progress in stages.	Information sharing with all/relevant suppliers is in full operation, using an SRM system and integration with suppliers' systems. Information sharing capabilities are continuously monitored, reviewed, and updated.
Information sharing through system integration with stakeholders, using stakeholder relationship management (StRM) and/or strategic enterprise management (SEM) systems	No interest in an StRM/ SEM system, and sharing information with stakeholders.	There is some interest in information sharing with stakeholders, no interest in an StRM/SEM system and integration with stakeholders' systems for information sharing, but not explicitly incorporated into corporate strategy.	Information sharing with stakeholders, deploying an StRM/SEM system and integration with stakeholders' system/s are being introduced.	Information sharing with stakeholders has been introduced. Implementation of an StRM/ SEM system and integration with stakeholders' systems are in progress in stages.	Information sharing with all/relevant stakeholders is in full operation, using an StRM/ SEM system and integration with stakeholders' systems. Information sharing capabilities are continuously monitored, reviewed, and updated.
Criterion 2: Operations Data for Supply Chain Improvement across the Industry/Sector					
Industry/sector specific supply chain data (e.g. manufacturing network of plants, suppliers, distribution network of warehouses, customers)	No unique data definitions for industry-specific supply chain data and no integration of supply chain data with enterprise-wide data.	Unique data definitions for industry-specific supply chain data, but no integration of supply chain data with enterprise-wide data.	Unique data definitions for industry-specific supply chain data, and there is limited integration of supply chain data with enterprise-wide data, using industry-specific ERP solutions.	Unique data definitions, integrated databases for enterprise-wide and supply chain data, using some integration of an ERP system and industry solution at the organisation level.	Unique data definitions, integrated databases for enterprise-wide and supply chain data, using full integration of an ERP system and industry solution at organisation level.

Sub-criteria for Assessing Seamless System-integrated Information Sharing	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
Criterion 2: Operations Data for Supply Chain Improvement across the Industry/Sector					
Industry/sector specific supply chain operations data (e.g. cross-plant production orders, multi-supplier purchase orders), using specific supply chain data, maintained in industry-specific ERP solutions	No formal data collection system for supply chain-specific data. Supply chain-specific operations data are collected manually by departments for their own usage as needed.	Required supply chain data are maintained/ collected digitally (e.g. financial/ accounting data by MYOB system) by some departments, and supply chain operations data available are current.	Supply chain operations data is collected digitally by most departments using relevant functional applications of the ERP system, but no integration with industry-specific solutions.	Comprehensive and automated structure across the enterprise for digital supply chain operations data collection. Arrangements in place to acquire and share supply chain operations data digitally with some important supply chain partners, using industry solutions.	Comprehensive and automated structure across the enterprise and with all key supply chain partners to acquire and share supply chain operations data digitally, using ERP integrated with other systems, such as SRM, CRM and StRM systems.
Criterion 3: Virtualisation across the Industry/Sector Level					
Industry-specific virtualisation standards	Not recognised as an important aspect for the organisation.	Industry-specific standards are recognised as important and are being considered for adoption.	Industry-specific standards have been adhered to in multiple areas of the organisation.	Industry-specific standards have been achieved across the entire organisation and are constantly monitored and upgraded with the latest updates on improvement.	Industry-specific standards have been achieved across the entire organisation and have been extended to cover applications of direct customers and suppliers.
Virtualisation at the system, storage, and network levels, and level of adoption (full, hardware layer, operating system-layer, server, application, resource, and storage virtualisation)	There is awareness but no plans to develop the capacity at the organisation level and no consideration of industry-specific virtualisation solutions.	Some virtualisation of resources (e.g. hardware, storage, network) are being planned at the organisational level, but no consideration of industry-specific solutions.	Some virtualisation of resources (e.g. hardware, storage, network) has been implemented and is not associated with industry standards.	Comprehensive use of virtualisation across the entire organisation, but limited to traditional resources, not associated with industry standards.	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).

CHAPTER 7

Industry 4.0 Readiness for the Circular Economy: Transition Trends and the Readiness of Thailand's Automobile Sector

Nuwong Chollacoop

The Thai government has consistently promoted and supported Thailand's automotive industry over the past four decades. Initially, the industry was focused on establishing domestic production for import substitution through various government incentive programmes like tax privileges on investment, lower import taxes on completely knocked-down (CKD) parts, and higher import taxes on completely built-up (CBU) parts to shift from whole car imports to car assembly in the country. The next phase was government support for the domestic production of automotive parts to strengthen the domestic auto industry. The import taxes on CKD parts and whole cars were raised with enforced local content requirements from 1 January 1975, with an increasing percentage of local content over time to sustain the whole production value chain. Furthermore, foreign investment in the auto industry has been strongly pursued with technology transfers through joint ventures. Nowadays, domestic automotive production uses locally produced parts amounting to over 80% in value.

Foreign investment in the automotive sector spiked in 1987 when the Japanese currency was so strong that the production base shifted from Japan to Thailand to maintain competitiveness. Later in 1997 during the economic crisis, the Thai government allowed a higher proportion of share-holding by foreigners in Thai companies, as well as involved foreign car companies in the automotive industry roadmap with an aim for Thailand to become a production hub in Asia, the 'Detroit of Asia'. Hence, domestic automotive production skyrocketed from 0.36 million units in 1997 to 1.99 million units in 2017, or an 8.9% compound annual growth rate.

Since 2008, domestic automotive production has changed from production for domestic consumption to production for exporting.

The key government policies in the automotive sector have focused on the following product champions. First, during 1997–2007, the first product champion was the 'one-ton pickup truck', with various incentives to attract big foreign car makers to invest in production lines in Thailand, such as by keeping the diesel fuel price lower than the price for than gasoline, specifying a very low excise tax of 3% for pickup trucks (compared to 30%–50% for passenger cars). Unsurprisingly, 70% of vehicle production in Thailand is for one-ton pickup trucks. Next, from 2009 until now, the automotive industry focus has shifted from one-ton pickup trucks to passenger cars, resulting in an increased share of passenger car production from 28% in 2007 to 50% in 2017. The second product champion was launched in 2009 and was the 'eco-car', which is defined as a small car with higher fuel efficiency. Additional incentives have been laid out to attract foreign investment in eco-cars with export conditions through 'Eco-car Phase I' in 2009 with fuel efficiency better than 5 litres/100 kilometres, and 'Eco-car Phase II' in 2015 with fuel efficiency better than 4.3 litres/100 kilometres. A major incentive was a great reduction in the excise tax from the typical 30%–35% for passenger cars to 17% and 12%–15% for Eco-car Phases I and II, respectively. In addition, government support for biofuel, especially ethanol-blended gasoline or 'Gasohol' of various percentages (10%, 20%, and 85%), has lowered the gasoline fuel price. Recently, since 2016, the vehicle excise tax scheme has been changed from being engine displacement-based to being carbon dioxide-emission based to further the support small car segment.

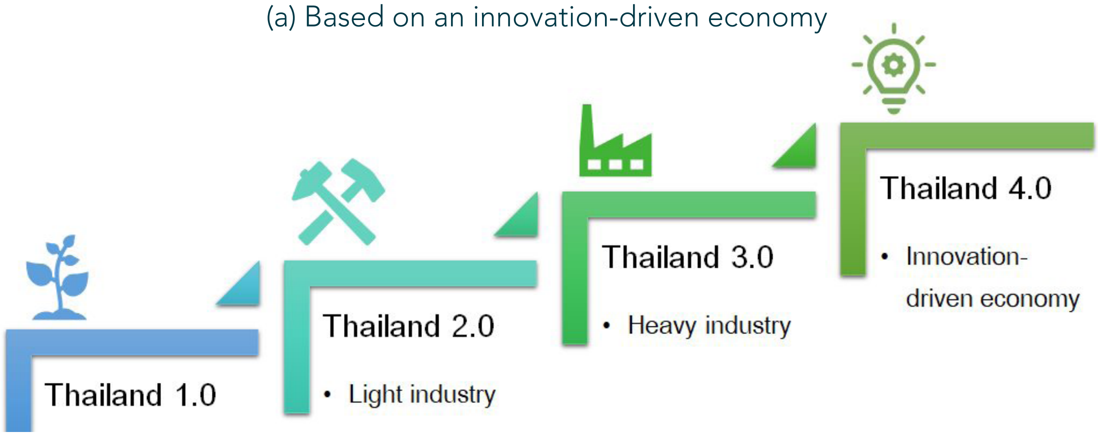
With the recent electric vehicle (EV) movement worldwide, it is not surprising that EV has become the third product champion, with many policy support programmes being drafted and launched for the EV value chain covering vehicles, motors, batteries, and charging stations. However, the Thai government has not followed the worldwide trend to boost EV demand through a direct subsidy in EV prices, but is rather using investment privileges like for the previous two product champions. Hence, the volume of EV, especially plug-in hybrid electric vehicles and BEV battery hybrid vehicles, has not grown so much.

1. Industry 4.0 Readiness for the Circular Economy Profiles of Firms and the Sector

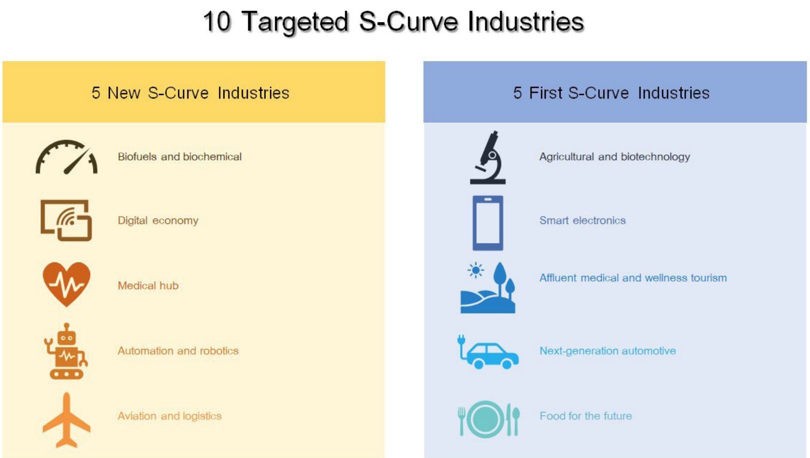
With the Fourth Industrial Revolution happening worldwide, Thailand has responded by establishing a new economic model under Thailand 4.0 based on an innovation-driven economy where five new S-curve industries and five first S-curve industries have been identified, as shown in Figure 7.1. In the case of Thailand, Industry 4.0 readiness (I4R) for the circular economy was assessed for the automotive sector, which is identified as one of the five first S-curve industries due to its well-established infrastructure and skilled personnel as a production hub for many foreign brand car makers.

Figure 7.1: Thailand 4.0 Scheme

(a) Based on an innovation-driven economy



(b) With five new S-curve industries and five first S-curve industries identified



Source: Author based on BOI (2018a).

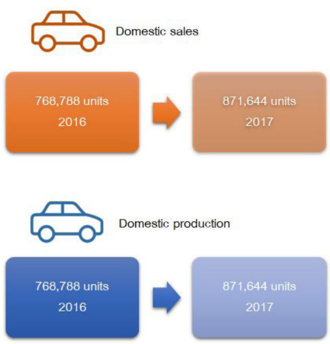
The automotive industry in Thailand has been one of the major contributions to economic prosperity. With production of almost 2 million motor vehicles, Thailand ranked 12th in the world in 2017 and currently has 18 international brands, as shown in Figure 7.2(a)–(b) (BOI, 2018b) scattered around the central and eastern parts of Thailand (see Figure 7.2(c)) (TAI, 2016).

Figure 7.2: Thailand as a Production Hub for Cars

(a) In 2017 (12th world ranking)

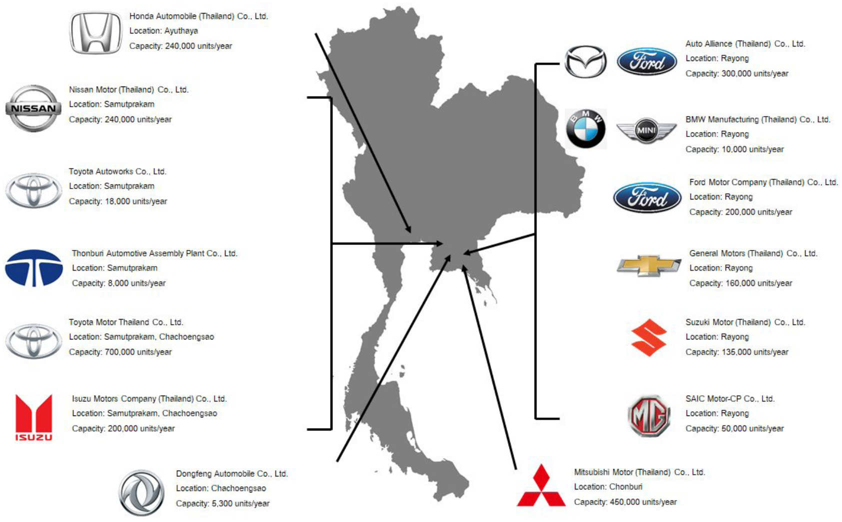
Global and Local Production

#	Country	Production (2017)
1	China	29.02
2	United States	11.19
3	Japan	9.69
4	Germany	5.65
5	India	4.78
6	Republic of Korea	4.11
7	Mexico	4.07
8	Spain	2.85
9	Brazil	2.70
10	France	2.23
11	Canada	2.20
12	Thailand	1.99

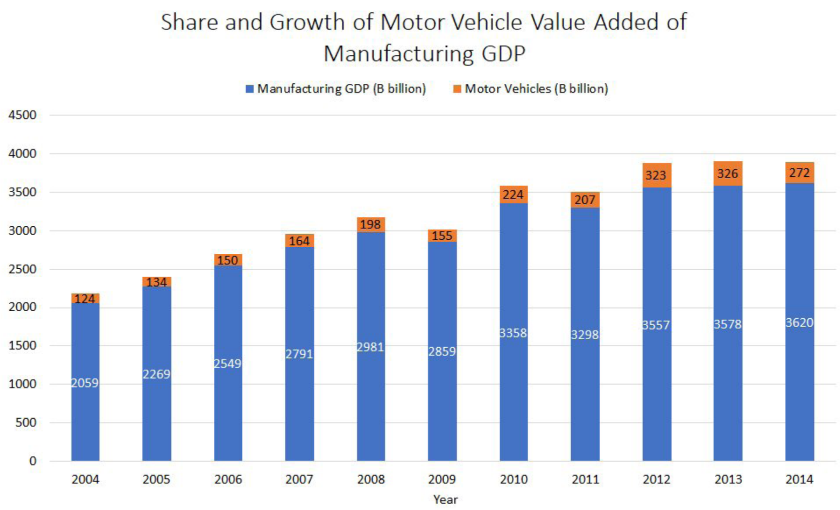


(b) With 18 international brands

(c) With production hubs in the central and eastern regions



(d) GDP

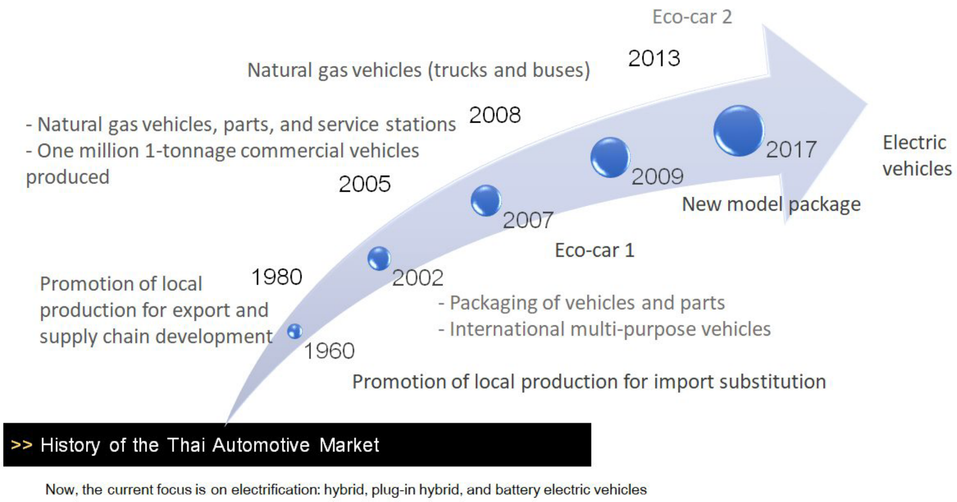


Source: Author based on BOI (2018b) and TAI (2016: 7).

