Chapter 2

Connecting Sustainable Lifestyle, Industry 4.0, and the Circular Economy

Heinrich Wyes

October 2018

This chapter should be cited as

Wyes, Heinrich (2018), 'Connecting Sustainable Lifestyles, Industry 4.0, and the Circular Economy', in Anbumozhi, Venkatachalam and F. Kimura (eds.), *Industry 4.0: Empowering ASEAN for the Circular Economy*, Jakarta: ERIA, pp.36-66.

Chapter 2

Connecting Sustainable Lifestyles, Industry 4.0, and the Circular Economy

Heinrich Wyes
Regional Environmental Centre for Central Asia,
Uzbekistan

Concepts at the interface between society and economics, such as sustainable development, Industry 4.0, and the circular economy have often been addressed in singularity by the business sector, by academia, and policy (Romero and Noran, 2015). The questions that arise are whether and how they complement one another. Could the integration of Industry 4.0 and the circular economy result in a further strengthening of the extractive, 'linear' economy or will it enable the decoupling of resource consumption from economic development and accelerate the transition towards the circular economy? Could an interface between Industry 4.0 and the concept of the circular economy unleash new gains in productivity and efficiency? How do we address societal uncertainties related to the integration of Industry 4.0 and the circular economy, for example, through the concept of multilevel governance systems? And what will be the challenges and role of the ASEAN region in this context?

This chapter addresses the interfaces between sustainable development, Industry 4.0, and the circular economy and whether productivity increases could provide an impetus for economic growth, providing examples with a view to better understand the prospects and impacts for the ASEAN region.

The chapter addresses the questions:

- Whether Industry 4.0 is ready for circular economy integration? Can the integration of Industry 4.0 and the circular economy lead to a reduced use of resources during both production and use and or consumption?
- How can the interface between Industry 4.0 and the circular economy look like? Can Industry 4.0 be regarded as a facilitator for the circular economy and thus enable closed loop systems?
- How much progress have the European region and the Asian region made in implementing the concepts of Industry 4.0 and the circular economy?
- What are enabling factors and or key barriers to implementation of such an integrated concept in the ASEAN region?,
- Can multilevel governance systems be a tool to turn this vision into reality? What are the policy implications for the ASEAN region and what kind of conclusion and recommendations can be drawn?

1. Introduction

Global awareness and attitudes towards the greening of both the economy and society have evolved since 1992 when the first United Nations Conference on Environment and Development in Rio de Janeiro called upon national governments to develop strategies for sustainable development. The goal of shaping the new foundation for the world's future – a world economy that is based on a cleaner, more sustainable production and consumption pattern, providing economic models for countries and societies to build wealthier and happier lives – has never been nearer (Buhr, 2015). The commitments of the major world economies to the post-2015 Development Agenda, the recent sustainable development goals, and the Paris Accord on Climate Change ensure that new political, economic, and trade arrangements between nations and the trading blocs are created, evolving into greener drivers of development. This, in turn, creates challenges and opportunities for all other nations (Richard,2005; von Stechow et al., 2015; Zhang and Wen, 2008).

The advantages of a transition to a resource-efficient and ultimately a regenerative circular economy have been acknowledged by governments, private sector, and civil society (Stern et al., 2002). Innovation and a systemic transition in the use and recovery of resources are needed to ensure future jobs and competitiveness; outline potential pathways in innovation, investment, and regulation; tackle harmful subsidies; increase opportunities for new business models; and set clear targets (Aghion et al., 2005).

Economic growth has long focused on the linear 'take, make, dispose' model (George, Lin, and Chen, 2015). On the back of the digital revolution, a circular alternative which enables an effective flow of materials, energy, labour, and information so that natural and social capital can be rebuilt, is emerging (Bundesministerium für Bildung und Forschung, 2015).

The circular economy is an economic model where the value of products, materials, and resources is maintained in the economy for as long as possible and where waste generation is minimised. The transition to a circular economy involves a fundamental change, which means rethinking the way products are designed, produced, consumed, and brought back into the value chain (Bilitewski, 2012).

Another new model to unlock the potential for more reuse, remanufacturing, and recycling of products, and for sometimes unconventional business models, derives from modern communication tools (Romero and Noran, 2015). The key to achieving this model is the internet of things (IoT) and the role of intelligent products. Digital technologies and devices can sense, store, and communicate information about themselves and their surroundings. Experts are describing this as the fourth industrial revolution or Industry 4.0 – a so-called fusion of technologies that blurs the lines between the physical, digital, and biological spheres (Dombrowski and Wagner, 2014).

Linking Industry 4.0 and the circular economy can help unlock creativity through the convergence of the digital and natural worlds, an intersection which could define how we govern and innovate. By decoupling economic value creation from resource consumption, the World Economic Forum in 2016 talked about a 'trillion-dollar opportunity' (Dutta, Geiger, and Lanvin, 2016). Understanding and harnessing the potential of this 'fourth industrial revolution' for society, the economy, and the environment, and relating it to the concept of a circular economy will be the goal. Industry 4.0 and IoT will be the glue that links material items which are being consumed with the changes in consumer behaviour, allowing recovery, material separation, and remanufacturing (Kagermann, 2014).

One of the key elements why advanced economies have only limited growth rates is that traditional efforts to make production processes more efficient have already been implemented to a large degree. Recent studies show that the concept of Industry 4.0 could increase productivity tremendously (Rüßmann et al., 2015). In Industry 4.0, the product itself will become the carrier of knowledge and information, which opens new business opportunities (Brettel et al., 2014). The resulting potentials of increases on productivity are impressive.

2. Can the Integration of Industry 4.0 and the Circular Economy Lead to a Reduced Use of Resources?

Industry 1.0 was based on the introduction of mechanical production equipment driven by water and steam power. Industry 2.0 was based on mass production achieved by division of labour and use of electrical energy. Industry 3.0 was based on the use of electronics and information technology to further automate production. Now, Industry 4.0, in a material-reliant industrial economy, is being based on the use of cyber-physical systems with the notion of connectivity as the 'new' relationship (Faller and Feldmüller, 2015).

