Chapter 4

Measuring and Benchmarking of Policy Factors Influencing I4R: A Reality Check for ASEAN

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CHAPTER 4

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

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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

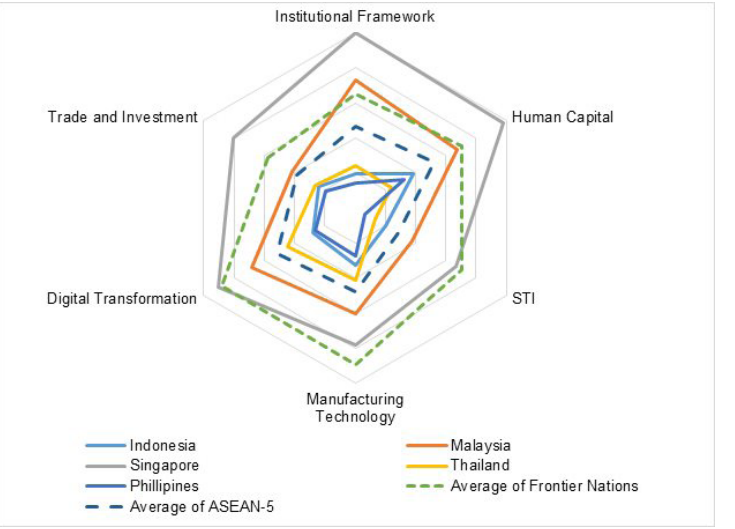
FDI = foreign direct investment, GDP = gross domestic product, ICT = information and communications technology, Lao PDR = Lao People's Democratic Republic, R&D = research and development.
Source: Author's computed normalised scores based on various sources (WEF (2018); Global Innovation Index, 2018;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

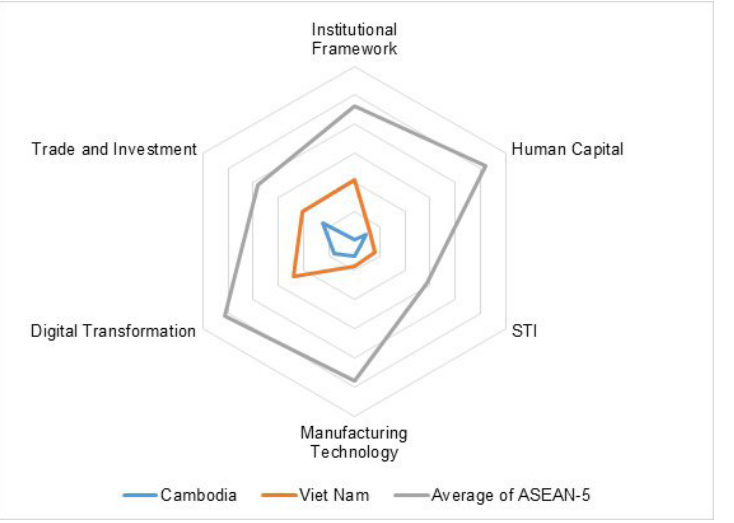
Figures 4.1 and 4.2 show the visual average score of the six pillars. We separately plot the main policy dimensions based on the development stage, separating Cambodia and Viet Nam and considering Singapore, Malaysia, and Thailand as the first tier with leading or strong readiness for future, and the 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.

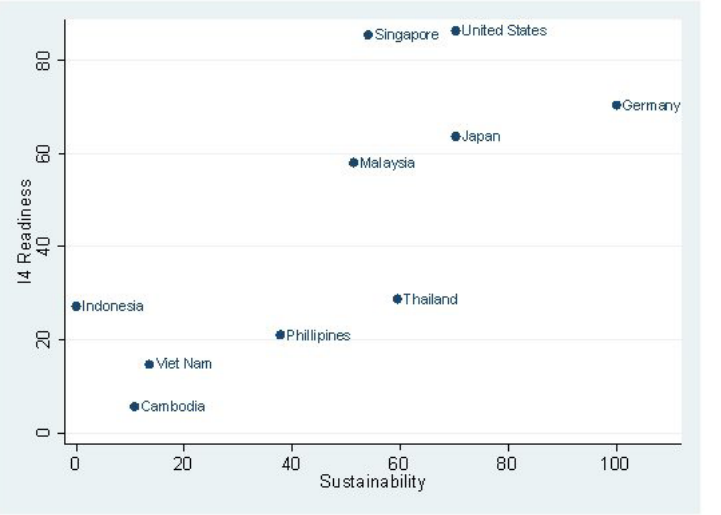
Table 4.4: Circular Economy Policy Readiness

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, CO2 intensity, CH4 intensity, N2O 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.