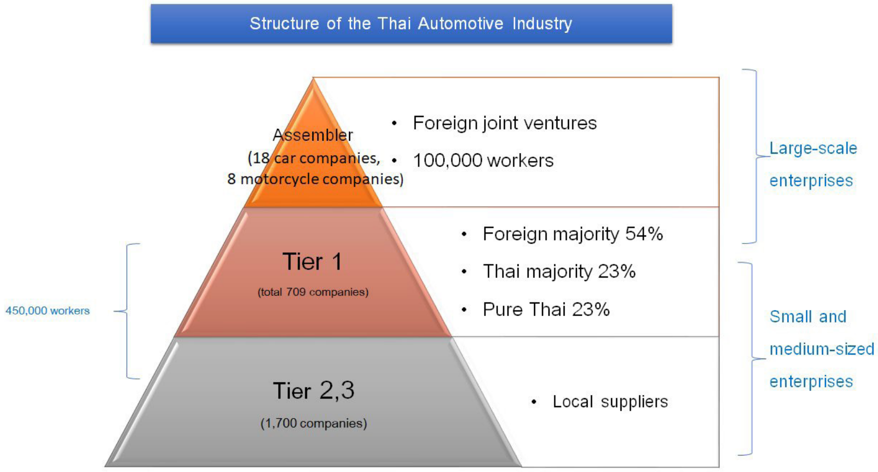
The contribution of the automotive industry to Thailand's gross domestic product (GDP) is in the range of 5%–9% (TAI, 2017). In 2017, more than half of vehicle production in Thailand was for exports, at 56%. With the history of the Thai automotive industry shown in Figure 7.3(a), the Thai government launched the National Automotive Master Plan in 2002, for which the 1st Automotive Master Plan (2002–2006) focused on the production of one-ton pick-up trucks as the first product champion with increased research and development investment and more value added content. The 2nd Automotive Master Plan (2007–2011) focused on eco-car production as the second product champion with a benchmark to international standards (UNECE) under Vision 2011 (TAI, 2017): 'Thailand is production base in Asia, which creates more value added to the country with strong automotive parts industry'. Under the current 3rd Automotive Master Plan (2012–2016), the Vision 2021, 'Thailand is a global GREEN automotive production base with strong domestic supply chains, which create high value added for the country' has been set forth with a strategic plan for three Centers of Excellence (COEs), namely the Research and Technology Development, Human Resource Development, and Entrepreneur Strength Enhancement, as well as two Good Business Environments, namely infrastructure and government policy.

Figure 7.3: Thailand's Automotive Industry

(a) History



(b) Structure

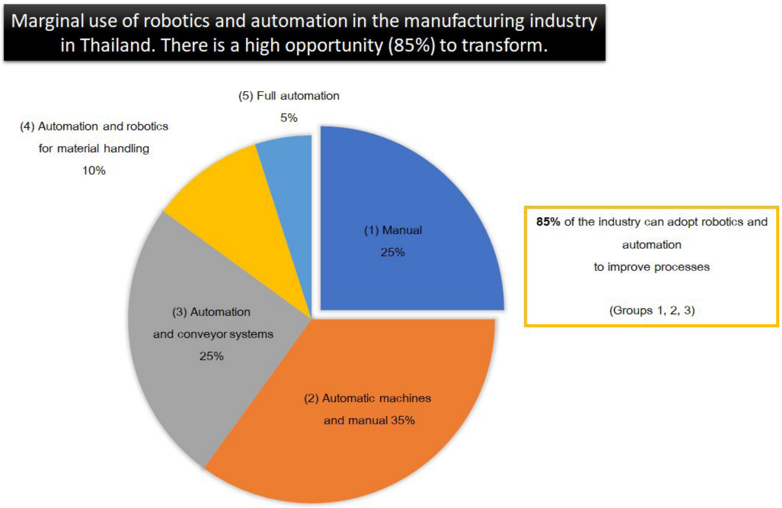


Source: Author based on BOI (2018b, 2018c).

To address the Industry 4.0 worldwide trend, Thailand's Ministry of Industry has established a 20-year roadmap for Industry 4.0 for 2017–2036 (MOI, 2016), where the next-generation automotive industrial sector is a focus for the 10 targeted S-curve industries, as shown in Figure 7.1(b). Given the structure of Thailand's automotive industry, as shown in Figure 7.3(b), large-scale enterprises (LSEs), including foreign brand car makers and large tier-1 companies, will be the first group to adopt Industry 4.0. From a recent survey of the manufacturing industry (Institute of Field Robotics, 2017), Figure 7.4 shows that 85% of the industry has the opportunity to adopt robotics and automation to improve processes (classified as Groups 1–3 according to their levels of robotics and automation), whereas 50% of industry is ready to adapt manufacturing processes to use robotics and automation within 1–3 years. On the other hand, demand for skilled labour will increase by 2–5 times in the next 5 years.

Figure 7.4: Status of the Manufacturing Industry in Thailand

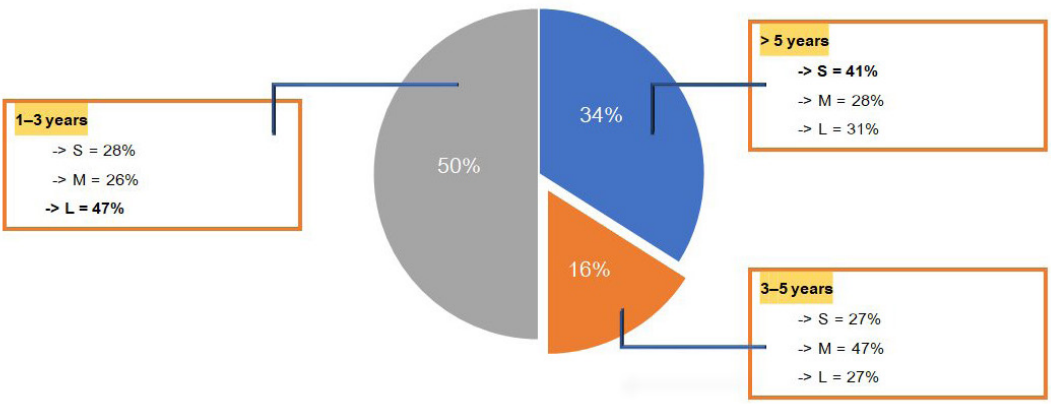
(a) Robotics and automation level



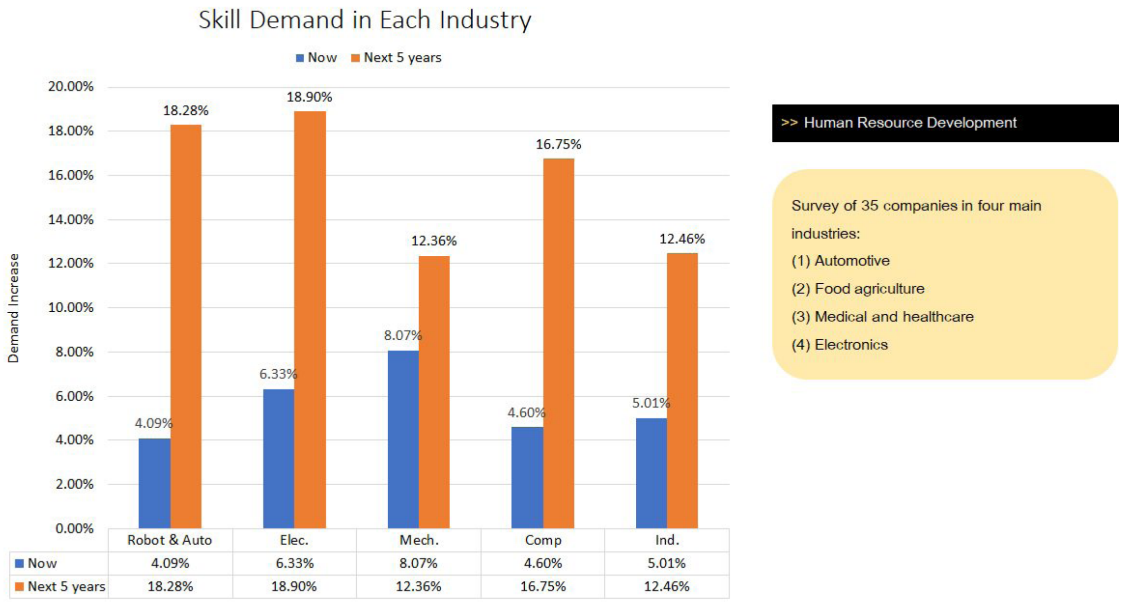
(b) Robotics and automation adoption

Fifty percent of the industry in Thailand is ready to adapt their manufacturing processes to use robotics/automation within 1–3 years

- Majority of **large** companies are ready to change in 1–3 years.
- Majority of **medium** companies are ready to change in 1–3 years.
- Majority of **small** companies are ready to change in 1–3 years.



(c) Skilled labour demand



Source: Author based on Institute of Field Robotics (2017).

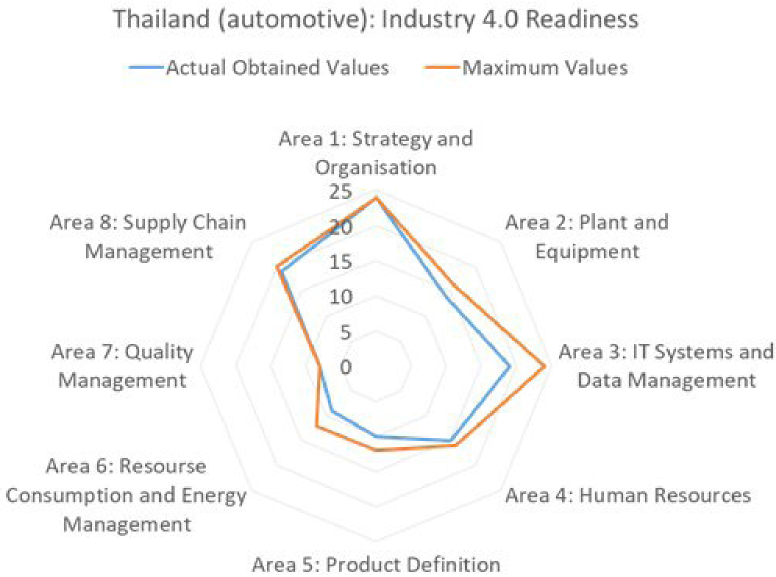
Focusing on automotive firms with well-established production lines as the first production champion, namely one-ton commercial vehicles or simply one-ton pickup trucks, as shown in Figure 7.3, two makers have a similar market share of 35% each in the over 6-million vehicle market (DLT, 2018). The Industry 4.0 readiness (I4R) and I4R for the circular economy (CE) assessment was conducted through a meeting lasting a few hours with a top executive in manufacturing from one of the makers. The results of the I4R and I4R for CE assessments are shown in Figures 7.5(a) and 7.5(b), respectively. The assessment focuses on eight areas, namely:

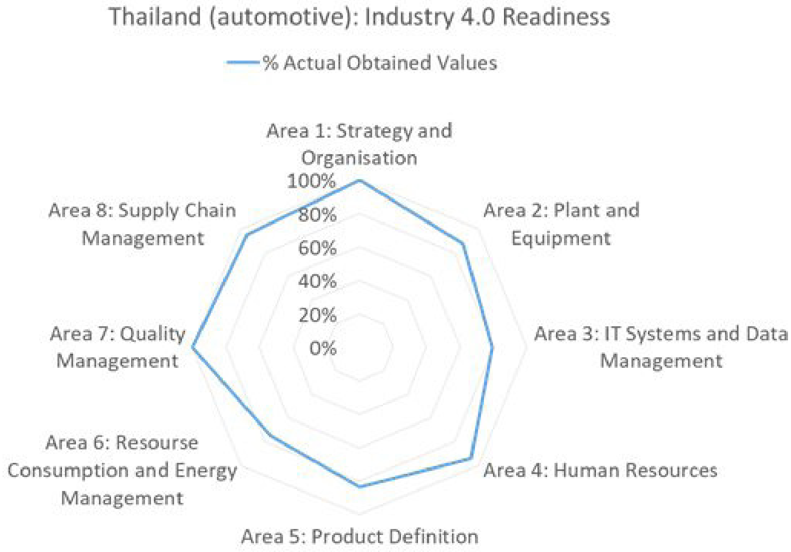
1. Strategy and organisation
2. Plant and equipment
3. IT systems and data management
4. Human resources
5. Product definition
6. Resource consumption and energy management
7. Quality management
8. Supply chain management

Figure 7.5(a) clearly shows that the firm has over 75% (average of 89%) readiness for Industry 4.0 since many of the company's policies comes from its headquarters in Japan, where Industry 4.0 has been a focus of industrial improvement. On the other hand, Figure 7.5(b) shows that I4R for CE has dropped to the level of 50%–75% (average of 71%) since the concept of I4 for CE is relatively new in Thailand, especially as implementation towards Industry 4.0 is usually associated with higher energy consumption from the utilisation of robotics and automation. Table 7.1 shows the classification of this large firm in terms of I4R and I4R for CE as an 'expert/frontrunner' and 'CE fast adopter'. It should be noted that the assessment results considered the company as a top runner since this large firm represents the sector of foreign joint investment, not the average automotive industry in Thailand.