The widespread adoption by the manufacturing industry around the world of information and communications technology (ICT) is paving the way for disruptive approaches to development, production, and the entire logistics chain. This networking within an 'IoT, services, data, and people' will transform the future of manufacturing (Wang et al., 2016). Industry 4.0 is on its way to become a fourth industrial revolution with four main characteristics:

- Vertical networking of smart production systems, such as smart factories and smart products; and the networking of smart logistics, production, marketing, services, with a strong needs-oriented, individualised, and customer-specific production operation.
- Horizontal integration by means of a new generation of global value-creation networks, including integration of business partners and customers, and new business and cooperation models across countries and continents.
- Through-engineering throughout the entire value chain, taking in not only the production process but also the end products – that is, the entire product life cycle.
- Acceleration through exponential technologies such as sensor technology and massive computing power.

Integrated analysis and use of data are the key capabilities for the industrial internet. Today, the efficient analysis and use of data is of great significance. Companies believe that the ability to analyse data will be critical to their business model in 5 years. These companies primarily focus on the efficient exchange of data within their own value chain, the digital labelling of the products, and the use of real time data to steer their production.

Digitisation of the product and service portfolio of businesses is the key to sustainable corporate success. A mechanically perfect product will no longer be enough to withstand international competition. Therefore, it is expected that most European manufacturers will have achieved a high degree of digitisation of their product and service portfolio within 5 years.

The fourth industrial revolution – characterised by the increasing digitisation and interconnection of products, value chains, and business models – has arrived in the European industrial sector, including manufacturing and engineering, automotive and process industries, as well as the electronics and electrical systems, and information and communications industries. The digital transition will lead to a significant transformation of the business sectors that will require considerable investment. It is estimated that the share of investments in Industry 4.0 solutions will account for more than 50% of planned capital investments for the next 5 years. German industry will invest a total of €40 billion in Industry 4.0 every year by 2020 (Bundesministerium für Wirtschaft und Energie, 2014). Applying the same investment level to the European industrial sector, the annual investments would be as high as €140 billion per annum.

These investments must be used along the entire value chain to achieve maximum success. In 5 years, more than 80% of companies will have digitised their value chains – one-quarter of the companies already achieved a high degree of digitisation of their value chains. However, thus far, only individual units and isolated applications have been mostly automated and digitised. The business sector expects that 86% of the horizontal and 80% of the vertical value chains will have a high degree of digitisation by 2020 and will therefore be closely integrated (Buhr, 2015).

The industrial internet increases productivity and resource efficiency, with an 18% increase in efficiency within 5 years. The industrial sector is required to produce ever larger quantities using fewer raw materials and less energy. The industrial internet allows higher productivity and resource efficiency and thus creates the conditions for sustainable and efficient production. The companies surveyed anticipate an average efficiency increase of 3.3% per year across all industry sectors due to the digitisation of value chains. This amounts to a total of 18% in the next 5 years. They expect annual savings of 2.6% with respect to cost reduction.

The industrial internet paves the way for new digital business models. The industrial internet will have a lasting effect on existing business models and will also generate new, digital – often disruptive – business models. The focal point of this trend comprises increasing customer benefits through a growing range of value solutions (instead of products) and increased networking with customers and partners. The unique quality of the digital change lies in the rapid acceleration of the speed of change. Disruptive innovations will also cause industry sectors like the information and communications industry to sustainably transform within a short period (Schulte, 2013).

Horizontal cooperation allows for improved satisfaction of customer needs. European companies have understood that closer cooperation with value chain partners – combined with increased horizontal interconnection – is of great significance. Its importance will further grow in the context of Industry 4.0 considering increased digitisation, particularly where new, digital business models should be established.

The industrial internet holds various challenges. The focus is on high investment levels and often unclear business cases for new industrial internet applications. Furthermore, sufficient skills to meet the needs of the digital world must be ensured. Binding standards must also be defined and tasks in information technology security should be solved (Finn and Wright, 2016). Policymakers and industrial associations need to address these latter challenges by advocating uniform industrial standards at a European or international level and promoting efficient rules for data security and data protection.

Digitised products and services generate approximately €110 billion of additional revenues per year for the European industry. Companies which have already digitised their product portfolio have grown above average in the past 3 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 revenues for the European industry in total.

The European example indicates that, as a result 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 to 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 et al., 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 European Union (EU) holds a third of the global market, which is worth a €1trillion, and it is expected to double by 2020 (European Commission, 2012).

Digital innovations in social, mobile, analytics, cloud, and machine-to-machine communication (M2M) are especially effective in connecting physical and digital channels, and in connecting customers more broadly and deeply than ever before.

- Mobile: Mobile technology spurs the adoption of circular business models by enabling universal and low-cost access to data and applications. As consumption behaviour goes mobile and online, it reduces the need for physical resources ranging from paper and entertainment to stores.
- M2M communication: Machines capable of communicating with one another are not new. M2M technology has long been used in factory control systems and vehicle telematics. But we are about to reach a critical mass for mainstream M2M use as wireless network coverage expands worldwide.
- Cloud computing: Dematerialisation – the process of replacing something physical with a digital alternative – has placed some industries (travel agents, music stores, and newspapers) on the endangered species list. Cloud computing is key to dematerialisation, along with mobile and social technologies.
- Social: While social media started as a way for people to find and connect with friends and family, it has evolved into so much more. Social technology is fundamental to sharing. It reduces the cost of setting up sharing platforms as it allows businesses to tap into existing social networks. It makes it cheaper and quicker for companies to receive consumer feedback to help improve offerings.
- Big data analytics: In a circular economy, many companies will generate their revenues from product use instead of sales, and growth will rely on how good they are understanding and catering to product use behaviour. This means companies need to monitor and analyse data in entirely new ways. Complex analytics is especially important for the circular supply chain, sharing platform, and product as service business models.

- Modular design technology: Modular design technology is not only revolutionising how products function but also the length and nature of customers' relationships with those products. When a modularly designed product breaks, only the defective part is replaced or repaired, keeping the product relevant to its users longer and extending its overall product life cycle.
- Advanced recycling technology: Recycling is not new and it has benefited from a great deal of innovations and some significant rapid returns on foothills of the coming changes. Initially, circular business model innovation was driven by start-ups. Now, large multinationals are making serious moves as well. This is illustrated by a joint Accenture and United Nations Global Compact study which found one-third of global chief executive officers actively seeking to employ circular economy investments. Because of the advances in recycling and its increased efficiency, more and more companies are turning to the circular economy as a source of growth.
- Life and material sciences technology: Life and material sciences play a key role in driving input substitution at a large scale. Ongoing innovation in this field will lead to new circular material input options. It will also bring on new ways to alter output so they can be used as inputs.
- Trace and return systems: Trace and return systems support circular business models by making it more cost effective to collect used products to service, repair, recover, reuse, refurbish, or recycle them through, for example, efficient and effective material sorting machines.
- Three-dimensional (3D) printing: 3D printing is steadily evolving to become a major player in the manufacturing world. It has also become one of the major drivers of circular business models. It facilitates repairing by making it possible to directly print suitable parts with the exact geometry. It also creates opportunities for circular inputs – inputs that are biodegradable or infinitely recyclable models.

The new business models offer the business sector options for embracing the circular economy. But it would not be possible to scale many of these business models without the support of the innovative technologies mentioned above.

Table 1. **Interactions of the Circular Economy and Intelligent Asset Value Drivers and Examples of Value Creation Opportunities**

Circular Economy Value Drivers	Knowledge of location of the asset	Knowledge of the condition of the asset	Knowledge of availability of the asset
Extending the use cycle length of an asset	• Guided replacement service of broken components to extend asset use cycle • Optimised route planning to avoid vehicle wear	• Predictive maintenance and replacement of failing components prior to asset failure • Changed use patterns to minimise wear	• Improved product design from granular usage information • Optimised sizing, supply, and maintenance in energy systems from detailed use patterns
Increasing **utilisation** of an asset or resource	• Route planning to reduce driving time and improve utilisation rate • Swift localisation of shared assets	• Minimised downtime through to predictive maintenance • Precise use of input factors (e.g. fertiliser and pesticide) in agriculture	• Automated connection of available shared asset with next user • Transparency of available space (e.g. parking) to reduce waste (e.g. congestion)
Looping/cascading an asset through additional use cycles	• Enhanced reverse logistics planning • Automated localisation of durable goods and materials on secondary markets	• Predictive and effective remanufacturing • Accurate asset valuation by comparison with other assets • Accurate decision making for future loops (e.g. remanufacture vs. recycle)	• Improved recovery and reuse/ repurposing of assets that are no longer in use • Digital marketplace for locally supplied secondary materials

Source: Ellen Mc Arthur Foundation, 2016.

3. The Prospects of the Circular Economy for the European and Asian Regions

The traditional linear 'take, make, dispose' industrial processes and the lifestyles that feed on them deplete finite reserves and create products that end up in landfills or incinerators (Roy et al., 2012). In contrast, the circular economy stands for an industrial economy that produces no waste and pollution, by design or intention, and has two types of material flows: biological nutrients designed to re-enter the biosphere safely, and technical nutrients designed to circulate at high quality in the production system without entering the biosphere (Ashby, 2016).

Transitioning to the circular economy presents an opportunity to organise production and consumption. At its essence, the circular economy represents a new way of looking at the relationships between markets, customers, and natural resources. The lens through which it is viewed is disruptive to new business models powered by new technology breakthroughs, particularly Industry 4.0.

Digitalisation disrupts the way of production and consumption through innovative business models established by innovative technologies. Blended together, the circular economy, innovative new business models, and digital revolution represent an opportunity to create a competitive advantage.

Research indicates a US$4.5 trillion reward for performing circular economy business models by 2030, stemming from the elimination of 'waste' and recognising that everything has a value, moving from efficiency to effectiveness in the way we manage inputs and outputs, and by forging a bond with consumers through product returns and customer engagement.

Global industry leaders as well as innovative start-ups are already beginning to reap huge rewards by tapping into these opportunities. The world's economy has generated unprecedented wealth over the past century. Part of the success is attributable to continuous improvements in resource productivity. At the same time, resource productivity remains hugely underexploited as a source of wealth, competitiveness, and renewal in the Asian context.

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 annual total benefits to around €1.8

trillion compared with today. This would translate into a gross domestic product (GDP) increase of as much as seven 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.

A circular economy vision enabled by the technology revolution would allow the Asian region to grow resource productivity. The circular economy concept was introduced in China to address environmental degradation and resource scarcity associated with rapid economic development. China has implemented the circular economy strategy as a means of conserving water, materials, energy, and land. China faces several challenges that, until recently, have held back complete implementation. These include lack of incentives for older industries to 'green' their operations, lack of financial support to expand the circular economy concept, and a broad-based need for heightened public awareness and participation in circular economy initiatives. Although circular economy initiatives have been successful in China, more is possible and more is needed.

The programme 'Made in China 2025' announced in 2015 aims to bring China on an equal footing with the Western industrial nations with respect to Industry 4.0. The ambition is for China to become the world's leading industrial power by the time it turns 100 in 2049. China remains on the fast track – from 2013 to 2015, Chinese inventors registered more than 2,500 patents for Industry 4.0-enabling technologies. In the United States (US), this number was 1,065 and in Germany, 441. With respect to patent quality, researchers believe that China has outperformed the US and Germany. Nevertheless, China is still in the early days with respect to the implementation of Industry 4.0 – 35 % of companies have not yet concerned themselves with the subject.

The 'Industry 4.0 index' for China indicated that companies in China are looking to seize the opportunities presented by digitalisation and networking. Most importantly, the subject of the smart factory is on the agenda for at least half of Chinese industrial companies.

4. Shaping the Link Between Industry 4.0 and the Circular Economy

The current views on Industry 4.0 focus mainly on production processes, its impact on supply chains and business-to-business relationships, and its transformative potential for different industry sectors. We now have to shift the attention to consumers and related sustainable lifestyle opportunities and ask ourselves the following questions:

- Can Industry 4.0 lead to a reduced use of resources during both production and use and/or consumption?
- Will smarter and decentralised production strengthen regional and local consumption and value creation?
- Can Industry 4.0 be regarded as a facilitator for the circular economy and thus enable closed loop systems?
- Will transparency along the supply chain increase and support more conscious consumption patterns?