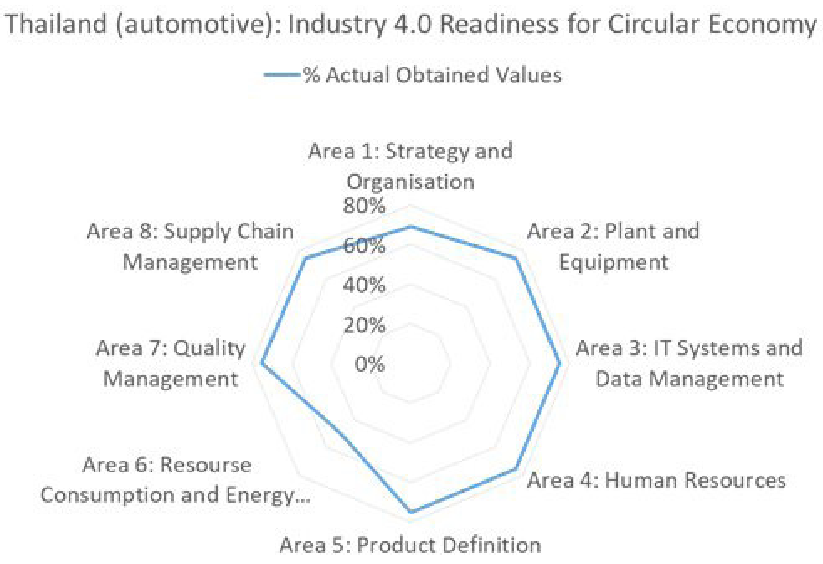
Figure 7.5: I4R and I4R for CE Assessment of a Large Automotive Firm win Thailand

(a) I4R assessment





(b) I4R for CE assessment



Source: Author.

Table 7.1: I4R and I4R for CE Survey Results for a Large Firm in Thailand's Automobile Sector

Rating Classification	Actual Obtained Value	Maximum Value	Readiness Classification	Rating
Industry 4.0 readiness	118	132	Expert/Front runner	0.89
Industry 4.0 readiness for the circular economy	40	56	CE fast adopter	0.71
Circular economy-adjusted Industry 4.0 readiness rating				0.64

Source: Author.

2. Gaps in Industry 4.0 Readiness and Industry 4.0 Readiness for the Circular Economy

For the case of the large firm in Thailand's automobile sector, the gap in I4R was not large since the policies from its headquarters are geared towards Industry 4.0, as shown in Figure 7.5(a). However, some gaps exist in I4R for CE because many early-stage actions for Industry 4.0, especially robotics, automation, and IT, require higher energy consumption but with better efficiency and fewer errors. These gaps will decrease over time when the implementation steps have been optimised to become a routine procedure.

3. Trends to Shape Future Opportunities

With global awareness and the realisation of Industry 4.0, there are plenty of future opportunities in Thailand, especially because the government has incorporated Industry 4.0 into many sectors, including industry and energy. Figure 7.6 shows the 20-year trend of the strategic development of Industry 4.0 (MOI, 2016), starting from building startups or 'one tambon one product' (where tambon is the Thai word for sub-district), strengthening small enterprises, and upgrading medium-to-large enterprises and finally sustaining them. Figure 7.6 shows how Industry 4.0 can support Thailand 4.0, the new model of Thailand's economic propulsion that aims to adjust its economic structure towards being a 'value-based economy' in order to step over the middle-income trap by transforming from traditional agriculture into new era agriculture with the following emphasis on technology management:

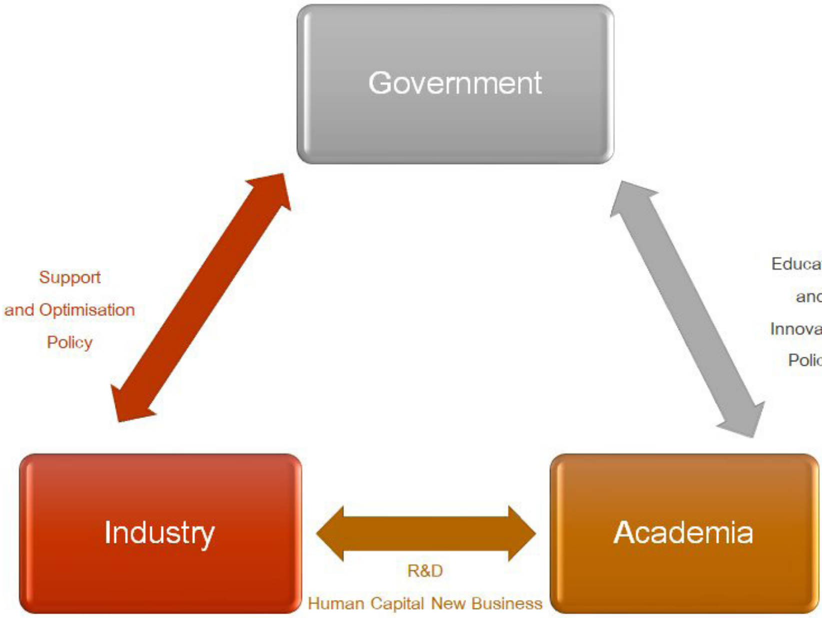
- Traditional small and medium-sized enterprises to smart enterprises with high capacity
- Low-value traditional services to achieve a high value
- Low-skilled labour to knowledgeable, specialised, and highly skilled labour

This is in order to transform the current 'industrialisation drive economy' into an 'innovation drive economy' as follows:

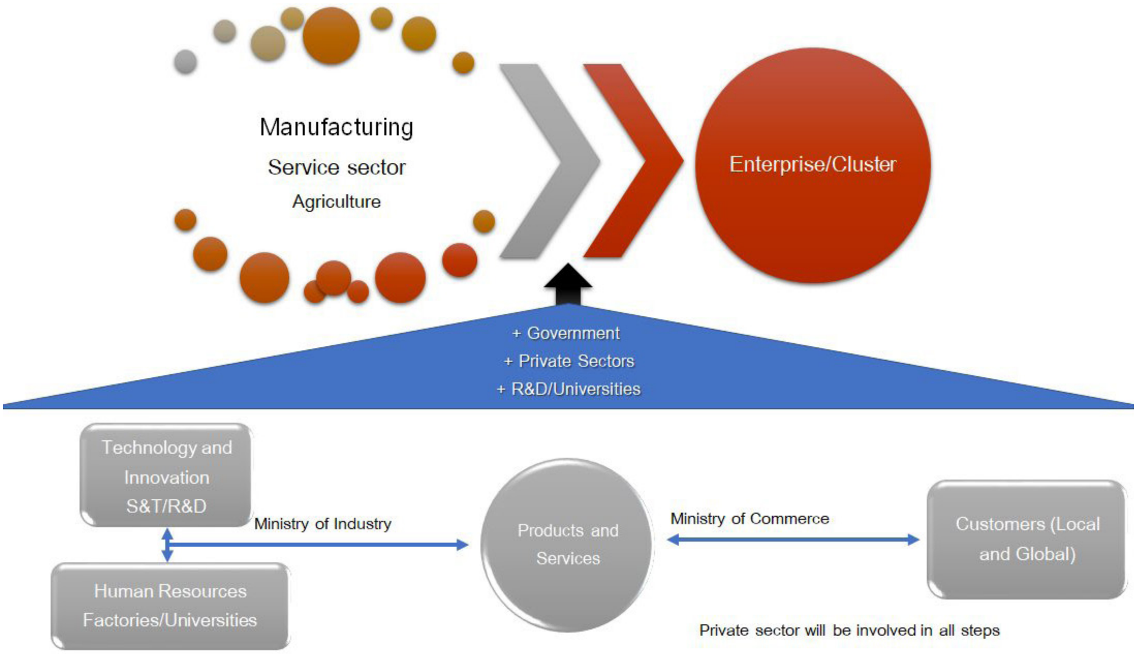
- Consumer commodities to innovative commodities
- Industry-based to technology-, creativity-, and innovation-based
- Industrial production to high value-added services

Figure 7.6: Twenty-year Industry 4.0 Roadmap

(a) To support Thailand 4.0



(b) With strategic framework



Source: Author.

The 20-year strategic plan for Industry 4.0 has the vision to move towards intellect-driven industry with linkages to the world economy and has the five following goals:

1. Average GDP growth from the industrial sector of at least 4.5% annually
2. Average investment growth of at least 10% annually
3. Average value growth from industrial exports of at least 8% annually
4. Average total factor productivity growth from the industrial sector of at least 2% annually
5. New private sector for emerging industry, 150,000 cases

4. Thailand to Prepare for the Transition

As shown in Figure 7.1(b), the transition towards Industry 4.0 will focus on first S-curve and new S-curve industries. The first S-curve industries are the following:

1. Agricultural and biotechnology
2. Smart electronics
3. Affluent medical and wellness tourism
4. Next-generation automotive
5. Food for the future

As industries are those in which Thailand has potential and expertise in production and they have created substantial economic and commercial value. However, if these industries do not invest in new technology for further improvement, they will reach saturation with low growth. Hence, new technology and innovation are keys for the continued growth of the first S-curve industries. On the other hand, new S-curve industries are:

1. Biofuels and biochemical
2. Digital economy
3. Medical hub
4. Automation and robotics

These are new industries that strongly utilise technology and innovation with a high potential for future growth. However, since these industries are new with a relatively small group of entrepreneurs, they are not yet strong and have less economic value than the first S-curve industries. Hence, it is necessary to nurture the growth of these industries' entrepreneurs. In addition to these two groups of industries, there are groups of industries that have been using traditional technology for production with limited growth potential. Some may have less economic value than the first and new S-curves industries. Hence, an industrial revolution is necessary and could comprise the following:

- Clustering of textiles, clothing, leather, and jewellery to become a fashion industry
- Increasing creative design, cultural-based design, and innovation-driven technology, like nanotech clothes for sports and specialty-clothing for medical and health applications
- Clustering of materials for industry, like composite materials development for sustainability
- Transforming petrochemical and plastic industries with clean and environmentally friendly technologies

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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

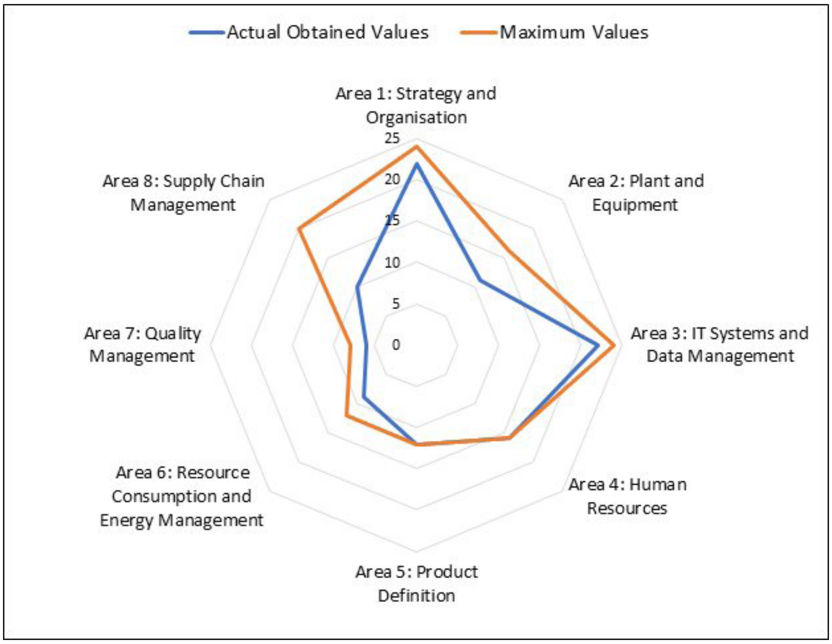
- ASEAN Proposal and Project Execution Hub from Low Voltage to High Voltage.
- Installation, commissioning, and after-sales service for the whole Siemens Energy
- The division has its factory at Pulomas Jakarta and it was established in 1975. The Pulomas factory is the oldest manufacturing facility of 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

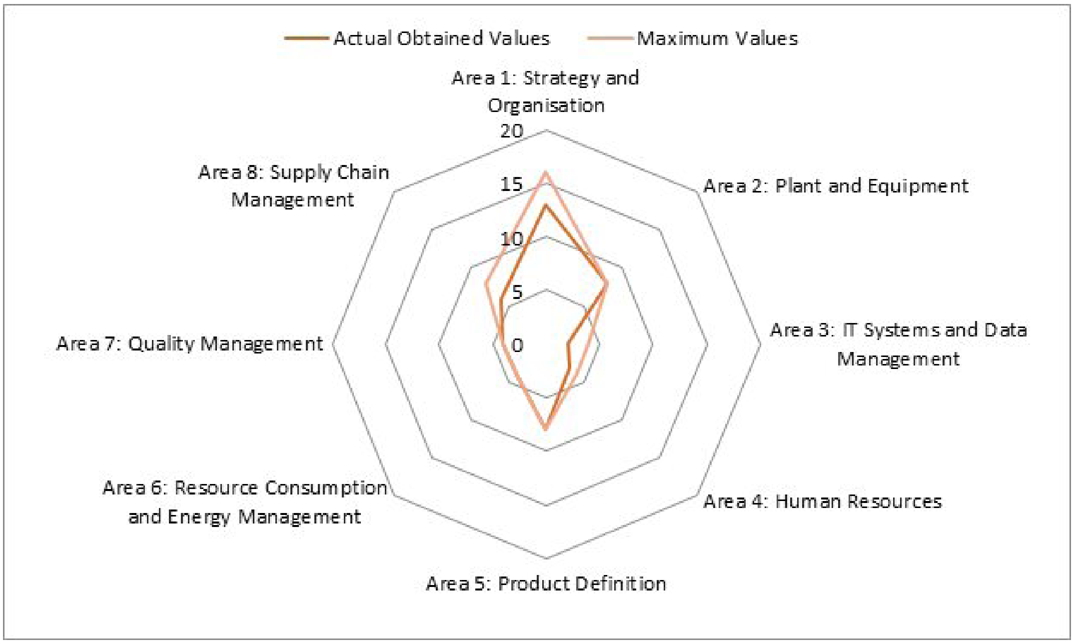
Source: Author.

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.

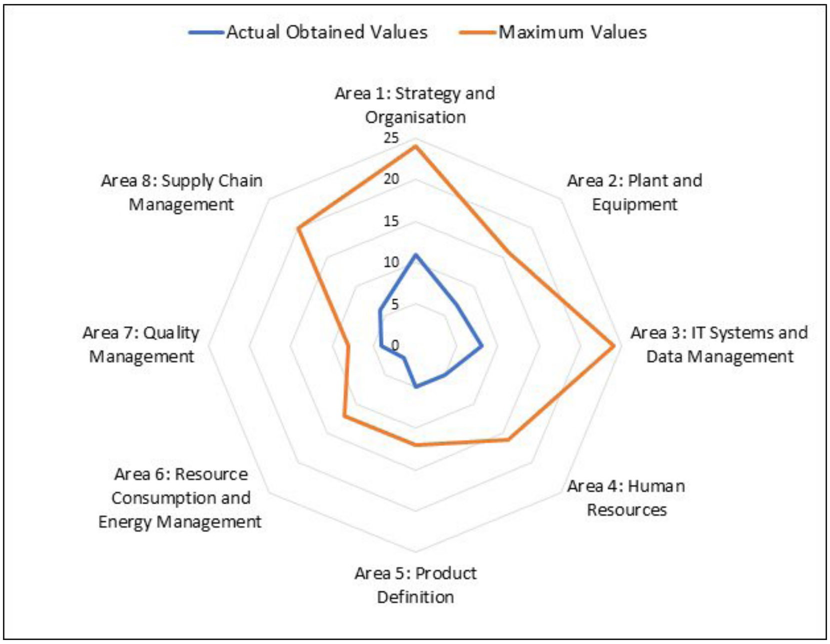
To evaluate the readiness of this industry toward Industry 4.0 for the circular economy, interviews were conducted with two textile industry experts in an office environment. The results are presented in the following Table 8.2, Figure 8.3, and Figure 8.4.