Connecting Industry 4.0 and the concept of circular economy is a vision which could unleash new gains in productivity and efficiency. As a prerequisite for linking the circular economy and Industry 4.0, products need to be designed in such a way that its components can communicate through simple 'If This Then That' commands, which would provide simple connections between products (Kolberg and Zühlke, 2015). The future of automation will be tied to the rise of the Why IP, instead of the Who IP, and thus provide the foundation to accelerate the IoT revolution and to achieve a transformational economic-wide impact in manufacturing, innovation, and global competitiveness.

On one hand, all parts must be digitally interlinked. Companies that are not able to deliver interactive components will become suppliers of low-value parts and can easily be replaced by other suppliers. These are small suppliers who have grown with intelligent products. This represents a shift from rigid, centralised factory control systems to decentralised intelligence (Chituc and Restivo, 2009). These will network with one another in an intelligent way, carry out their own configuration with minimal effort, and independently meet the varying requirements of production orders.

There is an impression that Industry 4.0 focuses on automation and computerisation; yet, at the centre of Industry 4.0 are the conceptualisations, designs of the products, and production rules and parameters. This provides the opportunity to link Industry 4.0 and the concept of the circular economy. Instead of end-of-the-pipe production of waste as in previous industrial concepts (Industry 1.0 to Industry 3.0), the conscious design of the product in Industry 4.0 provides the opportunity to link to the concept of the circular economy which has the design of products in its forefront instead of the concept of recycling (Allwood, 2014).

Industry 4.0 facilitates the vision and execution of 'smart factories' (Li et al., 2015). Within the modular, structured smart factories of Industry 4.0, cyber-physical systems monitor physical processes, create a virtual copy of the physical world, and make decentralised decisions (Wang et al., 2016). With IoT, cyber-physical systems communicate and cooperate with each other and with humans in real time and, via the internet of services, both internal and cross-organisational services are offered and utilised by participants of the value chain (Wang et al., 2016).

Companies that are not able to deliver interactive components will become suppliers of low-value parts and can easily be replaced by other suppliers. Small suppliers have understood to grow with intelligent products. This represents a shift from rigid, centralised factory control systems to decentralised intelligence (Chituc and Restivo, 2009). These will network with one another in an intelligent way, carry out their own configuration with minimal effort, and independently meet the varying requirements of production orders.

The crucial question that emerges is whether linking Industry 4.0 and the circular economy will lead to an acceleration of the extractive 'linear' economy of today, or it will enable the relative decoupling of resource consumption from economic development and accelerate the transition towards the circular economy. Circular economy drivers include extending the useful life and maximising the utilisation of assets, and regenerating natural capital. Industry 4.0 drivers include collating knowledge about the asset's location, condition, and availability. A broad range of opportunities emerges when these value drivers are being paired.

In Industry 4.0, individual workpieces will themselves determine what production installations they need to provide. In a linked system of the circular economy and Industry 4.0, the design of the product would allow the immediate recognition of those products and their components, and thus provide an impetus for a shift away from traditional recycling processes and towards the initial founding principles of the circular economy. Instead of the end-of-the-pipe production of wastes as in previous industrial concepts, the conscious design of a product in Industry 4.0 would link with the concept of the circular economy, which has the design of products in its forefront instead of the concept of recycling (Dalhammar, 2016).

The resources for linking the concepts of Industry 4.0 and the circular economy are readily available to help companies transition to Industry 4.0 and to connect elements of the circular economy across enterprises, value chains, and customers for improved performance. As a prerequisite for linking the circular economy and Industry 4.0, products need to be designed in such a way that its components could communicate through simple 'If This Then That' commands which would provide simple connections between products and the circular economy. The future of automation will be tied to the rise of the Why IP and thus provide the foundation to accelerate the IoT revolution, thus achieving a transformational economic-wide impact in manufacturing, innovation, and global competitiveness (Gao et al., 2015; Lin et al., 2015).

Companies such as Bosch, Dell, and Intel have joined forces with a German start-up named Relayr to create an IoT accelerator starter kit. The kit enables fast and cost-effective creation of industrial grade IoT solutions such as early developments to connect the circular economy and IoT. All the components and expertise needed to develop respective IoT solutions, such as sensors, configured hardware, and programmes to visualise the data are included. The Relayr kit allows one to create models which could be upgraded with a cloud installation to full-scale deployment.

Companies seeking the circular advantage will be required to develop new business models that are free of the constraints of linear zero-sum thinking.

Circular supply chain: When a company needs resources that are scarce or environmentally destructive, it can either pay more or find alternative resources (Ying and Li-Jun, 2012). The circular supply chain introduces fully renewable, recyclable, or biodegradable materials that can be used in consecutive life cycles to reduce costs and increase predictability and control. One example is CRAiLAR Technologies Inc., a company that produces renewable biomass resources using flax and hemp to create fibres as good as cotton without environmental impact.

Recovery and recycling: The recovery and recycling model creates production and consumption systems in which everything that used to be considered waste is revived for other uses (Allwood, 2014). Companies either recover end-of-life products to recapture and reuse valuable materials, energies, and components or they reclaim waste and by-products from a production process. Procter & Gamble Company operates 45 facilities on a zero-waste basis.

Product life-extension: This means shifting from merely selling things to actively keeping them alive and relevant (Du et al., 2015). It also means moving customers from transactions to relationships, tailoring upgrades, and alterations to specific needs. Through its refurbishment business, Dell Inc. Computers takes back old equipment and resells units when possible.

Sharing platform: In developed economies, up to 80% of the appliances of individual consumers are used only once a month. The sharing economy model, which is increasingly assisted by new forms of digital technology, forges new relationships and business opportunities for consumers, companies, and micro-entrepreneurs who rent, share, swap, or lend their idle goods (Cohen and Muñoz, 2016). Fewer resources go into making products that are infrequently used, and consumers have a new way to both make and save money. Examples of a growing field include Uber Inc., Airbnb Inc. and Lyft Inc.

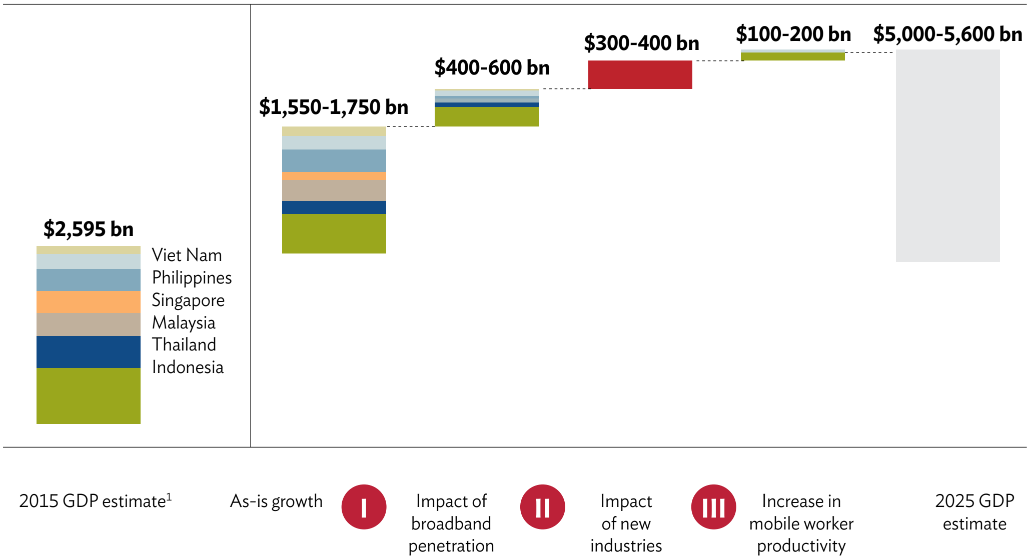
Product as a service: What if manufacturers and retailers bore the 'total cost of ownership?' Many would immediately adjust their focus to longevity, reliability, and reusability. When consumers lease or pay for products by use through the product as a service model, the business model fundamentally shifts in a good way. Performance trumps volume, durability tops disposability, and companies have an opportunity to build new relationships with consumers. Koninklijke Philips NV is using 'lighting as a service' to charge by output instead of unit sales.

5. The Prospect of Linking Industry 4.0 and the Circular Economy in the ASEAN Region

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

The ASEAN digital economy currently generates approximately US$150 billion in revenues per year. 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 15% compound annual growth rate over the next 5 years (Figure 1).

Figure 1. ASEAN's Digital Economy's Potential to Add an Incremental US$1 Trillion in Gross Domestic Product by 2025



bn = billion, GDP = gross domestic product.

[1] Based on current prices; uses 2015 as baseline to project future real GDP growth; as-is growth based on 5-year GDP forecasts.

Source: The ASEAN Digital Revolution – AT Kearney, 2016.

Major trends in the digital economy – the advent of the multiple screen environment, social networking, growth in big data and augmented reality, personalised advertising, and the rise of the cloud – will drive the 50% compound annual growth rate to 60% in data traffic in the future.

ASEAN's vibrant economy, favourable demographics, ICT investments, and ongoing economic integration have laid the foundation for the region to become a global leader in the digital economy. If ASEAN were a single country, with a combined GDP of US$2.5 trillion, it would be among the largest economies in the world, behind only the US, China, Japan, Germany, the United Kingdom, and France. The six largest economies in ASEAN, (Indonesia, Thailand, Malaysia, Singapore, the Philippines, and Viet Nam) contribute 99% of the total ASEAN GDP. Economists project GDP to grow at about 9% from 2015 to 2020, which falls between GDP growth forecasts for China and India.

ASEAN is home to more than 628 million people – around 10% of the world's population. The literacy rate is high at 94%. Some 40% of its citizens are under 30 years of age and are digital natives. This generation is learning to champion disruptive thinking and is primed to innovate.

ASEAN's ICT sector has evolved at a phenomenal pace in the past few years. ICT investment, which amounted to more than US$100 billion in 2014, is now growing at more than 15% annually. Indonesia alone has set aside US$150 billion for ICT investments over the next 3 years.

Moreover, the implementation of the ASEAN Economic Community, which pledges to promote free movement of goods, services, investment, skilled labour, and capital, has created a renewed sense of optimism and urgency for economic integration in the region. Growing integration should help the region's nascent digital economy realise greater economies of scale.

There remains a significant digital divide within ASEAN. Singapore is the only country in the top 10 of the United Nations ICT Index and the top 20 of the Economist Intelligence Unit Digital Economy ranking. ASEAN is not a monolithic bloc; there are three distinct groups of nations within the region:

- ASEAN 1 (Malaysia and Singapore) – matches the performance of developed countries but still lags in spectrum availability, innovation environment, regulatory environment, and digital literacy.
- ASEAN 2 (Thailand, Indonesia, and the Philippines) – displays significant gaps in market competitiveness, spectrum availability per operator, and regulatory environment.
- ASEAN 3 (Viet Nam, Myanmar, and Cambodia) – underperforms its ASEAN peers in all categories except regulatory environment.

In ASEAN member countries, the policy enablers for a digital economy have not kept pace with those in the EU. Policy enablers have two facets. First, each individual country must have the right regulations in place to support the digital economy. This entails ensuring that critical enablers, such as sustainable market structures, supportive spectrum policies, privacy laws, digital signature laws, data protection, and incentives are in place to support universal broadband access, mobile financial services, e-commerce, and other key areas of the digital economy. Second, these policies need to be extended and harmonised across the economic community to create a single digital market.