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

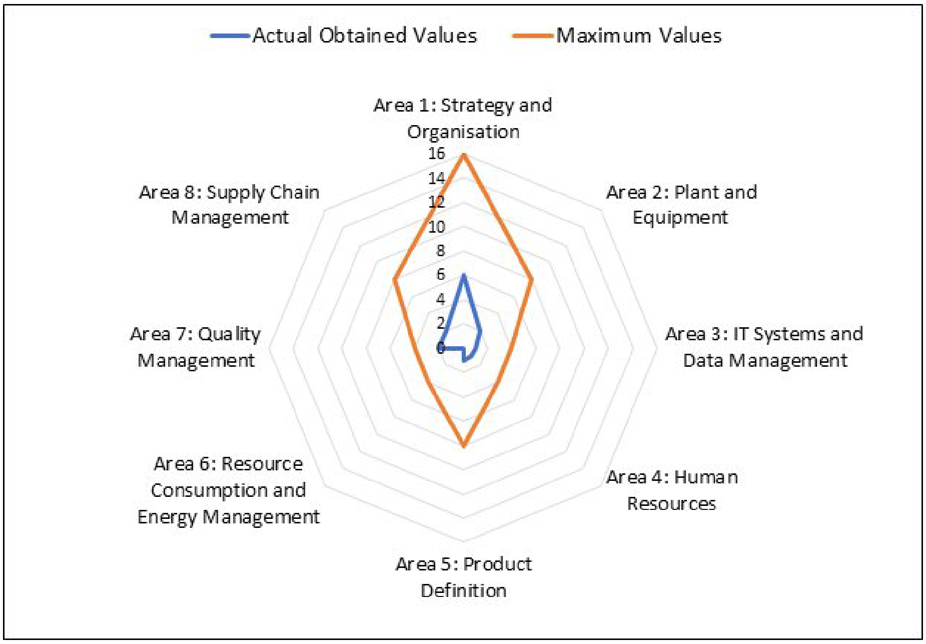
Source: Author.

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

CHAPTER 9

Benchmarking of Regional Initiatives and National Policies for Industry 4.0 and Circular Economy Transformation

Venkatachalam Anbumozhi and Michikazu Kojima

1. Overview

The Fourth Industrial Revolution and circular economy offer huge potential for transforming the Association of Southeast Asian Nations (ASEAN) and East Asian economies and realigning the future of growth towards sustainability. The widespread impacts of Industry 4.0 and the circular economy affect not only the role of governments but also the effectiveness of existing regulatory frameworks. There is a growing concern for governments' agility, adaptability, and responsiveness to the rapid change in technologies and practices for ensuring the overall welfare of society. Less attention, however, has been accorded to governments' role as enablers, or even drivers of the transformation into the circular economy that is assisted by Industry 4.0 technologies. This may partly be due to the fact that many – if not most – of these advanced technologies are largely invented, owned, disseminated, and utilised within the private sector domain. As a result, governments' abilities to minimise the unintended consequences are also limited given the extent of knowledge and access to full information of the potential and risk of those technologies. In addition, the transboundary nature of global connectivity, enabled by technological advancements, and social networks place further challenges on governments to maintain their regulatory space, particularly in the absence of a global regime for technological governance and increased global and systemic risks, such as cybersecurity (ERIA, 2019).

On the upside, Industry 4.0 and the circular economy offer a possibility for governments to promote transparent, evidence-based, participatory, and sustainable public policymaking and delivery through the deployment of advanced technologies and improved resource use. To enhance preparedness and successfully reap the benefits, a more proactive, overarching, and forward-looking approach is needed. Enhancing readiness for Industry 4.0 requires a transformation in the government's approach, work processes, and mindset, not only to provide an effective policy response but also to drive the necessary shifts in regulatory frameworks to unleash the full potential. Agile governance is a prerequisite for a country's success, which implies a policymaking process that is adaptive, people-centred, inclusive, and sustainable with multi-stakeholder efforts being put at the core (ERIA, 2018; Regional 3R Forum, 2018).

2. Regional Initiatives Related to Industry 4.0

ASEAN is creating the conditions for emerging digital technologies to benefit people and the planet under the ASEAN Community blueprints. Those initiatives are grouped under the four enabling thematic clusters of science, technology and innovation; regulatory frameworks; infrastructure and trade connectivity; and human capital.

2.1. Science, Technology, and Innovation

Science and technology: Providing an environment that is conducive to the rise of advanced technologies lies at the heart of ASEAN's regional efforts in promoting innovation and technology. This is done by setting up relevant platforms for further collaborative efforts. The ASEAN Declaration on Innovation, adopted in 2017, encouraged the establishment of regional networks of joint research, capacity building and innovation initiatives that focus on topics that enhance science, technology, and innovation collaboration with global partners through such network organisations. This is one of the policies that promote excellence and relevance in public research and encourages stronger links amongst government, academia, industry, and society to strengthen their impact on science, technology and innovation. Following this, in 2018, the ASEAN Innovation Network was established with the objective of creating deeper connections amongst the innovation ecosystems of the member countries and dialogue partners. Various elements in the ASEAN Economic Community Blueprint 2025 are linked to the dimension of innovation and technology, with relevant initiatives including those spearheaded by the regional Committee on Science and Technology and the Telecommunications and Information Technology Senior Officials Meeting, guided by the ASEAN Plan of Action on Science, Technology and Innovation 2016–2025 and the ASEAN ICT Masterplan 2020, respectively. Ongoing work under the Committee on Science and Technology includes the development of the Open Innovation and Entrepreneurship Platform, which was completed in 2019. The platform serves as a collective mechanism to engage and coordinate diverse regional and international stakeholders and to promote new entrepreneurs and technology development for the future and to challenge markets. Collaborative work with Dialogue Partners to set up new innovation platforms and centres is also being considered, including the ASEAN–India Innovation Platform and the ASEAN – Republic of Korea Innovation Centre.

Intellectual property: With the advent of technological advancements, intellectual property (IP) is a key vehicle to stimulate innovation and encourage technology commercialisation. Relevant work in ASEAN is guided by the 2016–2025 ASEAN Intellectual Property Rights Action Plan. Ongoing work includes the development of new networks of integrated IP services. There are 126 universities in ASEAN that have Technology Innovation Support Centres, which provide innovators with access to information and related services to help them exploit their innovation potential and create, protect, and manage their IP rights. Four ASEAN search databases on patents, trademarks, designs, and geographical indications are also available that support research and development work.

Patent: The number of patent applications filed in ASEAN has grown by about a 10% year-on-year average for the last five years since 2015 (Peramini, Fideles, and Karlina, 2019). New initiatives include the development of patent examination manuals on specialised fields, such as biotechnology and information and communication technology by IP Offices. Topics such as big data, Internet of Things (IoT), and artificial intelligence are all being integrated into capacity building activities to prepare the IP Offices for Industry 4.0.

Furthermore, the ASEAN Patent Examination Cooperation, a regional work-sharing programme launched in 2009, allows for the sharing of search and examination results amongst member states to expedite the process of patent applications.

Cybersecurity: Efforts have been undertaken in various technical committees. To date, work has been done under the purview of the ASEAN Ministerial Meeting on Transnational Crime, Telecommunications and Information Technology Ministers' Meeting, ASEAN Ministerial Conference on Cybersecurity, ASEAN Cyber Capacity Programme, ASEAN Regional Forum Inter-Sessional Meeting on ICT Security, and the ADMM-Plus Experts' Working Group Meeting on Cyber Security. The ministerial meetings reaffirmed the need for ASEAN to take a holistic and more coordinated approach to regional cybersecurity cooperation and capacity building. Enhancing coordination between various platforms of the three pillars of ASEAN was also underscored. The meeting participants proposed the use of the International Telecommunications Union's Global Cyber Security Index as a possible benchmark for assessing and developing ASEAN's cybersecurity readiness. Commitment towards ensuring cybersecurity is likewise echoed at the highest political level. At the 31st ASEAN Summit, the Leaders adopted the ASEAN Declaration to Prevent and Combat Cybercrime and noted the ongoing efforts to develop an ASEAN Cyber Centre and Hub to further enhance cooperation in addressing cybercrimes in the future. At the bilateral level, the Memorandum of Understanding on Cooperation to Counter International Terrorism between ASEAN and Australia was signed in March 2018. The memorandum, which implements the 2016 ASEAN–Australia Joint Declaration for Cooperation to Combat International Terrorism, provides a framework to strengthen cooperation and collaboration between ASEAN and Australia in several areas, including in law enforcement cooperation, capacity building, and technical assistance.

2.2. Regulatory Frameworks

E-commerce framework: The growth of e-commerce in ASEAN requires strong regulatory frameworks for its further development. The ASEAN Work Programme on Electronic Commerce 2017–2025 identifies updating e-commerce legal frameworks and transparent national laws and regulations on e-commerce as two of its targeted outcomes under the element of modernising the legal framework. Opportunities for regional cooperation are evident. As one of the outcomes of the work programme under the element of the e-commerce framework, ASEAN is currently developing the ASEAN Agreement on e-Commerce, which is expected to facilitate cross-border e-commerce transactions, create an environment of trust and confidence, and deepen cooperation on e-commerce in the region. The ASEAN Coordinating Committee on Electronic Commerce is also developing the ASEAN Guidelines on Accountability and Responsibilities of Online Intermediaries. Another relevant framework is the ASEAN Digital Integration Framework. The frameworks aim to monitor the progress of digital integration in ASEAN and improve ASEAN's digital ecosystem to maximise the benefits of ASEAN's digital integration initiatives.

Consumer protection: Amidst the fast-changing technological advancements, there is a heightened need for policymakers to ensure consumer protection. ASEAN work on consumer protection is guided by the ASEAN Strategic Action Plan for Consumer Protection 2016–2025, spearheaded by the ASEAN Committee on Consumer Protection. Ongoing initiatives include the development of the Guidelines on Cross-Border B2C Complaints and Code of Conduct for On-line Businesses.

Overall improvement in the quality of regulatory frameworks: An assessment is being done in specific areas related to Industry 4.0, such as e-commerce and consumer protection as explained above, as well as finance with the Working Committee on Financial Inclusion (WC-FINC) now developing the Guidance Notes on Digital Financial Services, overall improvements in the quality of regulatory practice remain key. Relevant initiatives in ASEAN include those under the ASEAN Work Plan on Good Regulatory Practice (2016–2025), such as the development of the ASEAN GRP Core Principles, which were finalised in 2018.

2.3. Infrastructure and Trade Connectivity

Infrastructure and connectivity: One of the characteristics of the ASEAN Economic Community Blueprint 2025 is enhanced connectivity and sectoral cooperation, which aims at enhancing economic connectivity involving various sectors, namely, transport, telecommunications, and energy, and in support of the vision and goals of the Master Plan on ASEAN Connectivity (MPAC) 2025.

Work is undertaken by the ASEAN Connectivity Coordinating Committee, National Coordinators, National Focal Points, and relevant ASEAN Sectoral Bodies, as well as Dialogue Partners and external parties, to implement projects under the 15 initiatives of the MPAC 2025. Efforts are currently undertaken to establish an initial list of potential priority infrastructure projects, conduct a study to advance sustainable urbanisation, and review how micro, small, and medium-sized enterprises (MSMEs) are responding to the challenges posed by the digital economy.

Trade facilitation and other relevant work: Relevant work in ASEAN also includes the timing to facilitate cross-border trade where the utilisation of technologies can serve as a means to achieving regional economic integration goals. Various initiatives under the different sectoral work plans, including on trade in goods, trade in services, and tourism as well as global value chains, can contribute to the enhancement of connectivity in the region. On trade facilitation, the ASEAN Solutions for Investments, Services and Trade was launched in 2016, providing a non-binding and consultative mechanism for the expedited and effective solution of operational problems encountered by ASEAN-based enterprises on cross-border issues. ASEAN has also developed the ASEAN Trade Repository, which provides a single point of access to all trade-related information of ASEAN Member States, such as tariff and non-tariff measures, rules of origin, national trade and customs laws and rules, and documentary requirements. While in tourism, the web-based ASEAN Tourism Professionals (ATP) Registration System, launched at the International Conference on ASEAN Mutual Recognition Arrangement on Tourism Professionals (MRA-TP) in 2016, provides not only a registration facility for certified ATPs but also serves as a job-matching platform between industry and ATPs across ASEAN, and a resource centre for all ASEAN MRA-TP related information.

2.4. Human Capital

ICT in education: Industry 4.0 has brought new challenges for human capital development, particularly given the different levels of access to training and education and the need to build digital capabilities. In the ASEAN Socio-Cultural Community (ASCC), strengthening the use of ICT in the education sector has been a key element in the ASEAN Work Plan on Education 2016–2020. To implement the work plan, new initiatives are undertaken through three main phases, namely the establishment of the

ASEAN Cyber University, as supported by ASEAN+3, to promote cross-border higher education mobility; improvement in online learning with a focus on higher education, led by the Republic of Korea (hereafter, Korea); and preparing ICT-ready teachers through the enhancement of teachers' competency, led by Singapore. These three phases aim to achieve the overarching goal of using ICT effectively for teaching and learning.

Technical and vocational education: Within the context of Industry 4.0, a greater focus has also been given to technical and vocational education. Work is currently underway towards the creation of ASEAN Technical and Vocational Education and Training (TVET) 4.0, which is part of Priority 4.2 of the ASEAN Work Plan on Education 2016–2020, i.e. strengthening regional harmonisation for the advancement of quality TVET transformation through networking, partnerships, and the mobilisation of TVET personnel and resources. Several expected outputs from the ASEAN TVET 4.0 initiative include the setting up of a strategic coordination platform to facilitate discussion on cross-cutting issues related to the harmonisation of TVET, including Industry 4.0, the development of regional guidelines and training modules/curricula for TVET personnel, such as teachers and in-company trainers, drafting of an orientation framework on quality in TVET, the establishment of a regional knowledge platform on TVET in the ASEAN region, and implementation of advanced regional training programmes for TVET personnel to develop pedagogical and institutional managerial capacity.

ICT and employment: Also under the ASCC, one of the activities in the ASEAN Labour Ministers' Work Programme 2016–2020, is a regional study on the impact of the use of ICT and outsourcing on employment relationships and on the adequacy of legislation in regulating employment relationships. Improvements in human capital are also addressed through initiatives to better integrate MSMEs into the digital economy. To this end, the ASEAN SME Academy provides online access to training and resources specifically developed and tailored to meet the needs of small and medium-sized enterprises (SMEs) operating in ASEAN. Meanwhile, the ASEAN SME Service Centre is a web portal with regional linkages, providing information crucial for SMEs to help them access regional and international markets.