Table 2. Digital Progress in the European Union and the ASEAN Region

	European Union	ASEAN
Region-wide digital vision	• Single digital agenda defined by seven growth pillars with 111 action items • Digital Economy and Society Index ranks EU countries across five segments and metrics	• e-ASEAN framework agreement consists of high-level guidelines, only no actions defined • Limited ranking and tracking to evaluate progress
Consumer protection (privacy, cybersecurity)	• EU-wide common privacy initiatives established by EU Data Protection Directive and ePrivacy Directive • Cybersecurity identified as regional priority under Single Digital Agenda (Pillar III), supported by 14 EU-wide action items	• Only three countries (Myanmar, Singapore, and the Philippines) have privacy laws in place • Cybersecurity addressed under 2/6 of the ASEAN ICT Masterplan 2015 strategic thrusts but no consensus on KPI targets or actions
Development of e-commerce and MFS	• Mobile only banks are operational, including Fidor bank, Number 26 (Germany) Hello bank (BNP-group France • Efforts underway to have an EU-wide payments platform	• ASEAN-wide initiatives to create regional mobile-payment systems are limited • Current initiatives are limited to traditional payment systems
Digital public services	• Large-scale pilots for EU-wide public services • e-ID: access another country's citizens' ID and information • eHealth: Interoperability between national health systems to check benefits anywhere in EU • Progress is regularly tacked and measured	• Statement of intent expressed in high-level framework agreement • No regional actions, monitoring, or ranking mechanisms to ascertain progress in digital public services
Industry structure (definition of digital, OTT)	• EC plans to increase telecommunications regulations with common rules covering OTT players and cable operators	• No comprehensive ASEAN-wide regulations on OTT players • No distinct approach to regulate operators vs. OTT

ASEAN = Association of Southeast Asian Nations, BNP = BNP Paribas Bank, EC= European Commission, e-ID = electronic identification, EU = European Union, ICT = information and communications technology, KPI = key performance indicators, MFS = mobile financial services, OTT = over the top content.

Sources: European Commission: Digital agenda for Europe; press reports: A.T. Kearney analysis.

Industry 4.0 might potentiate a threat to ASEAN economies. Recently, the World Bank has been trying to estimate the potential threat by using the Frey-Osborne approach. The results indicate that the relocation of industrial production from rich to poorer countries was just a stopover on the way to automation. Like the disruptive innovation of fracking in the oil and gas industry, which will allow producers in the USA to define prices for oil and gas and which led to a whole new set of small and medium-sized companies, Industry 4.0 has the potential to return the definition of industrial production away from Asia. This may create opportunities for Southeast Asian countries to participate in this process and/or to switch into an even higher gear such as linking Industry 4.0. to the circular economy.

The industrial internet is already a key subject in the industry and this trend will become increasingly more important in the future (Wang 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 potentials is also complex and diverse. There is an urgent need for more transparency and an exchange of experience across industry sectors (Buhr, 2015).

Employee qualification is an important topic across all industry sectors (OECD, 2017). The digital change will alter requirements for employees across all steps of the value chain – from development on through production to 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) is behind 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.

6. Perceived Key Barriers to the Implementation of an Integrated Industry 4.0 and the Circular Economy Concept in ASEAN

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, and 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 countries are lagging behind the potential of innovative sectors associated with the digital economy such as mobile financial services, e-commerce, and cloud services (OECD, 2017).

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: digitising product and service offerings (for example, remote health monitoring), digitising customer engagement (for example, digital channel for sales and digital self-serve channels), and 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 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 automotive to electrical and electronics, 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 among 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 Indonesia Digital. Thailand's 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's and Brunei's digital strategies are quite nascent, with Brunei Darussalam focusing mostly on digital government.

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 USA 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: 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; and foster digital innovation within ASEAN.

7. Turning the Vision into Reality: Multilevel Governance Systems

Turning the vision into reality at the society level is a challenge. Policymakers and industrial associations thus need to provide a framework for the transition using models that have been proven to significantly reduce costs while improving business capabilities (Foray and Raffo, 2014; and Qin, 2015).

Managing the process of linking Industry 4.0 and the circular economy could follow the multilevel governance practice in the EU, often described with the term subsidiarity (Weidenfeld, 2010). The analysis of societal complexity clarifies that uncertainties, non-linear processes of change and innovation, and emergence of systemic changes are important features of future economic transformation.

Over the last decades, a shift from the centralised government-based nation-state towards liberalised market-based and decentralised decision-making structures could be observed. Due to societal developments, the power of central governments to make policies and implement these policies has decreased, leading to increasingly diffused policy-making structures and processes that are stratified across sub-national, national, and supra-national levels of government (Wainstein and Bumpus, 2016).

There is an increasing degree of consensus that traditional forms of governance are not suitable for challenges with a high degree of complexity. Both classical top-down management as well as laissez faire approaches have proven to be ineffective management mechanisms to generate sustainable solutions for complex tasks, such as sustainable development, which has to consider the adverse side effects of modernisation and fundamentally redefine its own dynamics and workings, implying a new paradigm on managing economic and technology development (Winkelbach and Walter, 2015).

This means that understanding complexity is a means of leverage. Greater insight into the dynamics of a complex adaptive societal system leads to improved insight into the feasibility of directing and influencing it. Over the last decade, the policymaking process has been changing fundamentally because of the European integration, which has led to a multilevel governance structure whereby, at each level, different actors are involved in the decision-making process.

This development has led to multilevel participatory decision-making structures in which, for example, cities and regions are dealing directly with EU institutions, non-government organisations, and businesses that are involved in the development of policies, and top-down decisions are limited to the politically most controversial issues. But governance has also become common practice at the regional scale, where the influence of non-governmental organisations, business, and science slowly become part of policymaking (Bernauer et al., 2016).

Obviously, these need to be considered when conceptualising the management of the process of linking Industry 4.0 and the circular economy. While classical and top-down forms of management, steering, and organisation still have a function in modern society, the complexity of the tasks requires additional strategies and approaches (Allen et al., 2011).

8. Recommendations and Next Steps

The ASEAN region is both complex and diverse. Its political and cultural differences and variations in economic behaviour make it one of the most challenging regions for businesses to operate in. But ASEAN countries are moving in the right direction, striving to sharpen overall competitiveness through closer international collaboration. This integration will begin to drive positive change.

ASEAN member countries would be well advised to consider a comprehensive overhaul of both its domestic and cross-border (regional) regulations, addressing both supply-side and demand-side objectives. On the supply side, countries within ASEAN should strive to strengthen the business case for investment in digital infrastructure, revisit regulations for key sectors (such as financial services), and boost the local digital ecosystem. On the demand side, ASEAN countries should create a single digital market and take steps to aggressively expand access to broadband. If ASEAN can implement these policies effectively, realising this opportunity should be a top priority for the new ASEAN Economic Community.