3. National Policy Initiatives Related to Industry 4.0

A country's ability to implement Industry 4.0-type technologies is contingent on its economy-wide readiness, capacity, and alignment with its respective national priorities. A non-exhaustive list of major national initiatives related to Industry 4.0 undertaken by the countries in Southeast Asia is shown in Table 9.1. The focus is on the objectives of the initiatives, the implementing period, specific targets, priority areas, and implementing agencies. Most of the countries have put in place major, cross-sectoral, comprehensive national initiatives related to Industry 4.0. The strategic importance of having such cross-sectoral comprehensive initiatives is that it allows cross-sectoral cooperation and coordination, which is particularly important given the fact that the Industry 4.0 regime itself is emerging and is interdisciplinary in nature.

Table 9.1: List of Major National Initiatives in ASEAN Related to Industry 4.0

Country	Policy Initiatives/Strategies
Brunei Darussalam	National Digital Strategy 2016–2020 – National ICT White Paper for Brunei Darussalam (2016); The Digital Government Strategy 2015–2020 (2015); National Broadband Policy 2014–2017 (2014)
Cambodia	Cambodian ICT Masterplan 2020 (2014); Telecommunication ICT Development Policy 2020; signing of the MoU with Microsoft on ICT cooperation (2016)
Indonesia	Launch of 'Making Indonesia 4.0' Roadmap (2017); Indonesia Broadband Plan 2014–2019
Lao PDR	E-Government Development Plan 2013–2020 (2013); signing of the MoU with Microsoft (as part of Microsoft's National Empowerment Plan) (2016); National Strategies for Science and Technology Development 2013–2020 and Vision 2030 (2013)
Malaysia	Development of the National Industry 4.0 Policy Framework (2018); Establishment of Industry 4.0 High Level Task Force (2017); launch of the Centre of Excellence on Industry 4.0 (2017); launch of the Digital Free Trade Zone (DFTZ) Initiative and Pilot Project (2017); The Malaysian ICT Strategic Plan 2016–2020 (2016); launch of the National e-Commerce Strategic Roadmap (2016); 11th Malaysia Plan 2016–2020 (2015); National IoT Roadmap (2015); National Broadband Initiative (2006)
Myanmar	Development of the Digital Economy Development Masterplan (2017); Universal Service Strategy 2018–2020 (2018); e-Government Masterplan 2016–2020 (2014);
Philippines	Inclusive, Innovation-led Industrial Strategy (i3s) (2017); Philippines Digital Strategy 2011–2015 (2011); National Broadband Plan; e-Government Master Plan 2016–2020 (EGMP 2.0)

Country	Policy Initiatives/Strategies
Singapore	AI.SG Initiative (2017); Research Innovation Enterprise 2020 Plan (2016); Industry Transformation Programme (2016); Intelligent Nation 2015 (2015); National Robotics Program (2015); Smart Nation (2014)
Thailand	Digital Government 2017–2021 (2017); Thailand 4.0 (2016); National Digital Economy Master Plan (2016–2020); Digital Economy Master Plan (2015)
Viet Nam	Prime Minister's Directive 16/CT-TTg on Strengthening Access to the Fourth Industrial Revolution (2017); Ministry of Industry and Trade's Decision 4246/QD-BCT (2017); Prime Minister's Decision 844/QD-TTg (2016); 2020 Broadband Plan (2016)

ICT = information and communications technology, IoT = Internet of Things, MoU = memorandum of understanding.
Source : Compiled by the authors from various documents.

4. National Targets for Resource Use Efficiency under the Circular Economy Paradigm

In developing circular economy policies that are based on resource efficiency principles, governments should include provisions for measuring baselines, quantifying problems, setting targets, and monitoring the progress towards achieving them through benchmarking. Quantitative targets and indicators are useful in determining the level of change required while also allowing for comparisons between companies or different government initiatives (Park, Sarkis, and Wu, 2010). At the same time, targets are useful at the national level to orient action by governments. Furthermore, indicators can help in measuring the progress of specific actions to improve resource efficiency against the predefined targets.

Recent reviews of resource efficiency in the fast-growing economies of Asia have shown that the definition of national quantitative targets is important to show ambition, create a commitment, and send clear policy signals for a circular economy. For example, the World Energy Council (2008) found that quantitative targets for improving energy efficiency could help avoid disjointed actions and provide a long-lasting context for energy efficiency policies. Setting energy efficiency targets can form the basis for monitoring national policy outcomes and tracking progress.

Resource efficiency targets must be sufficiently clear for key stakeholders, such as specific government agencies, industry, and consumers, to understand them and act on them. The targets should integrate different policy fields and provide verifiable interim results for material flow indicators and targets (Li et al., 2010).

A recent evaluation showed that several countries in the region have now adopted national energy efficiency programmes with quantitative targets. Yearly monitoring is usually a requirement of such programmes.

ASEAN has initiatives to measure resource efficiency across its national economy. Table 9.2 presents the national targets for achieving material, energy, and water efficiency in selected countries. Some countries have set ambitious resource productivity, recycling, and waste reduction targets in the water and energy sectors. The targets undergo yearly performance measurements and are supervised. Japan, China, and Singapore are other countries that have set targets in all three key areas of resource efficiency, which includes material efficiency. Overall, targets for achieving resource efficiency are more commonly used than material or water efficiency targets.

Table 9.2: Resource Efficiency Targets in ASEAN and East Asia

Country	Material Efficiency	Energy Efficiency	Water Efficiency
Philippines	Achieve a waste conversion rate of at least 25% by 2025	Reach average annual energy savings of 23 million barrels of fuel oil equivalent	
Singapore	• Reach 60% of household waste recycling by 2025 • Achieve a recycling rate of 70% by 2030	Improve energy efficiency by 35% from 2005 levels by 2030	Reduce domestic water consumption to 140 litres per person per day by 2030
Thailand		Reduce energy consumption by 13% in 2010 and 20% in 2020	Reduce water use by 10% between 2020 and 2030
Viet Nam		Reduce total energy consumption by 3%–5% (2010–2015) and then by 5%–8% (2015–2020)	

Source: Compiled by authors from various documents.

5. National Policy Initiatives for the Circular Economy

Comprehensive policies comprising both regulatory and market-based tools are needed to achieve the circular economy. Once goals and targets for resource efficiency have been set, governments need to assess what policy tools and instruments are available to achieve them and how these can be effectively implemented. Several recent reports discuss policy instruments that may be used to promote resource efficiency. Currently, governments have a wide choice of different instruments to formulate a sound policy framework for resource efficiency. In ASEAN over the past two decades, policy instruments have gradually evolved from traditional command-and-control regulations to economic instruments, information-based measures, and voluntary initiatives. An optimal mix of policy instruments will frequently include all four of these approaches. It is unusual for a single market-based policy instrument, such as extended produced responsibility, to operate in isolation in ASEAN countries (Walls, 2006). In most situations, a mix of instruments is used to tackle a specific circular economy problem. There are many advantages to using a mix of policy instruments, including: (a) accounting for the multi-aspect nature of circular economy challenges, (b) enhancing the effectiveness of one instrument with the help of another and vice versa, and (c) reducing administrative costs and improving enforcement possibilities (Yoshida, Shimamura, and Aizawa, 2007).

The challenge for policymakers in ASEAN is to select an appropriate combination of policy instruments to meet specific objectives while also having a positive economic and social impact. Policy instruments should be combined in a way that provides a balanced and sound approach to promoting resource efficiency while being tailored to the unique context of local or national conditions. They must also be mutually reinforcing and without perverse incentives.

To achieve greater resource efficiency, policymakers try to shift companies' or householders' actions from current wasteful practices to those that conserve resources. These attempts usually call for a twofold policy approach, which includes both measures aiming to phase out the undesirable product and behaviour as well as measures to increase the market for more sustainable products.

In addition, shifting from less desirable products and behaviours (laggards) to better ones (front runners) requires policies that stimulate innovation, both for individual products and at the system level. For example, in addition to improving the fuel efficiency of automobiles, there is also a need to support the development of new energy sources for vehicles, to facilitate the dissemination of social innovations such as car sharing, to improve public transportation systems as viable alternatives to cars, and to reduce mobility needs through better city planning.

There are four generic groups of policy instruments being adopted in ASEAN countries that can be used to promote the circular economy. It is important to note that it is usually difficult to categorise a policy measure as being purely ‘regulatory’, ‘economic’, ‘information-based’, or ‘voluntary’. Instead, there is often overlap between them.

5.1. Regulatory Instruments

Traditional regulatory instruments set legal standards in relation to resource efficiency and performance, pressures, or outcomes. They are often referred to as command-and-control instruments in the economic literature and have traditionally been favoured by governments to carry out environmental policy. Regulatory instruments are policy mechanisms that are non-voluntary in nature and they compel resource use change by the threat of penalties for non-compliance. Penalties are set by legislation and are used to influence the behaviour of users by encouraging them to avoid punishment for non-compliance. Traditional regulatory instruments have several benefits, which explain their widespread use in circular economy policymaking. For governments, the setting of standards is inexpensive, and the goals for policy achievement are clear. They also impose minimum performance requirements and mandate compliance.

On the other hand, traditional regulatory instruments are often seen as inflexible and costly to enforce, and they provide incentives only to avoid penalties rather than to improve outcomes. Also, industries are reluctant to follow the regulations, arguing that uniform regulation ignores the unique situation of each company and imposes excessive costs due to the ineffective allocation of the compliance burden. This resistance can even make some regulations impossible to implement. The shortcomings of traditional regulatory instruments and the difficulties of implementing them effectively do not imply that they should be avoided or replaced. Rather, it is important to develop more dynamic and flexible policy approaches to a circular economy. This can be achieved by combining regulatory instruments with other types of policy tools and by introducing regulatory instruments sequentially.

In recent years, we have seen a trend in the development and implementation of more innovative and flexible regulatory instruments to promote resource efficiency in other parts of the world, which individual countries can look into. They typically not only include standards on emissions or technologies and environmental liability but also extend producers' responsibility via product take-back, environmental controls, enforcement through permits and inspection by authorities, and other measures to mobilise public action to change the patterns of production and consumption in order to improve resource efficiency.

Many countries in ASEAN and East Asia region have introduced regulatory instruments to promote resource efficiency. These include: (a) laws and regulations to promote energy efficiency and renewable energy (for example, New Zealand's Energy Efficiency and Conservation Act 2000, Japan's Energy Conservation Law 1997 and 2008 and its Top Runner standard programme, China's Energy Conservation Law 1998 and 2008, and India's Energy Conservation Act 2001); (b) laws and regulations to promote resource efficiency and sustainable production and consumption (for example, Japan's reduce, reuse, and recycle (3R) laws and China's Circular Economy Law 2008 and Cleaner Production Law 2002); and (c) laws to promote low-carbon and green growth, such as Korea's Framework Act on Low Carbon and Green Growth initiated in 2009. These new regulatory instruments typically define various stakeholders' responsibilities (including those of governments at all levels, businesses, and consumers) and combine the traditional command-and-control and legal liability approach with economic instruments, information disclosure, and governmental procurement measures.

5.2. Economic and Market-based Instruments

The two most notable advantages of economic instruments over traditional regulation are their cost-effectiveness and their ability to provide incentives for innovation and improvement beyond a certain level of performance.

However, in order to obtain the desired effects, economic instruments usually require sophisticated institutions for implementing and enforcing the instruments, particularly in the case of charges and tradable permits.

Charges and taxes need to be collected, and monitoring is required to avoid 'free-riding' practices. Tradable permits are particularly challenging in implementation; creating a well-functioning market may require a fairly large administration, and the regulated entities usually need training in how to use the permit market effectively. Another drawback of economic instruments is that their effects on resource consumption are not as predictable as under a traditional regulatory approach. There are many different types of economic instruments, such as subsidies (including the removal of environmentally harmful subsidies), taxes (on emissions or products), rebates (on tax and purchases of resource-efficient products), tradable permits, and deposit refund schemes.

5.3. Information-based Measures

Information-based measures have become more popular in ASEAN recently. This is partly because of the lower costs of dissemination brought by information technology. These policy instruments provide information about the resource efficiency of certain products, services, or systems in a standardised manner so that consumers and investors can make more informed decisions. Approaches such as public information campaigns, eco-labelling schemes, research and development, and the public disclosure of a company's environmental performance are used to generate knowledge about the adoption of resource-conserving practices. Information-based measures may be mandatory or voluntary.

One of the advantages of information-based measures is their low implementation costs compared with the complex administration need for regulatory instruments. In addition, they can raise public awareness about more sustainable consumption patterns and provide incentives to companies for reducing their environmental burden in order to avoid competitive disadvantage. Information-based measures can also enhance the effectiveness of economic instruments, such as environmental taxes, especially if they convey information on private benefits. Conversely, the effectiveness of information-based measures largely depends upon the reactions of the information recipients (Karl and Orwat, 1999). Approaches such as eco-labelling can be ineffective in markets where consumers have low awareness levels of environmental issues or where the amount of discretionary spending is low.

One of the most common information-based measures in ASEAN is the use of eco-labelling schemes. These schemes display information about the environmental performance of a product or service so that consumers can make informed choices when purchasing. Several states have introduced programmes to help create a market preference for resource-efficient products and equipment. For example, the Green Leaf Scheme has been developed to conserve resources, reduce pollution, and improve waste management. Environmental certification is awarded to products – such as refrigerators, computers, air conditioners, and building materials – which are shown to have the least detrimental impacts on the environment. Participation in the scheme is voluntary. Another regional example is Singapore's Energy Smart Building Labelling Programme, which seeks to promote energy-efficient buildings. This eco-label awards office buildings, hotels, and retail malls that perform in the top 25% in terms of energy efficiency within their cohort.

Education at the firm level and consumer level is another important information-based measure and is critical to the decision-making process. ASEAN countries have introduced educational programmes to enhance knowledge in their populations about resource-efficient behaviour. For example, the Government of Thailand introduced the 'Re-thinking Waste-in-Schools Education Programme' to promote awareness of resource efficiency issues within school communities. The Bureau of Energy Efficiency has proposed an environmental tax reform that entails a reconsideration of the present tax system. It seeks to use the revenue from environmental taxes to reduce the tax burden on beneficial economic activities, such as investment or employment. It thereby shifts the tax burden towards the 'bads', such as pollution, waste, and resource depletion and away from the 'goods' such as employment, income, and investment.

Opinions differ concerning the effectiveness of voluntary initiatives to achieve circular economy outcomes. On the one hand, voluntary initiatives are more flexible than traditional regulatory instruments.

Geller et al. (2006) found that voluntary agreements between governments and the private sector can be effective, especially in situations where regulatory instruments are difficult to enact or enforce. In Europe and Japan, for example, voluntary agreements have led to significant reductions in industrial waste use in a number of sectors.

In contrast, voluntary initiatives usually work well when people also have another incentive to change their behaviour. It is believed that voluntary initiatives are likely to be more effective if there is a threat of command-and-control regulation being put into use (Bengtsson et al., 2010). For instance, Price (2005) found that initiatives that combine voluntary efforts with a mix of incentives and penalties have higher participation rates and are generally more successful at meeting their predetermined targets.

Management standards, such as the ISO 14000 series, can also be understood as a voluntary initiative. Although such standards are not policy tools in a strict sense, they can be used by policymakers for circular economy goals, for example, by requiring all major suppliers and governmental agencies to be certified. In addition, ISO 14000 management systems require the certificate holder to identify key indicators of environmental impacts, set targets, and follow up on achievements.