The ASEAN region should accelerate the shift towards a circular economy by launching four efforts. Shifting to the new model starts with acknowledging the systemic nature of the change. All sectors and policy domains will be affected, and aligned action is required. Such a shared agenda could contain four building blocks: ASEAN-wide quest for learning, research, and opportunity identification; development of a value-preserving materials backbone – a core requirement for strengthening ASEAN's European industrial competitiveness; initiatives at the ASEAN, national, and city levels to enable inherently profitable circular-business opportunities to materialise at scale; and development of a new, more integrated governance system to steer the regional economy towards greater resource productivity, employment, and competitiveness.

The ASEAN region should regularly monitor the extent to which ASEAN companies have already positioned themselves in relation to this digital transformation and the opportunities that the switch to Industry 4.0 offers them. The very first step is to establish an independent ASEAN Digital Economy Promotion Board to consist of country representatives, industry experts, and key opinion leaders. This board will provide strategic direction, guidance, and advice to the ASEAN Economic Community and its member governments.

The independent advisory board should be responsible for oversight of the future state of digital and communications in ASEAN. The role and responsibilities of the board should reflect ASEAN's vision of the digital economy, while ensuring economic policies within ASEAN support the development of digital products and services. Its area of focus should include the fixed and mobile telecommunications landscape, spectrum, and future sectors such as Industry 4.0 and the circular economy.

The board should also monitor and measure ASEAN's and its members' performance to make sure they are on course to make the necessary changes. An example is the EU's Digital Economy and Society Index which summarises relevant indicators on Europe's digital performance and tracks the evolution of the EU member states' digital competitiveness. ASEAN should consider establishing a similar index.

The board should also enable easy sharing and exchanging of best practices, learnings, and information across countries, governments, and operators.

The factors to be monitored are:

- Competitiveness: Digital transformation to Industry 4.0 will increase their competitiveness. The digital transformation to Industry 4.0 will have an impact right across both local and global value chains in low-cost as well as high-cost ASEAN countries.
- Opportunities and risks: Industry 4.0 represents several major opportunities for the ASEAN region. It will open new ways for companies to integrate their customers' needs and preferences into their development and production processes, including via direct data-sharing with their machinery. It will also make it easier to analyse machine data, helping to enhance quality and avoid faults in the production process. In terms of risks, digital transformation to Industry 4.0 could further increase the already heightened cyber risk to the manufacturing industry.
- Human resources: The ASEAN region might have all the staff they need to make the digital transformation to Industry 4.0. If the digital transformation to Industry 4.0 is to be successful, however, it is essential that businesses in the ASEAN region continue to invest in appropriate skills and an excellent information technology infrastructure.
- Develop potential for individual business segments: Research and development, procurement and purchasing, production and warehousing, and logistics are currently at the heart of the digital transformation to Industry 4.0, while sales and services segments have the greatest potential to benefit from it. In these segments, individualised solutions have the capacity to take manufacturing into a whole new era of customisation and provide a window of opportunity for the ASEAN region. This will require the sector to switch from the 'push into the market' of better products for their customers to an individualised understanding of customers' needs and specialised industry-specific solutions.
- Use the impetus from exponential technologies such as 3D printing to accelerate the transformation of the manufacturing industry in the ASEAN region to Industry 4.0. To assist the ASEAN business community to manage the transformation to Industry 4.0, it needs to continue to address the following four major characteristics: vertical networking, horizontal integration, through-engineering, and exponential technologies.

References

Aghion, P., N. Bloom, R. Blundell, R. Griffith, and P. Howitt (2005), 'Competition and Innovation: An Inverted-u Relationship', *Quarterly Journal of Economics*, 120(2), pp.701–728.

Allen, C., J. Fontaine, K. Pope, and A. Garmestani (2011), 'Adaptive Management for a Turbulent Future', *Journal of Environmental Management*, 92(5), pp.1339–1345.

Allwood, J.M. (2014), 'Chapter 30 - Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies', *Handbook of Recycling*. Boston: Elsevier, pp.445–477.

Ashby, M.F. (2016), 'Chapter 14 – The Vision: A Circular Materials Economy', *Materials and Sustainable Development*. Boston: Butterworth-Heinemann, pp.211–239.

Bagheri, B., S. Yang, H. Kao, and J. Lee (2015), 'Cyber-physical Systems Architecture for Self-Aware Machines in Industry 4.0 Environment', *IFAC-PapersOnLine*, 48, pp.1622–1627.

Bernauer, T., R. Gampfer, T. Meng, and Y.S. Su (2016), 'Could More Civil Society Involvement Increase Public Support for Climate Policy-making? Evidence from a Survey Experiment in China', *Global Environmental Change*, 40, pp.1–12.

Bilitewski, B. (2012), 'The Circular Economy and its Risks', *Waste Management*, 32 (1), pp.1–2.

Brettel, M., N. Friederichsen, M. Keller, and M. Rosenberg (2014), 'How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective', *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, 8 (1), pp.37–44.

Buhr, D. (2015), 'Social Innovation Policy for Industry 4.0', Friedrich Ebert Stiftung, Berlin: Friedrich Ebert Stiftung.

Bundesministerium für Bildung und Forschung (2015), *Industrie 4.0, Innovationen für die Produktion von Morgen*. Berlin: BMBF.

Bundesministerium für Wirtschaft und Energie (2014), *Zukunft der Arbeit in Industry 4.0*. Berlin: BMWi.

Chituc, C. and F.J. Restivo (2009), 'Challenges and Trends in Distributed Manufacturing Systems: Are Wise Engineering Systems the Ultimate Answer?', Second International Symposium on Engineering Systems MIT, pp.15–17.

Cohen, B. and P. Muñoz (2016), 'Sharing Cities and Sustainable Consumption and Production: Towards an Integrated Framework', *Journal of Cleaner Production*, 134(A), pp.87–97.

Dalhammar, C. (2016), 'Industry Attitudes Towards Eco-design Standards for Improved Resource Efficiency', *Journal of Cleaner Production*, 123, pp.155–166.

Dombrowski, U. and T. Wagner (2014), 'Mental Strain as Field of Action in the 4th Industrial Revolution', *Procedia CIRP*, 17, pp.100–105.