Firm-based resource efficiency standards are also emerging as an important influence on the circular economy in ASEAN countries. These standards are uniformly applied to all plants worldwide and are not tied to the local regulatory requirements of the place where they are located. This typically means that a plant is required to go beyond compliance with local and national standards in order to meet firm-based global environmental standards. Economic globalisation is the underlying key driver for firm-based resource efficiency standards. There is also growing external pressure on firms and industries around resource efficiency and pollution issues, which makes firms face the risk of damage to their brand reputation (Angel and Rock, 2005). Nowadays, firms are challenged with managing complex global production networks at multiple sites of production with different regulatory expectations and with a need to respond to a variety of end-market regulations. As a consequence, firms are adopting their own global standards as a necessary way to operate their global production networks.

6. Current Sectoral Policies That Promote Resources Efficiency and Support the Circular Economy

6.1. Resource Efficiency

Resource efficiency can be defined as the amount of materials needed to produce a particular product. Material efficiency can be improved in two ways. First, by reducing the amount of materials contained in the final product. Second, by reducing the amount of materials that enter the production process but end up in the waste stream. Numerous countries in ASEAN have implemented national policies to promote material efficiency (Table 9.3).

Table 9.3: Examples of National Policies, Laws, and Regulations to Promote Resource Efficiency

Country	Policy Initiatives/Strategies
Cambodia	• Law on Environmental Protection and Natural Resource Management (1996) • Sub-decree on Solid Waste Management (1999)
Indonesia	• Environmental Protection and Management Act No. 32 (EPMA 32/2009) • Law No. 18/2008 on Municipal Solid Waste Management: 3R as the Principle Approach for Waste Management Law No, 33/3009 on Hazardous Waste • Government Regulation No. 81/2012 on 3Rs and EPR President Regulation No. 97/2017 on Policy and National Strategy of MSW • GP 101/204 Packaging under Law 18/2008; Government Regulation (e-waste) under Law 39/2009
Malaysia	• Solid Waste and Public Cleansing Management Act (2007): Aims to improve the collection, recycling, and disposal of solid waste. Prescribed recycling and separation of recyclables. • National Strategic Plan for Solid Waste Management (2005): Comprehensive efforts to promote the reduction, reuse, and collection of solid waste. There are eight regulations on 3R within the solid waste act. • Environmental Quality Act 1974
Philippines	• National 3R policies: Set the goal of achieving a waste conversion rate of at least 25% (2000). • Ecological Solid Waste Management Act (2000): Mandates management for 'zero waste' as a national policy. Requires local governments to recycle 25% of waste collected. • PD 1152 – Philippine Environment Code (1977), RA 8749- Philippine Clean Air Act of 1999 RA 9275- Philippine Clean Water Act of 2004

Country	Policy Initiatives/Strategies
Singapore	• Green Plan 2012: Has a 'zero landfill' objective. Includes a national recycling programme for households launched in 2001 with the target of 60% recycling by 2012. The recycling rate in 2009 was 57%, to 70% by 2030, with the goal of becoming a zero-waste nation. • Environmental Public Health (general waste collection) Regulations; Environmental Public Health (toxic industrial waste regulations)
Thailand	• Enhancement and Conservation of National Environmental Quality Act (1992), Factory Act (1992), and Public Health Act (1992); maintenance of public sanitary order Act 1992 • Regulation on National Waste Management System 2007, Draft WEEE Act, Draft Waste Management Act, Draft Promotion of 3Rs and Utilization of Waste • National Solid Waste Management Master Plan, Action Plan 'Thailand Zero Waste', 2016
Viet Nam	• National 3R Strategy: Sets 3R targets for 2020. • Environmental Protection Law (2005): Includes 14 provisions to promote 3R and related activities. • Law on Environmental Protection 2014 (amended in 2014) • National Solid Waste Management Master Plan to 2025, Vision to 2050

3R = reduce, reuse, recycle.
Source: Compiled by the authors.

Resource efficiency has also developed into an important issue for local governments, which introduced the smart city and eco-town concepts to support the circular economy and resource scarcity associated with rapid economic development. The smart city operation plan requires low resource consumption, low emissions of pollutants, and minimal waste discharge using the 3R principles. Smart city plans also recognise that the development of a circular economy is an important strategy for economic and social development, and industrial enterprises are required to reduce resource consumption and recycle waste materials (Organisation for Economic Co-operation and Development, 2016). The governments also allocate funds for businesses to encourage innovation in recycling technologies. Furthermore, the central government provides tax breaks to enterprises using resource-efficient technologies and equipment. The enforcement of smart cities requires the enactment of supporting regulations; some of these have been enacted while others are still being drafted. Another important future step outlined in the law is the development of a Smart City Development Plan, which will outline the major tasks and measures necessary for achieving a circular economy. In addition, it will define indicators for the rates of waste reuse and recycling.

6.2. Energy Efficiency

Energy efficiency is associated with economic efficiency and includes technological, organisational, and behavioural changes towards a circular economy. The introduction of energy efficiency policies brings multiple benefits to national economies. The industry sector in ASEAN countries accounts for about 30%–45% of total commercial energy consumption. It is one of the largest contributors to carbon dioxide emissions after the power sector. A broad analysis of industrial energy-use patterns shows that seven sectors account for about 60% of industrial energy consumption: (a) cement, (b) pulp and paper, (c) fertiliser, (d) iron and steel, (e) textiles, (f) aluminium, and (g) chlor-alkali. Most of the plants in these sectors are large units, and few of them are operating under the public sector. Although no detailed baseline of energy consumption data for industrial consumers is available from a single source, it has been found from several individual studies that significant potential exists for energy efficiency improvements in industry. Various energy sector studies also show that there are wide variations in specific energy consumption (energy required to produce one unit of the product) within the same industrial subsector using comparable technology. Though some units exhibit energy efficiency levels that are at the global frontier, a large number of units operate at much lower energy efficiencies. This indicates that there is substantial scope for energy efficiency improvements within industrial sectors.

Table 9.4: Examples of National Policies, Laws, and Regulations to Promote Energy Efficiency

Country	Policy Initiatives/Strategies
Indonesia	National Energy Policy (2006): Framework policy that seeks to increase energy efficiency and promote renewable sources of energy.
Malaysia	10th Malaysia Plan (2011–2015): Includes energy efficiency objectives, such as intensifying energy efficiency initiatives in the industry, transport, and commercial sectors, also promoting the greater use of renewable energy for power generation and by industry.
Philippines	• National Energy Efficiency and Conservation Program (2004): Seeks to achieve the efficient use of energy to minimise environmental impacts. Target to achieve average annual savings of 23 million barrels of fuel oil equivalent and 5,086 gigatonnes of carbon dioxide emissions avoidance. • Philippine energy efficiency Project (2009–2013); Lighting Industry Waste Management Guidelines

Country	Policy Initiatives/Strategies
Singapore	Energy Efficient Singapore Strategy (2009): Promotes the adoption of energy-efficient technologies and measures by addressing market barriers to energy efficiency. Builds capacity to drive and sustain energy efficiency efforts and to develop the local knowledge base and expertise in energy management. Raises awareness amongst the public and businesses to stimulate energy behaviour and practices. Promotes research and development to enhance Singapore's capability in energy-efficient technologies.
Thailand	• National Energy Strategy (2005): Key component was the efficient use of energy to reduce energy consumption by 13% by 2008, by 20% by 2009, and by 50% by 2030. • Energy Conservation Promotion Act (1992, revised in 2007): Promotes the use of energy-efficient materials and equipment by setting energy-efficient standards. • National Energy Policy and Development Plan (2006): Seeks to promote energy efficiency by setting standards for energy-intensive appliances and the labelling of products. • The National Integrated 5-Year Plan (2014–2021) on the Management of Waste Electrical and Electronic Equipment (WEEE) (2015)
Viet Nam	• National Energy Efficiency Program (2006–2015): Seeks to coordinate efforts for improving energy efficiency, reducing energy losses, and implementing extensive measures for the conservation of energy. • Law of Energy Conservation and Efficiency Use (2011–2015): Target to reduce total energy consumption by 3%–5% (2006–2010) and then by 5%–8%. • 16/2015/QD-TTg (batteries, lubricant oils, and end-of-life vehicles

Source: Compiled by authors.

7. Conclusion

With rapid economic growth, the resource consumption rate has increased greatly in ASEAN and East Asia. Soon, most of the countries will be facing formidable challenges in resource shortages. Therefore, implementing circular economy principles along with Industry 4.0 is crucial for Asia's process industries and municipal governments. Based on the meta-analysis in several economies of the region, it is understood that governments have instituted the basic policies for developing Industry 4.0 and a circular economy, with the aim of improving the efficiency of resources and energy and thereby achieving sustainable development.

Based on the trajectory of Industry 4.0-readiness and circular economy-enhancing initiatives, three stages of transformation can be conceptualised. The first stage is to implement initiatives on the areas of ICT, national broadband, and e-government. These are typically conducted by countries that just embark on their journey in the digital economy. National broadband initiatives usually give a focus on broadband access, both coverage and affordability. E-government has also been identified as a focus area in 'early stage' initiatives. These include Cambodia's ICT Masterplan 2020, Lao PDR's E-government Development Plan (2013–2020), and Myanmar's E-government Masterplan 2016–2020.

The second stage is to deliver a specific initiative on Industry 4.0 and a major national initiative on digital strategy for those at a later stage of Industry 4.0 readiness-enhancing development. In ASEAN, these include Thailand 4.0 and Making Indonesia 4.0, and ongoing efforts by Malaysia to develop the National Industry 4.0 Policy Framework as well as Brunei Darussalam's National Digital Strategy 2016–2020, the Philippines' Digital Strategy 2011–2016, and Viet Nam's Prime Minister Directive 16/CT-TTg on the Strengthening of the Ability to Access the Fourth Industrial Revolution. For the case of Thailand, however, Thailand 4.0 as an aspirational economic model came relatively early in the journey and has later driven the development of strategies such as those on digital government that were implemented by other ASEAN countries in the earlier stages.

The third stage focuses on more advanced technology-specific initiatives or themes. This is done by advanced countries such as Singapore, which is currently undertaking initiatives in areas such as artificial intelligence, robotics, IoT, advanced manufacturing, and smart nation. Other countries, such as Malaysia and Thailand, have also commenced similar initiatives, such as Robotics Malaysia, which is a government-academia-industry collaboration project to develop the resources needed to develop a sustainable robotics industry in Malaysia, and the setting up of the Center of Robotic Excellence in Thailand to develop at least 150 prototype robots.

However, more attention is needed for setting the targets, identification process, and institutional integration of Industry 4.0 for the circular economy. Traditionally, creating economic value and promoting environmental stewardship have been regarded as a zero-sum game. One important way of escaping this zero-sum game is to use innovative financing and an integrated policy approach involving the application of regulatory, economic, and voluntary policy instruments, as demonstrated by progress in implementing policies that support Industry 4.0 circular economy concepts.

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CHAPTER 10

ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool

Venkatachalam Anbumozhi and Dian Lutfiana

1. Overview

An important role in building a combined strategy for Industry 4.0 and the circular economy are the results of the assessment of the readiness to adopt and adapt the initiatives. The readiness of policymaking and the business community is often defined as the ability to capitalise on future productivity and resource efficiency opportunities, mitigate risks and challenges, and be resilient and agile in responding to unknown future uncertainties. Amongst the policy considerations for assessing the readiness of national economies for Industry 4.0 and the circular economy are categories such as technology and innovation, trade and investment, institutional arrangements, sustainable production, consumption, and human resources development. In the area of the company standalone assessment of readiness, several categories of indicators are influential, including strategy and organisation, smart factory, digitalisation of operations, eco-products, data-driven services, and connectivity in the supply chain.

The Economic Research Institute for ASEAN and East Asia (ERIA)-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (ERIA-I4RCE) is aimed to help policymakers and businesses think about their readiness for change and implement the related decisions. This tool is developed based on in-depth studies conducted by ERIA and complements information and research presented elsewhere (ERIA, 2016; ERIA, 2018) and the capacity building programmes conducted at ERIA.

It includes separate sections for policymakers and company managers. While grounded in research, theory, and practice, the self-assessment tool has been verified by policymakers in the region and validated with a pilot firm-level assessment.

2. Purpose and Target Audience

The ERIA-I4RCE self-assessment tool is primarily a tool for policymakers and firm-level managers and those who advise them to evaluate their country and company readiness with indicators encompassing policies and regulations, procedural efficiency, and cross-cutting issues. It comprises a suite of indicators assessing categories of drivers, modifiers, and facilitators of transformation to Industry 4.0 and the circular economy in an integrated way. Policymakers, business decision makers, researchers, and educators can use this tool to assess readiness in two ways:

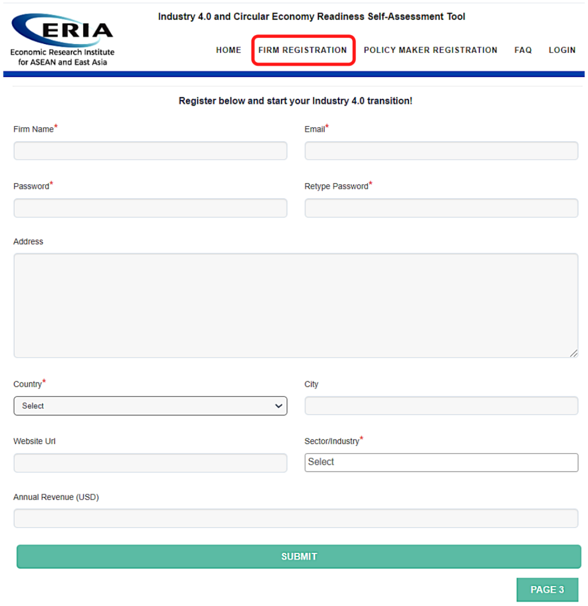
- Readiness to change from the established ways of doing things to address the identified strategy, needs, or opportunities available with Industry 4.0
- Readiness for the implementation of a specific programme, practice, or other policy intervention in support of the circular economy

The results of the integrated assessment will prepare the involved stakeholders for successful changes in initiatives and proactively build capacity in needed areas.

3. Tool Structure

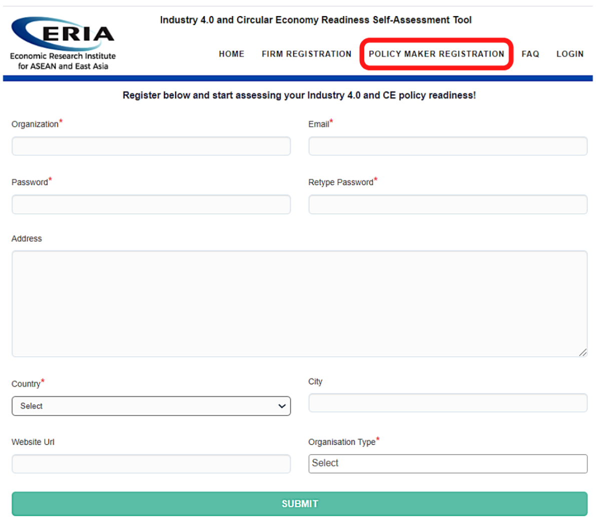
The self-assessment is divided into two sections: the firm section and the policymaker section. Each section has two parts to the assessment: first, assessment of Industry 4.0 readiness; and second, the extent of the circular economy in Industry 4.0, including an assessment of policy readiness for both Industry 4.0 and the circular economy. To begin the assessment, the assessor needs to register as either a firm or policymaker. The registration webpage aims to summarise the background of the organisation. Figures 10.1 and 10.2 show the registration page on the website.

Figure 10.1: Firm Assessment – Registration Webpage



Source: ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (http://i4r-eria.org/).

Figure 10.2: Policymaker Assessment – Registration Webpage



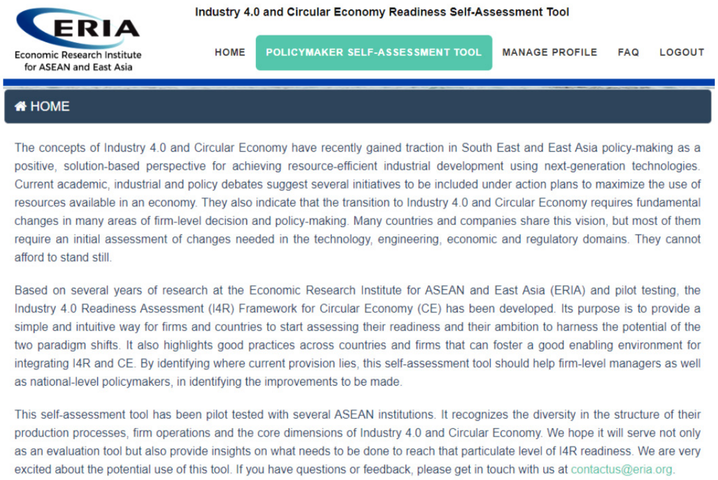
Source: ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (http://i4r-eria.org/).

After successfully registering, the user will be directed to the assessment page, which contains the assessment questions, assessor's profile page, and frequently asked questions (FAQ) as captured in Figures 10.3 and 10.4. An assessor can complete the assessment at a later time by logging in again to their account (Figure 10.5).

Figure 10.3: Firm Self-Assessment Webpage

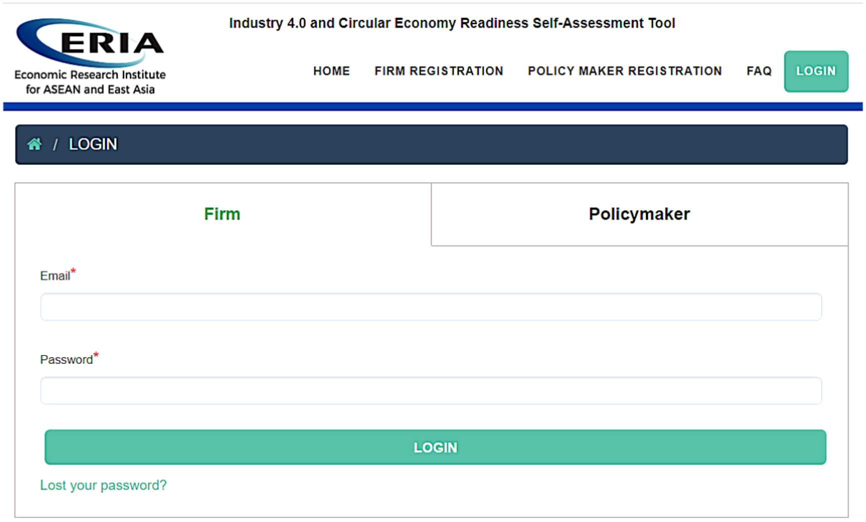
Source: ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (http://www.i4r-eria.org/survey)

Figure 10.4: Policymaker Self-Assessment Webpage



Source: ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (http://www.i4r-eria.org/survey)

Figure 10.5: Login Webpage



Source: ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (http://i4r-eria.org/login).

In terms of the question structure, the assessment uses a rating method for each indicator. The assessor needs to identify their firm or policy readiness based on level-based questions, where level 0 represent hesitators and level 4 represents frontrunners in considering implementing Industry 4.0 and the circular economy.

The next section provides more details on the assessment for both firms and policymakers.

3.1. Firm Self-Assessment

Industry 4.0 is talked about extensively as the Fourth Industrial Revolution that will have a major impact on manufacturing value-chains at both the local and global levels. This transformation is being driven by several foundational technological advances that enable sensors, machines, workpieces, and information technology (IT) systems to be linked along a value chain.

In such a rapidly evolving manufacturing landscape, nations and firms that are not ready to move towards an Industry 4.0 setting risk falling irrevocably behind their major competitors. From using Internet of Things (IoT) devices to providing teams with real-time supply chain data, and to utilising artificial intelligence (AI) for incorporate inbuilt intelligence into factory automation, innovative firms across the world are using Industry 4.0 advances to transform their manufacturing efficiency. However, transitioning to Industry 4.0 presents many difficulties for firms. The most critical is their inability to self-evaluate their state of development regarding their Industry 4.0 vision, thereby making it difficult for them to identify specific steps that need to be taken in terms of actions, projects, and programmes. Using Industry 4.0 is also crucial to make the transition from a linear to a circular economy happen. A circular economy represents a fundamental and necessary alternative to the take-make-consume-dispose model that currently predominates the industrial production system.

To help firms to carry out this self-evaluation, ERIA's self-assessment tool provides a scoring rubric that will enable firms to assess their strengths and weaknesses concerning critical determinants that can influence the pace and quality of transition to an Industry 4.0 setting. The first part of this rubric aims to help firms assess their Industry 4.0 readiness (I4R) based on a study of international best practices that have been adopted by Industry 4.0 leaders. The second part of this rubric enables users to assess their I4R from the circular economy perspective. From a circular economy perspective, if well-designed and used effectively, Industry 4.0 can help to minimise the leakage of both biological and technical materials, especially the loss of raw materials, energy, and labour. The second part of the rubric is, therefore, aimed at helping firms ascertain the extent to which they have explicitly built-in circular economy considerations into their Industry 4.0 actions, projects, and programmes. Collectively, the findings of the two sets of evaluations should help firms to benchmark themselves against Industry 4.0 leaders with respect to Industry 4.0 readiness as well as the extent of the circular economy focus in their Industry 4.0 readiness.

A. Firm-level Assessment Framework of the Status of Industry 4.0 Readiness

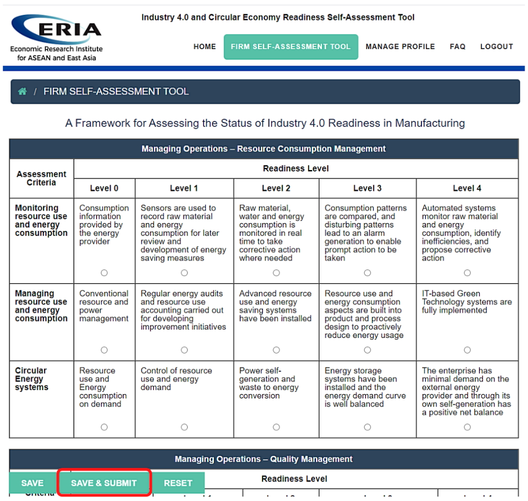
The assessor should complete each readiness criteria based on their experiences, and they suggested to involve the appropriate managers in charge of each determinant to reduce the bias of an individual manager. Additionally, it is suggested that the managers should be able to provide evidence to support the rating.

The assessment is organised into six components:

- Determinant 1: Strategy and Organisation – incorporating Industry 4.0 into the firm's strategies, innovation, leadership, and business models (6 items).
- Determinant 2: Plant and Equipment – readiness of the firm's infrastructure (i.e. machine, operating systems, IT, and data security) for implementing Industry 4.0 (4 items).
- Determinant 3: Information Technology Systems and Data Management – the level of the firm's IT systems, such as information sharing and interoperability using cloud storage (6 items).
- Determinant 4: Human Resources – human resource capabilities of the firm in utilising advanced technology (4 items).
- Determinant 5: Product Definition – the firm's delivery of products in association with its customisation potential, digital features, and life cycle assessment (3 items).
- Determinant 6: Managing Operations – resource consumption management (3 items), quality management (2 items), and supply chain management (5 items).

Figure 10.6 shows the readiness assessment for the determinant of 'Managing Operations – Resource Consumption Management'. If a manager needs further coordination in order to complete the assessment, they can save their progress and continue at a different time by clicking on the 'save' button.

Figure 10.6: Readiness Assessment of Resource Consumption Management



Source: ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (http://www.i4r-eria.org/survey)

B. Firm-level Assessment of Industry 4.0 Readiness for the Circular Economy

This assessment is to identify the readiness of the firms to integrate the circular economy into their business actions, projects, and programmes. Similar to the previous assessment of Industry 4.0 readiness, firms are suggested to involve multiple appropriate managers in charge of each area to respond to the criteria.

Similar to part A, it is organised into six similar determinants:

- Determinant 1: Strategy and Organisation – willingness to consider circular economy aspects in the firm's strategies (4 items).
- Determinant 2: Plant and Equipment – the plant's capability to accommodate resource conservative manufacturing/ResCoM (2 items).
- Determinant 3: Information Technology Systems and Data Management – consideration to incorporate circular economy principals into the firm's operations (1 item).
- Determinant 4: Human Resources – incorporating circular economy value into the firm's networks (1 item).
- Determinant 5: Product Definition – developing sustainable designs for the firm's products (2 items)
- Determinant 6: Managing Operations – resource consumption management (1 item), quality management (1 item), and supply chain management (2 items).

An example of the assessment criteria for the circular economy on a firm's plant and equipment (determinant 2) is illustrated in Figure 10.7.

Figure 10.7: Determinant 2 – Plant and Equipment

Economic Research Institute for ASEAN and East Asia

Industry 4.0 and Circular Economy Readiness Self-Assessment Tool

HOME | FIRM SELF-ASSESSMENT TOOL | MANAGE PROFILE | FAQ | LOGOUT

/ FIRM SELF-ASSESSMENT TOOL

Assessing the Extent of Circular Economy (CE) Focus in Industry 4.0 Readiness

Plant and Equipment					
Assessment Criteria	**Readiness Level**				
	Level 0	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Capability of plant and equipment and facilities layout to adopt the principle of 'remanufacturing' consisting of disassembly, cleaning, inspection and sorting, reconditioning, and reassembly	Adoption of the remanufacturing principle will not be possible with the current facilities layout and production processes	Some sections of the production process can be converted to adopt remanufacturing, but the organization has not initiated the move	The sections of the production process that can be converted to adopt remanufacturing are being suitably redesigned and renovated	Remanufacturing is adopted in several sections of the production process	The entire manufacturing facility is capable of adopting remanufacturing
Capability of plant and equipment and facilities layout to adopt resource conservative manufacturing (ResCoM, viz; conservation of energy, water, material, and value added through waste prevention and environmental protection)	Minimal or no capability to adopt ResCoM	Some sections of the production process can be converted to adopt ResCoM, but the organization 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

Information Technology Systems and Data Management					
Assessment Criteria	**Readiness Level**				
	Level 0	**Level 1**	**Level 2**	**Level 3**	**Level 4**

SAVE | SAVE & SUBMIT | RESET

Source: ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (http://www.i4r-eria.org/survey)

3.2. Policymaker Self-Assessment

National policies and institutions matter in driving both Industry 4.0 and the circular economy. Thus, the policy readiness assessment toolkit is specifically designed for government agencies and institutions who are involved in making national policy with regards to Industry 4.0 and the circular economy. The first part of the self-assessment provides a rubric to enable policymakers to assess their policy readiness with regards to Industry 4.0, while the second part enables policymakers to assess their policy readiness for the circular economy.

The policy readiness toolkit for Industry 4.0 is a macro-level policy assessment that focuses on policies that are directly related to driving Industry 4.0. The assessment mainly considers six important policy thrusts that would provide the environment for enabling the industry to transform their business activities. The policy thrusts include assessing the regulatory and institutional framework environment; education and human capital; science, technology and innovation policy; business technology promotion policy; digital transformation; and trade and investment policy environment. These policy environments are crucial in driving and catalysing the business uptake to move towards Industry 4.0.

Policymakers should consider all the dimensions as a holistic framework as each dimension is interrelated.

Similarly, the policy thrust for the circular economy considers five policy thrust areas. The intention is to capture the institutional and regulatory readiness for the circular economy as well as the driving factors, such as education and awareness, public-private collaboration, the business support system, and infrastructure system readiness to embrace the circular economy. For instance, the institutional and policy thrust incorporates various policies related to circularity, namely, waste management, energy and standards including strategies related to resource productivity, and the adoption of remanufacturing principles.

Collectively, the findings of the two sets of assessments should help policymakers to benchmark themselves concerning policy Readiness for Industry 4.0 and the circular economy at the national level. The findings of this evaluation should help policymakers to make the policy transition by identifying their strengths and weaknesses

This section elaborates the assessment from the policy perspective associated with the readiness for Industry 4.0 and the circular economy, aiming to measure the current status of policy readiness and identify policies that complement and catalyse the drivers to promote and accelerate Industry 4.0 and a sustainable economy.

A. Policy-level Assessment Framework for Industry 4.0 Readiness

This framework aims to identify the policy dimensions that are essential in driving industry 4.0 and the circular economy. There are six areas needed to be identified to stimulate market activities and prevent regulatory failure for Industry 4.0 and circularity implementation.

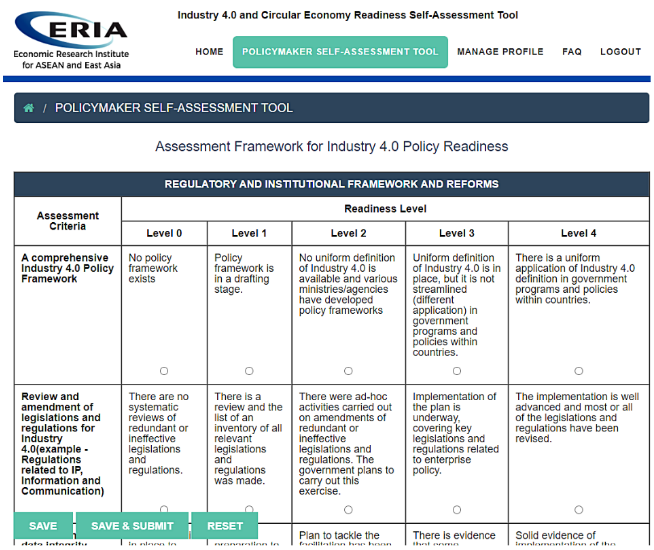
The rating system measures level 0 as the least ready and level 4 as a frontrunner/ expert in the matter. Therefore, the six areas are as follows:

- Area 1: Regulatory and Institutional Framework and Reforms – regulatory preparedness and institutional ability to coordinate activities in achieving Industry 4.0 (8 items).

- Area 2: Education – including human capital, to ensure the policy is ready to prepare the workforce and provide skills that are in demand by the newly emerging industries (4 items).
- Area 3: Science, Technology, and Innovation (STI) – related to a strategic approach to STI policies, R&D programmes, and innovation (4 items).
- Area 4: Business Technology Promotion – policy related to ICT technology and business promotion towards digitalisation (2 items).
- Area 5: Digital Transformation – related to smart technology standards, IoT, data security, and support for creative industries (3 items).
- Area 6: Trade and Investment Policies – emphasis on investment promotion in strategic sectors of Industry 4.0 and international cooperation (3 items).