Du, Y., Q. Yi, C. Li, and L. Liao (2015), 'Life Cycle Oriented Low-carbon Operation Models of Machinery Manufacturing Industry', *Journal of Cleaner Production,* 91, pp.145–157.

Dutta, S., T. Geiger, and B. Lanvin (2016), '*The Global Information Technology Report 2016*'. Geneva: World Economic Forum.

Ellen MacArthur Foundation (2016), *Intelligent Assets: Unlocking the Circular Economy Potential 2016*. https://www.ellenmacarthurfoundation.org/publications/intelligent-assets (accessed 5 August 2018).

European Commission (2012), *Mission Growth: Europe at the Lead of the New Industrial Revolution*, Brussels: European Commission. http://ec.europa.eu/growth/content/mission-growth-europe-lead-new-industrial-revolution-0_en (accessed 5 August 2018).

Faller, C. and D. Feldmüller (2015), 'Industry 4.0 Learning Factory for regional SMEs', *Procedia CIRP*, 32, pp.88–91.

Finn, R.L. and D. Wright (2016), 'Privacy, Data Protection and Ethics for Civil Drone Practice: A Survey of Industry, Regulators and Civil Society Organisations', *Computer Law & Security Review*, 32(4), pp.577–586.

Foray, D. and J. Raffo (2014), 'The Emergence of an Educational Tool Industry: Opportunities and Challenges for Innovation in Education', *Research Policy*, 43(10), pp.1707–1715.

Gao, G., Y.S. Liu, M. Wang, M. Gu, and J.H. Yong (2015), 'A Query Expansion Method for Retrieving Online BIM Resources Based on Industry Foundation Classes', *Automation in Construction*, 56, pp.14–25.

George, D.A.R., B.C. Lin, and Y. Chen (2015), 'A Circular Economy Model of Economic Growth', *Environmental Modelling & Software,* 73, pp.60–63.

Kagermann, H. (2014), 'Change Through Digitization – Value Creation in the Age of Industry 4.0', in H. Albach, H. Meffert, A. Pinkwart, and R. Reichwald (eds.), *Management of Permanent Change*. Wiesbaden: Springer Gabler, Wiesbaden, pp.23–45.

Kolberg, D. and D. Zühlke (2015), 'Lean Automation Enabled by Industry 4.0 Technologies', *IFAC-PapersOnLine*, 48, pp.1870–1875.

Li, D., B. Jiang, H. Suo, and Y. Guo (2015), 'Overview of Smart Factory Studies in Petrochemical Industry', in K.V. Gernaey, J.K. Huusom, and R. Gani (eds.), *Computer Aided Chemical Engineering*, 37, pp.71–76.

Lin, W., B. Liu, A. Gu, and X. Wang (2015), 'Industry Competitiveness Impacts of National ETS in China and Policy Options', *Energy Procedia*, 75, pp.2477–2482.

Organisation for Economic Co-operation and Development (2017), *Green Growth Indicators 2017*. Paris: OECD Publishing.

Qin, F. (2015), 'Global Talent, Local Careers: Circular Migration of Top Indian Engineers and Professionals', *Research Policy*, 44(2), pp.405–420.

Richard S.J.T. (2005), 'Adaptation and Mitigation: Trade-offs in Substance and Methods', *Environmental Science & Policy*, 8(6), pp.572–578.

Romero, D. and O. Noran (2015), 'Green Virtual Enterprises and their Breeding Environments: Engineering their Sustainability as Systems of Systems for the Circular Economy', *IFAC-PapersOnLine*, 48, pp.2258–2265.

Roy, J., A.M. Dowd, A. Muller, S. Pal, and N. Prata (2012), 'Lifestyles, Well-Being and Energy', in *Global Energy Assessment – Toward a Sustainable Future*. Cambridge, UK and New York, US and the International Institute for Applied Systems Analysis, Laxenburg, Austria: Cambridge University Press, pp.1527–1548.

Rüßmann, M., M. Lorenz, P. Gerbert, M. Waldner, J. Justus, P. Engel, and M. Harnisch (2015), *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*. Boston Consulting Group. https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx (accessed 5 August 2018).

Schulte, U.G. (2013), 'New Business Models for a Radical Change in Resource Efficiency', *Environmental Innovation and Societal Transitions*, 9, pp.43–47.

Stern, P., T. Dietz, N. Dolsak, E. Ostrom, and S. Stonich (2002), 'The Drama of the Commons', in *The Drama of the Common*s. Washington, DC: National Academies Press, pp.445–490.

Tukker, A. (2015), 'Product Services for a Resource-efficient and Circular Economy – A Review', *Journal of Cleaner Production*, 97, pp.76–91.

Von Stechow, C., et al. (2015), 'Integrating Global Climate Change Mitigation Goals with Other Sustainability Objectives: A Synthesis', *Annual Review of Environment and Resources*, 40, pp.363–394.

Wainstein, M.E. and A.G. Bumpus (2016), 'Business Models as Drivers of the Low Carbon Power System Transition: a Multilevel Perspective', *Journal of Cleaner Production*, 126, pp.572–585.

Wang, S., J. Wan, D. Zhang, D. Li, and C. Zhang (2016), 'Towards Smart Factory for Industry 4.0: a Self-organized Multi-agent System with Big Data-based Feedback and Coordination', *Computer Networks*, 101, pp.158–168.

Weidenfeld, W. (2010), '*Europäische Integration*', in *Politikwissenschaft in Deutschland*, Veröffentlichungen der Deutschen Gesellschaft für Politikwissenschaft Band 27, Baden Baden: Nomos Verlag.

Winkelbach, A. and A. Walter (2015), 'Complex Technological Knowledge and Value Creation in Science-to-industry Technology Transfer Projects: The Moderating Effect of Absorptive Capacity', *Industrial Marketing Management*, 47, pp.98–108.

Ying, J. and Z. Li-Jun (2012), 'Study on Green Supply Chain Management Based on Circular Economy', *Physics Procedia*, 25, pp.1682–1688.

Zhang, K.M. and Z.G. Wen (2008), 'Review and Challenges of Policies of Environmental Protection and Sustainable Development in China', *Journal of Environmental Management*, 88, pp.1249–1261.