For area 3 to area 6, these assessments are basically to identify policies related to infrastructure readiness to support Industry 4.0. Figure 10.8 shows some sample questions for area 1, 'regulatory and institutional framework and reforms'.

Figure 10.8: Sample Questions for Area 1: Regulatory and Institutional Framework and Reforms



REGULATORY AND INSTITUTIONAL FRAMEWORK AND REFORMS					
Assessment Criteria	Readiness Level				
	Level 0	Level 1	Level 2	Level 3	Level 4
A comprehensive Industry 4.0 Policy Framework	No policy framework exists	Policy framework is in a drafting stage.	No uniform definition of Industry 4.0 is available and various ministries/agencies have developed policy frameworks	Uniform definition of Industry 4.0 is in place, but it is not streamlined (different application) in government programs and policies within countries.	There is a uniform application of Industry 4.0 definition in government programs and policies within countries.
Review and amendment of legislations and regulations for Industry 4.0(example - Regulations related to IP, Information and Communication)	There are no systematic reviews of redundant or ineffective legislations and regulations.	There is a review and the list of an inventory of all relevant legislations and regulations was made.	There were ad-hoc activities carried out on amendments of redundant or ineffective legislations and regulations. The government plans to carry out this exercise.	Implementation of the plan is underway, covering key legislations and regulations related to enterprise policy.	The implementation is well advanced and most or all of the legislations and regulations have been revised.
			Plan to tackle the	There is evidence	Solid evidence of

Source: ERIA-Industry 4.0 and Circular Economy Readiness Self-Assessment Tool (http://i4r-eria.org/survey).

B. Assessment Framework for Circular Economy Policy Readiness

Five policy thrust areas are assessed to capture the policy readiness for circular economy implementation, as follows:

- Area 1: Institutional and Regulatory Framework for Circular Economy – related to circular economy policy frameworks, awareness initiatives, resource efficiency strategies, and standard regulation (8 items).
- Area 2: Education, Information and Awareness – promoting circular economy into the educational system and public campaigns (2 items).
- Area 3: Collaboration and Partnership Platforms – public-private partnerships, voluntary industry participation, and R&D programmes in the circular economy (3 items).
- Area 4: Business Support Systems for Circular Economy – policy-related financial incentives and non-financial support (2 items).
- Area 5: Public Procurement, Infrastructure and Technology – enabling public procurement and investment to promote Industry 4.0 and the circular economy (3 items).

4. Summary of Industry 4.0 Readiness for the Circular Economy Self-Assessment Results

For the readiness assessments for both firms and policymakers, the rating system uses measurements based on the scores obtained from each criterion. Firms and policymakers will obtain the following information based on the completed self-assessment.

1. Background information

This information will be necessary to grasp the nature of the firm or economy and its competitiveness status, future strategic plans, challenges, risks faced, and mitigation strategies set.

2. Rating 'Industry 4.0 readiness' and 'circular economy readiness' based on determinants and areas
Both for firms and policymakers, the results show the rating of the elements of 12 determinants and 6 sub-determinants for firms, and 11 areas of policy readiness assessment. Both assessments reflect the level of readiness for Industry 4.0 and the circular economy of the firm and policies.

In the case of a firm assessment, it is important to engage multiple managers that are in charge of these areas to determine the level of Industry 4.0 readiness and circular economy for Industry 4.0. This helps to avoid potential bias from an individual manager. Moreover, it is also necessary for the managers to provide evidence to support their responses.

After the completion of the assessment, the results will be presented in a scoring table and radar diagram. Firstly, the scores are calculated based on the responses for each criterion, where each level translates to a score, as elaborated in Table 10.1.

Table 10.1: Scoring Based on Readiness Level

Readiness Level	Score
Level 0	0
Level 1	1
Level 2	2
Level 3	3
Level 4	4

Source: Authors, based on Chapter 3 of this publication.

The following section shows the scoring system for firms' self-assessment, which is also applied for assessing the policy readiness of Industry 4.0 and the circular economy.

In this assessment, there are 33 criteria, and each criterion has a maximum score of 4. Therefore, the maximum score for all criteria is 132. Based on this scoring, the assessor will be able to determine the status of Industry 4.0 as listed in Table 10.2.

Table 10.2: Status of Industry 4.0 Readiness

Score Range	Classification
0–33	Hesitator
34–66	Potentialist
67–99	Experienced
100–132	Expert or frontrunner

Source: Authors, based on Chapter 3 of this publication.

For the circular economy assessment, there are only 14 criteria. Therefore, the maximum score for all criteria is 56. Based on this scoring, the status of the circular economy focus on Industry 4.0 readiness is classified as in Table 10.3.

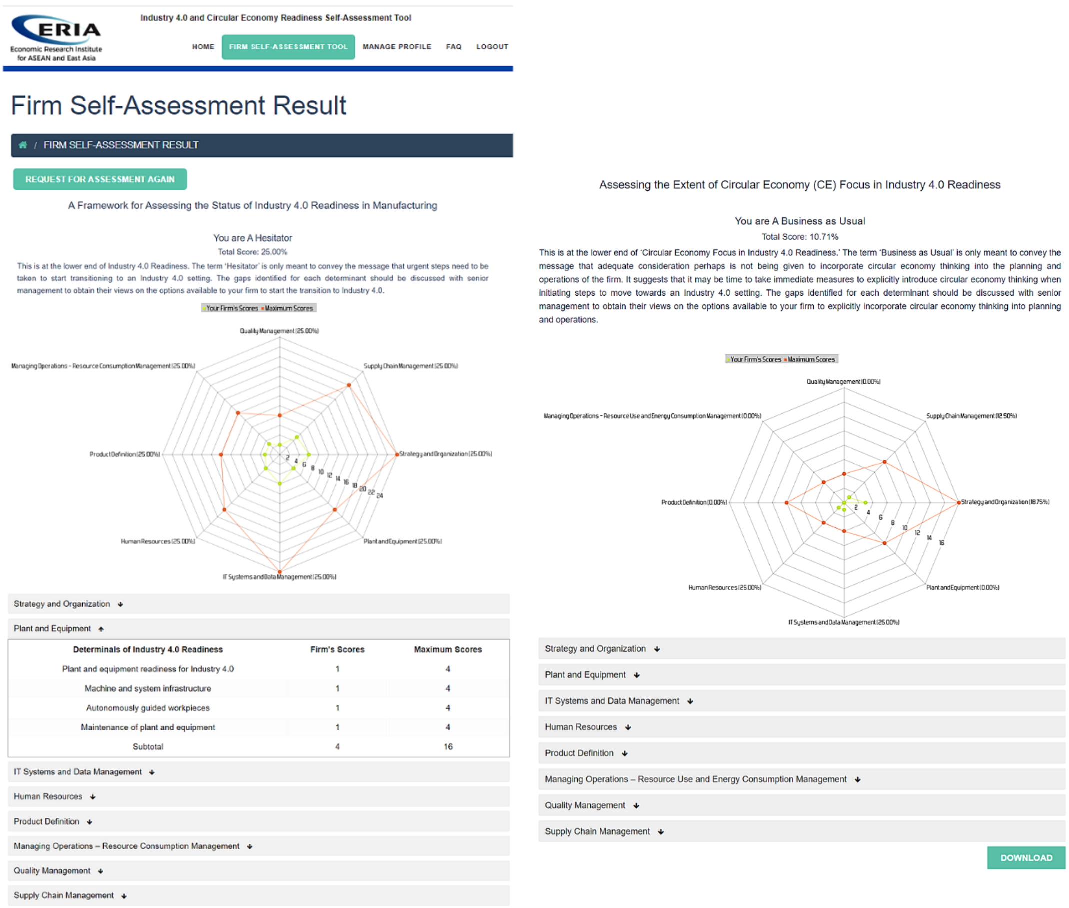
Table 10.3: Status of Circular Economy Focus on Industry 4.0 Readiness

Score Range	Classification
0–14	Business-as-usual
15–28	Circular economy beginner
29–42	Circular economy fast adopter
43–56	Circular economy leader

Source: Authors, based on Chapter 3 of this publication.

Furthermore, the accumulated results, generated from the actual values obtained and the maximum values, are illustrated using a 'radar diagram'. Two different radar diagrams represent the status of the Industry 4.0 readiness level and the circular economy focus on Industry 4.0. Essentially, the managers or policymakers can redo their assessment if there is a significant change in their industry or policies regarding Industry 4.0 and circular economy readiness. Figure 10.9 shows an example of the complete results of a firm self-assessment that can also be downloaded by the assessor.

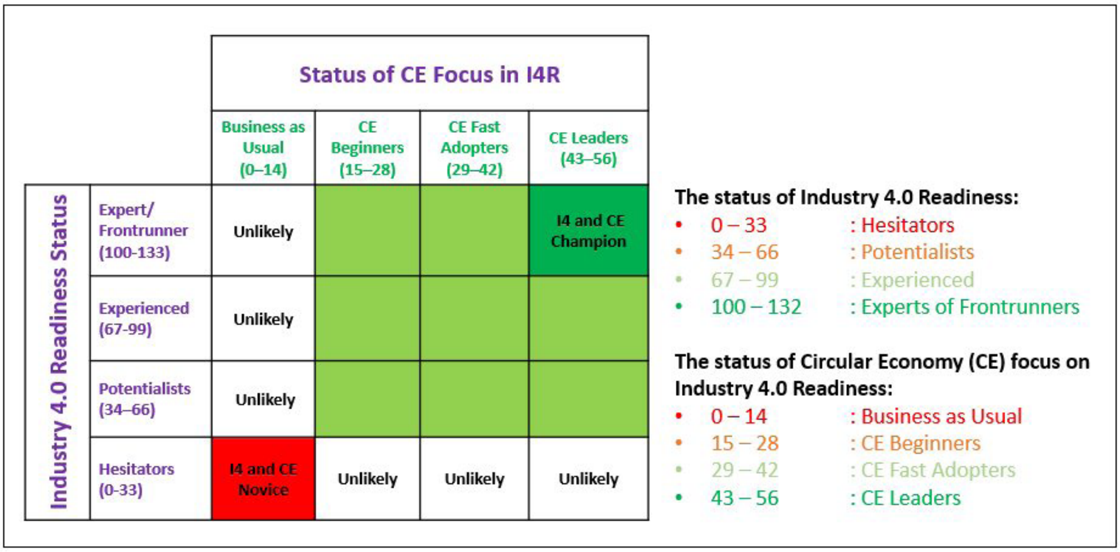
Figure 10.9: Example of Completed Results of a Firm Self-Assessment



Source: Authors' analysis.

Based on the two assessment frameworks and analysis, Figure 10.10 summarises a possible combination for Industry 4.0 readiness and the extent of circular economy focus on Industry 4.0 readiness. However, it should be noted that the matrix in Figure 10.10 shows possible combinations that are unlikely to be valid. For instance, it is somewhat unlikely that an Industry 4.0 'hesitator' would be a 'circular economy leader'. Thus, it is necessary to conduct further in-depth analysis to determine the position of the firm in the matrix.

Figure 10.10: Circular Economy-focused Industry 4.0 Readiness Matrix



I4.0 = Industry 4.0, I4R = Industry 4.0 readiness.
Source: Authors, based on Chapter 3 of this publication.

5. Development of a Blueprint for Transition towards an Industry 4.0 and Circular Economy Champion

The findings from the integrated assessment can be used to develop a collective, broad understanding of any institution's (firm/country) readiness for change and implementation and to identify areas of development. After the Industry 4.0 readiness and circular economy assessment has been carried out, the next stage will be identifying the approaches that should be taken to facilitate planning to become a champion in Industry 4.0 and the circular economy. This self-assessment suggests six steps that can be applied by decision makers (policymakers or firm managers) to plan their further actions towards becoming frontrunners.

- Step 1: Use the two assessment frameworks to reach a consensus on immediate feasible actions that can be taken.
- Step 2: Use the outcomes of the discussion in Step 1 to define a vision for the short term and the longer term.

- Step 3: Identify partnerships needed both at the upstream and downstream end of the supply chain to implement the actions, projects, and programmes.
- Step 4: Appoint a steering committee to review the implementation of the actions, projects, and programmes and ensure that the circular economy Industry 4.0 readiness transition proceeds as envisaged.
- Step 5: Build internal capabilities as well as supply chain capabilities to enable effective implementation.
- Step 6: Strive for perfection through radical improvements (kaikaku) supported by continuous improvement.

This information will inform the implementation, planning, and capacity building required in several areas.

6. Instructions to Users of the Readiness Self-Assessment Tool

Before using this self-assessment tool, institutions should consider who, when, and how it should be administered.

Who should participate in the self-assessment?

This self-assessment tool is designed to be used by individuals or institutions that are responsible for overseeing or guiding the Industry 4.0 and circular economy transformation efforts through changes and implementation processes. The team/individual should have diverse expertise and perspectives from across agencies and departments and be able to adapt and adopt the transformational changes.

When should the assessment tool be used?

Individuals or institutes may use this tool at different points in the design of the change and implementation process:

- At the beginning of the Industry 4.0 and circular economy change process, the firm-level manager or policymaker can use the assessment tool to check the readiness.
- Before selecting a specific category for technology and management intervention under the Industry 4.0 or circular economy categories, the tool can be used to assess the readiness for implementation.

- While researching or piloting an intervention, individuals or institutes can use the assessment tool to stimulate changes in readiness and identify capacity-building needs.

How should individuals or institutes administer the self-assessment tool?

Before administering the self-assessment tool, a designated individual or team of experts should clearly communicate the purpose of the tool and how it will be used. They may refer to the previous chapters of this book to orient themselves or others to have a clear understanding of the basic concepts of Industry 4.0 readiness for the circular economy. They should also remind participants of the importance of a candid examination of readiness and in assigning the scores so that assessment is impartial, motivated, and capacity is built.

A group of individuals as members of a team could also complete the assessment and take an average score to rate the extent of readiness. Some teams may ask members to complete the assessment individually, and then tally individual responses to inform a collective response and discussions. Government agencies or departments within a firm may find it useful to serve as a facilitator for discussions and help the group come to a consensus when rating various items.

To rate items, the individuals or teams that take the assessment will need to consider the existing sources of in-house information, data, and whether they need additional information. When necessary, collecting additional data may extend the time involved in the assessment process; however, doing so should better inform and shape decisions for moving forward. The assessment results obtained and the analysis of the hidden, and not obvious, knowledge of future actions can be of substantial benefit to the stakeholders related to the development of corporate strategies and policies for raising the index of readiness.

For further assistance with using this self-assessment tool and assessing the readiness of Industry 4.0 and the circular economy, please email: contactus@eria.org or visit www.i4r-eria.org.

References

Economic Research Institute for ASEAN and East Asia (ERIA) (2016), T*owards a Circular Economy: Corporate Management and Policy Pathways*. Jakarta: ERIA. https://www.eria.org/publications/towards-a-circular-economy-corporate-management-and-policy-pathways/

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